

RENEWABLES 2020

GLOBAL STATUS REPORT



2020

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RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY



REN21 is the only **global community** of renewable energy actors from science, academia, governments, NGOs and industry. We provide up-to-date facts, figures and peer-reviewed analysis of global developments in technology, policies and markets to decision makers. Our goal: encourage and enable them to make the shift to renewable energy happen – now!



The most successful organisms, such as an octopus, have a **decentralised intelligence** and "sensing" function. This increases responsiveness to a changing environment. REN21 incarnates this approach.



Our more than **2,000 community members** guide our co-operative work. They reflect the vast array of backgrounds and perspectives in society. As REN21's eyes and ears, they collect information and share intelligence, by sending input and feedback. REN21 takes all this information to better understand the current thinking around renewables and change norms. We also use this information to connect and grow the energy debate with non-energy players.



Our annual publication, the *Renewables Global Status Report*, is probably the world's most comprehensive crowdsourced report on renewables. It is a truly collaborative process of co-authoring, data collection and peer reviewing.

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REN21 is committed to mobilising global action to meet the United Nations Sustainable Development Goals.

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Together with REN21's annual **Renewables Global Status Report** (GSR), these two publications provide a comprehensive overview of developments in the renewable energy sector. The 2020 GTR edition was supported by the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety. It was released in May 2020 and can be downloaded at www.fs-unep-centre.org.



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FOREWORD

Every year, we launch the *Renewables Global Status Report* (GSR) to present the latest data and facts on renewable energy policies, markets and investments. This year, however, something is different. We collectively witnessed the adoption of immediate and drastic measures in response to the COVID-19 pandemic. Ensuing lockdowns and economic consequences have disrupted everyone's lives.

Time seems to be separated into a pre-COVID and a post-COVID period. Energy supply and demand have been disrupted, and carbon dioxide emissions fell. In such unprecedented times, stepping back to look at what happened in the renewable energy sector in 2019 may seem counterintuitive. But we need to do this.

It's clear that we need to study the global picture with a long-term view to make the right decisions going forward. If we don't, we risk getting sidetracked by a short-term perspective. As disruptive as COVID-19 has been, the crisis does not alter observable trends in the energy sector that have persisted for years. The truth remains: we need to enact a structural shift built on an efficient and renewable-based energy system if we want to decarbonise our economies.

Many of the same themes from prior years resurfaced again in GSR 2020. Year after year, we have reported success in the renewable power sector. And year after year, we have reported that renewables lag in other end-use sectors like heating, cooling and transport, and that these sectors suffer a lack of policy support. We need to report about successes as well as take a more critical look at areas where progress is weak, to enable better decision making and advance the uptake of renewables.

In the effort not only to provide accurate data but also to advance renewables in areas of weaker historic progress, GSR 2020 is different from former editions. Rather than only tracking support for renewables broadly, we decided to actively address the disconnect in progress among sectors. You will find some new figures and the start of ongoing data tracking on renewable energy policies, generation and use in different end-use sectors. We hope that this more specific look at each end-use sector (Buildings, Industry and Transport) will provide information needed to make better decisions.

At the halfway point of 2020, we find ourselves in a period of global flux. We are also in a moment of increasing consciousness: public support for renewables is at an all-time high, and many people are becoming more aware of the various benefits of renewable energy. Let's seize this unique moment to create lasting policies, regulations and targets, and an environment that enables the switch to an efficient and renewable-based energy system. Globally. Now.

Some things don't change, even after COVID-19. As with all REN21 publications, GSR 2020 is the product of a collaborative process built from an international community of renewable energy contributors, researchers and authors. This year's report consolidates data from more than 350 experts to provide an up-to-date snapshot of the state of play of renewables. On behalf of the REN21 Secretariat, I would like to thank all those who contributed to the successful production of GSR 2020. Particular thanks go to the REN21 Research Direction Team of Hannah E. Murdock, Duncan Gibb and Thomas André; Special Advisors Janet L. Sawin and Adam Brown; the chapter authors; our editor Lisa Mastny; and the entire team at the REN21 Secretariat.

We sincerely hope that GSR 2020 will contribute to important changes in the near future.



Rana Adib
Executive Director, REN21

June 2020

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RENEWABLES PROVIDING BASIC SERVICES TO COMMUNITIES, YEMEN



Conflict in Yemen has resulted in significant loss of life, forced people from their homes and hindered the provision of basic services. The Enhanced Rural Resilience in Yemen Programme (ERRY) helps rural communities better cope with the crisis by increasing their access to energy through renewable technologies, such as solar lanterns to light homes, businesses and schools; solar-powered refrigerators for vaccine storage in health facilities; solar-powered water systems to provide safe drinking water in cholera-affected locations; and solar irrigation pumps for small-scale farmers.

EXECUTIVE SUMMARY

01 GLOBAL OVERVIEW

Renewables grew rapidly in the power sector, while far fewer advances have occurred in heating and transport.

Renewable energy had another record-breaking year in 2019ⁱ, as installed power capacity grew more than 200 gigawatts (GW) – its largest increase ever. Capacity installations and investment continued to spread to all corners of the world, and distributed renewable energy systems provided additional households in developing and emerging countries with access to electricity and clean cooking services. Also during the year, the private sector signed power purchase agreements (PPAs) for a record amount of renewable power capacity, driven mainly by ongoing cost reductions in some technologies.

Shares of renewables in electricity generation continued to rise around the world. In some countries, the share of renewables in heating, cooling and transport also grew, although these sectors continued to lag far behind due to insufficient policy support and slow developments in new technologies. This resulted in only a moderate increase in the overall share of renewables in total final energy consumption (TFEC), despite significant progress in the power sector.

As of 2018, modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11% of TFEC, only a slight increase from 9.6% in 2013. The highest share of renewable energy use (26.4%) was in electrical uses excluding heating, cooling and transport; however, these end-uses accounted for only 17% of TFEC in 2017. Energy use for

transport represented some 32% of TFEC and had a low share of renewables (3.3%), while the remaining thermal energy uses accounted for more than half of TFEC, of which 10.1% was supplied by renewables. Overall, the slow growth in the renewable energy share of TFEC indicated the complementary roles of energy efficiency and renewables in reducing the contribution of fossil fuels in meeting global energy needs.

Among the general public, support for renewable energy continued to advance alongside rising awareness of the multiple benefits of renewables, including reduction of carbon dioxide (CO₂) and other greenhouse gas emissions.

Governments around the world have stepped up their climate ambitions, and by year's end 1,480 jurisdictions – spanning 28 countries and covering 820 million citizens – had issued “climate emergency” declarations, many of which were accompanied by plans and targets to transition to more renewable-based energy systems.

At the same time, while some countries were phasing out coal, others continued to invest in new coal-fired power plants, both domestically and abroad. In addition, funding from private banks for fossil fuel projects has increased each year since the signing of the Paris Agreement in 2015, totalling USD 2.7 trillion between 2016 and 2019. Although energy-related CO₂ emissions remained stable in 2019, the world is not on track to limit global warming to well below 2 degrees Celsius (°C), let alone 1.5 °C, as stipulated in the Paris Agreement.

ⁱ The *Renewables 2020 Global Status Report* focuses on developments in renewable energy in 2019, and therefore does not reflect the impact of the COVID-19 pandemic on global energy systems. For immediate impacts on the renewable energy sector as of mid-2020, see Sidebar 1. An overview of the full impacts of the COVID-19 crisis on the sector will be included in GSR 2021.

BUILDINGS

Renewables were the fastest growing energy source in buildings, yet this increase was limited by lack of policy support.

Renewable energy met less than 14% of total energy demand in buildings in 2017. More than three-quarters of global final energy demand in buildings was for heating and cooling end-uses, which remain heavily fossil-fuel based. In 2018, renewables contributed an estimated 10.1% of heating and cooling demand in buildings; this share has barely risen from 8% in 2010. Modern bioenergy still represented the largest renewable heat source in the buildings sector, followed by renewable electricity for heat, solar thermal and geothermal heat. Most of the share increase was due to growth in renewable electricity for heat and in solar thermal, while use of modern bioenergy has remained stable. The majority of renewable electricity in buildings was provided by utility-scale, grid-connected renewables with a growing share from rooftop solar photovoltaic (PV) systems.

Direct policy action to stimulate renewable energy uptake in buildings was lacking in 2019, although more local and national governments introduced bans on fossil fuels for heating. Global efforts to decarbonise buildings through net zero carbon / net zero energy buildings are promoting the uptake of renewable energy in the sector.

Although renewable electricity saw strong growth, it was not enough to account for global increases in
final energy demand.



INDUSTRY

The share of renewables in industrial energy use remains small, particularly in sectors that require high process temperatures.

Renewable energy met around 14.5% of industrial final energy demand, with bioenergy supplying more than half of the renewable share. Bioenergy was used primarily in sub-sectors that utilise low-temperature heat (below 100 °C), such as pulp and paper. Solar thermal and geothermal heat were used mainly for pre-heating water, drying and generating low-temperature steam in industries such as mining, food and beverage production, textiles and agriculture. Within the industrial sector, the most energy-intensive sub-sectors – those with the highest process temperatures – also use the lowest shares of renewable energy.

Renewable electricity was used to supply both electrical and thermal demands of some industrial processes. New projects were completed or announced in 2019 to use renewable electricity to produce steel and cement and to power mining operations. In addition, projects were commissioned to produce renewable hydrogen for industry, and companies announced plans and intentions to produce renewable hydrogen from offshore wind power.



TRANSPORT

Despite gains in energy efficiency and continued growth in both biofuels and electric vehicles (EVs), transport remains the sector with the lowest share of renewable energy.

Although it accounts for around one-third of TFEC, transport remained the sector with the lowest share of renewable energy, at only 3.3%. The vast majority of global transport energy needs were met by oil and petroleum products, with small shares met by biofuels and renewable electricity. Gains in energy efficiency and continued growth in both biofuels and EVs were largely offset by rising energy demand in transport. Biofuels remained by far the largest contributor of renewable energy to the transport sector in 2019.

Although rarely linked directly to renewable sources, EVs became more commonplace in more countries as a result of policies and targets adopted in prior years. With cities increasingly restricting the circulation of fossil fuel vehicles, new mobility service companies have expanded rapidly, with some committing to using renewable electricity in their EV fleets. Some regions also saw gradual increases in the use of renewable hydrogen and renewable synthetic fuels for transport, but these remained minimal overall. Many countries still lack a holistic strategy for decarbonising transport. Although positive developments occurred across transport modes, including in road freight, shipping and aviation in 2019, progress has been too slow to achieve global climate targets.



POWER

The renewable power sector experienced record-high increases in installed capacity, outpacing net installations in fossil fuel and nuclear power combined.

Installed renewable power capacity grew more than 200 GW in 2019 (mostly solar PV), the largest increase ever. For the fifth year in a row, net additions of renewable power generation capacity clearly outpaced net installations of fossil fuel and nuclear power capacity combined. Globally, 32 countries had at least 10 GW of renewable power capacity in 2019, up from only 19 countries a decade earlier. In most countries, producing electricity from wind and solar PV is now more cost effective than generating it from new coal-fired power plants. These cost declines have led to record-low bids in tendering processes, which became even more common during the year. However, competitive auctions have led to consolidation in some industries and have favoured larger multinational energy companies rather than smaller actors, including community-led groups.

Overall, installed renewable energy capacity was enough to provide an estimated 27.3% of global electricity generation by the end of 2019. Despite these advances, renewable electricity continued to face challenges in achieving a larger share of global electricity generation, due in part to persistent investment in fossil fuel (and nuclear) power capacity.



02 POLICY LANDSCAPE

In 2019, policy frameworks continued to evolve in response to changes in renewable energy technologies and markets.

Much of the progress in developing and deploying renewable energy technologies has been achieved thanks to effective government policies. Policy continues to be important to overcome economic, technical and institutional barriers. By the end of 2019, nearly all countries had renewable energy support policies in place, although with varying degrees of ambition, scope and comprehensiveness. Jurisdictions have adapted policies to meet their specific circumstances, including to support increasing renewable energy capacity and generation, to boost job creation, and to increase energy access and security. Trade policy also had an impact on the production, exchange and development of renewable energy products, as well as on renewable energy demand levels within specific countries.

CROSS-SECTORAL TARGETS AND POLICIES

Targets that align renewable energy policy across multiple levels of governance and multiple economic sectors remained rare in 2019.

Renewable energy policies typically are enacted at a single level of governance and tend to focus on a single end-use sector, although examples of integration and co-ordination are emerging. Co-ordinated policy efforts often are organised under energy or climate change strategies at the national or state/provincial level, such as those introduced in the Netherlands and Scotland during 2019.

Targets are a primary means of expressing commitment to renewable energy and have been aimed almost exclusively at the power (electricity) sector. By the end of 2019, 166 countries had renewable power targets, compared to 49 countries for heating and cooling and 46 for transport. Only one cross-sectoral target was adopted during 2019, in Spain.



RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

Climate change policies that directly or indirectly stimulate interest in renewables increased in 2019, spreading to new regions and reaching new levels of ambition.

In some jurisdictions, policies directly link climate change mitigation with the increased deployment of renewables – such as Costa Rica's economy-wide roadmap launched in 2019 to achieve net zero emissions by 2050. However, other climate policies – such as fossil fuel bans and phase-outs, greenhouse gas emissions targets, and carbon pricing and emissions trading systems – stimulate the uptake of renewables indirectly. By the end of 2019, at least 56 carbon pricing initiatives in 47 countries had been implemented (up from 54 initiatives in 45 countries in 2018, with the addition of Singapore and South Africa). Fourteen countries worldwide had a legally binding target for net zero emissions (while two countries have already achieved this target), and the European Commission proposed a European Green Deal to create the first carbon-neutral continent by 2050.

HEATING AND COOLING POLICY

Despite the enormous potential for renewable energy in heating and cooling, the number of related policies for buildings increased only slightly, while such policies for industry remained scarce.

Policies supporting renewable heating and cooling in buildings grew minimally in 2019, and include renewable heating and cooling mandates, building energy codes, support for renewable district heating and cooling, support for renewable natural gas, financial incentives, net zero emissions standards and fossil fuel bans for heating. No new countries adopted renewable heat mandates for the second year in a row, but at least four countries (Austria, Denmark, Norway and the United Kingdom) adopted targets to fully or partially ban the use of fossil fuels in heating.

Renewable energy support policies for the industrial sector are more limited, and new or revised policies in this area remained scarce in 2019. Although not always specific to the industrial sector, some policy developments related to renewable hydrogen took place in 2019, particularly in Australia, New Zealand, and Europe, while policy focus on hydrogen elsewhere occurred without a direct link to renewables.

Effective policy support

has been key to the advancement of renewables in power, while heating and transport lag behind.

TRANSPORT POLICY

In the transport sector, no new countries adopted biofuel blend mandates, but some countries with existing mandates strengthened their policies. Policy attention to EVs expanded but still without a direct link to renewables.

In 2019, policies to promote renewable energy in the transport sector continued to focus primarily on road transport, which accounts for the vast majority of energy use in transport. Rail, aviation and shipping received less policy attention despite being large energy consumers.

As in previous years, biofuels were the primary focus of road transport policy frameworks. Although no new countries introduced biofuel blending mandates for the second year running (with the total remaining at 70 countries), some countries with existing mandates added new ones, and several existing mandates were strengthened. The number of countries with targets for advanced biofuels reached 24, although nearly all were targeting shares in the single digits.

Policies aimed at the electrification of transport, while not renewable energy policies in themselves, offer the potential for greater penetration of renewable electricity in the transport sector. In 2019, numerous jurisdictions implemented policies to support the increased uptake of electric road vehicles – including targets, financial incentives, public procurement and support for charging infrastructure. Targeted bans on fossil fuel vehicles were in place in at least 18 countries, up from 12 in 2018. Austria remained the only country that had a policy directly linking renewables with EVs, while only three cities had e-mobility targets that were directly linked to a renewable electricity target.

The private sector also advanced renewable energy initiatives in the transport sector, particularly for aviation, shipping and rail.



POWER POLICY

Countries continued to turn to competitive auctions and tenders to support large-scale, centralised renewable power projects; however, rising attention was paid to decentralised systems.

The power sector continued to receive the bulk of renewable energy policy attention in 2019, and targets remained the most popular form of intervention. Many countries used competitive auctions and tenders in lieu of feed-in policies for large-scale, centralised projects. At least 68 renewable energy auctions or tenders were held across at least 41 countries at the national or state/provincial level, down from 48 countries in 2018. However, the total number of countries that have used this mechanism increased to 109 (up from 98 in 2018) as new countries held tenders for the first time. African countries were very active in 2019, although to a lesser degree than in 2018. Feed-in policies were in place in 113 jurisdictions by the end of 2019, with no change from 2018.

The uptake of policies targeting small-scale, distributed renewable power generation accelerated during the year. These policies include solar mandates, feed-in pricing, net metering (and virtual net metering) and public utility policy. Policies also were adopted to encourage community energy arrangements, including measures promoting community choice aggregation and shared ownership of renewables, especially in Europe and the United States.

The private sector engaged in various forms of renewable power procurement, including through PPAs, renewable energy certificates, utility-led procurement programmes and self-generation.

POLICIES FOR SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

A growing number of jurisdictions directed policies towards ensuring greater integration of variable renewable electricity (VRE).

The policy push for systems integration of renewables and enabling technologies, such as energy storage, remained focused on increasing power system flexibility and control, as well as grid resilience. Policies to advance the integration of VRE in 2019 were related mainly to market design, demand-side management, transmission and distribution system enhancements, grid interconnections and support for energy storage. Much of the policy development occurred in Europe and at the state level in the United States.

03 MARKET AND INDUSTRY TRENDS

BIOENERGY

Modern bioenergy provided 5.1% of total global final energy demand in 2018, accounting for around half of all renewable energy in final energy consumption.

The contribution of modern bioenergy to heat in industry has grown about 2% in recent years, while its use for heating in buildings (mainly in Europe and North America) has fallen slightly. Bioenergy provides around 9% of industrial heat demand and is concentrated in bio-based industries such as paper and board. Biofuels, mostly ethanol and biodiesel, provide around 3% of transport energy, and global biofuels production increased 5% in 2019. Ethanol production grew around 2%, despite a decline in the United States, the major ethanol producer. Biodiesel production increased 13%, and Indonesia became the world's largest producer, overtaking the United States, where production declined some 7%.

In the electricity sector, bioenergy's contribution rose 9% in 2019, to 501 terawatt-hours (TWh). China extended its lead as the largest country producer, and bio-electricity growth also was strong in the EU, Japan and the Republic of Korea.

Notable trends in the bioenergy industry included the continuing rise in wood pellet production, especially to serve growing markets in Japan and the Republic of Korea, and increasing investment in hydrotreated vegetable oil (HVO) production. Production of HVO/HEFA (hydroprocessed esters and fatty acids) increased 12% in 2019, and investments in numerous additional plants were announced.

Global biofuels
production

increased
5% in 2019.



GEOTHERMAL POWER AND HEAT

Geothermal electricity generation in 2019 totalled around 95 TWh, while direct useful thermal output reached around 117 TWh (421 petajoules).

An estimated 0.7 GW of new geothermal power generating capacity came online in 2019, bringing the global total to around 13.9 GW. As in 2018, Turkey and Indonesia led for new installations, followed closely by Kenya; together the three countries represented three-quarters of new installations globally. Other countries that added new geothermal power facilities (or added capacity at existing facilities) were Costa Rica, Japan, Mexico, the United States and Germany.

Direct use of geothermal energy for thermal applications has grown nearly 8% on average in recent years, with the fastest growing segment being space heating (around 13% annual growth). Among the most active markets are regions of Europe and China, the latter showing the fastest expansion. Just four countries – China, Turkey, Iceland and Japan – represented roughly 75% of all geothermal direct use in 2019.

As in many previous years, the global geothermal industry had mixed results. Construction activity and anticipation of further development remained intact in some key markets, but was largely predicated on government support. Elsewhere, the industry was inhibited by industry-specific challenges of high project costs and front-loaded project risks and by the corresponding lack of adequate funding and risk mitigation.

Continued research into new technologies and innovative processes and techniques, often supported by government programmes, helped fuel optimism for a path forward.



HYDROPOWER

The global hydropower market, as measured in annual capacity installations, contracted in 2019, continuing a multi-year trend of deceleration.

New capacity totalled an estimated 15.6 GW, raising the global installed capacity to around 1,150 GW in 2019. Hydropower generation increased 2.3% during the year 2019 to an estimated 4,306 TWh, reflecting not only increased capacity but also significant localised variability from shifting weather patterns and other operational conditions.

Brazil led in commissioning new hydropower capacity in 2019, followed by four Asian countries: China, Lao PDR, Bhutan and Tajikistan. This marked the first year since at least 2004 that China did not maintain a wide-margin lead over all other countries for new hydropower completions.

Pumped storage capacity grew minimally in 2019 (0.2%), with most of the increase being a single 300 megawatt (MW) facility completed in China. Total installed capacity at year's end was 158 GW. However, significant new capacity was being planned or under construction, in part to support growth in VRE from solar PV and wind power.

The hydropower industry continued to face a wide, interconnected, and evolving web of challenges and opportunities in a world of changing energy systems and priorities. Some are specific to the technical workings and economic considerations of the industry itself (such as the need for modernisation and climate resilience), while others pertain to hydropower's relationship with other renewable energy sources (such as integration of VRE), as well as other environmental, social, climate and sustainability imperatives.

OCEAN POWER

Ocean power represented the smallest portion of the renewable energy market, and most deployments to date have been small-scale demonstration and pilot projects.

Despite the slow developments in the sector, the ocean power industry began moving towards semi-permanent installations and arrays of devices. The resource potential of ocean energy is enormous, but the development trajectory of ocean power technologies has been volatile, and these resources remain largely untapped.

Following a turbulent 2018, the ocean power industry regrouped in 2019 and continued its gradual advance towards commercialisation. Net additions in 2019 were around 3 MW, with an estimated 535 MW of operating capacity at year's end. Significant investments and deployments were planned for 2020 and beyond.

Ocean power development has been concentrated mainly in Europe, where tidal stream devices generated 15 gigawatt-hours (GWh) in 2019 (up 50% from 2018). However, ocean power was gaining momentum in Canada, the United States and China, which offer generous revenue support and ambitious research and development (R&D) programmes.

SOLAR PHOTOVOLTAICS (PV)

Following a year of stable demand, the solar PV market increased 12% in 2019 to a record 115 GW (direct current), for a total of 627 GW.

The decade ended with strong demand in Europe, the United States and emerging markets around the world, more than making up for a substantial decline in China. Not including China, the global market grew around 44%. China continued to dominate the world market as well as manufacturing, having a significant influence on both.

In most countries, the need still exists for support schemes for solar PV, as well as for adequate regulatory frameworks and policies governing grid connections. Even so, interest in purely competitive large-scale systems is growing quickly, with a number of projects under construction. Corporate purchasing expanded considerably in 2019, and self-consumption (increasingly with battery storage) was an important driver for new distributed systems in several countries, including Australia and Germany.

The industry continued to face relentless competition that, coupled with policy vagaries and uncertainty, prompted cut-throat bids at some auctions and resulted in thin margins for some developers and manufacturers, contributing to ongoing consolidation. At the same time, competition drove declining prices, opening new markets, while the pressure of lower prices and expectations of rising global demand encouraged expanded and more efficient manufacturing, the entry of new companies into the sector and ongoing pursuit of innovation.

During the year, solar PV accounted for around 10.7% of total generation in Honduras and substantial shares also in Italy (8.6%), Greece (8.3%), Germany (8.2%), Chile (8.1%) and elsewhere. By year's end, enough capacity was in operation worldwide to produce an estimated 2.8% of global electricity generation.



CONCENTRATING SOLAR THERMAL POWER (CSP)

Global CSP capacity in operation grew exclusively in emerging markets.

Global CSP capacity grew 11% in 2019 to 6.2 GW, with 600 MW of capacity coming online. Although this was well below the average annual increase (24%) of the past decade, CSP continued to spread to new markets, including France, Israel and Kuwait. China and South Africa also brought new plants into service. For the first time, as much tower capacity as parabolic trough capacity was completed during 2019.

At year's end, an estimated 21 GWh of thermal energy storage (TES) was operating in conjunction with CSP plants across five continents. Nearly all commercial CSP under construction – located in Asia, the Middle East and Latin America – will include TES.

The CSP industry has become more geographically diverse, both in the locations of commercial plants and in the origins of developers, investors and contractors. Levelised costs of energy from CSP continued to decline during 2018 and 2019, with CSP increasingly being built alongside both solar PV and wind power to lower costs and increase capacity value. R&D activities during the year focused on further improving CSP economics and on addressing environmental impacts.

SOLAR THERMAL HEATING AND COOLING

Solar thermal capacity reached 479 gigawatts-thermal in 2019, with China accounting for 69% of the total.

For the first time, cumulative global capacity declined (1%) compared with the previous year, because installations in China did not cover the country's need for replacements. Additions in the other largest markets for solar heating and cooling remained stable, with noteworthy growth in Brazil, Cyprus, Denmark, Greece, South Africa and Tunisia balancing declines in Australia, Austria, Germany, Israel, Italy, Poland and Switzerland.

The year was bright for solar district heating in Denmark, China and Germany, with 24 systems (totalling 196 megawatts-thermal, MW_{th}) newly commissioned. Successful development also generated interest elsewhere in Europe.

Record-high capacity additions of solar heat for industrial processes (SHIP), totalling 251 MW_{th}, also occurred during the year, led by Oman, China and Mexico. Parabolic trough collectors dominated new installations, and by year's end at least 817 SHIP systems (a cumulative total of more than 700 MW_{th}) were supplying process heat to factories worldwide. To reduce project development times and costs, system suppliers created mutually beneficial partnerships with conventional energy technology providers and with third-party financiers.

The ongoing transition from small residential systems to large commercial and industrial plants resulted in consolidation among collector manufacturers, as large players gained market share through contracts for large fields or high numbers of systems.

WIND POWER

The global wind power market saw its second largest annual increase, with offshore wind accounting for a record 10% of new installations.

The global wind power market expanded 19% in 2019 to 60 GW, the second largest annual increase, for a total of 650 GW (621 GW onshore and the rest offshore). The rapid growth was due largely to surges in China and the United States in advance of policy changes and to a significant increase in Europe, despite continued market contraction in Germany. New wind farms reached full operation in at least 55 countries, and by year's end at least 102 countries had some level of commercial wind power capacity.

While falling prices are opening new markets, the global transition to auctions and tenders has resulted in intense price competition. Poorly designed tenders, permitting delays and lack of available land and grid access are challenging wind developers in many countries and causing attrition among turbine manufacturers. The industry is working to meet new challenges with improved technologies and other advances to further reduce costs and better integrate wind energy into existing energy systems.

Offshore wind power is playing an increasingly important role and accounted for a record 10% of 2019 installations. Interest in hybrid projects, combining wind power with solar and/or energy storage, is increasing to reduce energy prices while mitigating impacts of variability and expanding revenue opportunities.

Wind energy accounted for an estimated 57% of Denmark's electricity generation in 2019, with high shares also in Ireland (32%), Uruguay (29.5%), Portugal (26.4%) and several other countries. Capacity in operation worldwide at year's end was enough to provide an estimated 5.9% of global generation.



04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS (DREA)

DREA systems have become an effective, established solution for providing energy access, and benefited some 150 million people around the world in 2019.

Worldwide, the number of people lacking access to electricity dropped to 860 million (11% of the global population) in 2018, and an estimated 2.65 billion people (35% of the global population) were living without clean cooking facilities that year. DREA systems are present in both urban and rural areas of the developing world and provide a wide range of services, including for lighting, appliances, cooking, space heating and cooling, and productive uses. They represent a key solution for fulfilling modern energy needs and enabling the livelihoods of hundreds of millions of people who still lack access to electricity or clean cooking solutions.

Since 2010, more than 180 million off-grid solar systems have been sold, including 150 million pico solar products and 30 million solar home systems. The market for off-grid solar systems grew 13% in 2019 – the highest growth of the past five years – with sales totalling some 35 million units, up from 31 million units in 2018. In addition, renewable energy (mostly hydropower) supplied, either entirely or partially, around half of the 19,000 mini-grids installed worldwide by the end of 2019. Solar PV and solar hybrid mini-grids continued to gain momentum as more projects were developed across Africa and Asia.

Biomass cook stoves, biogas and solar cookers, and electric stoves were being deployed and piloted in many developing countries. An estimated 125 million people worldwide used biogas for cooking in 2018, and by the end of 2019 more than 3.9 million solar cookers were estimated to have been distributed, providing clean cooking solutions to around 14 million people.

Corporate-level investments in the DREA sector totalled around USD 468 million in 2019, down 8.5% from 2018. At the same time, capital flows in mini-grid start-ups surged 126% to a record USD 113 million. Development finance institutions, international organisations, philanthropic foundations and non-state actors provided significant support to the DREA sector in many countries by addressing policy barriers, enhancing the enabling framework, and offering technical assistance and financing to governments and companies.



05 INVESTMENT FLOWS

Global investment in renewable energy capacity remained nearly flat in 2019, although more capacity was financed due to continuous falling capital costs.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) totalled USD 301.7 billion in 2019, up 5% from 2018. Including investments in hydropower projects larger than 50 MW, total new investment in renewable power and fuels was at least USD 316.7 billion. Global investment in renewable energy capacity has exceeded the USD 200 billion mark every year since 2010, reaching USD 282 billion in 2019.

Dollar investment in new renewable power capacity (including all hydropower) again far exceeded investment in coal, natural gas and nuclear power capacity in 2019, accounting for 75% of the total committed to new power generating capacity. Investment in renewables continued to focus on wind and solar power, with wind power outweighing solar PV for the first time since 2010. Asset finance of utility-scale projects, such as wind farms and solar parks, secured USD 230.1 billion during 2019. Investment in small-scale solar PV installations (less than 1 MW) increased 43.5% to USD 52.1 billion worldwide.

Developing and emerging economies outweighed developed countries in renewable energy capacity investment for the fifth year running, reaching USD 152 billion. Although capacity investment declined in both China and India, outside these two countries it rose 17% in developing countries to a record USD 59.5 billion. In parallel, renewable energy capacity investments in developed countries increased 2% to USD 130 billion.

Renewable energy investment varied by region, rising in the Americas, including the United States and Brazil, but falling in all other world regions including China, Europe, India, and the Middle East and Africa. Considering all financing of renewable energy capacity (but excluding hydropower larger than 50 MW), China again had the largest share (30%), followed by the United States (20%), Europe (19%) and Asia-Oceania (16%; excluding China and India). Smaller shares were seen in Africa and the Middle East (5%), the Americas (excluding Brazil and the United States, 4%), India (3%) and Brazil (2%).

Developing and emerging economies outweighed developed countries in renewable energy capacity investment for the fifth year running.

06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

Countries integrated more solar PV and wind power than ever through a range of measures, supported by expanding markets for heat pumps, EVs and energy storage.

Growth in renewable energy is transforming energy systems around the world. In the power sector in particular, rapid growth in the installed capacity and penetration of variable renewable electricity sources – such as solar PV and wind power – has occurred in many countries. In 2019, VRE produced an estimated 8.7% of global electricity, while all renewables met 27.3% of global generation.

Improving power system flexibility is central to advancing the integration of VRE. Power system flexibility is being enhanced through: strategic market design that rewards or promotes flexibility; direct procurement of flexibility services from sources of generation, demand and energy storage; improved forecasting of electricity demand and of VRE generation and demand; and the improvement of grid infrastructure to support VRE uptake.

Several technologies are supporting the integration of renewables by enabling greater flexibility in energy systems or by promoting the linking of energy supply and demand across electricity, thermal and transport applications. These include mature or commercialised technologies such as heat pumps, EVs and certain types of energy storage, and emerging energy storage technologies including renewable hydrogen.

The heat pump market has grown rapidly in recent years, driven largely by rising demand for cooling in emerging economies and by strong sales of reversible air conditioning units used for both cooling and heating. Notable activity in 2019 included investments by large technology companies in specialised heat pump firms, a focus on incremental cost and efficiency improvements, and the integration of heat pumps alongside renewables and energy storage using digital technologies.

The global stock of electric cars (passenger EVs) grew more than 40% in 2019, up more than 2 million from 2018. However, growth was lower than in 2018, when the global stock jumped 63% from the previous year. The global stock of two- and three-wheeled EVs reached some 251 million in 2019, while sales of electric buses declined for the fourth consecutive year. The EV industry in 2019 was characterised by diverse commitments and investments from both dedicated EV manufacturers and traditional automakers. VRE was increasingly available on EV charging networks.

The global market for energy storage of all types reached 183 GW in 2019. Around 0.3 GW of pumped (hydropower) storage was added in 2019, while the leading markets for battery storage had mixed results. Renewables-plus-storage has emerged as a major driver of battery market growth. The energy storage industry saw significant cost improvements, increased manufacturing capacity, large investments and ongoing R&D during 2019, with many of these activities focused on short-duration storage applications and battery technologies.

07 ENERGY EFFICIENCY AND RENEWABLES

Global energy intensity has continued to fall in recent years, and an integrated approach for advancing both renewables and energy efficiency remains crucial.

International efforts to meet energy demand in a safe and reliable manner generally acknowledge the complementary nature of renewable energy deployment and energy efficiency measures. Both renewables and efficiency can contribute significant benefits including lower energy costs on a national, corporate or household level, increased grid reliability, reduced environmental and climate impacts, improved air quality and public health, and increased jobs and economic growth. Coalitions of governments, corporations, institutions and non-governmental organisations have boosted global energy efficiency efforts, recognising the potential to greatly reduce greenhouse gas emissions.

Global primary energy intensity – the amount of energy used per unit of GDP – fell more than 10% between 2013 and 2018, although the annual improvement slowed over the period. The decline in energy intensity has been facilitated in part by the uptake of renewables, as the use of some sources of renewable power – particularly hydropower, solar PV and wind power technologies – lessens the amount of primary energy needed to meet final energy needs by reducing the overall transformation losses in generation. Meanwhile, improvements in final energy intensity reduce overall energy demand, and can enable the same renewable energy sources to supply a larger share of the world's final energy needs.

In member countries of the Organisation for Economic Co-operation and Development (OECD), final energy intensity improved 14% between 2007 and 2017; during this same period, consumption of renewable energy increased around 42%, while the share of modern renewables in TFEC rose 44%. In non-OECD countries, the improvement in final energy intensity was even greater during the decade (25%), but these countries also saw large increases in energy demand driven by rapid economic growth and improved energy access. As a result, while the absolute amount of renewable energy in TFEC grew at a higher rate in non-OECD countries than in OECD countries (68%), the share of renewables in TFEC in these countries increased to a lesser extent (29%).

In buildings, total energy demand continued to increase steadily despite energy efficiency improvements, due primarily to increasing population and incomes. Energy demand for transport also surged during 2000-2018 and has far exceeded the effect of greater vehicle efficiency. Energy demand in industry has grown only slightly in recent years, mitigated by structural changes as well as by greater energy efficiency.

08 FEATURE: PUBLIC SUPPORT FOR RENEWABLES

Public support for renewables has expanded in general, although some individual projects have faced opposition. Governments are using a diverse range of levers to increase support for renewables.

The views of local communities are a key factor in the uptake of renewables but are only one part of the broader social acceptance of renewables. A number of complex factors can influence the public's reactions towards local or regional renewable energy projects, including perceptions of health and environmental impacts; perceptions of the distribution of economic costs and benefits; and the perceived fairness of the consenting process.

Opinion polls have consistently indicated strong public support for the expansion of renewables, due in part to the multiple benefits that these technologies provide. However, some individual renewable energy projects have faced opposition from local host communities. This creates an apparent "social gap" between strong overall support for renewables at the societal level and disapproval with specific proposed projects at the local level.

At a societal level, climate protests and litigation often are aligned with implicit support for renewable energy – such as the strikes and protests during 2019 involving millions of people across 150 countries demanding political action on climate change. On the other hand, perceptions of unfairness or a lack of transparency can lead the public to oppose policies intended to support an energy transition, such as in France, where protests emerged in late 2018 against government energy policies that disproportionately impacted lower-income households.

At the local level, movements for energy sufficiency and conservation have spread around the world, and the numbers of both community renewable energy projects and prosumers continue to increase. At the same time, host communities may oppose certain forms of infrastructure development including renewables because of the perceived impacts on the character of a neighbourhood or landscape.

Governments have sought to build public support through a wide range of measures, including public awareness campaigns, such as Mauritius' campaign to increase the presence of women in the renewable energy sector. Other popular measures include improving public participation in the development and procurement of renewable energy, which often is encouraged through the development of feed-in tariff schemes, peer-to-peer models and prosumer community groups.

Many governments have looked to share the economic benefits of renewables with host communities by establishing Just Transition Funds and by developing more "passive" forms of financial participation, such as community benefits packages and option-to-purchase share schemes. Some governments also have started to engage with the concept of energy democracy by requiring greater public participation in the project planning process for renewables. For example, developers of solar and hydropower plants in Kazakhstan and Tajikistan were required to consult with communities as part of their Stakeholder Engagement Plans.



Governments can
build citizen support
for renewables through a wide range of measures.

01



CLIMATE EMERGENCY DECLARATIONS AROUND THE WORLD



Climate emergency declarations have been made in 1,480 jurisdictions spanning 28 countries, and many have coincided with new policies to further renewable energy development. In 2016, Darebin Council in Australia became the first government in the world to declare a climate emergency, and it also developed a climate emergency plan emphasising the role of renewables in reducing emissions. In 2019, the United Kingdom became the first country to declare a climate emergency, legally committing to net zero emissions by 2050 by increasing the use of renewables, among other measures.

01 GLOBAL OVERVIEW

The *Renewables 2020 Global Status Report (GSR)* focuses on developments in renewable energy in 2019.

The emergence and rapid spread of COVID-19 that began in late 2019 had turned into a global pandemic by early 2020, creating a global health and economic crisis. This also affected the energy sector across the globe. Considering the importance of these impacts, developments from the first half of 2020 are presented briefly in this chapter.¹ (→ See *Sidebar 1*.) A more comprehensive overview of the impacts of the COVID-19 crisis on the renewable energy sector will be included in later editions of the GSR.

KEY FACTS

- Renewable energy grew three times faster than fossil fuels and nuclear over a five-year period, but accounted for less than one-third of the increase in total final energy demand.
- The largest advances have been in the power sector (in both capacity and generation), while significantly less progress has occurred in heating, cooling and transport.
- Renewables continued to meet low shares of final energy demand in the buildings, industry and transport end-use sectors, where support policy remained crucial to spurring uptake, yet was lacking.

Renewable energy had another record-breaking year in 2019, as installed power capacity grew more than 200 gigawatts (GW) (mostly solar photovoltaics, PV) – its highest increase ever. As in previous years, government policy was a main driver of both the growth and decline of renewable energy markets. Meanwhile, capacity installations and investment continued to spread to all corners of the world, and the private sector signed power purchase agreements (PPAs) for a record amount of renewable power capacity, driven in large part by ongoing cost reductions in some technologies. (→ See *Table 1*.)

Wind and solar energy have become mainstream electricity sources and are increasingly cost-competitive with fossil fuel power plants. Nearly everywhere in the world, producing electricity from new renewables is more cost effective than producing it from new coal-fired power plants.² In a growing number of regions, including parts of China, the European Union (EU), India and the United States, it has become cheaper to build new wind or solar PV plants than to operate existing coal-fired power plants.³ Renewables also are outcompeting new natural gas-fired power plants on cost in many locations, and are the cheapest sources of new electricity generation in countries across all continents (excluding Antarctica).⁴ (→ See *Sidebar 5*.)

Although several key countries and regions, such as China, Europe and the United States, have driven these trends and continued to have a large impact in 2019, **renewable power is growing in all corners of the world**. Globally, 32 countries had at least 10 GW of renewable power capacity in 2019, up from only 19 countries a decade earlier.⁵ In some countries, the share of renewables in heating, cooling and transport also has grown, although these sectors continue to lag far behind globally.

As in previous years, the use of renewables in the transport sector grew only slightly, and uptake of modern renewables for heating and cooling progressed at a slow pace. Although biofuels continue to dominate the renewable energy contribution in transport, the global stock of electric vehicles (EVs) has grown significantly, increasing opportunities to integrate renewables in road transport. The global market share of EVs remains low overall, however. Electrification of heating in buildings (and to some extent in industry) is garnering policymaker attention, but overall the uptake of renewables in buildings, industry and transport remains constrained by insufficient policy support and by slow developments in new technologies (such as advanced biofuels).

Actors at the local level are having a substantial impact on the uptake of renewable energy. Cities are responsible for many local policies and services that impact the uptake of renewables, especially in buildings and transport. Often, local governments set more ambitious targets and implement more ambitious policies than their national counterparts. (→ See Box 1.) Among the general public, a global consensus on support for renewable energy continued to advance in 2019 alongside rising awareness of the multiple benefits of renewables, such as improved public health through reduced pollution, increased reliability and resilience, mitigating climate change, increased access to modern energy services, reduction of energy poverty and job creation.⁶ (→ See Sidebar 2 and Feature chapter.)

The private sector is purchasing more and more renewable electricity. Corporate sourcing of renewable power set a record in 2019, with nearly 20 GW of PPAs signed in 23 countries during the year.⁷ This accounted for around 40% of the 50 GW of PPAs signed by firms over the previous decade.⁸ Most of the 2019 activity was in the United States, as Google became the world's largest corporate buyer of renewable power, adding 2.7 GW throughout the year.⁹ Corporate sourcing of renewables also continued to rise in Europe and to spread in other countries worldwide.¹⁰ By early 2020, more than 229 leading global corporations had joined the RE100 initiative – committing to using 100% renewable power – up from 167 corporations a year before.¹¹ (→ See Box 3 in Policy Landscape chapter.)

Despite an increase in final energy demand, global **energy-related carbon dioxide (CO₂) emissions** did not grow in 2019, following two years of increases.¹² This flattening was due mainly to declines in emissions from the power sector in some countries, which were related mostly to improvements in energy efficiency and to rising shares of renewable energy, but also to some extent to fuel switching from coal to gas.¹³

SIDEBAR 1. The COVID-19 Crisis and Renewable Energy

As governments worldwide instituted lockdowns in 2020 to slow the spread of the novel coronavirus (COVID-19) and to respond to the resulting global health crisis, economies ground to a halt and energy demand plummeted. Amid the pandemic, oil prices also tumbled due to recent dynamics in the global oil market.

Data for countries representing more than one-third of global electricity demand showed that every month of full lockdown reduced electricity demand 20% on average. Global electricity demand decreased 2.5% in the first quarter of 2020, and demand for coal and oil fell nearly 8% and 5% respectively. Renewables were the only source of electricity to record demand growth over this period, due to low operating costs and preferential access to electricity networks.

The carbon intensity of electricity systems also dropped, and cities across the globe benefited from unusually high air quality. Nonetheless, the concentration of CO₂ in the atmosphere continued to rise to record levels even as emissions decreased, highlighting that a structural shift would still be necessary to reach long-term climate and development targets.

The crisis has had immediate implications for the entire renewable energy sector, from network operators facing unprecedented shares of renewable energy generation, to project developers hit by labour and supply chain disruptions. The long-term impacts of the crisis will depend on a multitude of complex and interlinked factors, including the response of governments, markets and societies.

Electricity networks in major markets were able to accommodate huge changes in the energy mix as of mid-2020, despite the challenges of maintaining operations amid social distancing rules. The share of supply met by renewables reached historic highs in China, Europe, India and the United States. In China, thermal power generation dropped 9% in January and February, whereas wind and solar power generation increased 1% and 12% respectively. In the EU and the United Kingdom, coal-based power generation fell 29% between 10 March and 10 April, while renewables delivered 46% of all power generation, up 8% compared to 2019.

Operators in a few regions curtailed renewable power generation in the face of structural challenges: limited options for storing or exporting excess generation; reduced demand-side flexibility as industrial plants went offline; and inaccurate load forecasts owing to a lack of historical data on electricity demand during a pandemic.

Project developers have faced significant labour shortages and supply chain disruptions, although the impacts vary by technology and region. Solar PV projects stalled amid factory closures in China, which accounted for 70% of global module supply as of early 2020, and large job losses were reported by companies reliant on residential installations.

Impacts to the onshore wind power supply chain raised the possibility that *force majeure* clauses would be invoked to stop work on projects, triggering a chain reaction that reverberated across the sector. Although the majority of European wind turbine and component factories continued to operate, supplies of components and materials from China were interrupted, and a number of turbine manufacturers withdrew their earnings guidance for investors. Offshore wind power was largely unaffected in the short term, as most projects were in the late stages of construction as of mid-2020.

To ensure that such delays did not cause developers to miss deadlines for financial support and tax credits, some governments moved quickly to extend deadlines for such policies.

Distributed renewables for energy access (DREA) systems proved invaluable in many rural and remote communities during the early phases of the pandemic, powering health facilities and other essential services. However, measures to contain the virus imperiled projects and the future of the sector, leading to calls to recognise DREA as an “essential service”, to fast-track procurement and funding procedures, and to establish relief funding.

Suppliers faced difficult choices in relation to power purchase agreements, risking cash-flow shortages if they continued to pay generators under existing PPAs, while delayed payments would expose them to potential legal action in the future. At the same time, some developers signalled that they would be hesitant to negotiate new PPAs while power prices were unusually low.

Analysts widely expected an **economic recession** to follow the immediate health crisis, placing pressure on public and private budgets that could affect investment in renewables. There already was an unprecedented downturn in stock markets and a reduction in the availability of credit, and lenders began requesting more granular detail on new renewable energy projects in the face of uncertainty about future demand. Renewable energy technologies that compete against fossil fuels also were under pressure from low oil and gas prices. The capacity of developers to cope with such short-term shocks varies – those with strong balance sheets have been able to absorb additional costs, while others face cash-flow shortages.

As the focus has shifted **from rescue to recovery**, governments have considered options for “building back better”. A

comprehensive study of fiscal recovery packagesⁱⁱ concluded that “green” recovery measures, such as investment in renewables and building efficiency, are more cost effective than traditional stimulus measures, creating more jobs and delivering higher returns. Renewable energy also offers a range of other proven benefits, including increasing energy security, reducing emissions and improving human health.

Calls for a **“green recovery”** have gained momentum, with a broad coalition of actors from all corners of society advocating an ambitious stimulus package that: prioritises renewable energy, energy efficiency, grid modernisation and resource-efficient transport; makes bailouts for emissions-intensive industries conditional on emissions reductions; promotes “green finance”; and puts a price on carbon.

- i A term adopted by the international community in the Sendai Framework for Disaster Risk Reduction 2015-2030.
- ii The study considered 700 stimulus responses to the 2008 financial crisis and surveyed 231 central bank officials, finance ministry officials and other economic experts from G20 countries on the relative performance of 25 major fiscal recovery archetypes.

Source: See endnote 1 for this chapter.



Momentum for renewable energy continued to build in 2019. Governments and businesses alike made additional commitments and showed increased ambition. More actors also showed support for renewables and took action to tackle climate change, which often directly or indirectly supports renewable energy uptake. Notable developments during the year included:

- Climate strikes – driven by young people – took place in at least 150 countries worldwide, reflecting a growing sense among youth of the urgency of action on climate change.¹⁴ By year's end, 1,480 jurisdictions – spanning 28 countries and covering 820 million citizens – had issued “climate emergency” declarations.¹⁵ In parallel, opinion polls across several countries demonstrated increased awareness of climate change and strong public support for renewable energy.¹⁶
- More institutions committed to divestingⁱ either fully or partially from fossil fuels, including the European Investment Bank, Norway's sovereign wealth fund and the US investment bank Goldman Sachs.¹⁷ Combined, global divestment totalled USD 11 trillion of managed assets by year's end.¹⁸ Meanwhile, the first major divest-invest conference in the Global South was held with delegates from more than 44 countries.¹⁹
- The G5 Sahel heads of state endorsed Desert to Power, an initiative by the African Development Bank that aims to guarantee access to renewable electricity in 11 African countries in the Sahel region.²⁰
- Globally, 77 countries, 10 regions and more than 100 cities announced their commitment to net zero carbonⁱⁱ emissions by 2050, and the European Commission proposed a European Green Deal roadmap to create the first carbon-neutral continent by 2050.²¹
- The Zero Carbon Buildings for All Initiative, launched in 2019 at the United Nations Climate Action Summit, aims to develop decarbonisation roadmaps for buildings and to mobilise USD 1 trillion in funding by 2050.²² In the maritime industry, leaders launched the Getting to Zero Coalition with the objective of operating zero emission vessels along deep-sea trade routes by 2030.²³
- More than half of the countries that have submitted Nationally Determined Contributions (NDCs) towards reducing greenhouse gas emissions under the Paris Agreement have noted interest in implementing a carbon tax; however, by year's end carbon pricing initiatives were in place in only 47 countries around the world, covering 20% of global emissions.²⁴ Furthermore, although 132 NDC plans mentioned renewables in the context of the power sector and 112 mentioned energy efficiency, only 25 plans mentioned renewable energy in the context of heating and cooling, and 25 in the context of transport.²⁵

■ Several cities adopted commitments to reduce greenhouse gas emissions, including 94 mayors who announced their support for a Global Green New Deal for cities, committing to limiting global warming to 1.5 degrees Celsius (°C) above pre-industrial levels.²⁶ As of mid-year, nearly 10,000 cities and local governments had committed to jointly reducing emissions through the Global Covenant of Mayors for Climate & Energy.²⁷

77 countries, 10 regions and more than 100 cities announced their commitment to net zero carbon emissions by 2050.

Investment in renewable energy again grew in 2019, albeit slowly, and much more investment flowed to renewable power technologies than to other electricity-generating technologies, including coal, natural gas and nuclear power generating plants.²⁸ Overall, global new investment in renewable power and fuels grew 2% compared to 2018 – as costs continued to decrease – reaching some USD 301.7 billion.²⁹ Wind and solar power accounted for nearly all of this investment; notably, investment in wind power outweighed investment in solar power for the first time since 2009.³⁰

China and other developing and emerging economies accounted for a higher share of total renewable energy investment than developed countries for the fifth consecutive year, and China again had the highest total investment despite a decrease for the second year in a row.³¹ (→ See *Investment chapter and Table 2*.) Several small-island developing states – such as Dominica, Nauru and the Solomon Islands – invested equivalent or higher amounts in renewable power and fuels than developed countries on a per gross domestic product (GDP) basis.

The growing trend among major energy companies to invest in renewable energy highlights both the cost-competitiveness and public appeal of renewables. The world's largest oil and gas companies continued to invest in the renewable energy sector in 2019 (as well as to acquire companies already active in the sector) and to invest in enabling technologies such as electric mobility.³² Many electric utilities also have made commitments to shift their electricity production to 100% renewable. (→ See *Power section in this chapter*.)

Even so, major fossil fuel companies still invested heavily in oil and gas extraction projects, and only a minor share of their overall investments goes to the renewable energy sector, with some companies expected to miss their own “green energy” investment targets.³³ In addition, these companies and the coal industry continued to spend upwards of USD 200 million

i Divestment indicates making binding commitments to exclude any fossil fuel company (coal, oil and natural gas) from either all or part of their managed asset classes, or to selectively exclude companies that derive a large portion of their revenue from coal and/or tar sands companies.

ii Net zero carbon emissions and carbon neutrality refer to the achievement of a state in which every tonne of CO₂ emitted to the atmosphere is compensated by an equivalent tonne removed (e.g., sequestered). In the case of carbon neutrality, emissions can be compensated by carbon offsets. See Glossary and K. Levin, J. Song and J. Morgan, “COP21 glossary of terms guiding the long-term emissions-reduction goal”, World Resources Institute, 2 December 2015, <https://www.wri.org/blog/2015/12/cop21-glossary-terms-guiding-long-term-emissions-reduction-goal>.

annually on lobbying to delay, control or block climate change and renewable energy policies, and on advertisements to influence public opinion.³⁴

Distributed renewable energy systems continued to provide remote households with access to electricity and clean cooking services in developing and emerging countries. In 2018, around 171 million people had access to electricity through solar PV lighting, solar home systems and renewable-based mini-grids.³⁵ The global population without access to electricity continued to shrink, although 860 million people (11% percent of the world's population) still lacked electricity access in 2018, nearly 70% of them in sub-Saharan Africa.³⁶

Countries adopting integrated planning – an approach to electrification that includes grid extension, mini-grids and solar home systems – have achieved faster results in electricity access; in recent years, Bangladesh, Cambodia, India, Kenya, Myanmar, Nepal, Rwanda and Tanzania experienced the most rapid gains in electrification.³⁷ In parallel, an estimated 450 million people gained access to cleanⁱ cooking fuels and technologies between 2010 and 2018, although primarily using liquefied petroleum gas (LPG).³⁸ In 2018, the global population lacking access to clean cooking remained unchanged at around 2.6 billion people.³⁹ (→ See *Distributed Renewables* chapter.)

i The GSR refers to clean and/or efficient cook stoves or fuels as per the methodology of the Multi-Tier Framework. See endnote 38 for this chapter.

BOX 1. Renewable Energy in Cities

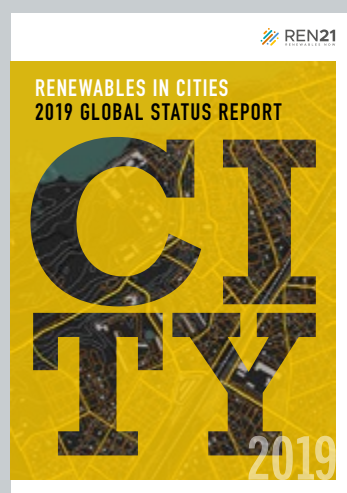
Cities play an important role in the effort to address climate, energy and sustainable development issues. They account for around two-thirds of global final energy use and some three-quarters of global CO₂ emissions. At the same time, local governments have a direct impact on the daily lives of their citizens, such as through urban planning decisions or providing urban services, including public housing, waste and wastewater management, and public transport. They are well positioned not only to grow the use of renewable energy in municipal operations, but also to encourage and support the deployment and use of renewables in cities more broadly. Thus, cities can play a major role in advancing the transition towards renewable energy in the heating and cooling and transport sectors, to accelerate deployment in the power sector, and to foster the integrated approaches needed to decarbonise energy use in all sectors.

Globally, thousands of cities have adopted renewable energy-specific targets and action plans, and by mid-2019 more than 250 cities worldwide had targets for 100% renewable energy, not only for the power sector, but also covering heating and cooling, and transport. To achieve these targets, many cities have adopted renewable energy (and energy efficiency) measures for buildings, for example through financial and fiscal incentives for the installation of solar PV or geothermal systems. Cities also can link the development of renewables with other urban services, such as by using waste and wastewater to produce biogas and biomethane, simultaneously improving waste management and supporting the local production and use of renewables. As the electrification of transport gains momentum, some cities are facilitating the integration of

EVs and renewable power supply, installing EV charging stations or public transport infrastructure that relies on renewable electricity.

Renewable energy deployment in cities is often part of wider urban strategies to develop infrastructure, while at the same time achieving local objectives such as reducing air pollution to improve public health, mitigating climate change, creating jobs, supporting the local economy and building resilient infrastructure.

REN21's *Renewables in Cities Global Status Report* series is establishing continuous and reliable data on urban renewable energy developments in order to create a clearer and more comprehensive picture of renewables in cities around the world. (→ See <https://www.ren21.net/cities>.)



Despite the growing deployment of renewable energy around the world, the share of renewables in **total final energy consumption** (TFEC) has seen only a moderate increase. As of 2018ⁱ, modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11% of TFEC, only a slight increase from 9.6% in 2013.⁴⁰ The largest portion was renewable electricity (5.7% of TFEC), followed by renewable heat (4.3%) and transport biofuels (1.0%).⁴¹ (→ See Figure 1.)

The slow increase in the share of renewables has occurred despite tremendous growth in some renewable energy sectors. Total demand for modern renewables grew strongly (7.3 exajoules, EJ) between 2013 and 2018, rising around 4.0% annually.⁴² Nearly half of this growth (48%) was due to consumption of electricity from wind power and solar PV.⁴³ During the 2013-2018 period, TFEC grew 25.3 EJ, or around 1.4% annually.⁴⁴ Thus, renewable energy increased at nearly three times the rate of TFEC, accounting for 29% of the total increase in energy demand.⁴⁵

However, this means that other energy sources (predominantly fossil fuels, growing at a rate of 1.3% annually) accounted for 71% of the total increase in energy demand, highlighting the challenge that renewables faced in gaining greater TFEC shares during

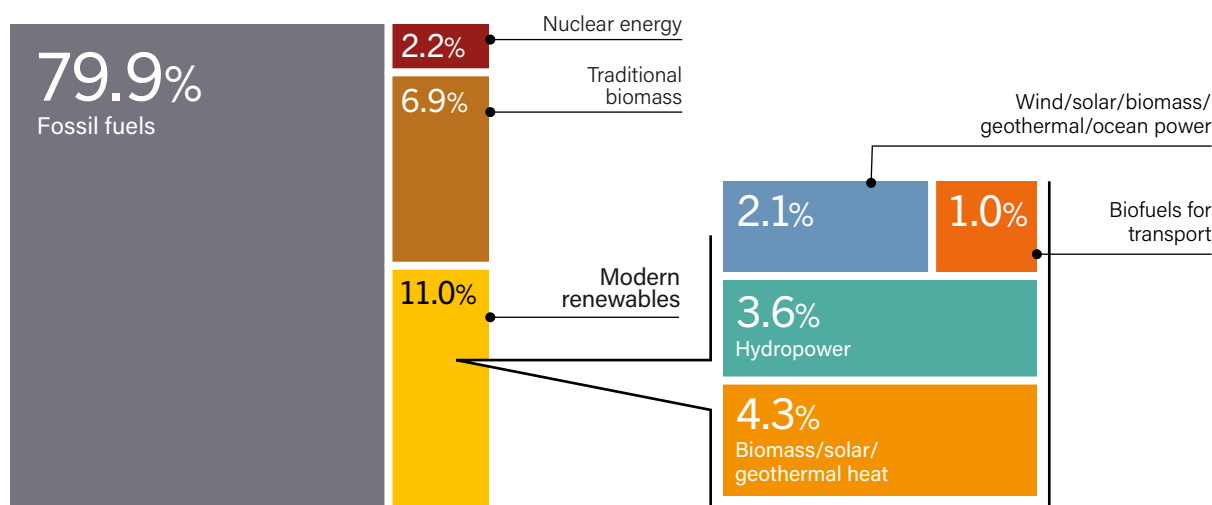
the five-year period.⁴⁶ (→ See Figure 2.) This slow progress points to the complementary roles of energy efficiency and renewables in reducing the contributions of fossil fuels in meeting global energy needs.

The share of renewables in final energy demand varies depending on how this energy is used. The highest share of renewable energy use is in the power sector (excluding electricity for heating, cooling and transport), such as lighting and appliances in buildings, where it continues to grow quickly.⁴⁷ However, these end-uses accounted for only 17% of TFECⁱⁱ in 2017.⁴⁸ Energy use for transport represented some 32% of TFEC, and had the lowest share of renewables (3.3%).⁴⁹ The remaining thermalⁱⁱⁱ energy uses, which include space and water heating, space cooling and industrial process heat, accounted for more than half (51%) of TFEC; of this, some 10.1% was supplied by renewables.⁵⁰ (→ See Figure 3.)

Modern renewable energy accounted for **only 11%** of total final energy consumption in 2018.

i At the time of publication, global data for TFEC and the contribution of energy sources to meet energy demand were available for the year 2017; values for 2018 are estimates. See Methodological Notes for more information.
 ii Electricity generation still accounts for a far greater portion of primary energy consumption. See Glossary for definitions.
 iii Applications of thermal energy include space and water heating, space cooling, refrigeration, drying and industrial process heat, and any use of energy other than electricity that is used for motive power in any application other than transport. In other words, thermal demand refers to all end-uses of energy that cannot be classified as electricity demand or transport.

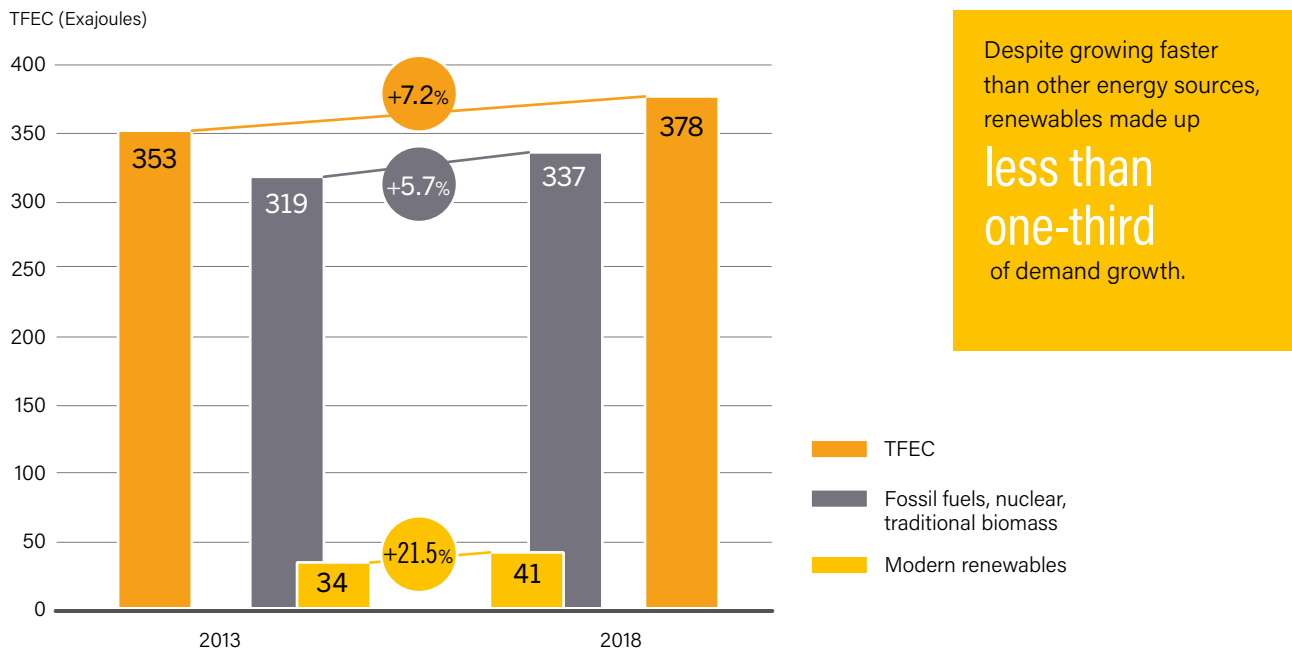
FIGURE 1. Estimated Renewable Share of Total Final Energy Consumption, 2018



Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Totals may not add up due to rounding.

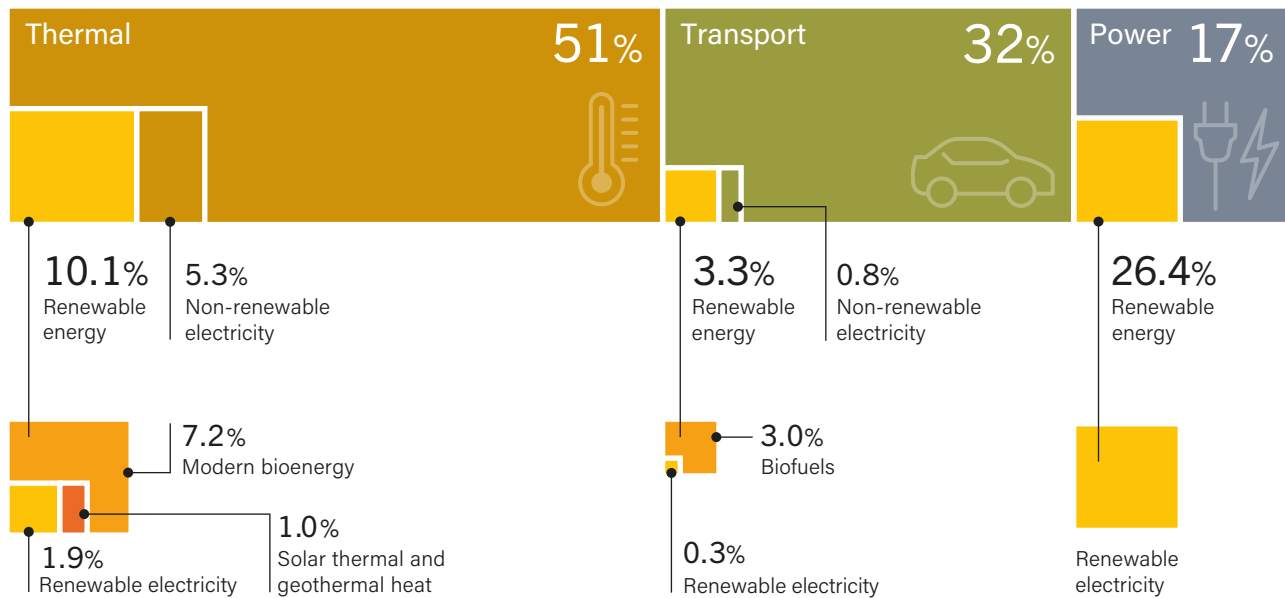
Source: Based on IEA data. See endnote 41 for this chapter.

FIGURE 2. Estimated Global Growth in Renewable Energy Compared to Total Final Energy Consumption, 2013-2018



Source: Based on IEA data. See endnote 46 for this chapter.

FIGURE 3. Renewable Share of Total Final Energy Consumption, by Final Energy Use, 2017



Note: Data should not be compared with previous years because of revisions due to improved or adjusted methodology.

Source: Based on IEA data. See endnote 50 for this chapter.



A key reason for the low penetration of renewables in the final end-uses of thermal and transport energy is the lack of supporting policies in these sectors. Renewable energy **targets** are in place in nearly all countries, and the number of renewable energy **support policies** again increased in 2019, mostly for renewable electricity. However, the number of countries with mandates for renewable heat did not grow, and policy examples for renewable energy support in industry remained scarce. No new countries added regulatory incentives or mandates for renewable transport, although some countries that already had mandates added new ones or strengthened existing ones. Only one country (Austria) had a policy directly linking renewables and EVs by year's end.⁵¹ (→ See *Policy Landscape* chapter.)

Conversely, policies and targets at the sub-national level tend to be more ambitious and often are more integrated than those at the national level.⁵² In addition, the renewable energy sector is greatly influenced by trade policy: a growing number of protectionist measures in recent years has restrained the growth in trade in renewable energy products. (→ See *Sidebar 3*.)

Another challenge to increasing the share of renewables has been persistent subsidies for fossil fuel consumption and production. Global **subsidies** for the consumption of fossil fuels reached an estimated USD 400 billion in 2018, a 30% increase from the previous year.⁵³ For context, this is more than double the estimated support for renewable power generation.⁵⁴ Whether supported by subsidies or not, low prices for fossil fuels encourage further demand for these fuels and challenge renewable energy markets.⁵⁵ The true cost to society of fossil fuels is an estimated USD 5.2 trillion, including the estimated costs of negative externalities such as air pollution, effects of climate change and traffic congestion.⁵⁶

In many countries, investment in new fossil fuel production and related infrastructure continued. While some countries were phasing out coal, others invested in new coal-fired power plants, both domestically and abroad. Many coal-fired plants announced closures in Europe and the United States, whereas most of the still-operating and new plants were located in developing and emerging Asia.⁵⁷ Public finance from China funded by far the largest amount of coal capacity in other countries, followed by funding from Japan, the Republic of Korea, France, Germany and India, nearly all of which was directed towards developing and emerging countries.⁵⁸ Funding from private banks for fossil fuel projects also has increased annually since the signing of the Paris Agreement in 2015, totalling USD 2.7 trillion between 2016 and 2019.⁵⁹ Conversely, the European Investment Bank announced in 2019 that it would stop funding fossil fuel projects beginning in 2021.⁶⁰














Although energy-related greenhouse gas emissions remained stable in 2019, **the world is not on track** to limit global warming to well below 2 °C, let alone 1.5 °C, as stipulated in the Paris Agreement. Moreover, the annual review of the United Nations' (UN) Sustainable Development Goal 7 (SDG 7) reiterated that the objectives for renewables, energy efficiency and energy access for 2030 will not be achieved unless efforts are greatly scaled up. Global climate protests have underlined the growing public pressure for political action, but the annual UN climate conference held in Madrid, Spain in December 2019 concluded without any meaningful agreement.⁶¹ The UN later announced that the 2020 meeting would be postponed, thus increasing the uncertainty about when such agreement would be reached.⁶²

The following sections discuss key developments and trends in renewable energy in 2019 in the sectors of buildings, industry and transport, followed by a discussion on renewable power capacity and renewable electricity generation.

Although energy-related CO₂ emissions were stable in 2019, the world is **not on track** to limit global warming to 2°C.



■ Table 1. Renewable Energy Indicators 2019

		2018	2019
INVESTMENT			
New investment (annual) in renewable power and fuels ¹	billion USD	296.0	301.7
POWER			
Renewable power capacity (including hydropower)	GW	2,387	2,588
Renewable power capacity (not including hydropower)	GW	1,252	1,437
 Hydropower capacity ²	GW	1,135	1,150
 Wind power capacity	GW	591	651
 Solar PV capacity ³	GW	512	627
 Bio-power capacity	GW	131	139
 Geothermal power capacity	GW	13.2	13.9
 Concentrating solar thermal power (CSP) capacity	GW	5.6	6.2
 Ocean power capacity	GW	0.5	0.5
HEAT			
 Modern bio-heat demand (estimated) ⁴	EJ	13.9	14.1
 Solar hot water demand (estimated) ⁵	EJ	1.4	1.4
 Geothermal direct-use heat demand (estimated) ⁶	PJ	384	421
TRANSPORT			
 Ethanol production (annual)	billion litres	111	114
 FAME biodiesel production (annual)	billion litres	41	47
 HVO biodiesel production (annual)	billion litres	6.0	6.5
POLICIES⁷			
Countries with renewable energy targets	#	169	172
Countries with renewable energy policies	#	158	161
Countries with 100% renewable energy in primary or final energy targets	#	1	1
Countries with 100% renewable heating and cooling targets	#	1	1
Countries with 100% renewable transport targets	#	1	1
Countries with 100% renewable electricity targets	#	57	61
Countries with heat regulatory policies	#	23	23
Countries with biofuel blend mandates ⁸	#	70	70
Countries with feed-in policies (existing)	#	87	87
Countries with feed-in policies (cumulative) ⁹	#	113	113
Countries with tendering (held during the year)	#	48	41
Countries with tendering (cumulative) ⁹	#	98	109

¹ Data are from BloombergNEF and include investment in new capacity of all biomass, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately; all ocean power projects; and all biofuel projects with an annual production capacity of 1 million litres or more. Total investment values include estimates for undisclosed deals as well as company investment (venture capital, corporate and government research and development, private equity and public market new equity).

² The GSR strives to exclude pure pumped storage capacity from hydropower capacity data.

³ Solar PV data are provided in direct current (DC). See Methodological Notes for more information.

⁴ Includes bio-heat supplied by district energy networks and excludes the traditional use of biomass. See Reference Table R1 and related endnote for more information.

⁵ Includes glazed (flat-plate and vacuum tube) and unglazed collectors only. The number for 2019 is a preliminary estimate.

⁶ The estimate of annual growth in output is based on a survey report published in early 2020. The annual growth estimate for 2019 is based on the annualised growth rate in the five-year period since 2014. See endnote 64 in Geothermal section of Market and Industry chapter.

⁷ A country is counted a single time if it has at least one national or state/provincial target or policy. See Table 3 and Reference Tables R3-R12.

⁸ Biofuel policies include policies listed both under the biofuel obligation/mandate column in Table 3 and in Reference Table R10.

⁹ Data reflect all countries where the policy has been used at any time up through the year of focus at the national or state/provincial level. See Reference Tables R11 and R12.

Note: All values are rounded to whole numbers except for numbers <15, biofuels and investment, which are rounded to one decimal point. Totals may not add up due to rounding. FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil.

■ Table 2. Top Five Countries 2019

Annual Investment / Net Capacity Additions / Production in 2019

Technologies ordered based on total capacity additions in 2019.

	1	2	3	4	5
Investment in renewable power and fuels capacity (not including hydropower over 50 MW)	China	United States	Japan	India	Chinese Taipei
☀ Solar PV capacity	China	United States	India	Japan	Vietnam
🌬 Wind power capacity	China	United States	United Kingdom	India	Spain
💧 Hydropower capacity	Brazil	China	Lao PDR	Bhutan	Tajikistan
🔥 Geothermal power capacity	Turkey	Indonesia	Kenya	Costa Rica	Japan
☀ Concentrating solar thermal power (CSP) capacity	Israel	China	South Africa	Kuwait	France
☀ Solar water heating capacity	China	Turkey	India	Brazil	United States
🍷 Ethanol production	United States	Brazil	China	India	Canada
🍷 Biodiesel production	Indonesia	United States	Brazil	Germany	France

Total Capacity or Generation as of End-2019

Countries in **bold** indicate change from 2018.

	1	2	3	4	5
POWER					
Renewable power capacity (including hydropower)	China	United States	Brazil	India	Germany
Renewable power capacity (not including hydropower)	China	United States	Germany	India	Japan
Renewable power capacity <i>per capita</i> (not including hydropower) ¹	Iceland	Denmark	Sweden	Germany	Australia
🍷 Bio-power capacity	China	United States	Brazil	India	Germany
🔥 Geothermal power capacity	United States	Indonesia	Philippines	Turkey	New Zealand
💧 Hydropower capacity ²	China	Brazil	Canada	United States	Russian Federation
💧 Hydropower generation ²	China	Brazil	Canada	United States	Russian Federation
☀ Solar PV capacity	China	United States	Japan	Germany	India
☀ Concentrating solar thermal power (CSP) capacity	Spain	United States	Morocco	South Africa	China
🌬 Wind power capacity	China	United States	Germany	India	Spain
HEAT					
☀ Solar water heating collector capacity ³	China	United States	Turkey	Germany	Brazil
☀ Solar water heating collector capacity <i>per capita</i>	Barbados	Cyprus	Israel	Austria	Greece
🔥 Geothermal heat output ⁴	China	Turkey	Iceland	Japan	New Zealand

¹ Per capita renewable power capacity (not including hydropower) ranking based on data gathered from various sources for more than 70 countries and on 2018 population data from the World Bank.

² Country rankings for hydropower capacity and generation can differ because some countries rely on hydropower for baseload supply whereas others use it more to follow the electric load to match peaks in demand.

³ Solar water heating collector rankings for total capacity and per capita are for year-end 2018 and are based on capacity of water (glazed and unglazed) collectors only. Data are from International Energy Agency Solar Heating and Cooling Programme. Total capacity rankings are estimated to remain unchanged for year-end 2019.

⁴ Not including heat pumps. Data are from 2015.

Note: Most rankings are based on absolute amounts of investment, power generation capacity or output, or biofuels production; if done on a basis of per capita, national GDP or other, the rankings would be different for many categories (as seen with per capita rankings for renewable power not including hydropower and solar water heating collector capacity).

BUILDINGS

The buildings sector consumes around one-third of final energy and releases some 28% of global energy-related CO₂ emissions.⁶³ Energy use in the sector is growing at around 1% per year, as global increases in both population and the building floor area continue to overcome any reductions in demand resulting from energy efficiency measures.⁶⁴ Renewable energy is the fastest growing source of energy for buildings, yet in 2017 it met less than 14% of total energy demand in the sector.⁶⁵ (→ See Figure 4.) Energy efficiency remains critical for curbing demand and for increasing the share of renewables in final energy consumption in buildings.⁶⁶ (→ See *Energy Efficiency* chapter.)

Around 77% of global final energy demand in buildings in 2017 was for **heating and cooling** end-uses, including space heating and cooling, water heating and cooking.⁶⁷ Total heating and cooling demand has grown slowly (0.6% annually since 2010), although energy used for cooling (around 6% of building energy consumption) – the fastest growing energy end-use in buildings – rose 4% per year between 2010 and 2018.⁶⁸ The remaining final energy demand in buildings (23% in 2017) is for **electrical end-uses**ⁱ, including lighting and appliances.⁶⁹ Global electricity use in buildings rose moderately during 2010-2018, at more than 2% per year.⁷⁰

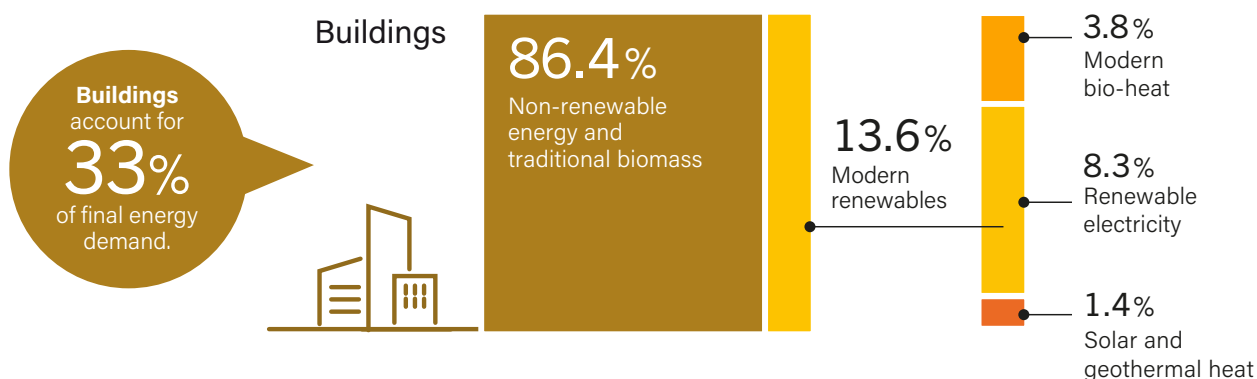
Overall, energy for heating and cooling remains highly dependent on fossil fuels. In 2018, modern renewables contributed an estimated 10.1% of heating and cooling demand in buildings, up from 8% in 2010.⁷¹ (→ See Figure 5.) Most of this increase was due to growth in renewable electricity for heat and in solar thermal, while the share of modern bioenergy remained stable.⁷²



i This includes electricity for heating and cooling. The GSR considers all electricity used for heating and cooling to contribute to the final heating and cooling demand in each end-use sector, rather than to the respective final electricity demand. In order to determine total electricity consumption, demand of electrical end-uses and electricity for heating and cooling should be summed. See Methodological Notes for more information.

ii This does not account for the large amount of energy used to generate electricity, the majority of which is lost as heat. See Energy Efficiency chapter.

FIGURE 4. Renewable Share of Total Final Energy Consumption in Buildings, 2017



Note: Modern bio-heat includes heat supplied by district energy networks. Totals may not add up due to rounding.

Source: Based on IEA data. See endnote 65 for this chapter.

Modern bioenergy represents the largest source of renewable energy use in the buildings sector and directly provided around 4.6% of total heat demand in buildings in 2018.⁷³ However, bioenergy use in buildings is growing only slowly and its share has remained relatively stable, as bio-heat consumption has grown at the same rate as building thermal demand.⁷⁴ Renewable electricity supplies the second largest renewable heat demand.⁷⁵

Solar thermal and **geothermal heat** together contributed some 2.0% of thermal energy demand in buildings in 2018.⁷⁶ Demand for these sources has grown more rapidly than bioenergy use in recent years, although starting from a smaller base.⁷⁷ (→ See *Market and Industry chapter*.)

Renewable energy delivered by **district heating and cooling networks** supplies a minor share of building heat demand worldwide.⁷⁸ Nevertheless, some European countries have achieved high shares of renewables in the district heat supply (more than 50% in at least six countries as of 2017⁷⁹).⁷⁹ Shares also are growing significantly in Lithuania as well as in Finland, France and Switzerland, among others – helping to boost the share of renewables in Europe’s buildings.⁸⁰

The use of **renewable electricity for heat** in buildings is growing rapidly at 5.3% per year.⁸¹ Electrification of building heat is seen increasingly as an efficient and cost-effective method both to reduce building energy use (for example, through use of electric heat pumps) and to grow the share of renewables in the sector.⁸²

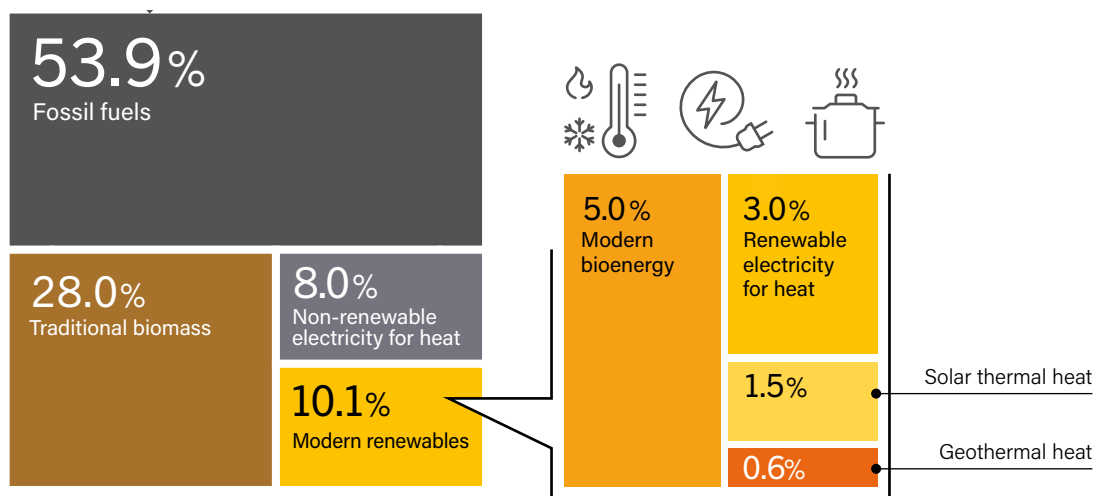
Several initiatives and studies demonstrating the benefits of electrification of buildings were launched or completed in 2019, notably covering specific regions of the United States as well as multiple countries around the world.⁸³ In Europe, electrification is considered a central element of the strategy to increase the share of renewable heat in buildings.⁸⁴

Overall, the global share of renewable electricity used for heating and cooling in buildings was an estimated 3% in 2018, up from around 2% in 2010.⁸⁵ Over this period, electricity contributed more than one-third of the overall demand growth for renewable building heat, the most of any renewable energy source.⁸⁶ However, most of this increase was due to the growing share of renewables in the global electricity supply, rather than to rising electrification of heating in buildings.⁸⁷

The use of traditional biomass for **cooking** – predominantly in open fires or inefficient indoor stoves – leads to significant health problems, particularly in developing and emerging economies. In these countries, the use of gaseous fuelsⁱⁱⁱ overtook traditional biomass use in 2009 and reached 48% of the population in 2018 (compared to 37% for traditional biomass).⁸⁸ The share of the population using coal in rural areas and kerosene in urban areas was 2% each in 2018.⁸⁹ At the same time, the share of electric cooking rose to 7%; however, the use of renewable energy for cooking depends on the overall renewable electricity share in national power grids.⁹⁰

- i When accounting for bioenergy delivered by district energy networks, the share rises to around 5%.
- ii The six countries were, in descending order, Iceland, Norway, Sweden, Lithuania, Denmark and France.
- iii Gaseous fuels refer to LPG, natural gas and clean biogas, with LPG comprising the majority.

FIGURE 5. Estimated Renewable Share of Heating and Cooling in Buildings, 2018



Note: Includes space heating, space cooling, water heating and cooking. Modern bioenergy includes heat supplied by district energy networks.

Source: Based on IEA data. See endnote 71 for this chapter.

Compared to heating and cooling, **renewable energy** supplies a higher share of electricity end-uses in buildings, at around 26%.⁹¹ (→ See Figure 3.) This share continues to grow, with the majority of the electricity provided by utility-scale, grid-connected renewables and a growing share by rooftop solar PV systems.⁹² In some places, solar PV self-consumption grew and met high shares of building electricity use throughout the year.⁹³ Solar-plus-storage installations in buildings also continued to grow. (→ See *Systems Integration* chapter.)

In developing and emerging economies, distributed renewable energy systems provide **electricity access** to growing shares of the population. As of mid-2019, some 420 million people had gained access to basic residential electricity services through the use of renewable technologies, mainly solar PV lighting systems (330 million people) and solar home systems (90 million people).⁹⁴ In addition, some 19,000 mini-grids provided electricity access to around 47 million people during the year; most of the systems were powered by diesel fuel, followed by hydropower and solar PV-hybrid systems, with the latter seeing the most rapid growth.⁹⁵

Direct policy action to stimulate renewable energy uptake in buildings is lacking, particularly related to heating and cooling end-uses. California (United States) was the only jurisdiction to introduce a new technology mandate for renewable energy in buildings in 2019. However, policies prohibiting fossil fuel use for building heat can encourage the adoption of renewables and are a main factor driving the electrification of building heating.⁹⁶ Many sub-national (and at least four national) governments introduced or committed to bans on certain types of fossil fuels for heating in buildings during the year.⁹⁷

At the same time, global efforts to decarbonise buildings, specifically through **net zero carbon/energy buildings**ⁱ, are simultaneously promoting the uptake of renewables in the sector.⁹⁸ As of early 2020, 6 states and regions, 28 cities, and 48 businesses and organisations had signed the Net Zero Carbon Buildings Commitment.⁹⁹ In 2019, the EU's Energy Performance in Buildings Directive mandated that new *public* buildings in the regionⁱⁱ be "nearly zero energy buildings", and the standard was set to apply to *all* new buildings starting from 2021.¹⁰⁰

In terms of climate commitments, renewable energy in the buildings sector continues to be underrepresented in countries' NDCs for reducing emissions under the Paris Agreement. Of the 136 countries that mentioned actions on buildings, only 51 identified actions related to renewables in buildings; meanwhile, only 25 countries mentioned policies related to renewable heating and cooling.¹⁰¹

Ambitious and comprehensive building energy codes that promote renewable energy are a key tool to support the increased decarbonisation of buildings. In 2019, building energy codes that were mandatory for the entire sector were in place in 90 jurisdictions across only 41 countries.¹⁰² However, the scope of application of energy codes typically is limited to new builds and retrofits.¹⁰³ As such, there is growing attention to the need to increase **energy-efficient renovation rates**ⁱⁱⁱ in countries and regions with mandatory building energy codes, and some initiatives have called for an increase in renovation rates of up to 3%.¹⁰⁴ In 2019, the EU suggested doubling its renovation rate by 2050 (from only around 1% as of 2019).¹⁰⁵



Only

51 countries

defined actions on
renewables in buildings in
their NDC commitments.

i Various definitions have emerged of buildings that achieve high levels of energy efficiency and meet remaining energy demand with either on- or off-site renewable energy. See Glossary and endnotes 49 and 50 in Energy Efficiency chapter.

ii In the EU, additional legislative initiatives such as the Energy Efficiency and Renewable Energy Directives may further facilitate ambitious minimum requirements for the development of renewable energy in buildings and accelerate the overall renovation rates of Europe's existing building stock.

iii The energy-efficient renovation rate (or "refurbishment rate") is the share of the building stock that is annually refurbished for energy efficiency improvements. See endnote 104 for this chapter.

INDUSTRY

Energy use in industryⁱ accounts for around 35% of total final energy consumption.¹⁰⁶ Direct energy-related industrial CO₂ emissions (excluding agriculture and land use) make up some 23% of the global total.¹⁰⁷ Energy use in the sector is growing modestly at less than 1% per year, although in certain energy-intensive sub-sectors such as chemicals and non-ferrous metals processing, energy use has grown much faster (between 2% and 3.5% per year).¹⁰⁸

Around 75% of the energy used in industry is for thermal end-uses, which include industrial process steam as well as drying, refrigeration and other energy needs.¹⁰⁹ The remaining share is for electrical end-uses, including the operation of machinery and lighting.¹¹⁰

Renewable energy meets around 14.5% of total industrial energy demand.¹¹¹ (→ See Figure 6.) Most of this renewable energy is in the form of **low-temperature heat** (below 100 °C) and is supplied by bioenergy in sub-sectors such as pulp and paper and other industries that produce on-site biomass waste and residues.¹¹² Overall, bioenergy continues to supply nearly 90% of the demand for renewable heat in industry.¹¹³ Solar thermal and geothermal heat are used mainly for pre-heating water, drying, and generating low-temperature steam in industries such as mining, food and beverage production, textiles and agriculture.¹¹⁴ Renewable electricity is consumed both for **electrical end-uses** as well as to meet thermal demands of some industrial process, for example through the use of industrial heat pumps (up to around 160 °C) and electric arc furnaces.

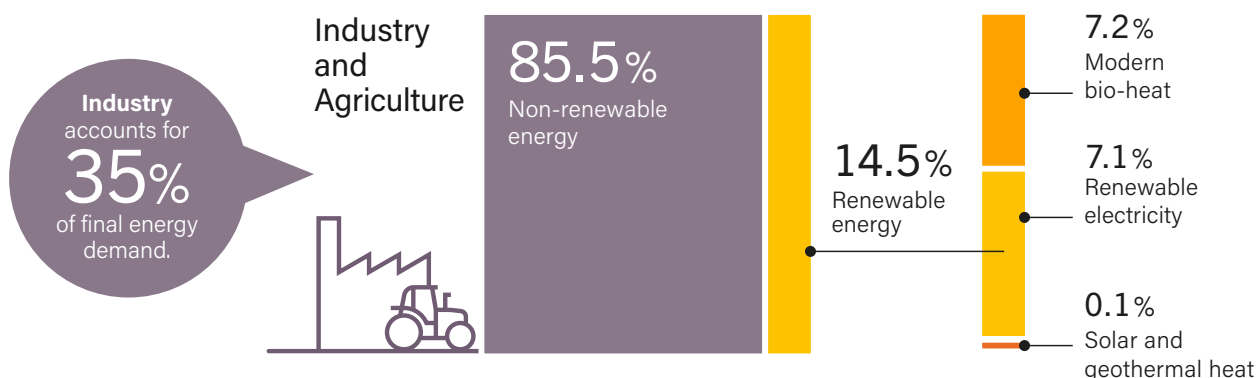
Within the industrial sector, the most energy-intensive sub-sectors – those with the highest process temperatures – also use the lowest shares of renewable energy.¹¹⁵ The sectors with the highest penetration of renewables are pulp and paper (46%), wood products (37%) and food industries (27%); in each of these sectors, bioenergy supplies more than 75% of the renewable energy, with renewable electricity accounting for the remainder.¹¹⁶ Overall, bioenergy supplies around 7% of global industrial energy use, while renewable electricity (including electricity for heat) accounts for slightly less, and geothermal and solar thermal heat have negligible shares.¹¹⁷ By the end of 2019, solar heat systems in industrial processes were supplying more than 700 megawatts-thermal worldwide.¹¹⁸

Direct use of renewables for industrial process heat occurs mainly in lower-temperature applications, and renewables face limitations in meeting heat demands directly above 200 °C to 400 °C.¹¹⁹ To overcome this, researchers in Europe and the United States undertook pilot projects during 2019 that demonstrated the potential for solar thermal technology to generate high-temperature heat for industrial processes, such as cement production.¹²⁰

Policy attention to the use of renewables in industry is limited, but some support policies and other measures were introduced or announced in 2019.¹²¹ The EU announced the development of its Industrial Strategy, although early details did not include firm commitments for the uptake of renewable energy in industry.¹²² Also during the year, Australia began the first phase of an AUD 461,000 (USD 322,000) initiative to promote the adoption of renewable energy in process heat; the second phase was launched in January 2020.¹²³

i Including manufacturing and materials processing, resource extraction, construction and agriculture.

FIGURE 6. Renewable Share of Total Final Energy Consumption in Industry and Agriculture, 2017



Note: Modern bio-heat includes heat supplied by district energy networks. Totals may not add up due to rounding.

Source: Based on IEA data. See endnote 111 for this chapter.

Projects to use **renewable electricity** in industry – notably in steel production – were announced or completed in 2019. The production of secondary steel (using recycled scrap metal) has potential for electrification with renewables, as up to 25% of these processes are driven by electric arc furnaces.¹²⁴ Construction was completed on a USD 250 million steel plant in the US state of Missouri, which upon opening in January 2020 became the country's first steel plant to run on wind energy; solar PV projects in part to produce steel also were announced in Australia and the US state of Colorado.¹²⁵ One multinational steelmaker noted its intention to create a fossil-free value chain for steel production based on electric arc furnaces powered by renewable electricity, with some plants based entirely on renewables by 2022.¹²⁶

In the cement and chemicals industries, two companies completed a pilot study for electrifying cement production, and six petrochemical companies launched a consortium to investigate the use of renewable electricity in their chemical processes.¹²⁷

Major companies in the mining industry are installing and procuring renewable electricity to power their activities, driven in part by the declining costs of solar PV and wind power and by compliance with social and environmental standards (including a low-carbon energy supply).¹²⁸ By the end of 2019, the mining industry had commissioned or announced nearly 5 GW of renewable energy capacity across 88 sites in 26 countries.¹²⁹ The bulk of these projects were solar PV, followed by wind power and hybrid projects (solar PV, wind power and storage).¹³⁰

During the year, a 20% reduction in energy costs led an Australian mining giant to sign four PPAs for renewable energy at two mines in Chile, with the aim of running the mines on 100%

renewable electricity by 2025.¹³¹ In early 2020, an Argentinian mining company signed a 10-year PPA with a wind power plant to cover 50% of the mine's electricity demand.¹³²

The production and use of renewable hydrogenⁱ is a potential route for growing the share of renewables in industrial processes, particularly in steel production. In 2019, a 6 MW electrolyser was commissioned in Austria to produce hydrogen from renewable electricity for steelmaking; a European offshore wind developer announced plans to supply renewable hydrogen produced from offshore wind to industrial processes, while several other developers took steps in the same direction.¹³³ Three Swedish companies announced an SEK 200 million (USD 21.4 million) investment in a storage facility for the world's first planned pilot-scale use of renewable hydrogen and electricity for steel production.¹³⁴

Renewable energy is procured increasingly for use in data centres, which account for around 1% of global electricity use.¹³⁵ Because of advances in hardware and infrastructure efficiency, overall energy use in this area did not rise between 2015 and 2018, even as the service demands on data centres doubled.¹³⁶ Companies such as Amazon, Aligned Energy, Google, Microsoft and Netflix have made commitments to high shares of renewables in their data centres, as well as signing PPAs and purchasing renewable energy certificates.¹³⁷ (→ See Box 3 in *Policy Landscape* chapter.)

i Renewable hydrogen refers to hydrogen produced from renewable energy, most commonly through the use of renewable electricity to split water into hydrogen and oxygen in an electrolyser. Virtually all hydrogen globally is still produced from fossil fuels, and the majority of policies and programmes focused on hydrogen do not include a focus on renewables-based production. See Systems Integration chapter and Box 1 in *Policy Landscape* chapter.



New projects were completed or announced in 2019 to use renewable electricity to produce **steel and cement** and to power mining operations.

TRANSPORT

Energy for the transport sector accounted for around one-third (32%) of total final energy consumption globally in 2017.¹³⁸ However, transport remains the sector with the lowest share of renewable energy: in 2017, the vast majority (96.7%) of global transport energy needs were met by oil and petroleum products (including 0.8% non-renewable electricity), with small shares met by biofuels (3.0%) and renewable electricity (0.3%).¹³⁹ (→ See Figure 7.) These shares remain unchanged from the previous year.

Despite gains in **energy efficiency**, particularly in road transport, global energy demand in the transport sector increased 2.2% annually on average between 2007 and 2017.¹⁴⁰ This was due mostly to the growing number and size of vehicles on the world's roads (and increases in tonne-kilometres and passenger-kilometres travelled), as well as to a reduction in average passenger-kilometres travelled per person for buses, and to a lesser extent to rising air transport.¹⁴¹ (→ See *Energy Efficiency chapter*.) The result of the increased energy demand has been a global increase in greenhouse gas emissions from the transport sector, even as transport emissions in some regions (such as the EU and the United States) have fallen.¹⁴² The sector as a whole accounted for nearly one-quarter of global energy-related greenhouse gas emissions in 2019.¹⁴³

Many countries lack a **holistic strategy** for decarbonising transport, although cities often are well placed to take more comprehensive action, especially in road transport.¹⁴⁴ Such strategies include reducing the overall need for motorised transport; transitioning to more efficient transport modes, such as (renewables-based) public transport and rail or non-motorised transport, and “active transport” (such as walking and cycling); and improving vehicle technology and fuels, such

as through higher fuel efficiencies and emission standards along with greater incorporation of renewable energy.¹⁴⁵

The main entry points for renewables in the transport sector are: the use of biofuels blended with conventional fuels, as well as of higher blends (including 100% liquid biofuels); natural gas vehicles and infrastructure running on biomethane; and the electrification of transport modes, including through the use of battery-electricⁱⁱ and plug-in hybrid vehicles and of renewable hydrogen, synthetic fuels and electro-fuels, provided that the electricity is itself renewable.¹⁴⁶ Some renewable energy carriers (biofuels) can be used in the internal combustion engines of conventional vehicles, whereas others require the shift to alternative drivetrains, such as in battery-electric or fuel cell vehicles.¹⁴⁷

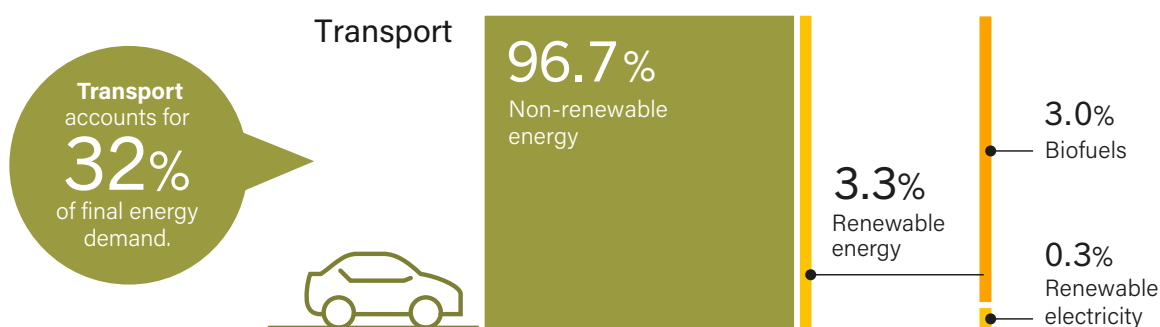
Growth in **biofuels** continued in 2019, and they remain by far the largest contributor of renewable energy to the transport sector. Although rarely linked directly to renewable sources, the expansion of **EVs** and the use of electricity in transport also advanced during the year. Electrified vehicles – including plug-in hybrid and fully electric passenger cars, electric scooters, electric bicycles and electric waste trucks – became more commonplace in more countries, often as a result of policies and targets adopted in prior years.¹⁴⁸ Some regions, including California (United States), China, Europe and Japan, also saw gradual increases in the use of renewable hydrogen and renewable synthetic fuels for transport, but these remained minimal.¹⁴⁹

Overall, the transport sector is **not on track** to meet global climate targets for 2030 and 2050.¹⁵⁰ By the end of 2019, around 80% of countries worldwide had acknowledged the transport sector's role in mitigating emissions by including transport in their NDCs under the Paris Agreement.¹⁵¹ However, just 11% of the NDCs included measures for renewables-based transport.¹⁵²

i These actions, together commonly referred to as Avoid-Shift-Improve, seek to address broader concerns among policy makers in the transport sector at the national and sub-national levels, such as environmental and health impacts (e.g., congestion, pollution, road safety), transport security and equity in access to mobility. See Figure 60 in the Energy Efficiency chapter.

ii EVs include any transport vehicles that use electric drive and can take an electric charge from an external source, or from hydrogen in the case of fuel cell electric vehicles. See Glossary.

FIGURE 7. Renewable Share of Total Final Energy Consumption in Transport, 2017



Source: Based on IEA data. See endnote 139 for this chapter.



Road transport accounted for around 75% of global transport energy use in 2018, with passenger vehicles representing more than two-thirds of this.¹⁵³ In 2017, biofuels comprised nearly all (91%) of the renewable energy share in road transport energy use.¹⁵⁴ By the end of 2019, at least 70 countries had blending mandates for conventional biofuels, while at least 9 countries had mandates or incentive programmes for advanced biofuels, and at least 24 countries had future targets for advanced biofuels.

The number of electric passenger cars on the road neared 7.2 million in 2019 (3.4 million of them in China), up 40% from the previous year.¹⁵⁵ Also during the year, investments in charging infrastructure further enabled the electrification of road transport, including the first electric highway in Latin America.¹⁵⁶ China reportedly installed more than 1,000 EV charging stations *per day* in 2019.¹⁵⁷ (→ See *Systems Integration chapter*.) Increased electrification of transport can help to dramatically reduce CO₂ emissions in the sector, particularly in countries that are reaching high renewable shares in their electricity mix.¹⁵⁸ EVs also offer the potential for significant final energy savings, as they are inherently more efficient than comparable internal combustion engine vehicles.¹⁵⁹

However, only limited examples exist of direct **policy** linkages between EVs and renewable electricity.¹⁶⁰ As of early 2020, only one country (Austria) and three cities had an e-mobility policy or target that was directly linked to renewables.¹⁶¹ Nevertheless, at least 28 cities and 39 countries or states/provinces had *independent* targets both for EVs and for renewable power generation, which could result in greater use of renewables for transport, especially when combined with

financial incentives or other policy support.¹⁶² In addition, by early 2020 at least 18 jurisdictions (national and sub-national)ⁱⁱ had committed to banning sales of new fossil fuel vehicles or internal combustion engine vehicles in favour of lower-emission alternatives (sometimes explicitly EVs) by 2050 or before, up from 12 jurisdictions a year before.¹⁶³ Some cities such as Madrid (Spain) also have greatly restricted circulation of fossil fuel vehicles.¹⁶⁴ (→ See *Transport section in Policy Landscape chapter*.)

Partly in response to these policy developments, some private companies have committed to using renewable electricity in their EV fleets.¹⁶⁵ This trend also is apparent among some new mobility service companies, including micro-mobility services, which have expanded rapidly since emerging in 2017.¹⁶⁶ (→ See *Box 2*.) Although many challenges remain for scaling up EVs, further electrification of road transport has the potential to ease the integration of solar PV and wind power by providing balancing services to the grid.ⁱⁱⁱ Vehicle-to-grid (V2G)^{iv} is still in its infancy, but during 2019 more pilots were launched and more companies invested in the technology.¹⁶⁸

A modal shift to **active transport** and **public transport**, implemented as part of a more holistic strategy for decarbonising transport, can greatly decrease energy demand (and associated greenhouse gas emissions) in the sector and thus allow for the renewable share in transport to increase. As more local governments transition to EVs in their fleets due to falling prices, a few are linking EVs with renewable energy.¹⁶⁹ For example, as of October 2019 a bus charging station in Jinjiang's Binjiang Business District (Fujian Province, China) was charging its electric buses using solar power.¹⁷⁰

i Bulgaria, Croatia, France, Italy, Luxembourg, the Netherlands and the Slovak Republic have mandates, while the United States and the United Kingdom have incentive programmes. See Reference Table R10.

ii Targets include the following: Cabo Verde, Canada, British Columbia (Canada), Hainan Province and Taipei (China), Costa Rica, Denmark, France, Iceland, Japan, Netherlands, Norway, Slovenia, Balearic Islands (Spain), Sri Lanka, Sweden, United Kingdom and Scotland. See endnote 163 for this chapter and Reference Table R10.

iii EVs could ease the integration of variable renewable electricity (VRE) provided that market and policy settings ensure the effective harmonisation of battery charging patterns and/or hydrogen production with the requirements of the electricity system.

iv Vehicle-to-grid (V2G) is a system in which EVs – whether battery-electric or plug-in hybrid – communicate with the grid in order to sell demand response services by returning electricity from the vehicles to the electric grid or by altering their rate of charging.

Many more cities are running public urban rail systems on electricity, sometimes directly linked to renewables and in other cases using biofuels. The first urban train service in Japan relying entirely on renewable energy sources began running in March 2019.¹⁷¹ Also in 2019, Melbourne (Australia) connected a 128 MW solar PV system to its grid network specifically to power the city's tram system.¹⁷²



As the most highly electrified transport sector, **rail transport** accounts for around 1.8% of the total energy used in transport.¹⁷³ Around three-quarters of passenger rail transport, and nearly half of freight rail transport globally, is electric.¹⁷⁴ With more than a quarter of the electricity used in rail transport estimated to be renewable, renewable energy contributes an estimated 11% of global rail-related energy consumption.¹⁷⁵ Some jurisdictions have increased the share of renewables in rail transport to well above the share in their power sectors.¹⁷⁶

Road freight consumes around half of all diesel fuel and is responsible for 80% of the global net increase in diesel use since 2000, with the increase in road freight activity having offset any efficiency gains.¹⁷⁷ Fuel economy standards stimulate manufacturers to pursue efforts to improve fuel efficiency and facilitate the adoption of alternative drivetrains based on low-carbon solutions, including renewable energy.¹⁷⁸ Although fuel economy standards apply to 80% of light-duty vehicles globally, only five countries apply them to heavy-duty vehicles – Canada, China, India, Japan and the United States – covering just over half of the global road freight market.¹⁷⁹

ⁱ Heavy-duty vehicles constitute the fastest-growing source of oil demand worldwide. Even though they account for less than a quarter of total freight activity, they account for three-quarters of the energy demand and CO₂ emissions from freight. See endnote 179 for this chapter.

BOX 2. Renewables in New Mobility Services

So-called new mobility services have increased dramatically worldwide in recent years. These include modes such as electric sidewalk/"kick" scooters and dockless bicycles (both electric and traditional), as well as electric moped-style scooters and ride-hailing and car-sharing services. Many new mobility service companies have committed to sustainability measures, including the use of renewable electricity for charging vehicles as well as for operations.

Some sidewalk scooter operators have committed to using 100% renewable electricity to charge the scooters themselves as well as the vehicles that circulate to collect them. Other operators and some ride-hailing services buy renewable energy credits to account for 100% of the electricity used, or they purchase renewable electricity directly from local utilities. Other ride-hailing service companies incentivise EV use (without necessarily incentivising renewable electricity at the same time), particularly in jurisdictions that have placed restrictions on fossil fuel or internal combustion engine vehicles. For example, in London (United Kingdom), Uber offers a subsidy scheme for EV drivers and has a target for all of its cars to be electric by 2025.

In addition, companies are engaging in new partnerships to reach their goals. Although most of these efforts support increasing EVs or charging infrastructure, but do not include renewables, a few explicitly factor in the source of electricity, as in the case of Lime partnering with energy provider Octopus Energy to charge its electrically assisted bicycles with renewable electricity in the United Kingdom. Others are taking a fully integrated approach: in New Zealand, the company Mercury has partnered with electric sidewalk scooter and electric bike companies, offers electric car rentals, and is one of just four energy companies in the world that supply 100% renewable electricity.

Source: See endnote 166 for this chapter.

The larger the vehicles and the longer the range, the more challenging it is to find cost-effective alternatives to diesel.¹⁸⁰ Although not all from renewable sources, many alternative fuelsⁱ are already commercially viable, and technological development continues. For example, during 2019 Finnish and Swedish companies introduced to their fleets trucks that run on liquefied biogas (LBG).¹⁸¹

The internationally co-ordinated maritime and aviation sectors rely almost exclusively on the use of fossil fuels, contributing greatly to global greenhouse gas emissions.



Maritime transport consumes around 10% of the global energy used in transport and is responsible for around 2% of global energy-related CO₂ emissions; so far, renewables do not feature significantly in the maritime fuel mix.¹⁸² In 2019, the International Maritime Organization agreed on stricter energy efficiency targets and new fuel and emission standards beginning in January 2020, and the industry called for speed limits on commercial vessels to reduce emissions.¹⁸³

In addition to the use of biofuels or other renewable-based fuels (for example, renewable hydrogen or ammonia) for propulsion, maritime transport has the possibility to directly incorporate wind power (via sails) and solar energy, although the most immediate option is to use biofuels in existing engines.¹⁸⁴ In 2019, some shipping companies in Scandinavia entered into agreements to use LBG.¹⁸⁵ By early 2020, trials had begun on the use of ammonia as a shipping fuel, with the potential to produce it with renewable electricity.¹⁸⁶

By the end of 2019, at least four new **ports** had joined the World Ports Climate Action Program to advance reductions in maritime

transport emissions in support of the Paris Agreement, adding to the seven founding ports the year before.¹⁸⁷ Ports outside of the programme also have committed to decarbonising. For example, the Port of Houston (United States) agreed to purchase renewable electricity port-wide starting in 2020, making it the first US port to administer such a programme.¹⁸⁸ Also, the Port of Gothenburg (Sweden) began offering LBG to ships.¹⁸⁹ The use of “cold ironing”ⁱⁱⁱ offers the potential to increase the use of renewable electricity when ships are at berth, depending on the share of renewables in the port’s electricity mix; this was a capability in nearly 80 ports by the end of 2019, three-quarters of which are located in Europe.¹⁹⁰

Aviation accounts for around 11% of the total energy used in transport and for just over 2.5% of global energy-related CO₂ emissions.¹⁹¹ Despite the more than 50% decrease in carbon emissions per passenger-kilometre between 1990 and 2019 (due to fuel efficiency improvements), global demand for air travel has increased, and emissions from commercial air travel have grown more rapidly than expected.¹⁹² In 2019, new policy measures were aimed at helping to put aviation on track towards decarbonisation – including new taxes to discourage air travel in France and Germany.¹⁹³

At the same time, support for and use of renewable fuels in the aviation sector made slight progress during the year. By early 2020, 119 member states of the International Civil Aviation Organization (ICAO – representing 94.3% of global air traffic) had submitted State Action Plans – up from 111 a year before – to support the production and use of “sustainable alternative”ⁱⁱⁱⁱ aviation fuels, specifically drop-in fuels^v produced from biomass, including different types of organic waste.¹⁹⁴ Meanwhile, more than 200,000 commercial flights had flown on blends of alternative fuels, up from 150,000 a year before.¹⁹⁵ At least 8 airports had regular distribution of blended alternative fuel, up from 5 the year before, while at least 14 airports had batch deliveries of such fuels.¹⁹⁶

In 2019, as during the previous year, some companies announced targets for their own aircraft to run on biofuels, and were developing planes made specifically to do this. However, technological limitations continue to hinder significant biofuel use in aviation. (→ See *Bioenergy section in Market and Industry chapter.*)

Although interest in the electrification of aviation is increasing, so far only drones or small planes for 1 to 12 passengers have been developed (or are under development), and some companies are aiming for hydrogen-powered electric planes.¹⁹⁷

- i Alternative fuels for heavy-duty vehicles refer to alternative propulsion systems to the traditional diesel (or petrol) internal combustion engine and are not exclusively from renewable sources. Alternative fuels include biofuels, synfuels or low-carbon liquid fuels produced from agriculture crops or waste, liquefied natural gas (LNG) or compressed natural gas (CNG), and biomethane. Other propulsion systems that are reaching commercial viability include hydrogen fuel cells, electric and hybrid vehicles, and electric roads (electric-powered vehicles where the energy source is external, for example through overhead wires). Another option under development is the use of solar PV for road surfaces to charge vehicles while they are in motion.
- ii Cold ironing consists of connecting a ship to the power grid while at berth in a port so that the electricity demand from the ship while hotelling is supplied directly by the grid rather than by the generator on the ship, which is typically diesel powered.
- iii The ICAO considers such fuels to be a sustainable alternative when they are produced from three families of bio-feedstock: the family of oils and fats, or triglycerides, the family of sugars and the family of lignocellulosic feedstock. See ICAO, “Alternative Fuels: Questions and Answers”; <https://www.icao.int/environmental-protection/Pages/AltFuel-SustainableAltFuels.aspx>, viewed 14 April 2020.
- iv Drop-in biofuels have properties enabling them to replace fossil fuels directly in transport systems, or to be blended at high levels with fossil fuels.

POWER

More than 200 GW of new renewable power generating capacity was installed in 2019, raising the global total to 2,588 GW by year's end.¹⁹⁸ (→ See Figure 8.) Installations were well above 2018 levels, maintaining the more than 8% average growth rate of installed renewable power capacity over the previous five years.¹⁹⁹

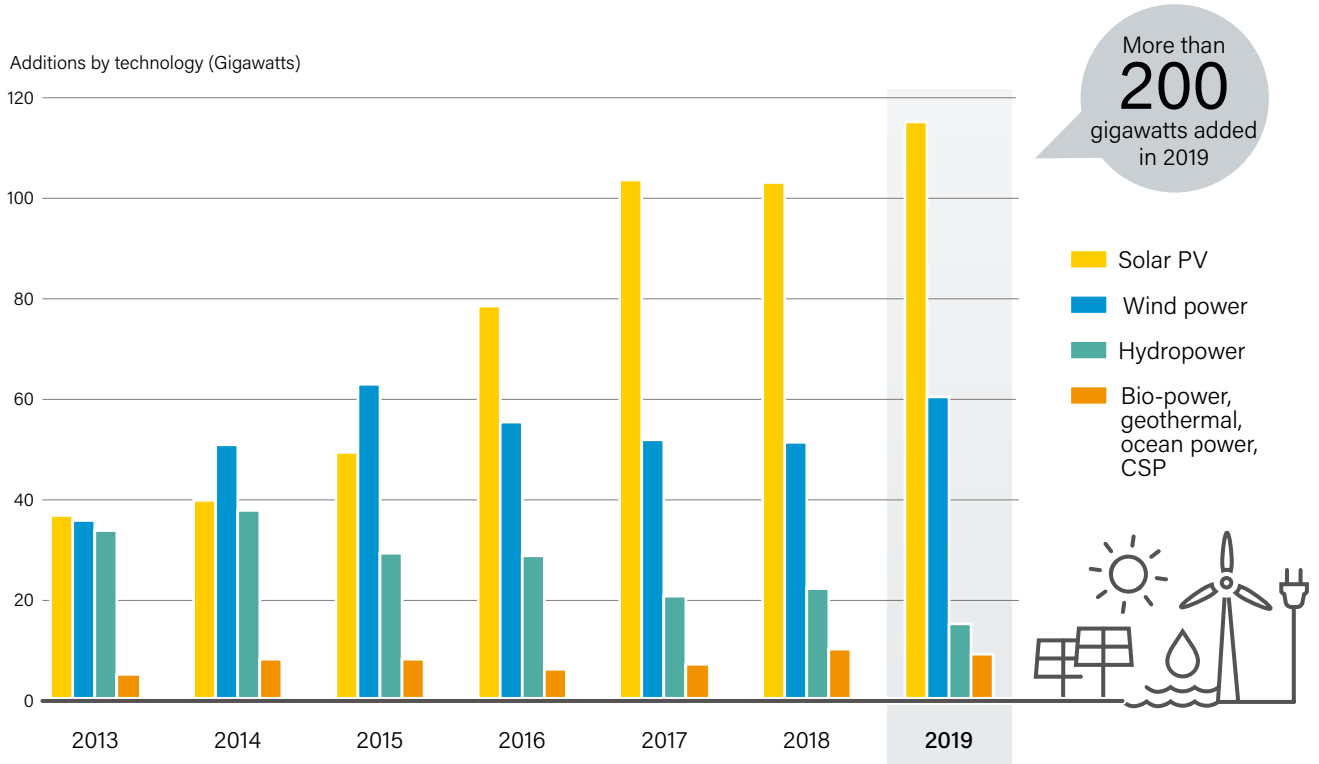
Around 115 GW of solar PVⁱ was added worldwide in 2019, cementing the technology's status as the leader in new electricity generating capacity.²⁰⁰ During the year, 57% of renewable power capacity additions were of solar PV (direct current), followed by wind power (around 60 GW for 30%) and hydropower (some 16 GW for 8%).²⁰¹ The remaining 5% of additions were from bio-power, geothermal power and concentrating solar thermal power (CSP).²⁰² For the fifth year in a row, net additions of renewable power generation capacity clearly outpaced net installations of both fossil fuel and nuclear power capacity combined.²⁰³ (→ See Figure 9 and Reference Table R1.)

Considering cumulative renewable energy capacity, China remained the global leader (789 GW) at year's end, followed by the United States (282 GW), Brazil (144 GW), India (137 GW) and



i For consistency, the GSR endeavours to report all solar PV capacity data in direct current (DC). See endnotes and Methodological Notes for more information.

FIGURE 8. Annual Additions of Renewable Power Capacity, by Technology and Total, 2013-2019



Note: Solar PV capacity data are provided in direct current (DC). Data are not comparable against technology contributions to electricity generation.

Source: See endnote 198 for this chapter.

Germany (124 GW).²⁰⁴ (→ See Table 2.) China also led the world in capacity added during the year at 67 GW, followed by the United States (22 GW), India (13 GW) and Brazil/Japan, each with around 8 GW.²⁰⁵ Despite their overall markets being too small to make the top-five list, Argentina, Australia, Israel, Mexico, Turkey and Vietnam each saw significant growth in total operating capacity of at least two renewable power technologies.²⁰⁶

By the end of 2019, at least 32 countries had more than 10 GW of renewable power capacity (including hydropower) in operation, up from 19 countries in 2009.²⁰⁷ The shift is even more impressive when excluding hydropower, as markets for both solar PV and wind power have grown dramatically in recent years. At least 17 countries had more than 10 GW of non-hydropower renewable capacity at the end of 2019, up from 5 countries in 2009.²⁰⁸ As in previous years, the top country for non-hydropower renewable capacity was China, followed by the United States, Germany, India, Japan and the United Kingdom; the top countries for non-hydro renewable power capacity per inhabitant were Iceland, Denmark, Sweden, Germany and Australia.²⁰⁹ (→ See **Reference Table R2**.)

Overall, installed renewable energy capacity was enough to provide an estimated 27.3% of global electricity generationⁱ

at the end of 2019.²¹⁰ Hydropower still made up the majority (58%) of this estimated generation share, followed by wind power (22%), solar PV (10%) and bio-power (8%).²¹¹ (→ See Figure 10.)

Renewable electricity shares are rising rapidly in many countries and regions. Over the past decade, the EU saw strong growth in its share of renewables in electricity generation, up from 19% in 2009 to an estimated 35% in 2019.²¹² In certain European countries, the shift was even more dramatic, such as in Denmark (from 39% to 77%), Germany (16% to 42%) and the United Kingdom (8% to 38%).²¹³ In the United States, the share of renewable electricity generation increased from 10.2% to 17.4% between 2009 and 2019.²¹⁴ The renewable share of electricity generation in China grew from 16.6% to 26.4%, despite a more than doubling of total electricity production during the decade.²¹⁵ The share of renewables in electricity generation also increased

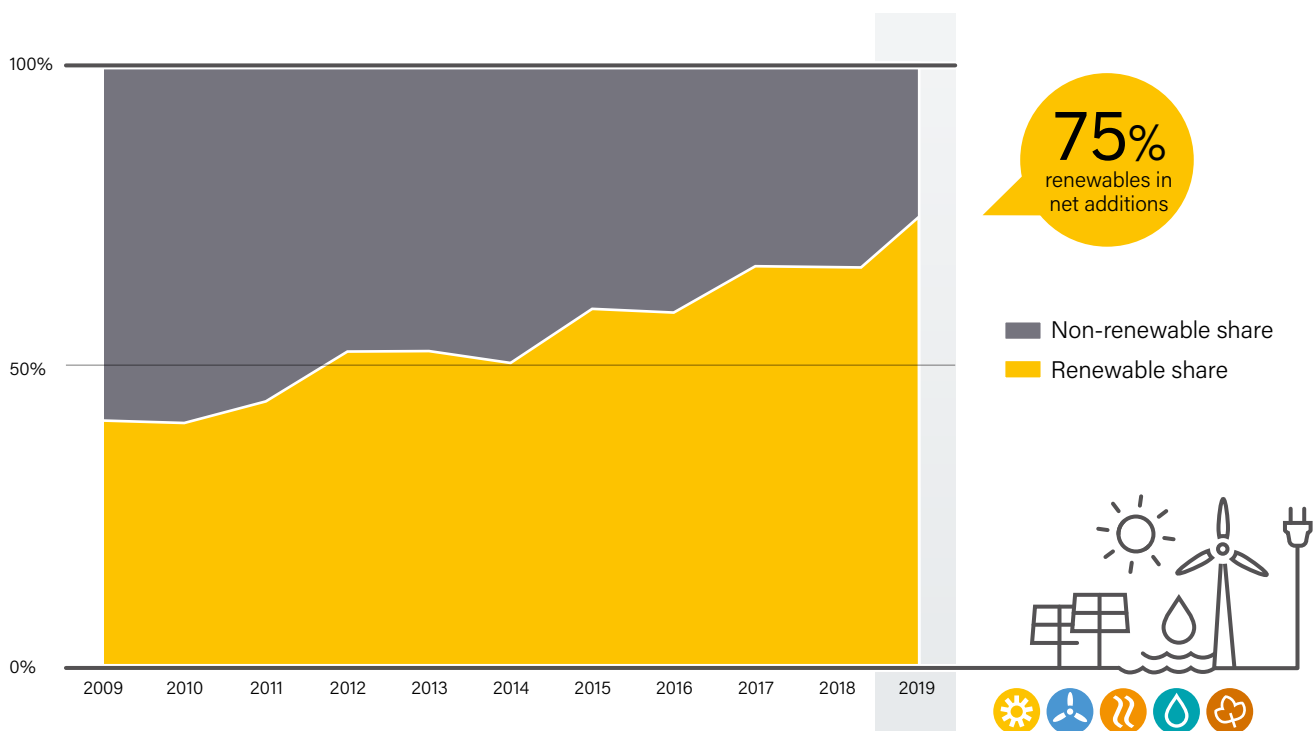
At least

32 countries

had more than 10 GW of renewable power capacity in operation at the end of 2019.

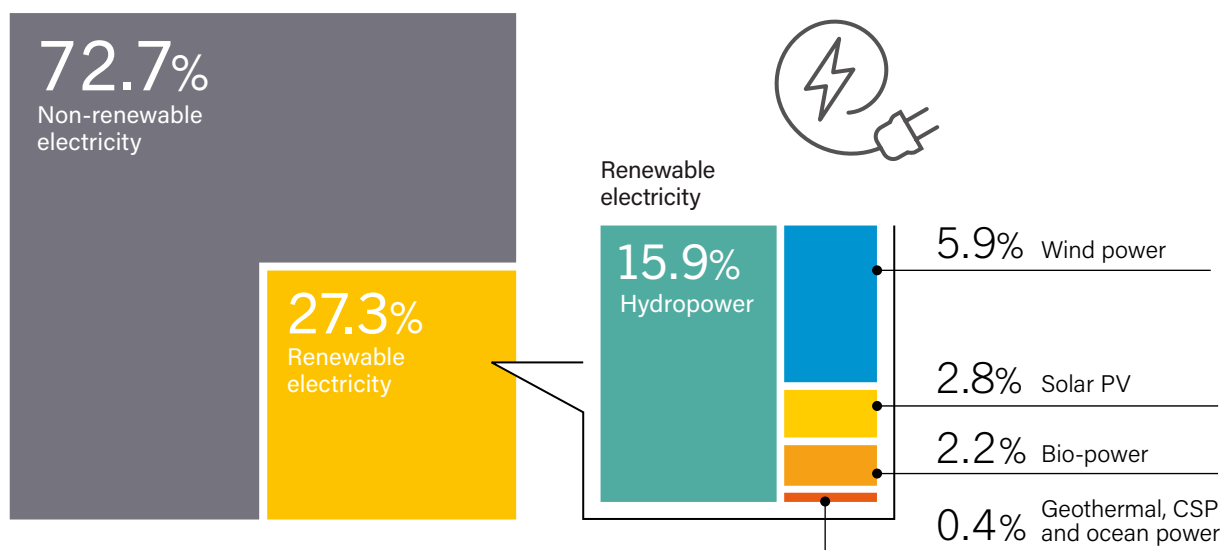
ⁱ Methodological adjustments and data revisions contribute in part to the variation of the share of renewable energy in global electricity production between GSR years. Data should not be compared with previous years, and this value is not intended to suggest any trend.

FIGURE 9. Renewable and Non-renewable Shares of Net Annual Additions in Power Generating Capacity, 2009-2019



Source: See endnote 203 for this chapter.

FIGURE 10. Estimated Renewable Energy Share of Global Electricity Production, End-2019



Note: Data should not be compared with previous versions of this figure due to revisions in data and methodology.

Source: See endnote 211 for this chapter.

notably in many other countries, including Australia (from 8% to 24%), Ethiopia (89% to 100%), Kenya (57% to 81%) and Uruguay (70% to 98%), even as total electricity generation rose sharply in several of these countries.²¹⁶

Despite these advances, renewable electricity continued to face challenges in achieving a larger share of global electricity generation, due in part to persistent investment in fossil fuel (and nuclear) power capacity. In 2019, investment in new coal, natural gas and nuclear power generating capacity totalled USD 99 billion.²¹⁷ (→ See *Investment chapter*.) Changes to **power market rules** could facilitate the participation of renewable energy in electricity markets. Some governments (such as the EU, Germany, Singapore and some US states) were revising rules during the year to allow more actors to participate in power and ancillary markets, which can enable faster and more flexible operations and allow distributed renewable energy resources to participate on a more even footing with large-scale fossil and nuclear generators.²¹⁸

Policy attention to renewable energy remained focused on the power sector in 2019. Although few countries set new or revised targets during the year, action continued at a sub-national level. The total number of countries that held renewable power auctions decreased during the year (from 48 to 41), but the capacity being auctioned increased significantly, and several new countries held auctions for the first time, raising the total number of countries having used this policy to 109.²¹⁹ Feed-in tariffs were present in 113 jurisdictions at year's end.²²⁰

As in previous years, developments in the renewable power sector continued to be influenced heavily by government **policy and regulatory frameworks**. Policy uncertainty in China and India, among other drivers, contributed to slowdowns in the national solar PV markets, and in Spain the removal of the so-called Sun Tax in late 2018 contributed to growth in the rooftop solar PV market in 2019.²²¹ In Germany, regulatory issues including permitting, planning and a proposed setback regulation for wind turbines led to a contraction in the country's onshore wind power market of roughly two-thirds compared to 2018.²²² Developments in the geothermal power and hydropower sectors were both constrained by government policies on permitting and protected areas in some countries.²²³ (→ See *Market and Industry chapter*.)

Auctions and tenders for renewable power became more common in 2019, with 11 new countries either adopting a mechanism for auctions or holding them for the first time.²²⁴ Most auctions were technology-specific for either solar (PV or CSP) or wind power, while only two were technology-neutral (among renewable energy technologies). (→ See *Policy Landscape chapter*.) In one technology-neutral auction in Brazil, solar PV won the round over natural gas and wind power.²²⁵

Overall, the shift to auctions has created a highly competitive bidding environmentⁱ that has placed strong downward pressure on price levels for renewable power projects. Developers around the world continued to submit tenders at record-low prices for CSP, utility-scale solar PV and wind power.²²⁶ However, low bid prices in tendering processes do not necessarily reflect overall

i Competitiveness in auctions does not necessarily relate to inclusivity, and the number of auction participants has declined in some countries.



Renewable electricity shares are

rising rapidly

in an increasing number of countries and regions.

costs of technology.²²⁷ For example, prices depend on resource availability and local labour costs, while tendering conditions might include the provision of grid connection to developers.²²⁸

This mounting price competition has shrunk margins for manufacturers and project developers around the world, leading to consolidation and bankruptcies within several renewable energy industries including wind power and solar PV.²²⁹ Some developers are thought to be betting on future revenue streams from wholesale markets to allow them to submit such low bids.²³⁰ In certain cases, tendering processes have led to a decrease in the number of auction participants and have favoured larger companies such as utilities and multinational energy companies, forcing out smaller actors, including community-led groups.²³¹ (→ See *Feature chapter*.)

In addition to many municipal utilities, **major electric utilities** in India, Spain and the United States made commitments in 2019 to reach zero emissions, to eliminate their coal-fired power capacity or to transition to 100% renewables.²³² Tata Power, one of India's largest electric utilities, announced that the majority of its future new power capacity would be renewable rather than coal.²³³ The decision of power producers to switch to renewable energy is becoming less dictated by policy and more by their own business interests.²³⁴ In Europe, energy utilities continued to reshuffle their operations to adapt to the emergence of low-cost wind and solar energy, while some of the world's largest multinational energy companies from Asia, Europe, the Middle East and the United States planned to scale up investment in renewables.²³⁵

The share of electricity generated by variable renewable electricity (wind and solar PV) continued to rise in several countries around the world. While VRE contributed an estimated 8.7% of global electricity production as of the end of 2019, during the year it met much higher shares of generation in some countries, such as

Denmark (60%), Uruguay (33%), Ireland (32%), Germany (30%) and Portugal (29%).²³⁶ Overall, at least nine countries produced more than 20% of their electricity from VRE in 2019.²³⁷

In recent years, some countries have made efforts to increase the flexibility of their energy systems in order to integrate rising shares of VRE. Expanding or modernising grid infrastructure can help achieve higher levels of flexibility needed to maximise VRE integration.²³⁸ Many countries (including Australia, Brazil, Chile, China, Colombia, Germany, India, South Africa and the United States, among others) are building or investing in transmission infrastructure specifically to accommodate rising shares of variable renewables.²³⁹ (→ See *Systems Integration chapter*.)

Hybrid systemsⁱ, consisting of at least two renewable energy technologies and/or energy storage, are able to provide grid flexibility as well as decrease costs and deliver technical benefits (including higher capacity factors) due to co-localisation.²⁴⁰ In 2019, hybrid projects combining solar PV, wind and/or energy storage were announced or commissioned in Australia, the Netherlands, the Philippines, the United States and India, where more than 1.4 GW of solar PV and wind hybrid project capacity had been awarded as of late 2019.²⁴¹

Hydropower facilities also are being built or retrofitted with (floating) solar PV. In 2019, hybrid projects of hydropower co-location with solar PV were announced or commissioned in Brazil, the Philippines, the Russian Federation and Uganda.²⁴² CSP plants are already commonly built with (thermal) energy storage and increasingly are co-located with solar PV and/or wind power. CSP projects were announced, under construction or commissioned during the year in Chile, China, Israel, Morocco and the United Arab Emirates that combined solar PV (and in China, also wind power) with energy storage at the CSP plant.²⁴³

i Hybrid renewable energy systems, for example, PV-hydro, PV-wind, PV-CSP, or any VRE with energy storage, use the complementarity of generation patterns of different renewable energy technologies in certain locations to reduce variability in aggregate production and bring about more efficient use of transmission infrastructure and land. See endnote 240 for this chapter.

SIDEBAR 2. Renewable Energy-Related Jobs in Energy Access

In 2018, around 11 million people were employed in the renewable energy sectorⁱ. In regions and countries where a lack of energy access is a significant concern, the share of renewable energy-related jobs is typically much lower. For example, around 227,000 people were employed in the renewable energy sector in sub-Saharan Africa (excluding South Africa), just 2% of the global total. Only 52% of the population in the world's least-developed countries had access to electricity in 2018, and in some countries, rural access rates were well below 10%. Around 600 million people in sub-Saharan Africa lived entirely without electricity. (→ See *Distributed Renewables chapter*.) As access to energy has improved in these countries, and as renewable energy technologies have been deployed, the number of associated jobs has continued to increase.

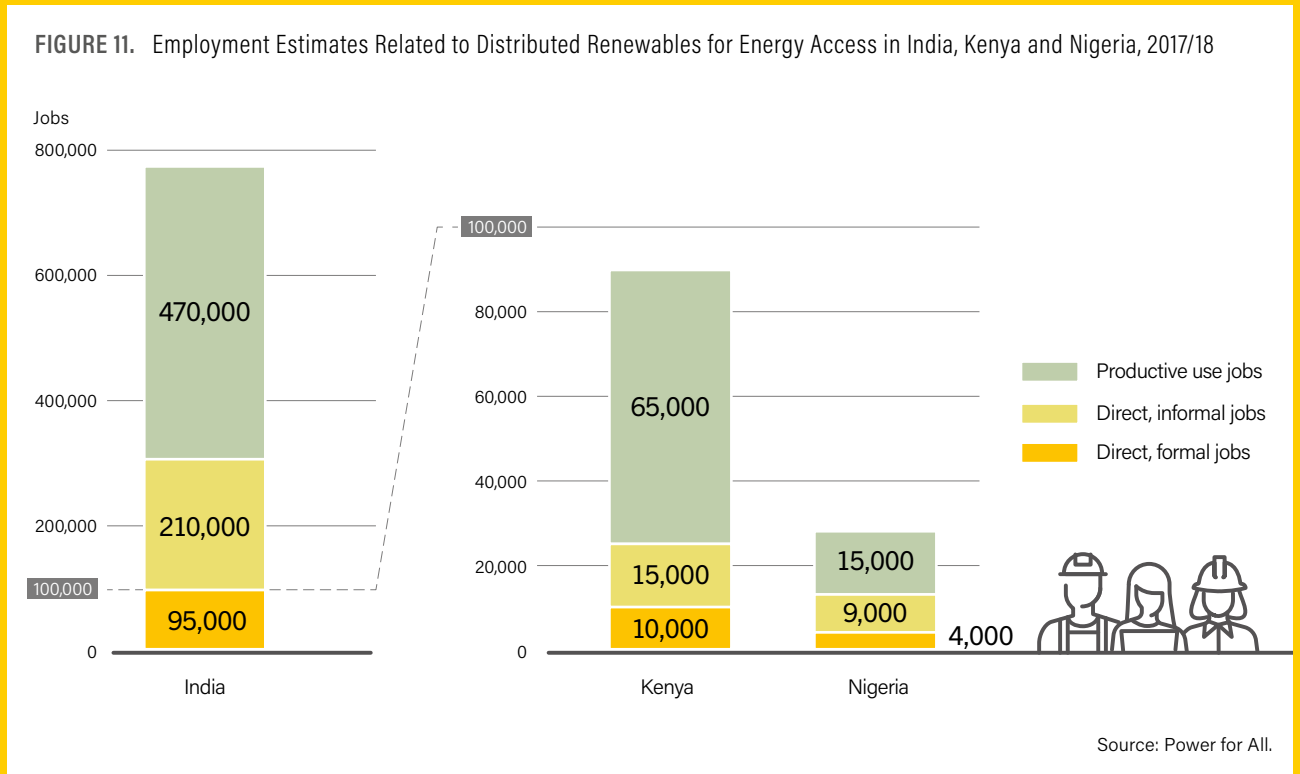
Distributed renewables for energy access (DREA) companies operating locally already contribute significantly to direct and indirect employment in some developing and emerging countries, for example in India, Kenya and Nigeriaⁱⁱ. (→ See *Figure 11*.) In India, although the DREA sector is still nascent and just

beginning to scale, these companies directly employed 95,000 workers in 2017/18ⁱⁱⁱ, as many as in the traditional utility-scale power sector. In Kenya, DREA companies accounted for 10,000 jobs – compared to 11,000 provided by the national utility KPLC. Informal employment from DREA during 2017/18 was almost double the size of the direct, formal workforce in these countries: 210,000 informal jobs in India, 15,000 in Kenya and 9,000 in Nigeria.

Job creation also is related to productive uses of energy, which are activities that generate income, increase productivity, enhance diversity and create economic value, such as crop irrigation, light mechanical work (for example, water pumping) and small and medium-scale production such as agri-processing (grinding, milling and husking). Early and rough estimates of jobs related to productive uses of energy in 2017/18 totalled 470,000 in India, 65,000 in Kenya and 15,000 in Nigeria. These data demonstrate the deep connection between delivering energy access and stimulating the broader economy within communities being electrified.

- i This sidebar is drawn primarily from Power for All's *Powering Jobs Census 2019: The Energy Access Workforce*, with additional analysis from the International Renewable Energy Agency (IRENA), including the reports *Renewable Energy and Jobs – Annual Review 2019* and *Renewable Energy: A Gender Perspective (2019)*.
- ii Only data for India, Kenya and Nigeria were available in Power for All's *Powering Jobs Census 2019*. Although not comprehensive global coverage, data for these countries are presented here to give an indication of status and trends. The *Powering Jobs Census* will be expanded to include all energy-poor countries, ultimately providing a global view.
- iii Data were collected across the one-year period from the fourth quarter of 2017 to the fourth quarter of 2018.

FIGURE 11. Employment Estimates Related to Distributed Renewables for Energy Access in India, Kenya and Nigeria, 2017/18



DREA companies delivering electricity access create skilled jobs that largely fall within the middle-income range for their respective countries. Employee retention is also better than for utility-scale power: more than two-thirds of DREA jobs are full-time and long-term, and a similar percentage of the workforce is skilled, compared to 50% for the global workforce in the utility-scale solar sector. Despite this, major skill gaps exist in the DREA sector, including a growing shortage of job-ready talent to finance, develop, install, operate and market the sector. Management skills in particular represent a critical gap for unlocking further sectoral growth.

Unemployment rates in the rural communities of developing and emerging economies are high and increasing, with women and youth among the most heavily impacted. Women comprise around 25% of the DREA workforce in India, Kenya and Nigeria; by comparison, they hold 32% of jobs across the global renewable energy sector as a whole, and only 22% of jobs across the entire energy industry. Lower participation of women in the DREA sector is related to broader socio-cultural challenges around gender stereotypes, recruitment biases, discriminatory business cultures, perceptions of gender roles and women's representation in STEM (science, technology, engineering and mathematics) education. Youth account for 40% of all jobs in DREA, making the sector an important contributor to youth employment in emerging economies.

Off-grid and decentralised renewable energy systems are increasingly recognised as the most cost-effective solutions for the poorest and most remote communities, providing both

livelihoods and income-generating opportunities. Factors that have been identified to help expand employment in the DREA industry include:

- increasing public-private collaboration to develop standardised, accredited, industry-relevant curricula and to establish career development programmes for both university and vocational training programme graduates;
- strengthening recruitment channels to ensure a strong talent pipeline;
- developing and implementing gender awareness measures and mainstreaming policies and practices, such as gender equality selection criteria for grants and tenders, as well as directly encouraging greater participation of women in education and training programmes;
- developing pathways to recognise and certify skilled, but uncertified, technicians to formalise rural employment opportunities;
- expanding the scope and standardisation of employment data, especially on informal and productive-use jobs, and improving access to government data on energy planning, demand and market development; and
- further exploring opportunities around local assembly and manufacturing of components for the decentralised renewable energy sector.

Source: Power for All and IRENA. See endnote 6 for this chapter.



02



COMMUNITY POWER ENTERPRISES, JAPAN



Inspired by movements developed in Denmark and Germany, community power projects started to emerge in Japan in the early 2000s. The Fukushima nuclear disaster of 2011 and the introduction of a national feed-in tariff in 2012 helped further spur the development of these projects. By the end of 2016, nearly 200 community power enterprises were active in Japan, including Hotoku Energy in Odawara, Obama Onsen Energy in Nagasaki, Shizuoka Mira Energy in Shizuoka and Tokushima Regional Energy in Tokushima.



02 POLICY LANDSCAPE

KEY FACTS

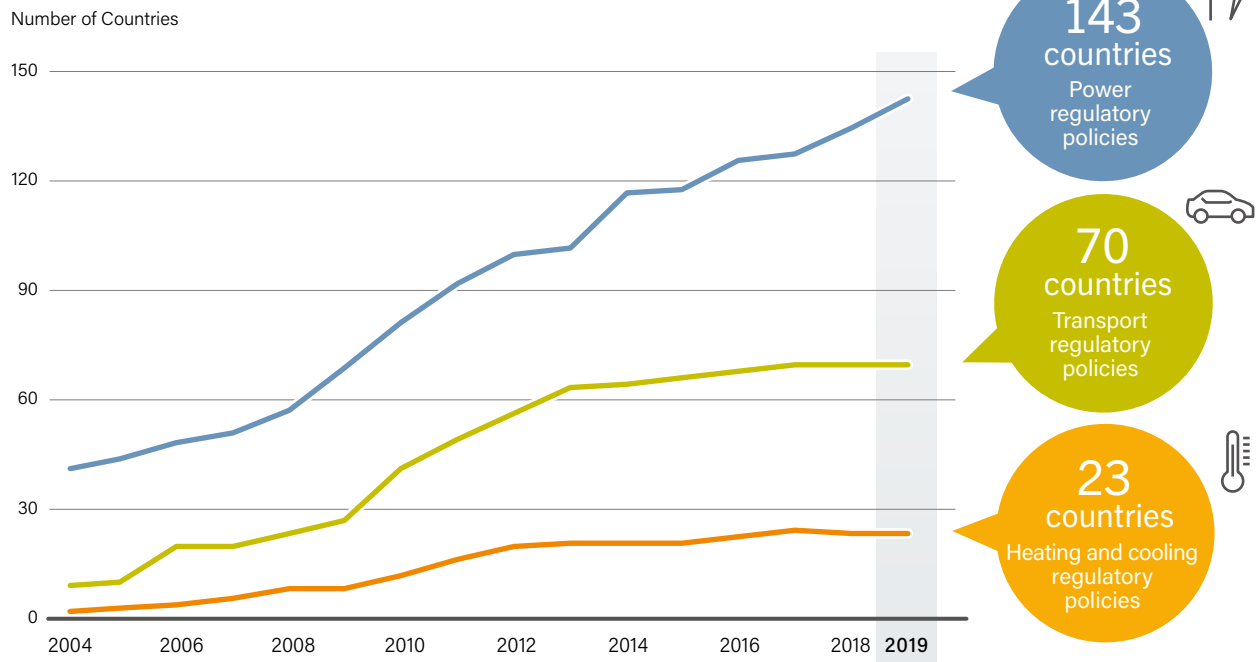
- Effective policy support has been key to the uptake of renewables.
- Policy frameworks continued to evolve in response to changes in renewable energy technologies and markets.
- The focus of policies and targets continued to be on the power sector, with policies for the heating and cooling and transport sectors advancing at a much slower pace.
- Targets that align renewable energy policy across multiple levels of governance and multiple economic sectors remained rare.
- Climate-related policies that directly or indirectly stimulate interest in renewables increased, spreading to new regions and reaching new levels of ambition.

Global deployment of renewable energy has increased significantly over the past decade, with new records being set each year and a growing number of countries committing to expanding the use of renewables and enabling technologies. (→ See *Global Overview chapter*.) Much of the advancement in renewables technology development and deployment has been achieved thanks to effective government policies, and policy continues to be important to overcome economic, technical and institutional barriers.¹ By the end of 2019, nearly all countries worldwide had renewable energy support policies in place, although with varying degrees of ambition.² (→ See *Figure 12, Table 3 and Reference Tables R3-R12*.)

Policy support for renewable energy can be categorised as direct policy and indirect policy. Direct policies, such as mandates or financial incentives, explicitly target the increased deployment of renewables and enabling technologies, while indirect policies support effective operating conditions and the integration of renewables and enabling technologies into energy systems and markets. Although this chapter is focused on direct policy support, it also covers supporting policy for the specific end-use sectors of heating and cooling, transport and electricityⁱ.

ⁱ This is a change from previous editions of this chapter, which discussed only direct policy support for renewable energy. Here, discussion of policy can include both binding legislation and regulation as well as government commitments to action, such as roadmaps, action plans, programmes and non-binding targets. In general, however, binding policy is given preference in the discussion.

FIGURE 12. Number of Countries with Renewable Energy Policies, 2004-2019



Note: Figure does not show all policy types in use. In many cases countries have enacted additional fiscal incentives or public finance mechanisms to support renewable energy. A country is considered to have a policy (and is counted a single time) when it has at least one national or state/provincial level policy in place. Power policies include feed-in tariffs (FITs) / feed-in premiums, tendering, net metering and renewable portfolio standards. Heating and cooling policies include solar heat obligations, technology-neutral renewable heat obligations and renewable heat FITs. Transport policies include biodiesel obligations/mandates, ethanol obligations/mandates and non-blend mandates. For more information, see Table 3 in this chapter and Reference Tables R3-R12.

Source: REN21 Policy Database. See endnote 2 for this chapter.

The suite of renewable energy policies being deployed has evolved in response to changes in technologies and markets, as well as the evolving needs and realities of different jurisdictions. In more mature markets where large shares of renewables are installed, decision makers are adapting policy to support the technical and market integration of renewables and to address the impacts of large or rising shares of variable renewable electricity (VRE), including small-scale distributed generation. (→ See *Systems Integration* section in this chapter.) In less mature renewable energy markets and in some developing and emerging economies, policy remains focused on increasing renewable energy capacity and generation to meet basic energy demand, promote job creation and energy security, and provide increased access to modern energy services.³ (→ See *Distributed Renewables* chapter.)

Policies to advance renewable energy production and use can be targeted at any and all end-use sectors, including heating and cooling (in buildings and industry), transport and electricity. Renewable energy policy can exist across all levels of governance, including international and regional; national, state and provincial; and municipal governments. In jurisdictions with regulated power systems, national and sub-national public utility commissions (also called energy commissions or energy regulators) develop policies that apply to regulated utilities. Trade policy also has an impact on the production, exchange and development of renewable energy products, as well as renewable energy demand levels within specific countries.⁴ (→ See *Sidebar 3*.)

Policies and targets for renewables in power remain more ambitious and more numerous than those for other sectors.



SIDEBAR 3. Trade Policy, Trade Agreements and Renewables

As a key defining feature of the globalising world economy, trade has greatly shaped the production, exchange and technological development of renewable energy products. It allows for the formation of larger and more competitive markets for these technologies, leading to greater availability and lower costs. Trade creates the conditions for more-efficient producers to expand and capture economies of scale, helping to make renewable energy products more affordable.

Although trade is often referred to as occurring between countries (such as between China and the United States), it is essentially an entrepreneurial activity organised by companies. Renewable energy companies look to foreign markets and suppliers as they scale up their operations and production. Supply chain trade has grown as companies have systemised their production across multiple countries, especially for multi-component goods such as wind turbines and solar panels. Many renewable energy products are made by an international division of labour organised by supply chain trade arrangements.

Governments (national and sub-national) and the World Trade Organization (WTO) set the rules for trade, including measures that restrict or promote international trade in renewable energy goods and services. For example, WTO regulations prohibit export subsidies that distort international market competition by giving “unfair” trade advantages to subsidy-receiving exporters. Governments also can apply trade “safeguard” or “remedy” measures against alleged unfair imports, or they can apply tariffs or other protectionist measures to defend domestic producers against foreign competition. Certain rules are trade-facilitating, including technical and environmental standards that enable renewable energy products exported from one location to be accepted and used in foreign locations.

The international trade environment has become more challenging. Protectionist measures have risen from just over 600 in January 2017 to more than 1,100 by the end of 2019. Rising or high-level protectionism restrains the growth in trade in renewable energy products. Meanwhile, many trade conflicts remain unresolved. For example, China, India and the Republic of Korea all have pending disputes with the United States at the WTO regarding trade remedy measures applied to their solar photovoltaic (PV) exports. Similar conflicts have arisen related to the wind industry and to rare earth materials used to manufacture renewable energy products.

Trade in renewable energy goods and services will be limited where production and exchange are inherently localised, for example for hydropower dams and tidal barrages, whose construction entails primarily the use of locally sourced bulk materials (such as cement). Ever taller wind turbines make international trade in large components such as towers, blades and nacelle casings less economic due to the transport costs of moving heavy bulk items. Offshore wind turbines in particular are produced near their installation sites, although often by foreign-investing firms.

Meanwhile, smaller-scale, multi-component and multi-material renewable energy technology products and fuels lend themselves to international supply chain trade. Bioenergy products such as wood pellets and ethanol are traded worldwide as bulk cargo. Cross-border trade in hydro-electricity (for example, in Southeast Asia) is also well established. However, the chronic lack of global-level data on renewable energy trade impedes analysis of wider trends.

Conventional trade policy measures generally affect renewable energy trade on the demand side. For example, the raising and lowering of import tariffs affect end prices that in turn determine demand levels. Domestic-level policy measures tend to affect renewable energy trade more on the supply side – typically industrial policies aimed at strengthening the trading capacity of home producers of renewable energy products. Many governments have used “local content requirements” to develop their solar and wind energy industries, mandating that domestic and foreign-investing producers source certain percentages of their materials and components locally. Rules of origin applied in free trade agreements can have similar trade-diverting effects, especially when they set high national content ratios for products to qualify for free trade treatment.

Environmental measures have been included in free trade agreements (FTAs) since the 1970s, when renewable energy trade focused mainly on promoting hydropower in developing countries. More recently, climate change has raised renewable energy’s profile and coverage in FTAs. Of the more than 300 agreements in force as of early 2020 (up from just 15 in 1990), around 50 had measures promoting renewable energy trade and development, although many are primarily aspirational soft law clauses calling on signatory countries to deepen their co-operation on renewables.

The WTO itself has no specific agreements or rules on renewable energy or climate action, and its interaction with the United Nations Framework Convention on Climate Change on trade remains extremely limited. Furthermore, the WTO’s grip on the global trade system has weakened. In the last two decades it has been FTAs that have set new innovative measures on renewable energy trade. In 2019, for example, Costa Rica, Fiji, Iceland, New Zealand and Norway launched talks for the Agreement on Climate Change, Trade and Sustainability (ACCTS), which could prove a landmark pact not just for promoting renewable energy trade and development, but for more effectively aligning trade with climate action efforts generally.

Source: See endnote 4 for this chapter.

CROSS-SECTORAL TARGETS AND POLICIES

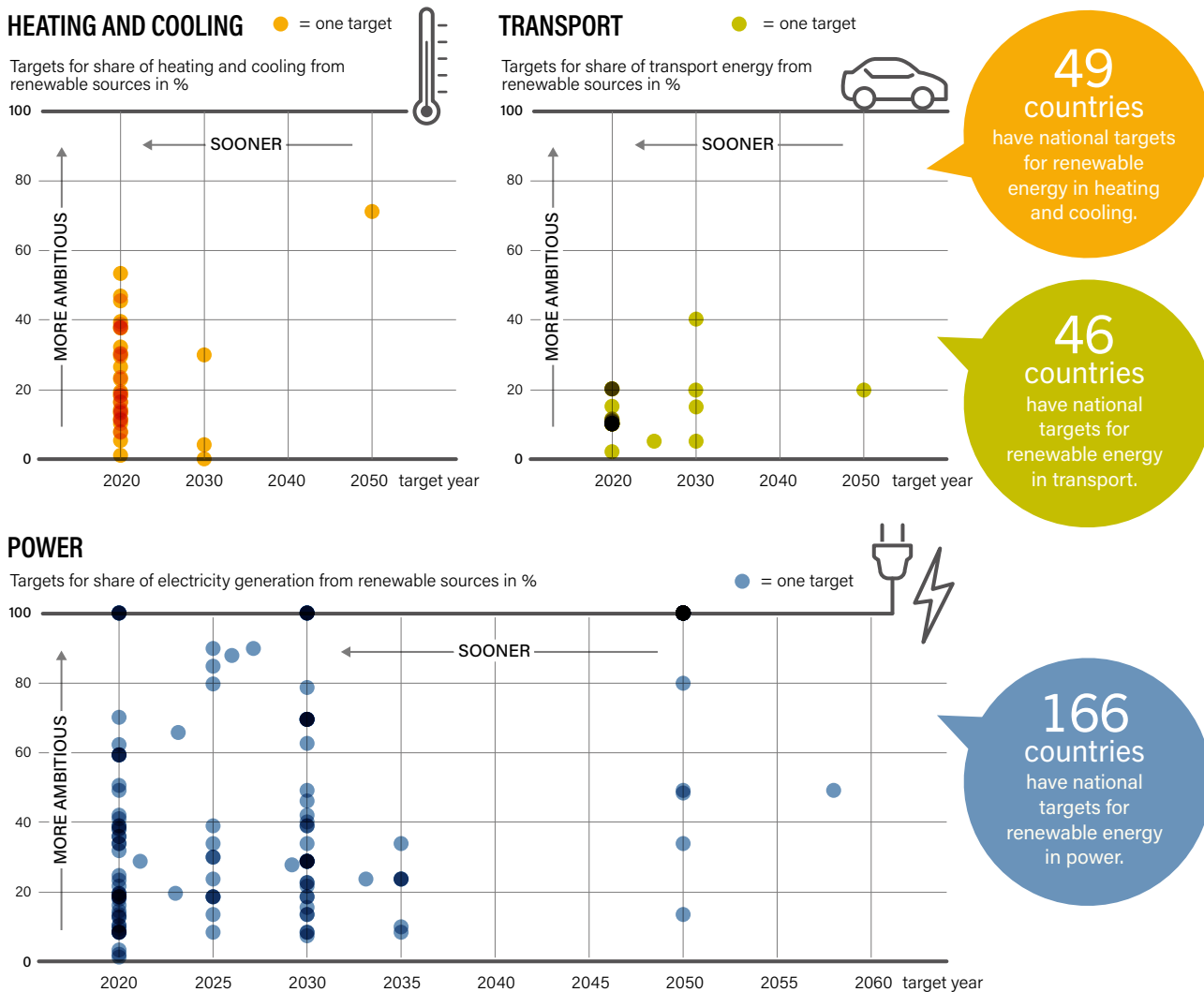
Renewable energy policies typically are enacted at a single level of governance and tend to focus on a single end-use sector. Strategies to align renewable energy policy across multiple levels of governance and across multiple economic sectors are rare. Although most renewable energy policies are not integrated or co-ordinated across sectors or levels of governance, examples of integration and co-ordination are emerging. Co-ordinated policy efforts often are organised under national or state-/provincial-level energy or climate change strategies. For example, in 2019 Scotland introduced a comprehensive programme that sets out policies at multiple levels of governance (national and local) to promote renewables across all sectors of the economy.⁵ Also, the Netherlands offered EUR 5 million

(USD 5.6 million) to support the production of renewable electricity, renewable gas, renewable heat, and combined heat and power for companies, institutions and non-profit organisations.⁶

Targetsⁱ are a primary means of expressing commitment to renewable energy and sending a positive signal to market players.⁷ Although targets on their own are generally insufficient to stimulate investment in renewables, they may be converted into action through the adoption and implementation of complementary policies. Globally, most renewable energy targets are aimed exclusively at the power (electricity) sector. However, some jurisdictions have enacted independent targets in the heating and cooling and transport sectors, and some (although fewer) have committed to cross-sectoral, economy-wide renewable energy targets. (→ See Figures 13 and 14.)

i The term "targets" can be implied to include aspirational goals, vision statements and other non-binding remarks or declarations. In this chapter, only official targets are discussed.

FIGURE 13. National Sector-Specific Targets for Share of Renewable Energy by a Specific Year, by Sector, in Place at End-2019



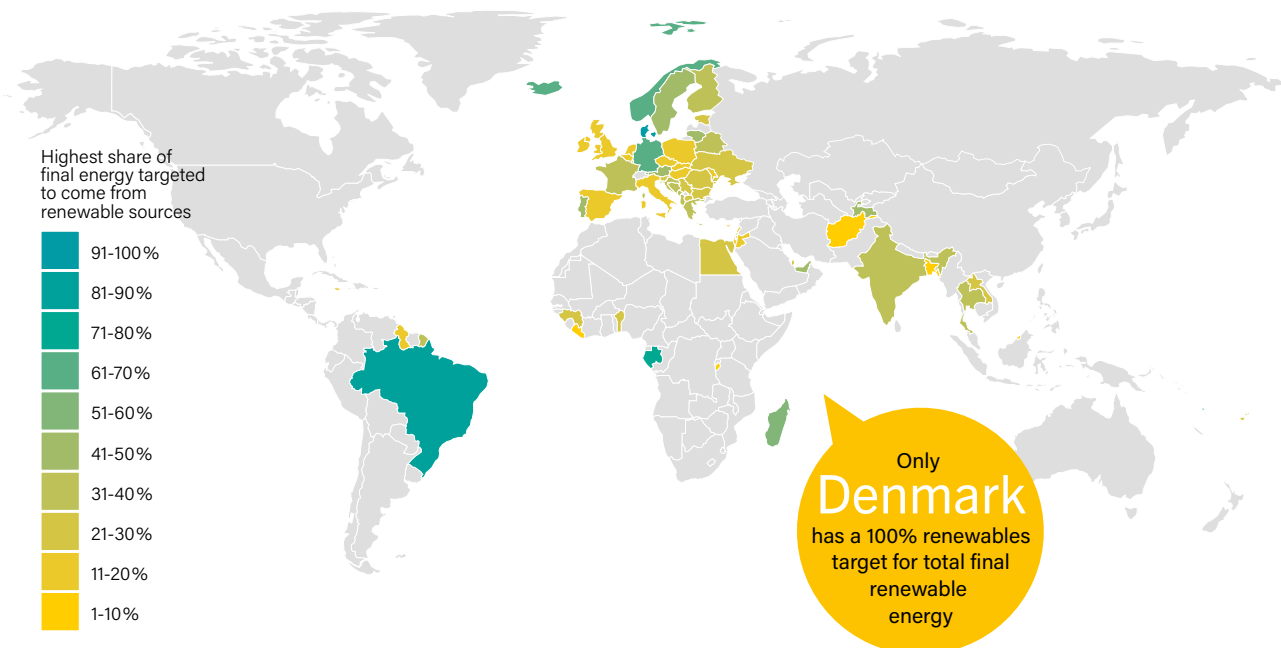
Note: Each dot can represent more than one country and is based on the highest target that a country has set at the national level. Figure includes only countries with targets in these sectors that are for a specific share from renewable sources by a specific year, and does not include countries with other types of targets in these sectors. The total number of countries with any type of target for renewable energy (not specific to shares by a certain year) is 49 in heating and cooling, 46 in transport and 166 in power.

Source: REN21 Policy Database. See endnote 2 for this chapter.

Only one cross-sectoral target was adopted during 2019. Spain committed to an economy-wide renewable energy target of 42% of final energy consumption by 2030 – which is more ambitious than the European Union’s (EU) target of 32% by 2030 – and also committed to individual targets for renewables in electricity generation and transport, and to improvements in energy efficiency.⁸ By comparison, 166 countries had targets for renewable power alone as of the end of 2019. (→ See **Reference Tables R3-R8.**)



FIGURE 14. National Targets for Share of Renewable Energy in Final Energy, by a Specific Year, in Place at End-2019



Note: Map shading is based on the highest target that a country has at the national level, although time frames (and qualifying technologies) to reach these targets vary significantly, from 2020 to 2050. For details, see Reference Tables R3-R8. Some targets shown may be non-binding.

Source: REN21 Policy Database.
See endnote 2 for this chapter.

Just one

new country adopted an economy-wide renewable energy target during 2019.



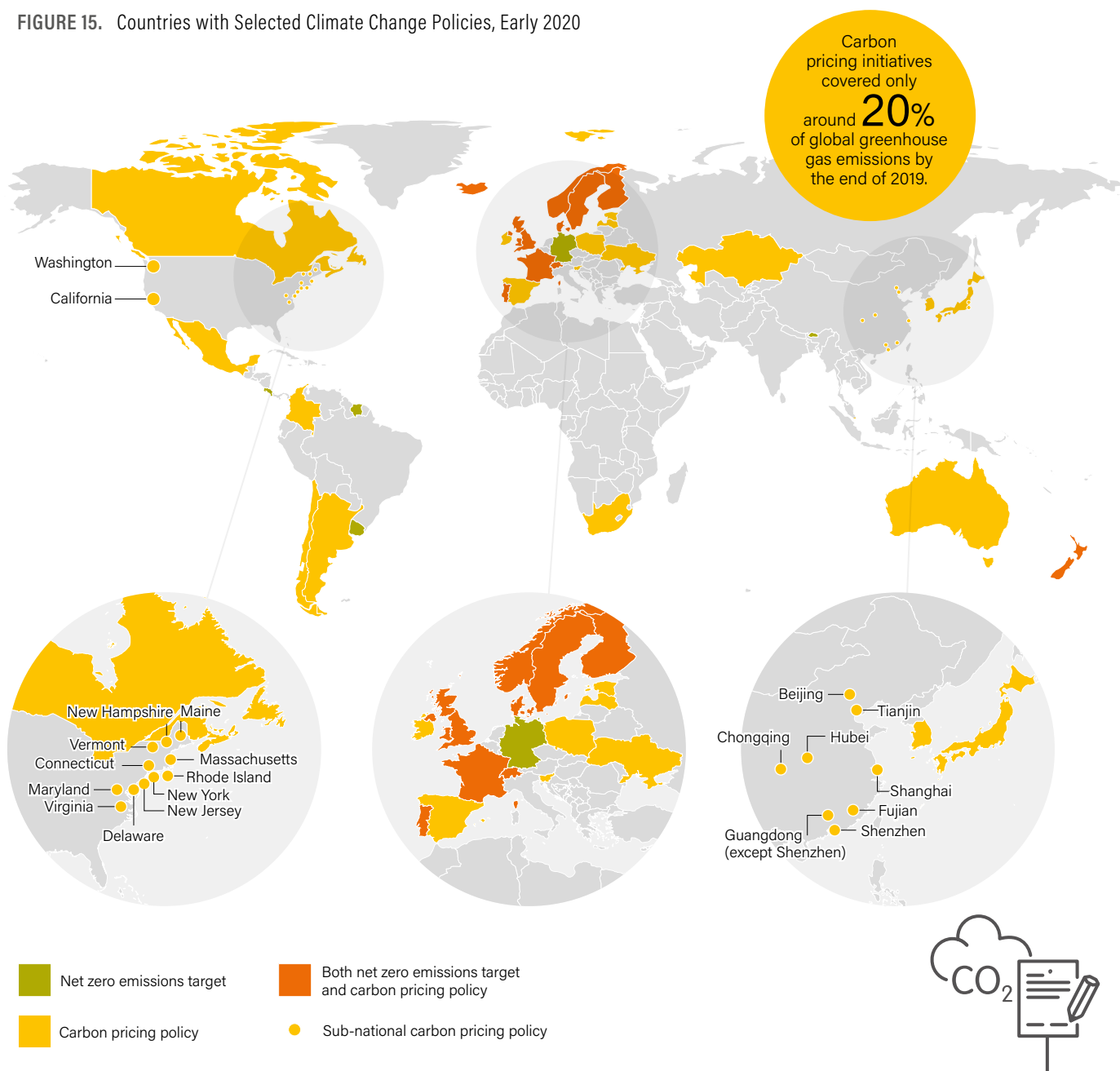
RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

Policies enacted to help mitigate climate change can directly or indirectly stimulate renewable energy deployment across all end-use sectors by mandating a reduction or elimination of

greenhouse gas emissions, phasing out the use of fossil fuels and/or increasing the costs of energy from fossil fuels relative to renewables.⁹ Climate change policies include banning or phasing out fossil fuels, enacting targets to reduce greenhouse gas emissions (including, for example, “net zero” commitments), and development and participation in carbon pricing and emissions trading programmes. (→ See Figure 15.)

i Net zero carbon emissions and carbon neutrality refer to the achievement of a state in which every tonne of CO₂ emitted to the atmosphere is compensated by an equivalent tonne removed (e.g., sequestered). See Glossary. In contrast, a gross zero target would reduce emissions from all sources to zero. In a net zero scenario, emissions are “allowed” as long as they are offset by removals. Reaching net zero emissions may be linked to activities such as carbon offsetting, and does not necessarily include the use of renewable energy.

FIGURE 15. Countries with Selected Climate Change Policies, Early 2020



Note: Figure does not show all climate policies but only carbon pricing policy use and net zero emissions targets. Carbon pricing policies include emissions trading systems and carbon taxes. Net zero emissions targets shown are binding and include those that are in law or policy documents, as well as those that have already been achieved.

Source: Based on World Bank and Energy and Climate Intelligence Unit. See endnote 9 for this chapter.

During 2019, some jurisdictions enacted policies that tie **climate change mitigation** directly to increasing the deployment of renewable energy. Costa Rica launched an economy-wide roadmap to achieve net zero emissions by 2050, which included specifications for policies to increase the use of renewables in industry as well as in the power and transport sectors.¹⁰ Germany's new EUR 54 billion (USD 60.5 billion) climate change plan includes greenhouse gas emissions reduction targets as well as policies to advance the use of renewable energy across the economy.¹¹ In the US state of New York, new climate change legislation set out targets for reducing greenhouse gas emissions and achieving 70% renewable electricity by 2030.¹²

Other policies to mitigate climate change, including **bans or phase-outs of the use of fossil fuels**, can stimulate the adoption of renewables indirectly. In 2019, Germany committed to shutting down all of its coal-fired power plants by 2038, and Chile announced a plan to phase out coal-fired power generation by 2040.¹³ At the sub-national level, the US states of New Mexico and Washington, and the territory of Puerto Rico, committed to closing their coal-fired power plants by 2031, 2025 and 2020, respectively.¹⁴ Many cities worldwide also are focused on banning fossil fuel use for heating and for some forms of road transport. (→ See *Heating and Cooling and Transport sections in this chapter.*)

Although greenhouse gas **emissions targets** – including net zero commitments as well as countries' Nationally Determined Contributions (NDCs) for emissions reductions under the Paris Agreement – may not be coupled explicitly with renewable energy policies, they can stimulate the uptake of renewables indirectly by mandating the reduction or removal of greenhouse gas-emitting technologies. However, many NDCs include measures that directly impact renewable energy, although mostly in the power sector alone. As of the end of 2019, of the more than 200 NDC plans that countries had submitted, 25 mentioned renewables in the context of heating and cooling, 25 in the context of transport, and 132 in the context of the power sector, while 112 mentioned energy efficiency.¹⁵

In 2019, the European Commission (with the abstention of Poland) proposed a European Green Deal to create the first carbon-neutralⁱ continent by 2050.¹⁶ Two countries in Europe – France and the United Kingdom – committed to national targets for net zero emissions by 2050, while Spain's draft National Energy and Climate Plan would commit the country to a carbon-neutral economy by 2050.¹⁷ Outside of Europe, New Zealand passed legislation to achieve net zero emissions by 2050.¹⁸

Other countries have committed to greenhouse gas reduction targets other than net zero, while some have decreased their ambitions. In 2019, Denmark agreed on a new target of a 70% reduction in greenhouse gas emissions by 2030.¹⁹ Japan became the 12th country to submit to the United Nations Framework Convention on Climate Change (UNFCCC) its long-term strategy for low-emission development, which outlines the country's

plans to reduce emissions in the energy, industry and transport sectors 80% by 2050.²⁰ The Russian Federation formally adopted the Paris Agreement in 2019; however, by year's end it had abandoned plans to impose emissions quotas, carbon caps on the country's largest emitters and penalties on large businesses that exceed quotas.²¹

Several cities also adopted greenhouse gas emissions commitments in 2019, including 94 mayors who announced their support for a Global Green New Deal for cities, committing to limiting global warming to 1.5 degrees Celsius above pre-industrial levels.²² Also, as of mid-2019, nearly 10,000 cities and local governments had committed to jointly reducing greenhouse gas emissions through the Global Covenant of Mayors for Climate & Energy.²³

Carbon pricing and emissions trading schemes also are increasingly widely implemented climate change policies. These measures have the potential to indirectly increase the deployment of renewable energy technologies – or to increase renewable generation – by increasing the relative cost of energy from fossil fuels.²⁴ At the international level, countries participating in the 2019 UNFCCC negotiations in Madrid failed to decide on regulations for new international carbon markets.²⁵ Some progress was made at the national level, however: both Singapore and South Africa implemented carbon taxes during the year, and Switzerland agreed to link its emissions trading system to the EU Emissions Trading System starting in 2020.²⁶

In Canada, legislation enacted in 2018 allowed the federal government to use a carbon price "backstop", which applied a carbon fee to provinces and territoriesⁱⁱ that do not have their own carbon pricing systems.²⁷ In 2019 and early 2020, the backstop was applied to five provinces and two territories.²⁸ At the sub-national level, the US state of Pennsylvania committed to joining 10 other statesⁱⁱⁱ in the Regional Greenhouse Gas Initiative cap-and-trade programme.²⁹ By the end of 2019, at least 57 national and sub-national governments and the EU had adopted some sort of price on carbon through either direct taxation or a cap-and-trade programme; these initiatives span 47 countries and cover around only 20% of global greenhouse gas emissions.³⁰

Nearly
10,000
cities and local govern-
ments had committed
to jointly reducing
greenhouse gas emissions
by mid-2019.

i The term "carbon neutral" means having a balance between emissions of carbon and the absorption of carbon from the atmosphere (by way of carbon sinks).

ii As of early 2020, federal backstop jurisdictions were Alberta, Manitoba, New Brunswick, Nunavut, Ontario, Saskatchewan and the Yukon.

iii The 10 other states are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont.

HEATING AND COOLING

Heating and cooling in buildings and industry is a large energy end-use and an important contributor to global greenhouse gas emissions.³¹ The potential for renewable energy to meet heating and cooling energy demands is enormous. Biomass, geothermal and solar thermal technologies all can provide thermal energy directly, and electricity generated from renewables also can be used to provide heat or cold. Despite this potential, policies and targets to advance the use of renewables for heating and cooling continue to be less common and generally less ambitious than those in the power sector.

By the end of 2019, only 49 countries had renewable heating and/or cooling targets, compared with 166 countries with renewable power targets.³² This is due in part to the complexity and unique requirements that characterise the heating and cooling sector, particularly compared with the power sector. Policy approaches aimed at increasing the use of renewables in heating and cooling generally are tailored to the contextual differences in demand and infrastructure within the sector, and often are implemented alongside policies to advance energy efficiency.³³

Whereas some renewable heating and cooling policies focus exclusively on either buildings or industry, others do not distinguish between the two. Some policies in the sector are

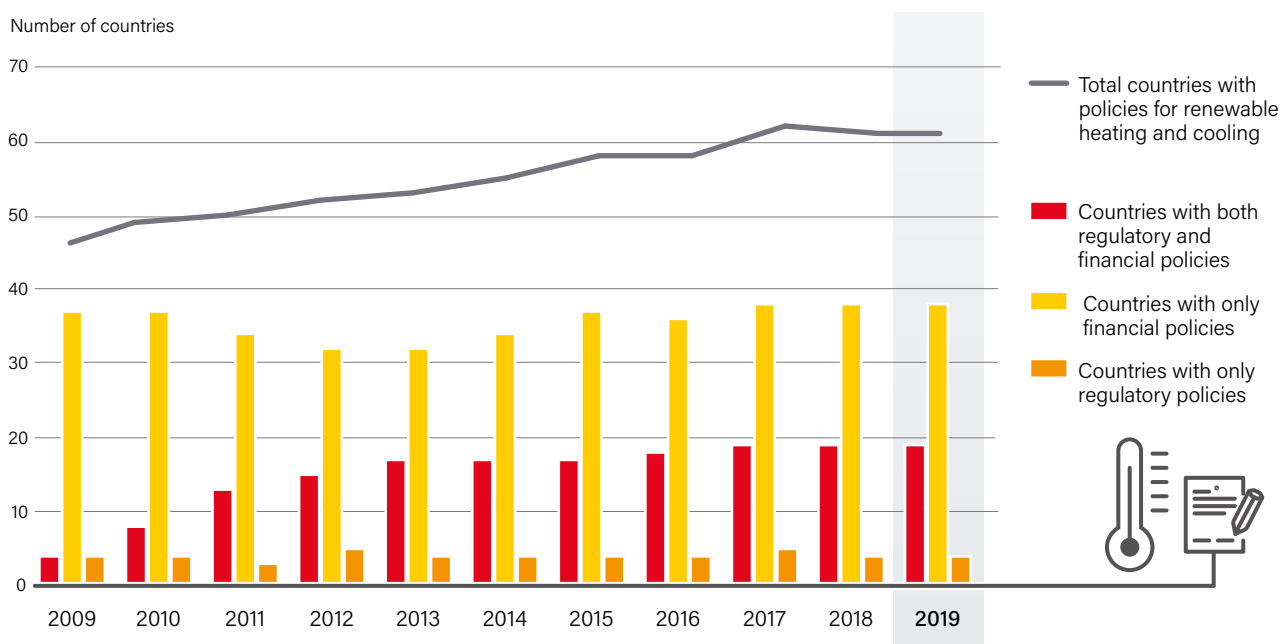
enacted in a bid to save power. For example, Zimbabwe banned the installation of new grid-connected electric water heaters but allowed the installation of water heaters accompanied by on-site solar water heating systems.³⁴ In some cases, **financial incentives** – including grants and tax credits – have been used to encourage renewable heating and cooling in both industry and buildings. Overall, at least 54 countries had some type of financial policy for the deployment or use of renewable energy in the heating and cooling sector in 2019, a number that has remained stable since 2017.³⁵ (→ See Figure 16.)

Policies that mandate or support the injection of renewable natural gas (RNG)ⁱ into natural gas pipelines typically result in increased penetration of renewables in both the building and industrial sectorsⁱⁱ. In 2019, France announced EUR 7-9 billion (USD 8-10 billion) in support for RNG under the umbrella of a mandatory target of 10% RNG in the country's gas grid by 2030.³⁶ Quebec (Canada) adopted a regulation that targets a minimum share of RNG (1% by 2020 and 5% by 2025) to be produced and injected into the provincial gas grid for use in buildings or industry.³⁷ Also in 2019, the US state of Oregon adopted legislation that creates voluntary targets for RNG injection into the gas grid and directs the state public utility commission to establish mechanisms by which regulated utilities can recover the costs of their RNG investments.³⁸

i Renewable natural gas (RNG) is a pipeline-quality gas that is fully interchangeable with conventional (fossil) natural gas. Unlike conventional natural gas, RNG is produced from biogas, the gaseous product of the decomposition of renewable organic matter.

ii Although these renewable natural gas policies do not focus exclusively on heating and cooling, they impact heating and cooling as an end-use.

FIGURE 16. Countries with Policies for Renewable Heating and Cooling, 2009-2019



Note: Regulatory policies include solar heat obligations, technology-neutral renewable heat obligations, renewable heat FITs, and fossil fuel bans for heating and cooling at the national or state/provincial level. Financial policies include investment subsidies, grants, rebates, tax credits, tax deductions and exemptions, and loans.

Source: REN21 Policy Database. See endnote 35 for this chapter.

BUILDINGS

Direct policy interventions for buildings include renewable heating and/or cooling targets, building energy codes, renewable heating and cooling mandates or ordinancesⁱ, renewable district heating initiatives and financial incentives. Indirect policies include fossil fuel bans, fuel taxes, net zero emissions standards for buildings and performance standards for renewable heating and cooling equipmentⁱⁱ. In 2019, the policy tools that achieved slightly higher uptake were financial incentives and indirect measures such as fossil fuel bans and emissions standards for buildings. (→ See **Reference Table R9**.)

No new **renewable heating and cooling mandates or ordinances** for buildings were adopted at the national level during the year, but California's public utility commission approved six municipal energy ordinances for energy efficiency standards in buildings, and two cities in the state (Menlo Park and West Hollywood) included solar energy requirements in their ordinances, with West Hollywood providing the option to meet requirements using solar thermal installations.³⁹

Mandatory **building energy codes** can play an important role in promoting the deployment of renewables and energy efficiency technologies in buildings – particularly in new construction or retrofits – if they require the deployment of renewable energy systems (often solar PV) and specific standards for energy efficiency.⁴⁰ Building energy codes that were mandatory for the entire sector were in place in at least 90 jurisdictions at the national or state/provincial level by the end of 2019.⁴¹ No new renewable energy requirements or energy efficiency mandates were added to national building energy codes during the year. At the local level, however, 23 municipalities in British Columbia (Canada) voluntarily adopted energy efficiency provisions that were more stringent than those in the mandatory provincial building code.⁴²

Financial incentives for buildings to stimulate the installation or use of renewable heating and cooling and improvements in energy efficiency include grants, rebates, tax incentives and loan programmes. In 2019, France announced an increase in financial support for residential energy efficiency and renewables, as well as for heat pumpsⁱⁱⁱ.⁴³ Lithuania announced that, beginning in January 2020, compensation payments would be made for the conversion of inefficient biomass boilers to efficient biomass boilers or heat pumps.⁴⁴ In early 2020, Germany made grants available to cover 40% of the costs of replacing outdated oil boilers with natural gas condensing boilers that are supported by solar space heating units.⁴⁵

At the sub-national level, Alberta (Canada) passed Property Assessed Clean Energy (PACE)^{iv} legislation to provide municipal low-cost financing for property owners to install renewable energy systems and make energy efficiency upgrades.⁴⁶ Mexico City (Mexico) announced MXN 150 billion (USD 8 billion) in funding for 750,000 square metres of solar thermal panels for dedicated water heating for commercial and industrial buildings.⁴⁷ Itabashi (Japan) offered grants covering up to 5% of the initial cost of installing solar thermal systems.⁴⁸

Policy packages that include multiple, **integrated policies** targeting renewable heating and cooling as well as power in buildings are rare, but in 2019 New York City (United States) enacted a new climate law that includes multiple policies to support renewables in buildings, including greenhouse gas emissions caps for buildings larger than 25,000 square feet (2,323 square metres) and financial incentives in the form of a new PACE programme for energy efficiency building improvements, as well as a solar PV mandate for new construction and buildings undergoing certain types of major renovations.⁴⁹



No new countries

have adopted renewable energy financial support policies for heating and cooling since 2017.

- i Mandates, or ordinances, typically include a technology-specific requirement, whereas building codes are usually technology-neutral and describe the standard of energy performance that must be met.
- ii Equipment performance standards provide a resource to help consumers make informed decisions when selecting renewable energy equipment, and ensure that the equipment works as intended.
- iii Electric heat pumps are not strictly a renewable energy technology, but could enable the use of renewable electricity in the heating and cooling sector. See Heat Pumps section in Systems Integration chapter.
- iv See Glossary for definition.

District heating and cooling can provide another entry point for renewables to reach end-users. In 2019, Europe's REWARDHeat project supported low-temperature district heating and cooling projects with an overall budget of nearly EUR 20 million (USD 22 million).⁵⁰ France's Fonds Chaleur programme also offered financial assistance for renewable heating and cooling, as well as heat recovery, in the country's district heating and cooling systems.⁵¹ Poland committed to setting up a programme to promote renewable district heat and thermal storage.⁵² Amsterdam (Netherlands) announced new investments to modernise its district energy system to boost the city's reliance on renewable energy.⁵³

Indirect policies to incentivise renewables in buildings in 2019 included **banning the use of fossil fuels** for heating. Austria banned the installation of liquid or solid fossil fuel boilers in new buildings from 2020, Norway banned the use of mineral oil to heat buildings from 2020, and the United Kingdom committed to a ban on natural gas boilers in new homes starting in 2025.⁵⁴ Poland adopted emissions standards for heating appliances in single-family homes and banned the use of coal in 11 of its 16 regions beginning in 2022.⁵⁵

At the sub-national level, Vienna (Austria) announced a ban on oil and natural gas heaters for 80% of new homes beginning in 2020.⁵⁶ Berkeley (California) became the first US city to ban the use of natural gas in most new buildings, and several other cities in the state followed suit later in 2019.⁵⁷ Montreal (Canada) committed to phasing out the use of oil for heating by 2030.⁵⁸ Rather than banning fossil fuels for heating, Seattle (Washington) implemented a USD 0.24 per gallon (0.06 per litre) tax on heating oil to fund rebates and grants for nearly 3,000 households to transition to electric heat pumps.⁵⁹

Another indirect policy implemented in 2019 to incentivise renewables in buildings was government commitments to **net zero emissions building standards**. Although no national or provincial/state governments made such commitments during the year, several cities adopted standards to require net zero heating and cooling and electricity generation and use. Oslo (Norway) and Heidelberg (Germany) joined 23 other citiesⁱ that have signed on to C40's Net Zero Buildings Declarationⁱⁱ to ensure that all new buildings operate at net zero carbon by 2030, and all buildings by 2050.⁶⁰ A coalition of eight additional citiesⁱⁱⁱ pledged in 2019 to decarbonise their existing building stocks by 2050.⁶¹

Equipment performance standards may indirectly support the deployment of renewable technologies in buildings by ensuring consumer confidence in renewable heating and cooling equipment. In 2019, Australia published its first equipment performance standard for solar air conditioning technologies.⁶²



INDUSTRY

Industrial processes use thermal energy (heat) to meet various energy needs. These demands can be met directly by thermal energy from renewables – including bioenergy, solar heat and geothermal heat – or indirectly from renewable electricity, for example via electric arc furnaces. (→ See *Global Overview*). In addition, renewable hydrogen can be used to meet certain energy demands within industry^{iv}.⁶³ (→ See *Box 1*). Policies focused on the use of renewables in industrial heating and cooling remained scarce in 2019. Only one country, Finland, set an **industry-specific target** during the year, aiming for bio-based fuel oil to replace 10% of heating for construction machines and fitted motors starting in 2021.⁶⁴

A limited number of new **financial incentives for renewables in industry** were introduced in 2019. The EU announced a EUR 10 billion (USD 11 billion) Innovation Fund for demonstrations of "low-carbon" technologies – including renewable energy and energy storage – in energy-intensive industries.⁶⁵ The EU also committed to increasing the use of renewables under its new industrial strategy.⁶⁶ Ireland opened the second phase of its Support Scheme for Renewable Heat, which provides businesses and farms with support for the installation and ongoing use of biomass and anaerobic digestion heating systems.⁶⁷

i The 23 cities are Cape Town, Durban, Johannesburg and Tshwane (South Africa); Copenhagen (Denmark); London (UK); Los Angeles, New York City, Newburyport, Portland, San Francisco, San Jose, Santa Monica, Seattle and Washington, D.C. (US); Medellin (Colombia); Montreal, Toronto and Vancouver (Canada); Paris (France); Stockholm (Sweden); Sydney (Australia); and Tokyo (Japan).

ii As part of C40's Net Zero Buildings Declaration, mayors pledge to enact regulations and policy and report annually on progress.

iii The eight cities are Budaörs (Hungary), Dublin (Ireland), Eskişehir (Turkey), Leeds (UK), Madrid (Spain), Padova (Italy), Velika Gorica (Croatia) and Wrocław (Poland).

iv In some cases, hydrogen also can be used as a feedstock for some chemical processes. Virtually all hydrogen globally was produced from fossil fuels in 2019. See Systems Integration chapter.

BOX 1. Policies for Renewable Hydrogen

Renewable hydrogen is an energy carrier produced through renewables-driven electrolysis or gasification using renewable feedstocks. Apart from the potential for hydrogen to be stored and converted into electricity when needed, it can be used to increase the penetration of renewables beyond the power sector, mainly in industry and transport but also possibly in buildings. (→ See *Systems Integration* chapter.)

A number of notable policy developments related to renewable hydrogen occurred in 2019, particularly in Australia, which released a National Hydrogen Strategy. The strategy allocates AUD 1.1 billion (USD 0.76 billion) to help fund renewable hydrogen research and development, hydrogen refuelling infrastructure, and a "clean energy" innovation hub to explore hydrogen storage, distribution and the potential for the use of renewable hydrogen in gas appliances. The country also created an Advancing Hydrogen Fund to support new renewable hydrogen projects nationwide. The state of Western Australia launched a strategy that includes funding for grants to study the production of renewable hydrogen for export, the use of hydrogen in mining operations, hydrogen blending with natural gas and the use of hydrogen as a transport fuel.

Outside of Australia, energy ministers from 25 EU countries agreed to promote renewable hydrogen through the region's Hydrogen Initiative. The UK government announced a GBP 12 billion (USD 15 billion) plan to generate hydrogen using offshore wind power. New Zealand also launched a roadmap for the development of a new renewable hydrogen industry.

Hydrogen production and use are being pursued in other countries as well, although the focus is not necessarily on renewable hydrogen. Japan and the Republic of Korea each undertook actions in 2019 to promote hydrogen fuel cells for road transport. Japan proposed a plan to set up 10,000 hydrogen refuelling stations and 10 million hydrogen fuel cell vehicles worldwide within 10 years. The Republic of Korea introduced a roadmap for a hydrogen economy, which outlines the country's plans to increase the production and use of hydrogen vehicles, expand the production of fuel cells and build a system for the production and distribution of hydrogen.

Source: See endnote 63 for this chapter.



TRANSPORT

Although the global transport sector has the second highest share of total final energy consumption, it remains the sector with the lowest penetration of renewables and continues to rely heavily on fossil fuels.⁶⁸

By the end of 2019, only 46 countries had some form of renewable transport target. Although the adoption of renewable energy policies for transport has not been as rapid as in the power sector, policy makers increasingly are exploring expanding the use of renewables in the transport sector as a means to improve local air pollution and meet greenhouse gas emissions targets.⁶⁹

Policies that support the production and use of liquid and gaseous biofuels for transport are the most common type of direct renewable energy policy in the sector, and biofuels continue to make the largest contribution of renewable energy to transport. However, policies aimed at the electrification of transport, particularly road transport, also have increased in importance and number.⁷⁰ Electric mobility – including electric road vehicles, rail and other modes of transport – is only renewable to the extent that the electricity used for charging is generated from renewable sources. (→ See **Reference Table R10**)

By the end of 2019, only **46 countries** had some form of renewable transport target.

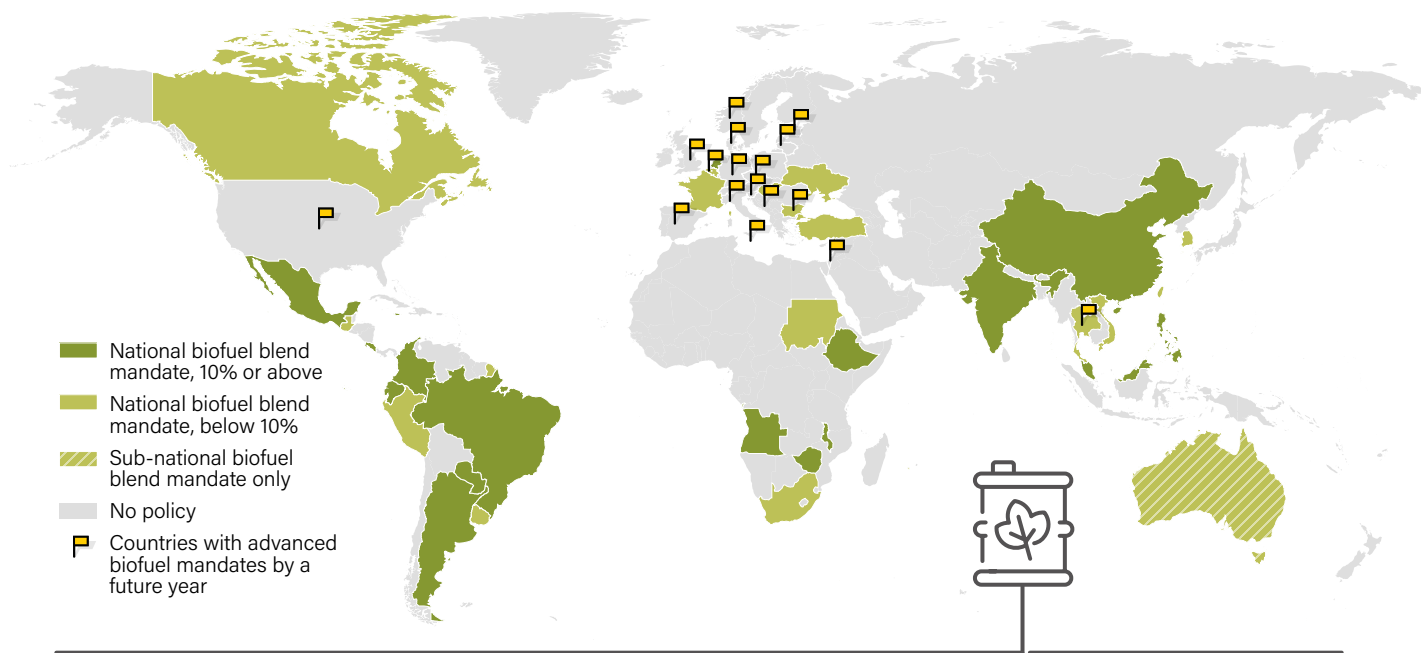


In 2019, policies to promote renewable energy in the transport sector continued to focus primarily on road transport, which accounts for the vast majority of energy use in transport, with rail, aviation and shipping seeing less attention despite being large energy consumers.

ROAD TRANSPORT

In the road transport sector, direct policies that explicitly promote the use of renewables are focused mainly on increasing the production and use of biofuels. Although the number of jurisdictions with some type of EV policy rose sharply in 2019, these measures generally lacked a direct link to renewable electricity. As in previous years, most road transport policy targeted light-duty vehicles. (→ See **Figures 17 and 18**.)

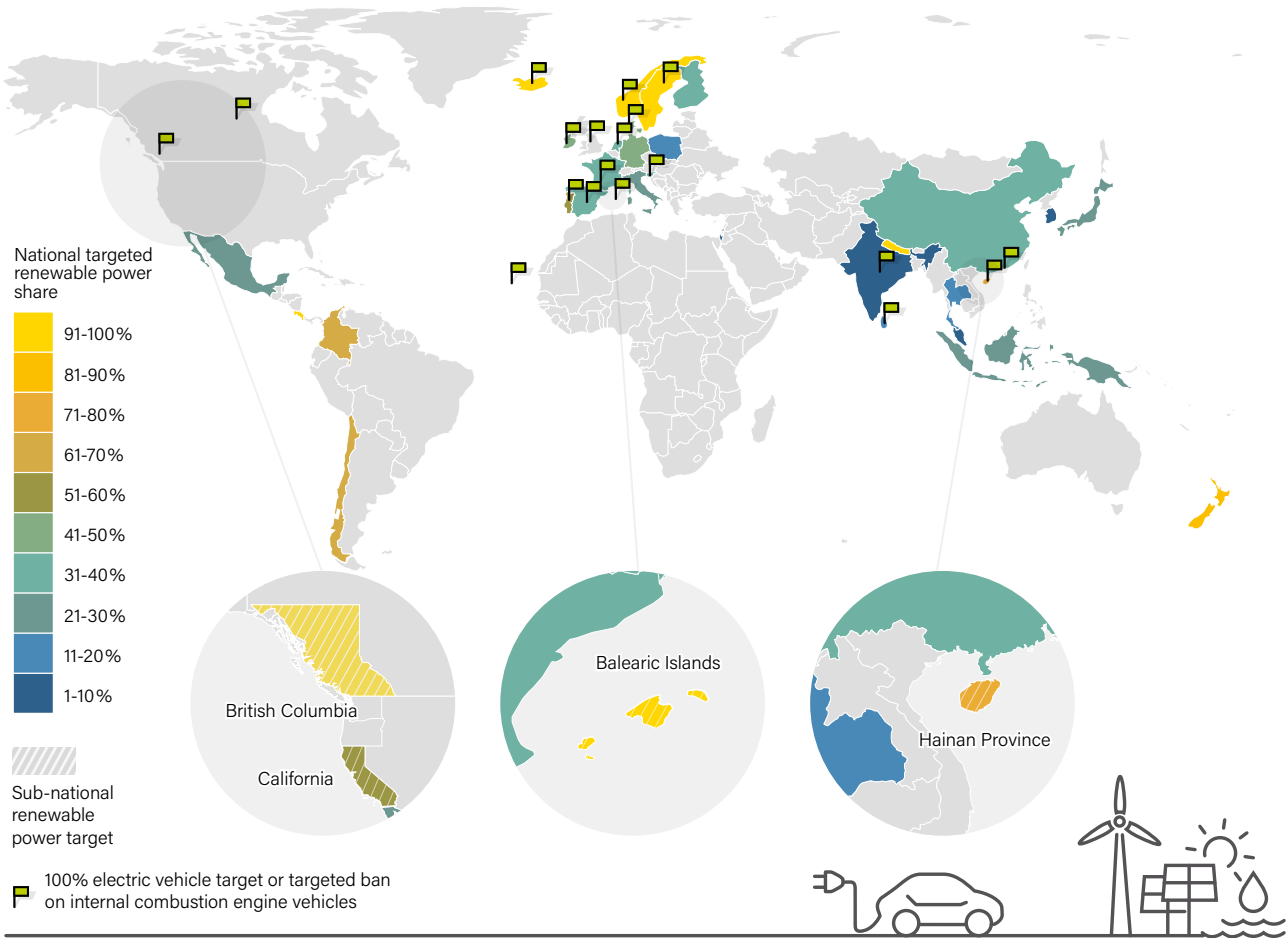
FIGURE 17. National and Sub-National Renewable Transport Mandates, as of End-2019



Note: Shading shows countries and states/provinces with mandates for either biodiesel, ethanol or both. At the regional level, the EU has an advanced biofuels target. See Reference Table R10.

Source: REN21 Policy Database. See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

FIGURE 18. Targets for Renewable Power and Electric Vehicles, as of End-2019



Note: Renewable power targets include only targets for a specific share of electricity generation by a future year. Where a jurisdiction has multiple targets, the highest target is shown. Electric vehicle targets vary; see Reference Tables R5 and R10 for details.

Source: See endnote 2 for this chapter.



At least 18 jurisdictions had **100% EV targets** or targeted bans on internal combustion engine vehicles by end-2019.

Biofuels in Road Transport

Despite a trend towards greater electrification of road transport, biofuels (including ethanol and biodiesel) account for more than 90% of renewable energy in the transport sector and remain central to many national and sub-national renewable transport policy frameworks.⁷¹ Policies supporting the production or use of biofuels include blending mandates, financial incentives, public procurement, and support for fuelling and blending infrastructure and advanced biofuels. Biofuels continued to receive policy attention in 2019 as a means to foster wider use of renewables in the sector, to support energy security and economic development, and because biofuels can be used in existing internal combustion engine vehicles.⁷²

Biofuel blending mandates – the most widely adopted policy type for increasing renewable fuels in road transport – are prevalent across all regions and countries.⁷³ The number of countries with biofuel blending mandates remained stable between 2018 and 2019, totalling 70 countries at year's end.⁷⁴ However, blending mandates are not always enforced.⁷⁵

Several existing mandates were strengthened during 2019.⁷⁶ Indonesia launched a mandate for 30% biodiesel blending in petrol (B30, up from the previous B20 requirement), the highest mandatory mix in the world.⁷⁷ France raised the minimum biofuel blend to 7.9% in 2019 and 8.2% in 2020.⁷⁸ Finland adopted a law to gradually increase the share of biofuels to 30% and the share of advanced biofuels to 10% by 2029 for use in road transport.⁷⁹ Brazil approved a new biodiesel blend of B11 (up one percentage point from 2018) and announced approval of the sale and use of B15.⁸⁰ By contrast, the US Environmental Protection Agency (EPA) expanded the number of exemptions from biofuel blending that it granted to smaller refiners.⁸¹

With respect to advanced biofuels, by the end of 2019, eight countriesⁱⁱⁱ had **mandates in place for advanced biofuels**, and the EU had a voluntary 0.5% blending mandate for these fuels.⁸² Meanwhile, at least 24 countries had future targets in place for advanced biofuels.⁸³ At the sub-national level, Quebec (Canada) proposed lowering the blending requirement for ethanol that has at least 10% cellulosic content^{iv}.⁸⁴

Financial incentives to support the production and use of biofuels are less common but do exist. In 2019, Thailand enacted a policy to subsidise the retail price of B10 by THB 2 (USD 0.06) per litre through January 2020, when it would replace B7 as the diesel option at pumps.⁸⁵ In the United States, the biodiesel tax credit of USD 1 per gallon (USD 0.26 per litre), which expired in 2017, was extended retroactively to 2022, and the cellulosic ethanol

tax credit was extended through 2020.⁸⁶ A 2019 resolution in Brazil, part of the country's RenovaBio programme, included an estimated BRL 9 billion (USD 2.2 billion) in support for the ethanol sector and another BRL 4 billion (USD 1 billion) for increased sugarcane production.⁸⁷ The programme also introduced **emissions reduction targets** for fuel distributors, with the option to demonstrate compliance by buying **traded emissions reduction certificates** awarded to biofuel producers.⁸⁸

Biofuel blending mandates

remain the most widely adopted renewable energy support policy in the transport sector.



Some cities have implemented **public procurement programmes** to support biofuels. In 2019, Toronto (Canada) began installing new equipment to transform biogas produced from the city's organic waste into RNG to fuel its waste collection trucks.⁸⁹ Santa Barbara (United States) replaced petroleum diesel with renewable diesel in its municipal bus fleet.⁹⁰

Other jurisdictions promote biofuels for road transport by **supporting biofuel infrastructure**. For example, the US state of Minnesota enacted a grant programme in 2019 that provides funding for biofuel blending infrastructure.⁹¹

i There is ongoing debate about the environmental impacts of some first-generation biofuels on climate change, air and water quality, land use and biodiversity. See Bioenergy section in Market and Industry chapter.

ii The US refining industry is required by law to blend ethanol and other biofuels into the country's petrol under the US Renewable Fuel Standard (RFS). As part of the RFS, the EPA can exempt small refineries if they prove that compliance would cause "disproportionate economic hardship".

iii The eight countries are Bulgaria, Croatia, France, Italy, Luxembourg, the Netherlands, the Slovak Republic and the United States.

iv Under the proposal, the blending requirement would be 9% instead of 10% in 2021, and 13.5% instead of 15% in 2025.

Electric Vehicles

Electric vehicle (EV) policies are not renewable energy policies by themselvesⁱ. However, while EVs may not always increase the renewable energy share in the transport sector, they do offer the potential for greater penetration of renewable electricity, increased efficiency and lower emissions. Therefore, such vehicles can be important enabling technologies. (→ See *Systems Integration chapter*.)

Policies to support EVs can indirectly or directly promote the use of renewable electricity in the transport sector. Indirectly, in jurisdictions that have policies supporting an increased share of grid-connected renewable power, policies that promote electric mobility ultimately increase the penetration of renewables in transport.⁹² Policies also may directly support renewables by requiring EVs to be charged with renewable electricity. In 2019, Austria remained the only country that had a **policy directly linking renewables with EVs**.⁹³ At the municipal level, of the more than 50 cities worldwide that had e-mobility targets as of mid-year, only 3 – Copenhagen (Denmark); Honolulu (Hawaii, United States); and Paris (France) – had e-mobility targets that were directly linked to a renewable electricity target.⁹⁴

Policies to support the increased uptake of EVs include binding targets, financial incentives, public procurement and public support for charging infrastructure. Incentives such as congestion charging, free parking and preferred access also can contribute to greater EV uptake. Targets and financial incentives are two of the most common forms of policy for EVs. By the end of 2019, at least 39 national, sub-national and regional jurisdictions had targets for EVs, and at least 13 jurisdictions had some form of financial support in place for the vehicles.⁹⁵

During the year, targets and **financial incentives** for EVs often were implemented in parallel. Canada announced deployment targets as well as various financial incentives for zero emission vehicles such as EVs.⁹⁶ India launched its National Electric Mobility Mission Plan, which includes a target of 7 million hybrid and electric vehicles by 2020, and it also implemented the Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME Phase II) scheme, which includes a USD 1.4 billion budget over three years to reduce the purchase price of hybrids and EVs through rebates.⁹⁷ Pakistan approved a national EV policy with targets and incentives aimed at a 30% EV share of all passenger vehicle and heavy-duty truck sales by 2030, and 90% by 2040.⁹⁸

Several governments announced plans for **public procurement** of EVs. As part of its economy-wide roadmap to achieve net zero emissions by 2050, Costa Rica committed to public procurement of electric buses and taxis and the provision of funds to create an electric train line.⁹⁹ India's National Electric Mobility Mission Plan calls for replacing the national government's fleet of petrol- and diesel-powered vehicles with EVs.¹⁰⁰ The US state of Virginia dedicated USD 20 million to fund a new initiative to accelerate the deployment of electric school buses, and New York City committed

USD 1.1 billion to purchase and deploy 500 electric buses for public transit.¹⁰¹ Chile's capital city, Santiago, deployed 200 e-buses in 2019 as part of a plan to cut emissions and reduce air pollution.¹⁰²

Incentives such as congestion charging, free parking and preferred access for EVs also contribute to the uptake of these vehicles. In 2019, Colombia passed a new law that established incentives for EVs, including discounts on insurance premiums, exemptions on vehicle traffic restriction measures, and preferential parking.¹⁰³

In 2019, Cabo Verde developed an **integrated set of policies** to promote the use of EVs. The country's Electric Mobility Policy Charter (CPME) includes targets aimed at replacing all internal combustion engine vehicles in its fleet with EVs by 2050; developing nationwide charging infrastructure by 2030; replacing the public transport fleet with 100% EVs by 2030; and creating financial incentives for the use of EVs and charging infrastructure (including investment incentives, tax incentives and customs incentives).¹⁰⁴

In some regulated power markets, public utility commissions have the authority to design public policy to encourage and facilitate increased EV uptake by enacting **policies that specifically target energy utilities**. In 2019, the public utility commission in the Indian state of Uttar Pradesh implemented EV-specific electricity pricing structures for utility customers designed to encourage EV uptake.¹⁰⁵ In the United States, the public utility commission of New York state introduced a **time-of-use rate** for residential EV charging customers, and the Maryland public utility commission required utilities to develop time-of-use rates and rebates for residential chargers.¹⁰⁶

Indirect Policies for Road Transport

Most direct policies to advance the use of renewables in road transport apply to either biofuels or EVs specifically. Likewise, some types of indirect policies (including vehicle emissions and fuel economy standards as well as support for EV charging infrastructure) aim specifically to increase the uptake of EVs, while other indirect policies (such as fossil fuel vehicle bans and the creation of low-emission vehicle zones) can increase the uptake of both EVs and biofuels in road transport.

Vehicle emissions standards for light-duty vehicles typically apply to greenhouse gas emissions and/or ground-level air pollutants. Both of these forms of emissions standards may indirectly incentivise the uptake of EVs, as manufacturers are required to produce low or zero emission vehiclesⁱ, and EVs do not directly emit greenhouse gases or air pollutants. In 2019, Kenya adopted Euro 4ⁱⁱⁱ vehicle emissions standards to replace the more lenient measures in the country since 2000.¹⁰⁷ At a sub-national level, the US state of Minnesota implemented two standards to reduce emissions of CO₂ and other pollutants from light-duty passenger cars, trucks and sport utility vehicles (SUVs).¹⁰⁸ The EU reached a provisional agreement on the first-ever CO₂ emission standards for trucks.¹⁰⁹

i Likewise, so-called "zero emission vehicles" are not necessarily fuelled from renewable sources.

ii "Zero emission vehicles" typically refer to vehicles that produce no atmospheric pollutants during operation (such as EVs and hydrogen-fuelled vehicles). Zero emission vehicles are not necessarily fuelled by renewable sources; in most cases, the term refers to EVs, albeit without reference to the source of the electricity.

iii Since 1992, new car models in the EU have had to meet increasingly stringent emissions limits, known as the Euro emissions standards, before they can be sold. The Euro 4 emissions standard relates to the EU standard for pollutants put in place in 2005. The Euro 4 emissions standard covers carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter.

By the end of 2019,

only **37**
countries

had fuel economy policies for light-duty vehicles, and just 5 countries had fuel economy standards for trucks.

Vehicle fuel economy policies and standards

help to increase the efficiency of vehicles and limit the amount of fuel that is used (as well as the resulting emissions) to go a given distance. In many jurisdictions, such policies have reduced reliance on fossil fuels for transport, although the

impact of such measures may have been offset by trends towards larger vehicles, particularly in recent years. By the end of 2019, only 37 countries had fuel economy policies for light-duty vehicles, a total that is unchanged since 2017.¹¹⁰ Meanwhile, just five countries – Canada, China, India, Japan and the United States – had fuel economy standards for trucks, with no new countries adopting such standards during 2019.¹¹¹

The creation of **low-emission vehicle zones** could increase the uptake of both EVs and biofuels. In 2019, London (United Kingdom) introduced a municipal ultra-low emission zone (ULEZ), which imposes a charge for diesel vehicles whose engines are not certified to the latest Euro 6 standardⁱ, as well as for most petrol cars older than 14 years.¹¹²

Another indirect policy with the potential to incentivise both EVs and biofuel-based transport is a **ban on fossil fuels in road transport**ⁱⁱ. In 2019, both Ireland and Sweden announced plans to ban the sale of new petrol and diesel vehicles by 2030, and Canada announced a similar ban by 2040, while Colombia announced a partial ban.¹¹³ France passed a transport law upholding a ban on the sale of fossil fuel cars by 2040 and facilitating the uptake of EVs.¹¹⁴ At year's end, China was considering testing a ban on petrol-fuelled vehicles in some parts of the country and setting a timetable to eventually phase out such vehicles.¹¹⁵ The United Kingdom's ban on sales of new petrol, diesel or hybrid cars was moved up by five years, from 2040 to 2035.¹¹⁶

By the end of 2019, at least 18 countries, states and provinces had committed to banning the sale of fossil fuel vehicles by 2050 or beforeⁱⁱⁱ, up from 12 jurisdictions the year before.¹¹⁷ At the local level, at least 35 major cities worldwide had plans to ban or heavily restrict the use of diesel vehicles, and circulation restrictions for petrol- and/or diesel-powered vehicles had already been adopted in several more.¹¹⁸

One type of indirect policy focused on EVs exclusively is **policy support for EV charging infrastructure**. In 2019, India's FAME Phase II scheme included a target of 2,700 charging stations in cities with more than 4 million inhabitants, as well as fast and ultra-fast charging stations along major highways.¹¹⁹ Canada

announced nearly CAD 100 million (USD 76.5 million) in funding to deploy new EV charging (and hydrogen fuelling) stations.¹²⁰ The Netherlands committed to installing 2,000 charging points to support electrification of its national government fleet.¹²¹ At the sub-national level, the US state of New York provided USD 31.6 million to its regulated utilities to build up to 1,075 fast-charging stations to expand EV use.¹²²

Public utility commissions also have enacted policies to incentivise EV charging infrastructure.¹²³ For example, in 2019, the public utility commissions for the US states of Maryland and New York authorised utilities to recover the cost of EV charging infrastructure from electricity rate-payers.¹²⁴

In addition to government initiatives, many private companies have implemented their own initiatives and programmes to support the uptake of EVs and renewables in the sector.¹²⁵ (→ See Box 2.)

AVIATION, RAIL, SHIPPING AND PORTS

The rail, aviation and maritime transport sectors continued to receive less policy attention than the road transport sector. Aviation and shipping are the fastest growing transport sectors and account for a large share of the total final energy used in transport, with aviation accounting for 11% and shipping for 10%.¹²⁶ They also are the two most difficult transport sectors to convert to the use of renewable fuels and electricity.¹²⁷ Barriers to the commercialisation of renewables in aviation and shipping include the cost of advanced biofuels, challenges related to battery weight and range, and jurisdictional factors related to the regulation of cross-border industries. Rail, on the other hand, consumes around 1.8% of the total final energy used in transport and is the most highly electrified transport sector.¹²⁸ (→ See *Transport section in Global Overview chapter*.)

By the end of 2019, no countries had implemented renewable energy mandates for **aviation**, although four countries (Finland, Norway, Brazil and Indonesia) had announced biofuel aviation targets, while other countries had adopted policies that could indirectly support the use of renewables in the sector.¹²⁹ The Finnish government announced a target of a 30% biofuels share in aviation, to be achieved through a biofuel blending obligation.¹³⁰ Scotland's 2019 Green New Deal policy package included a net zero aviation commitment by 2040.¹³¹ The United States announced up to USD 55 million in funding for two programmes to support the development of electric aviation technology and powertrain systems, although these are not directly linked to renewable electricity.¹³²

One type of supporting policy – a tax on air travel – does not directly target increased use of renewable energy in the aviation sector but may provide a disincentive for air travel and indirectly

i The Euro 6 emissions standard relates to the EU standard for pollutants put in place in 2015 and covers the same pollutants as Euro 4 (see footnote iii on previous page).

ii Although bans on fossil fuels may incentivise both EVs and biofuels, a ban specifically on internal combustion engine vehicles may encourage EVs but adversely affect the uptake of biofuels.

iii Targets include the following: Cabo Verde, Canada, British Columbia (Canada), Hainan Province and Taipei (China), Costa Rica, Denmark, France, Iceland, Japan, Netherlands, Norway, Slovenia, Balearic Islands (Spain), Sri Lanka, Sweden, United Kingdom and Scotland. See endnote 117 for this chapter and Reference Table R10.

BOX 2. Private Sector Initiatives in Renewable Transport

The private sector is pushing forward with its own renewable energy initiatives in transport, sometimes regardless of government policy support. Some companies are taking advantage of increasing electrification in road transport to couple EV charging with renewable electricity. In 2019, EVgo, the largest public EV fast-charging network in the United States, contracted for 100% renewable electricity. Another US company, EnelX, is undertaking a project in Hawaii to maximise EV charging at times when solar electricity generation is highest. In Europe, Fastned (Netherlands) won a tender in the United Kingdom to build and operate five fast-charging EV stations that will deliver 100% renewable electricity.

In the aviation sector, some airports and airlines have pushed forward with their own renewable energy strategies. The US carrier Delta Air Lines announced that it would invest USD 2 million to partner with Northwest Advanced Bio-Fuels for a feasibility study of a biofuel production facility to produce sustainable aviation fuel and other biofuel products. Halmstad Airport in Sweden made a commitment to require at least 5% of an airline's fuel uptake at the airport to be sustainable aviation fuel. At least 8 airports had regular distribution of blended alternative fuel as of early 2020, up from 5 the year before, while at least 14 airports had batch deliveries of such fuels. (→ See also *Bioenergy section in Market and Industry chapter*.)

Other airports are focusing on using solar PV to power their services. As of 2019, Indonesia's Aji Pangeran Tumenggung Pranoto International Airport was set to become the country's first airport to use solar power. Airport operators in four major US cities have committed to coupling on-site solar generation with electric-powered ground service equipment and shuttle bus fleets.

Private companies are investing in renewables in shipping and rail as well. The Dutch company GoodFuels partnered with Reinplus Fiwado Bunker in 2019 to launch the first inland vessel that runs on 100% sustainable biofuels. Mediterranean Shipping Company, the world's second largest container line, committed to using biofuel blends on a regular basis when bunkering vessels in the Dutch port of Rotterdam.

In the rail sector, Tokyu Corp in Japan began running the Setagaya Line in Tokyo with electricity generated 100% from renewable energy sources. Also in 2019, the United Kingdom saw the launch of its first railway line to be directly supplied with solar power, a pilot project from a group of private companies, a charity and a university.

Source: See endnote 125 for this chapter.

incentivise renewables and energy efficiency. In 2019, France committed to taxing air travel starting in 2020 – with the proceeds directed towards less carbon-intensive modes of transport, such as trains.¹³³ Similarly, Germany increased air passenger taxes on flights while reducing taxes on long-distance rail.¹³⁴

As with aviation, few countries have enacted policy to advance the use of renewable energy in the **shipping** sector. Norway released an Action Plan for Green Shipping in 2019 that outlines the government's ambitions to halve emissions from domestic shipping and fisheries by 2030 and to promote the development of low- and zero emission solutions for all vessel categories. The plan includes allocations via the Green Fund for Climate of NOK 485 million (USD 55 million) to Enova, a government agency that promotes energy efficiency and renewables.¹³⁵ In addition, the United Kingdom published a Clean Maritime Plan, the "route map" for its Maritime 2050 strategy, which includes research on incentives for zero emission shipping and consultations on encouraging the uptake of low-carbon fuels.¹³⁶

Some **ports** are adopting targets to increase the use of renewable fuels, increase energy efficiency and/or decrease greenhouse gas emissions. By the end of 2019, at least 11 ports had joined the World Ports Climate Action Programme to develop measures for such goals, up from 7 ports the year before.¹³⁷ Also during the year, the Port of Houston in the US state of Texas announced that it

would purchase renewable electricity port-wide starting in 2020, making it the first US port to administer such a programme.¹³⁸

For the **rail** sector, a small number of jurisdictions implemented policies aimed at electrification of rail in 2019. Scotland's Green New Deal package includes commitments to electrify its rail network and to use battery-powered trains, and the city of New Delhi (India) approved a target for complete electrification of its railway network by 2022-2023.¹³⁹ However, neither effort was linked specifically to renewables.



POWER

The power sector continued to receive the bulk of renewable energy policy attention in 2019. As in previous years, most of the renewable power capacity added globally was in large-scale, centralised projects. However, the capacity of decentralised renewable systems (such as rooftop solar PV) continued to increase rapidly.¹⁴⁰

Many jurisdictions have adopted targets for renewable capacity and generation, as well as policies aimed at promoting both large- and small-scale renewable power to achieve these targets. In 2019, targets continued to be the most popular form of intervention to spur investment in both large- and small-scale renewables. By the end of the year, 166 countries had in place some form of renewable electricity target, up from 162 countries in 2018.¹⁴¹ In addition, corporate sourcing of renewables continued to advance during the year, due in part to government support policies.¹⁴² (→ See Box 3.)

Several countries adopted new targets in 2019. For example, Pakistan committed to a renewable electricity target of 30% by 2030, and Mauritius committed to a target of 35% renewables by 2025 in its Renewable Energy Roadmap 2030 for the Electricity Sector.¹⁴³ Angola set a goal of 800 megawatts (MW) of renewables (representing 74% of its installed power base) by 2025.¹⁴⁴ Ghana adopted a target to increase the share of renewable electricity in the energy mix in order to reduce dependence on traditional biomass, provide distributed renewable energy options for off-grid communities, and promote local content and local participation in the renewables industry by 2030.¹⁴⁵

At the sub-national level, the Australian Capital Territory committed to 100% renewable electricity starting in 2020.¹⁴⁶ At least three large US cities (Chicago, Los Angeles and Philadelphia) also committed to 100% renewable electricity by 2045.¹⁴⁷

Some countries made existing targets more ambitious. Chinese Taipei passed amendments to its Renewable Energy

BOX 3. Corporate Sourcing of Renewable Electricity

Declining costs and greater technological maturity coupled with favourable policy attention to renewable energy, have contributed to rising corporate interest in sourcing renewables. (→ See *Market and Industry* chapter in this report, and *Feature* chapter in *GSR 2018*.) As of December 2019, more than 200 international corporations – including large multinationals such as Amazon, Apple, Coca-Cola, Ikea, Microsoft and Visa – had pledged to achieve 100% renewable electricity.

Corporations typically source renewable electricity through power purchase agreements (PPAs), renewable energy certificates (RECs) or guarantees of origin (GO), utility-led procurement programmes or self-generation.



The ability of corporations to procure renewable energy depends on the policy environment and on the electricity market structure in which companies operate, although opportunities to use policy to facilitate corporate renewable energy use exist in both liberalised and vertically integrated markets. In traditionally regulated electricity markets, corporations generally procure renewable electricity from the utility or install their own renewable systems on-site, unless they procure a REC/GO. In these markets, public utility commissions can enable or mandate utilities to offer renewable electricity procurement programmes such as utility green pricing and utility green tariffs.

Corporate PPAs, particularly virtual PPAs, have gained in popularity in recent years. In 2019, the United States was still home to most of the corporate PPAs being signed, but the practice was expanding rapidly to other parts of the world, particularly Europe. The EU's updated Renewable Energy Directive includes provisions for the uptake of corporate PPAs in the region, including requirements for Member States to remove "unjustified barriers" to PPAs. Portugal announced new rules for renewable electricity self-consumption that allow excess electricity to be sold into the spot market or through bilateral PPAs.

In Asia, Chinese Taipei amended its Renewable Energy Development Act to support corporate PPAs by confirming that, if a renewable power generation enterprise has signed a PPA with a private entity, it subsequently can switch to selling the electricity to the government while still being able to take advantage of the feed-in tariff programme.

Source: See endnote 142 for this chapter.

Development Act to increase its renewable electricity target from 10 gigawatts (GW) to 27 GW by 2025.¹⁴⁸ Nine Latin American countriesⁱ set a collective target of 70% renewable electricity by 2030.¹⁴⁹ Bulgaria, France and Greece all pledged to update their national renewable electricity targetsⁱⁱ for 2030.¹⁵⁰ The Republic of Korea increased its renewable electricity target to 35% by 2040, more than four times the previous target.¹⁵¹

CENTRALISED RENEWABLE ELECTRICITY

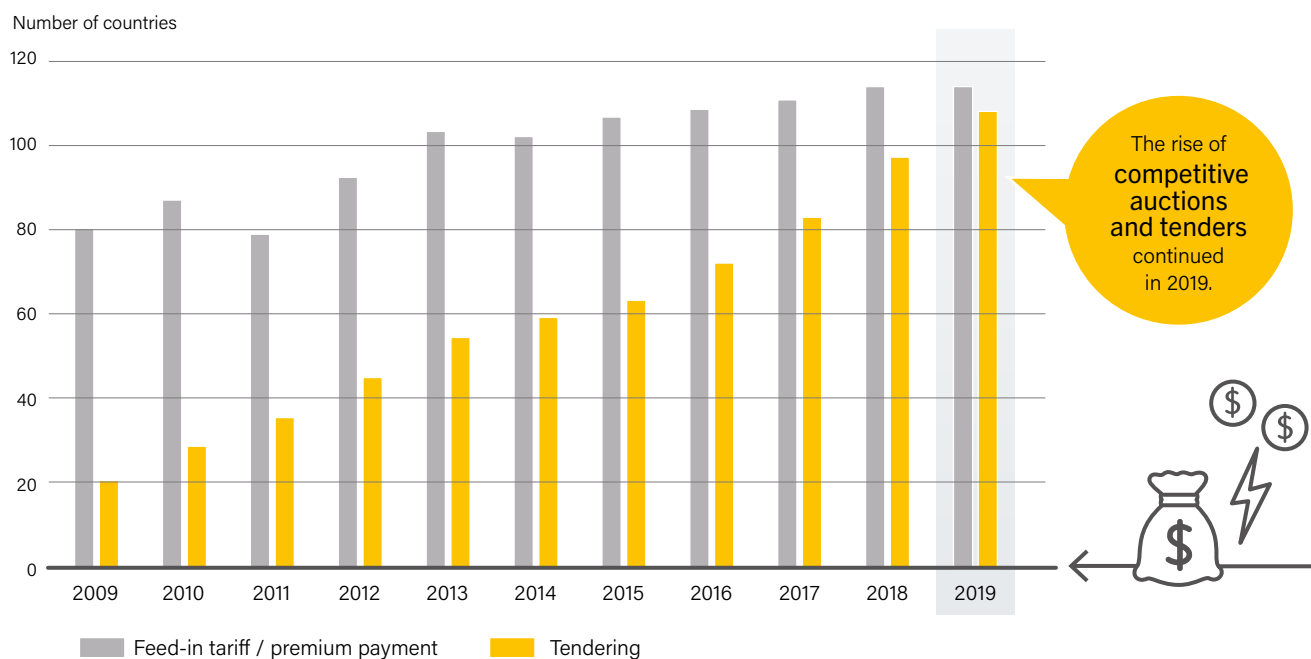
Policy mechanisms that promote large-scale, centralised renewable power include renewable portfolio standards (RPS) and other quota obligations, feed-in policies (tariffs and premiums), renewable power tenders and auctions, financial incentives (for example, grants, rebates and tax credits) and more recently community choice aggregation programmes. In 2019, the shift continued away from feed-in policies and towards mechanisms such as auctions and tenders.¹⁵² (→ See *Figure 19*.)

Feed-in policiesⁱⁱⁱ have been used to promote both large-scale, centralised renewable energy and decentralised renewables. By the end of 2019, feed-in policies were in place in 113 jurisdictions at the national, state or provincial levels, with no change from 2018.¹⁵³ (→ See *Reference Table R11*.)

A number of jurisdictions updated their existing feed-in tariff programmes to keep up with changing market conditions. China announced new FIT amounts for large-scale solar PV, which became effective from July 2019.¹⁵⁴ These new FIT amounts were coupled with a scheme to award capacity through a reverse auction, where interested parties bid for a premium to be paid on top of regional benchmark electricity prices^{iv}.¹⁵⁵ China also implemented new FITs for centralised ground-mounted solar PV systems.¹⁵⁶ In Spain, in response to litigation sparked by retroactive reductions in financial support amounts in the FIT programme, the government approved a plan in 2019 to offer 7% in guaranteed returns for more than a decade to renewable energy projects that agree to scrap ongoing lawsuits over the FIT phase-out.¹⁵⁷

- i The nine countries are Chile, Colombia, Costa Rica, the Dominican Republic, Ecuador, Guatemala, Haiti, Honduras and Peru.
- ii The increases were as follows: France from 32% to 33%, Greece from 31% to 35% and Bulgaria from 25% to 27%.
- iii Feed-in policies may focus on a certain type or scale of renewable energy technology or may apply to many types and scales of technologies.
- iv In June 2018, China imposed installation caps and reduced the FIT for solar PV projects in the country. The 2018 policy change was highlighted as the main reason for the large decrease in renewable energy investment in China that year, which had a significant impact on total global investment in renewables. See Investment chapter in GSR 2019.
- v Plants up and running before 2013 will be offered a fixed 7.398% remuneration rate until 2031, but these incentives will be denied to firms still pursuing litigation over the FIT cuts or those already granted compensation after winning court disputes. Those pledging to give up lawsuits or the related compensation will become eligible.

FIGURE 19. Cumulative Number of Countries with Feed-in and/or Tendering Policies, 2009-2019



Note: A country is considered to have a policy (and is counted a single time) when it has at least one national or state/provincial-level policy. Some countries have used both policies.

Source: REN21 Policy Database. See endnote 2 for this chapter.

A number of FIT programmes were cancelled, or scheduled to be cancelled, in 2019. The United Kingdom's FIT programme ended at the end of March, and in December 2019 Vietnam announced plans to switch from FITs for large-scale solar PV to a new auction mechanism, marking a shift from earlier plans to reboot its FIT scheme.¹⁵⁸ However, in April 2020 Vietnam decided to allow solar PV projects that would commence commercial operation before the end of that year to continue participating in the FIT programme, while all other projects would transition to an auction mechanism.¹⁵⁹

A number of US states and territories updated their **RPS quota obligations** in 2019. New Mexico committed to an RPS of 100% "carbon-free" electricity by 2045, with at least 80% from renewable sources.¹⁶⁰ Nevada and Maryland committed to 50% renewable generation by 2030, and Puerto Rico set a 100% RPS by 2050.¹⁶¹

Most jurisdictions with RPS or other quota obligations also permit the use of **tradeable renewable energy certificates** (RECs, also called guarantees of origin, or GO, in Europe). The demand for GOs in Europe increased during 2018 and 2019 as demand for renewable electricity increased.¹⁶² In 2019, the EU required its Member States to recognise GOs issued by other Member States.¹⁶³

Many countries continued to turn to competitive **auctions and tenders** in lieu of feed-in policies to deploy large-scale, centralised renewable energy projects.¹⁶⁴ During 2019, renewable energy auctions or tenders were held in at least 41 countries at the national or state/provincial level, down from 48 countries in 2018.¹⁶⁵ However, the total number of countries that have used this mechanism increased to 109 (up from 98 in 2018) as new countries held tenders during the year for the first time.¹⁶⁶ Of the at least 68 auctions held in 2019, most focused exclusively on solar PV or wind power, and some included solar PV plus storage (also called solar-plus-storage); just two of the auctions were technology-neutral (among renewable energy technologies).¹⁶⁷ (→ See **Reference Table R12**.)

Auctions and tenders were held in nearly all world regions, and in a trend continued from the previous year, 2019 again saw many auctions and tenders in Africa. For example, Nigeria issued a tender for a 15 MW solar PV project with a 5 MW battery energy storage system.¹⁶⁸ Auctions in 2019 also continued to reveal record-low bids. Cambodia's auction resulted in the lowest solar PV power purchase tariff seen in Southeast Asia.¹⁶⁹ In Portugal, a solar PV auction yielded the world's lowest bid to date.¹⁷⁰ Outside of solar power, several tenders were held for on- and offshore wind.¹⁷¹ Globally, far fewer tenders were held for technologies other than wind power and solar power. One example was in Mexico, where the public power utility announced a tender for drilling two wells as part of the Los Azufres geothermal project, which would increase the steam supply for the utility's power generation units.¹⁷² (→ See **Market and Industry chapter**.)

Although many successful auction events were held in 2019, several of the year's scheduled auctions were undersubscribed or cancelled. For example, five of the six onshore wind tenders in Germany were undersubscribed (although the country's last onshore wind tender in the year was oversubscribed, and its solar tender was oversubscribed by two and a half times).¹⁷³ Mexico cancelled its fourth renewable energy auction early in 2019 because of administrative changes in the entities involved.¹⁷⁴

At least
68 auctions
were held across
41 countries in 2019,
mostly for solar PV or
wind power.

Also during the year, at least 11 new countries either adopted auction policies for renewable energy or held auctions for the first time. Ukraine's Law on Renewable Energy Auctions went into effect, introducing auctions in the country.¹⁷⁵ Poland's energy regulator launched a wind and solar electricity auction, and Pakistan announced plans to introduce renewable energy auctions starting from December 2019.¹⁷⁶ Mongolia introduced proposed amendments to its Renewable Energy Law that, if passed, would introduce a renewable energy auction in the country.¹⁷⁷ At year's end, Kenya was developing the mechanisms required to establish an auction system as provided for in the country's Energy Act of 2019.¹⁷⁸

Some governments innovated with auction design. Colombia established new rules for the country's second long-term renewable energy auction that includes time blocks within which electricity generators and buyers must make offers.¹⁷⁹ Italy's new auction and incentive scheme for large-scale renewable power projects includes a premium on top of the market price of electricity.¹⁸⁰

Financial incentives for the power sector can play a role in spurring investment in the manufacture and installation of renewable technologies. By the end of 2019, at least 135 countries offered some form of financial incentive for renewable energy and renewable power technologies.¹⁸¹ Uzbekistan adopted a new law that includes tax incentives for manufacturers of renewable energy equipment as well as for electricity producers.¹⁸² In the United States, the production tax credit for wind power was extended through 2020, a year longer than anticipated.¹⁸³ Chinese Taipei's amendments to its Renewable Energy Development Act included establishing a fund to support its new renewable energy targets.¹⁸⁴

i A REC certifies the ownership of 1 megawatt-hour (MWh) of renewable electricity. Unbundled RECs may be bought and sold separately from the physical sale of electricity.

ii African nations were again very active in 2019, although to a lesser degree than in 2018, with auctions held in Burkina Faso, Cabo Verde, Ethiopia, the Gambia, Ghana, Guinea Bissau, Mali, Mauritius, Morocco, Nigeria, Seychelles, Togo, Tunisia, Zambia and Zimbabwe. Auctions also were held in Asia and Oceania (Australia, Cambodia, China, India, Japan, Malaysia, the Russian Federation, Tonga, Vietnam), in Europe (Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Lithuania, the Netherlands, Poland, Portugal, Turkey), in the Middle East (United Arab Emirates, Iraq) and in North America, Latin America and the Caribbean (Brazil, Colombia, Mexico). See Reference Table R12.

DISTRIBUTED RENEWABLE ELECTRICITY

Distributed renewable energy generationⁱ, which is typically dispersed and small-scale in nature, accounts for only around 1% of electricity generation worldwide, but its uptake is accelerating.¹⁸⁵ The rapid rise of distributed renewable generation presents new opportunities and challenges. For individual consumers and businesses, opportunities include the ability to install their own renewable energy systems to generate their own electricity, reducing the need to rely on the grid. The reasons for self-generation vary from place to place, but can include increased reliability and reduced electricity costs.

Distributed renewable energy generation also may provide grid flexibility services and the ability to mitigate challenges arising from grid constraints during peak demand. Challenges associated with renewable distributed generation relate to grid integration and operations and the need to mitigate the impacts of adding new renewable generation to existing transmission and distribution grids.¹⁸⁶ (→ See *Systems Integration chapter*.)

Policies and regulations that advance the deployment of distributed renewable technologies and increase renewable generation include solar mandates, feed-in pricing and net metering (and virtual net metering), as well as measures that support community aggregation (such as community solar policies) and public utility commission policies that target utility activities and investments (for example, grid modernisation).¹⁸⁷ Policies aimed at promoting renewable generation are sometimes incorporated within broader distributed energy resource policies.¹⁸⁸ (→ See *Systems Integration section in this chapter*.)

In 2019, the US state of California implemented a new **solar mandate** that took effect in 2020, making it the first state in the country to make rooftop solar PV mandatory for most new houses.¹⁸⁹ Also in the United States, New York City adopted a solar PV mandate for new construction and buildings undergoing certain types of major renovations.¹⁹⁰

Just as **feed-in policies** incentivise large-scale renewable generation, these policies also encourage small-scale, renewable distributed generation. In 2019, Japan continued to offer a FIT for small-scale renewable generation (as well as geothermal and biomass), although the country replaced its FIT programme for large-scale solar and wind power with a wholesale tender system.¹⁹¹ After cancelling its FIT in 2019, the United Kingdom introduced legislation to guarantee that small-scale renewable energy plants will get paid for exporting electricity to the grid by way of a “smart export guarantee” to pay renewable energy generators with a capacity up to 5 MW.¹⁹² Luxembourg raised its FITs for most solar PV power generators, and small-scale solar PV systems were the main beneficiaries of the new FIT regime.¹⁹³ At a sub-national level, Los Angeles (United States) committed to expanding its FIT to include solar-plus-storage.¹⁹⁴

Many small-scale residential and commercial installations benefited from **net metering policies**, which compensate system owners for surplus electricity fed into the grid. By the end of 2019, 70 countries had net metering policies at the national level, and numerous provinces and states in the United States and Canada had net metering policies at the sub-national level.¹⁹⁵ Albania introduced its first net metering programme during the year, and Turkey introduced its first net metering programme for solar systems under 10 kilowatts (kW) of capacity.¹⁹⁶ Kenya introduced legislation that requires electricity distributors and retailers to make net metering available to customers.¹⁹⁷ The Indian state of Goa also finalised net metering regulations.¹⁹⁸

The year also saw rollbacks and cancellations of some net metering programmes. In India, the state of Uttar Pradesh cancelled net metering for all consumers.¹⁹⁹ In the United States, the state of Louisiana reduced the amount paid to rooftop solar PV owners under revised net metering rules, and Michigan cancelled its net metering law.²⁰⁰ In Canada, the province of Saskatchewan cancelled its net metering programme.²⁰¹

Virtual net metering (VNM)ⁱⁱⁱ has emerged as a mechanism to facilitate participation in shared renewable energy projects, in which multiple customers can receive net metering credits tied to their portion of a single distributed system.²⁰² Policies supporting VNM increased in 2019. Spain approved a new regulation that allows multiple consumers to be associated with a single installation, regardless of where the electricity is generated.²⁰³ New Delhi (India) expanded its net metering policy for solar PV to allow for group net metering and VNM.²⁰⁴ A number of US states also developed new VNM policies, including New Mexico, which passed a law allowing the development of community solar projects.²⁰⁵ By the end of 2019, at least 16 US states had policies supporting VNM.²⁰⁶

Financial incentives also play a role in spurring investment in distributed renewable energy generation. For example, in 2019, Poland launched a rebate scheme for residential solar PV with a budget of PLN 1 billion (USD 0.26 billion), which will grant rebates for residential PV projects ranging from 2 kW to 10 kW in capacity.²⁰⁷

In some regulated power markets the point of market entry for distributed renewable energy generation is through **procurement of electricity by utilities**.²⁰⁸ In markets regulated by public utility commissions, these commissions may enact policy related to utility investments in distributed renewable generation.²⁰⁹ In 2019, public utility commissions in Canada and the United States enacted a range of policies requiring utilities to consider distributed renewable energy generation in their investment plans, as well as to incentivise utilities to take advantage of renewable (and other) distributed generation to reduce customer costs.²¹⁰

- i Distributed generation, also called on-site generation or decentralised generation, is the term for generation of electricity from sources near the point of consumption, as opposed to centralised generation sources such as large power plants. Distributed generators can be renewable (e.g., rooftop solar PV) or fossil-based (e.g., distributed natural gas generation). This chapter focuses only on policies that support renewable distributed generation.
- ii A distributed energy resource is a resource sited close to customers that provides all or some of a customer's electricity needs, and that also can be used by the system to reduce demand, provide supply, or satisfy energy, capacity or ancillary needs. Distributed energy resources can include distributed generation, storage, demand response, EVs and microgrids. In many instances, policy and legislation do not focus exclusively on distributed renewable energy generation. Rather, distributed generation is included as part of a broader policy or legislative activity that is focused on all distributed energy resources.
- iii Virtual net metering utilises the same compensation mechanism and billing schemes as net metering without requiring that a customer's distributed general system (or share of a system) be located directly on site. See Glossary.

COMMUNITY RENEWABLE ENERGY ARRANGEMENTS

Through community energy arrangements, residents, businesses and others within a relatively small geographic area initiate, develop, operate, own, invest in and/or directly benefit from a renewable energy project. Communities vary in size and shape (for example, schools, neighbourhoods, city governments, etc.), and projects vary in technology, size, structure, governance, funding and motivation.²¹¹ Policy plays a crucial role in permitting or fostering the deployment of community renewable energy projects. FIT schemes, net metering and VNM, and policies dedicated to supporting community energy arrangements all have the potential to incentivise community renewable energy initiatives. (→ See *Feature chapter*.)

At a municipal level, **community choice aggregation** (CCA) programmes (also called municipal aggregation) allow municipalities and other local governments to procure renewable energy on behalf of their residents and businesses while still receiving transmission and distribution services from existing utilities. By aggregating the demand of multiple residents, communities gain leverage to negotiate better rates and opt for renewable energy sources.²¹²

CCAs have been around for over a decade, and increasingly cities are using them as a means to procure more renewable energy than is offered by the local utility.²¹³ In Japan, municipal governments in Yamagata and Gunma prefectures provide renewable energy to consumers through CCA-like arrangements.²¹⁴ In the United States, San Diego voted to approve a CCA programme in co-ordination with other cities in the region for the purpose of achieving 100% renewable energy by 2035.²¹⁵

Similar to VNM policy, policies encouraging aggregation and **shared ownership**ⁱ of distributed renewable generation are increasing the adoption of renewables, particularly solar PV. In 2019, policy makers increased their attention on community solar PV arrangements (also known as shared solar, or collective self-consumption)ⁱⁱ, especially in the United States and Europe.

After ending its “Sun Tax”ⁱⁱⁱ in late 2018, Spain passed new solar PV regulations that allow for self-consumption from individually owned residential rooftop systems as well as from shared installations.²¹⁶ Portugal announced new provisions for collective self-consumption, which provide a legislative framework for energy communities and enable homeowners and businesses that are willing to become prosumers^{iv} to aggregate their efforts in collective projects and to share generation units.²¹⁷ A few regions in Belgium adopted new legislative frameworks promoting collective self-consumption of renewable energy.²¹⁸ In the United States, the state of Maine approved new community solar PV legislation, and Maryland extended the end date for its community solar PV pilot programme from 2020 to 2024.²¹⁹

i Shared ownership refers to the collective ownership and management of renewable energy assets.

ii Community solar is a distributed solar PV arrangement that allows customers to buy or lease part of a larger, off-site shared solar PV system without having to install their own system.

iii Spain's so-called Sun Tax charged owners of self-consumption solar PV for the electricity they generated and self-consumed, as well as charged them to access the electricity grid.

iv Prosumers both produce and consume electricity.

v Power system flexibility refers to the capability of a power system to maintain continuous service in the face of rapid and large swings in supply or demand.

vi ACER helps ensure that the single European market in gas and electricity functions properly. It assists national regulatory authorities in performing their regulatory function at the European level and, where necessary, co-ordinates their work. The EU legislation will allow ACER to streamline regulatory procedures by introducing direct approval by ACER instead of separate approvals by national regulators.

SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

As the share of variable renewable electricity (VRE) in global electricity production increases year over year, a growing number of jurisdictions are directing their policy efforts to ensuring the successful integration of VRE into the wider energy system. The policy push for systems integration of renewables and enabling technologies (such as energy storage) is focused primarily on increasing power system flexibility^v and control, as well as grid resilience. Flexibility, in particular, is an important requirement for systems integration of renewables as the share of VRE generation rises.²²⁰ (→ See *Systems Integration chapter*.)

Policies that can advance the integration of both centralised and distributed VRE and increase the flexibility of the power system pertain to, for example: market design, demand-side management, transmission and distribution system enhancements, and grid interconnections. Policies also may support the deployment of enabling technologies, such as energy storage, which in addition to supporting power systems in general may help to integrate renewable electricity into the transport and heating and cooling sectors.

In 2019, the US state of New Jersey developed an Energy Master Plan that includes **policies to advance sector coupling** – such as coupling battery storage with solar PV and/or EVs – as a means to achieve renewable energy and greenhouse gas emission targets.²²¹ New Jersey's plan also calls for reinforcing electricity grid infrastructure to better manage the integration of VRE, distributed energy resources such as solar PV and battery storage, and EVs.²²²

Changes to **power market rules** can increase the ability of VRE and distributed energy resources to participate in electricity markets. Some governments are revising rules to allow more actors to participate in power and ancillary markets, a change that can enable faster and more flexible operations, and allow distributed renewable energy resources to participate on a more even footing alongside large-scale fossil and nuclear generators.²²³ In 2019, the EU adopted legislation that redesigns the region's electricity market rules to facilitate the integration of renewables into the grid, enable the active participation of consumers in energy markets, establish common rules for storage, allow for more cross-border electricity trade and enhance the role of the Agency for the Cooperation of Energy Regulators (ACER)^{vi}.²²⁴ Also during the year, Germany was testing a market-based approach to use distributed energy resources to provide localised flexibility services to relieve network congestion.²²⁵

Outside of Europe, Singapore fully liberalised its retail electricity market in 2019, enabling distributed energy resources to provide flexibility services.²²⁶ In the United States, California continued work on its Day-Ahead Market Enhancements to improve grid reliability, and New York was in the process of reforming state market rules to enhance opportunities for distributed energy resources to participate in wholesale markets.²²⁷

Policies to **improve electricity infrastructure**, including policies to invest in expanding or modernising transmission and distribution infrastructure, can lead to facilitating VRE integration.²²⁸ In 2019, the Indian states of Gujarat and Rajasthan invested in transmission infrastructure to facilitate utility-scale renewable energy deployment.²²⁹ A number of US states also committed to improving the resilience of the grid and its ability to deal with rising VRE penetration; for example, New York announced funding to support improvements in grid resilience, flexibility and integration of renewables, and Michigan unveiled a grid modernisation initiative to support similar goals.²³⁰

In addition to a focus on infrastructure, policies exist that aim to **streamline the interconnection approval process** for grid connections for renewable energy systems. For example, in the United States both the state of Minnesota and the territory of Puerto Rico updated their interconnection standards in 2019 to simplify and shorten the interconnection approval process.²³¹

Other jurisdictions have pursued opportunities to **develop cross-border electricity supply routes** to gain more access to renewables. Malaysia and Singapore discussed cross-border power supplies in 2019 as a means of enabling Singapore to increase its access to renewable electricity.²³²

Policies that promote the deployment of **enabling technologies** are an important element of systems integration. Energy storage systems can help smooth the output from renewable power facilities and minimise curtailment.²³³ The EU's new electricity market design includes enhancing the use of energy storage and encouraging regulatory authorities to invest in energy storage facilities.²³⁴ In 2019, Portugal announced plans to hold its first capacity auction for dispatchable renewables and included battery storage among acceptable technologies.²³⁵

Also during the year, a directive from the US Federal Energy Regulatory Commission required system operators and transmission organisations in the United States to open wholesale energy, ancillary service and capacity markets to energy storage resources.²³⁶ At the sub-national level, New York provided USD 280 million for energy storage projects as part of a USD 400 million investment to achieve the state's energy storage deployment target of 3 GW by 2030.²³⁷ In Massachusetts, regulations were adopted to give owners of energy storage systems the right to generate revenue from selling into the Forward Capacity Market and to participate in net metering programmes.²³⁸

Solar-plus-storage support policies also advanced in 2019. The Italian region of Lombardy committed to providing EUR 4.4 million (USD 5 million) in rebates to support the adoption of solar-plus-storage for residential and commercial systems.²³⁹ The US state of Oregon launched a USD 2 million solar-plus-storage rebate programme.²⁴⁰ Through direct procurement, Abu Dhabi in the United Arab Emirates launched a large virtual battery plant in early 2019 to ensure efficient and optimum use and integration of solar electricity.²⁴¹

Demand-side management policies, such as those to encourage demand responseⁱ, can enable the integration of renewables by allowing for a better match between demand and supply.²⁴² The EU's adoption of new market design rules as part of the Clean Energy for All Europeans package includes opening European electricity markets not only to renewables and storage, but also to demand response.²⁴³ The Australian Energy Market Commission also released proposals to open the wholesale electricity market to demand response.²⁴⁴

Many US states and Canadian provinces already had in place policies to increase the use of demand-side managementⁱⁱ, and additional US states followed in 2019. For example, Montana enacted a new law allowing electric utilities to implement demand-side management programmes with approval from the state's public utilities commission, and South Carolina enacted a law that requires utility integrated resource plans to include energy efficiency and demand response programmes.²⁴⁵

In jurisdictions with regulated energy markets, **utility-focused regulatory policy** can help to enhance the integration of distributed energy resourcesⁱⁱⁱ. In 2019, several policy developments in this area occurred at the state level in the United States. Regulators in Arkansas and in the District of Columbia developed grid modernisation policies to ensure that the grid can accommodate increased quantities of distributed energy resources.²⁴⁶ Minnesota became the first US state to officially update its interconnection regulations to enable streamlined adoption of smart inverters and more sophisticated communications and control technologies for distributed energy resources.²⁴⁷ To support the connection of such resources where they are most easily integrated into the grid, New York state investigated replacing net metering with a means of compensating customer-owned distributed energy resources based on their locational and temporal value^{iv}.²⁴⁸

Policies for systems integration of renewables are focused primarily on increasing flexibility, control and resilience.

i Demand response refers to changes in electricity consumption in response to price signals or specific requests.

ii Many of these demand-side programmes have been in place for a long time and are unrelated to promoting renewable energy.

iii To the extent that distributed energy resources are adopted by non-utility third parties (for example, utility customers), utilities need the capability to manage the integration of these resources on their grids.

iv Net metering compensates all distributed energy resources uniformly regardless of where or when the power is provided. Because of this, net metering compensation does not always align with the actual value of the power being generated.

Table 3. Renewable Energy Targets and Policies, 2019

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies						Fiscal Incentives and Public Financing				
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO ₂ , VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
High Income Countries													
Andorra		●	●									●	
Antigua and Barbuda	P	●											
Argentina	P	●	●	●	●	●		●	●	●	●	●, ☆ ⁶	
Australia	E(R), E*(N), P*	●	☆*	●	◐	◐	●	◐	●			●, ☆ ⁶	
Austria	E, P, HC, T	●	●		●				●	●		●, ☆ ⁶	
Bahamas, The	P	●											
Bahrain	P(R), E(R)	●			●							●	
Barbados ¹	P	●			●							●	
Belgium	E(N), P, HC, T	●		◐	◐	●		●	●, ○	●		◐	
Bermuda			☆*										
Brunei Darussalam	E, P												
Canada	P*	●	◐	◐	◐	☆*		☆	◐	●	●	●, ☆ ^{6,7}	
Chile	E(R), P(R)	●	●	●	●				●	●	●	●, ☆ ⁶	
Croatia	E(R), P, HC, T	●	●		●							● ⁵	
Cyprus	E, P, HC, T	●	●		●				●			●	
Czech Republic	E, P, HC, T	●	●		●							●	
Denmark	E(R), P, HC, T	●	● ⁶		●	● ^{8,9}		●	●, ○	●		●	
Estonia	E(R), P, HC, T	●	●		●							●, ☆ ⁶	
Finland	E, P, HC(R), T(R)	●	●		☆	☆		●	●	● ^{6,7}		●	
France	E(R), P(N), HC, T	●	●		☆	● ³ , ☆		●	●, ○	●	●	☆ ⁶	
Germany	E(R), P(R), HC, T	●	●, ☆*		●	●		●	●, ○	●		● ⁶ , ☆	
Greece	E(R), P(R), HC(R), T	●	●	●	●	● ³		●	●, ○	●		●, ☆ ⁶	
Hungary	E, P, HC, T	●	●		●							● ⁵	
Iceland	E, T	●			●								
Ireland	E(R), P(R), HC, T	●	●		☆	● ³		●	●, ○	● ⁶		☆ ^{6,7}	
Israel	E, P, T	●	●	●	●	●				● ⁶		●	
Italy	E, P, HC, T	●	●		●				●, ○	●		● ^{6,7} , ☆*	
Japan	E, P	●	●		●				●, ○	●		●, ☆ ⁶	
Korea, Republic of	E(R), P(N)	●	●	●	●	●		●		●		● ³	
Kuwait	E(R), P	☆											
Latvia	E, P, HC, T	●	●		●								
Liechtenstein		●	●										
Lithuania	E(R), P, HC(R), T(R)	●	● ⁶	●	●	● ³			○	● ⁶		●, ☆ ⁶	
Luxembourg	E, P, HC, T	●	☆		●							●, ☆ ⁶	
Malta	E, P, HC, T	●	●		●							● ³	
Monaco		●	●										
Netherlands	E, P, HC, T	●	●		●	● ³		●	●, ○	☆ ⁶	● ⁶	●	☆ ⁶
New Zealand	P	●		◐	●							●	
Norway	E, P, T	☆	●		●	● ⁷		●	●			● ⁵	
Oman	E(R), P(N)	☆											
Palau	E, P	●	●		●								
Panama	E	●	●		●								
Poland	E, P, HC(R), T	●	●	●	●	●		●	●, ○	●		● ⁵ , ☆	
Portugal ²	E(R), P(R), HC(R), T(R)	●	●		●	●		●	○	●		●, ☆ ⁶	
Qatar	E(R), P(R), T	●											
San Marino		☆	●										
Saudi Arabia	E(R), P(R)	●	●		●								
Seychelles	P	●			●				●, ○	●		●	
Singapore	P	●			●				●			●	
Slovak Republic	E, P, HC, T	●	●		●			●		● ⁷		● ⁵	
Slovenia	E, P, HC, T	●	●		●			●				● ⁵	
Spain ³	E, P(R), HC, T	●		☆	●	● ³		●		☆	●	● ⁵	
St. Kitts and Nevis		●											
Sweden	E, P, HC, T	●	●		●			●		●		●	
Switzerland	E, P	●	●					●		●		● ⁵	
Trinidad and Tobago	P	☆											
United Arab Emirates	E, E*(N), P	●		◐	◐	●			◐, ○			◐	
United Kingdom	E, E*(N), P, HC, T	●	●		☆	● ³		●	●, ◐	●		● ⁵ , ☆ ⁷	
United States	E*, P*, P(R), T	●	◐	☆*	☆*	●, ◐	◐	◐	◐	●	● ⁷ , ◐	● ⁵ , ☆ ⁷ , ☆*	
Uruguay	HC(N)	●	●		●	●		●		●		● ⁵	

Note: Please see key on last page of table.

■ Table 3. Renewable Energy Targets and Policies, 2019 (continued)

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO ₂ , VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Upper-Middle Income Countries													
Albania	E, P, T	●	●	●	●	●		●	●	●	●	●	
Algeria	E, P(R)	●	●		●				●		●	●	
Armenia	P	●	●		●				●			● ⁶	
Azerbaijan	P	●										●	
Belarus	E, P	●	●	●						●		●	
Belize	P	●							●				
Bosnia and Herzegovina	E, P	●	●						●				
Botswana									●			●	
Brazil	E(R), P	●		●	●	☆			●	○	●	●	
Bulgaria	E(N), P, HC, T		●			●						● ⁶	
China	E, P(R), HC, T	●	☆	☆		●	●		●	○	●	●, ☆ ^{6,7}	
Colombia	E(R), P(R)					●			○		●	●	
Costa Rica	P	●	●		●	●			●		● ⁶		
Cuba	P	●											
Dominica	P	●											
Dominican Republic	E(R), P(R)		●		●				●		●	●	
Ecuador		☆	●			●			●			●	
Equatorial Guinea		☆											
Fiji	E, P	●									●	●	
Gabon	E, P	●											
Grenada	E, P	●			●						●		
Guatemala	E, P	●			●	●			●		●		
Guyana	E, P	●									●	●	
Iran	P	●	●							●	●	●	
Iraq	P(R)	●							●	○			
Jamaica	E, P	●			●	●			●		●		
Jordan	E(R), P(R), HC	●	●		●		●		●			●, ☆ ⁶	
Kazakhstan	P	●	●					●	●			●	
Lebanon	E(R), P, HC	☆			●						● ⁶	● ⁶	
Libya	E(R), P(R), HC										●	● ⁶	
Macedonia, North	E, P, HC, T	☆	●								● ⁶	● ⁶	
Malaysia	P, HC(N)	●	●	●	☆	☆			●	○		●	
Maldives	P	●	●										
Marshall Islands	P	☆											
Mauritius	P	●			●				●	○		● ⁶	
Mexico	E(R), P, HC				●	●			●	○	☆	●, ☆ ⁶ , ☆	
Montenegro	E, P, HC, T	●	☆			●			●				
Namibia	P	●					●						
Nauru		●											
Paraguay	P	●				●					●		
Peru	E(R), P(R)	●	●	●	●	●			●			●	
Romania	E, P, HC, T			●	☆	●		●				● ⁶	
Russian Federation	E(R), P	●	●						●	○		●	
Samoa	E, P	●											
Serbia	E, P, HC, T	●				●						●	
South Africa	P	●		●		●			●			● ⁶	
St. Lucia	E, P	●			●						●		
St. Vincent and the Grenadines ¹	P	●			●								
Suriname		☆			●				●				
Taipei, China	E(R), P(R)		☆								☆		
Thailand	E, P, HC, T	●	●		●	●					●	● ⁶ , ☆ ⁷	
Tonga	P	●							●	○			
Turkey	E(R), P	●	● ⁶		●	●	● ⁶		●	○		● ⁶	
Turkmenistan		●											
Tuvalu	P	●											
Venezuela	P	☆											

Note: Please see key on last page of table.

Table 3. Renewable Energy Targets and Policies, 2019 (continued)

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies						Fiscal Incentives and Public Financing			
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Lower-Middle Income Countries												
Angola	E	●	●			●						●
Bangladesh	E, P	●						●		●		●
Bhutan	P, HC	●										
Bolivia	P	●	●	●	●			●	○	★	●	●
Cabo Verde	P	●			●				○			
Cambodia	P	●										
Cameroon	P	●								●		
Congo, Republic of	P	●										
Côte d'Ivoire	E, P	●						●		●		
Djibouti	E (N), P(R)	●										
Egypt	E(R), P(R)	●	●		●					● ⁶		●
El Salvador		●						●		●	●	●
Eswatini		●						●				
Georgia		●										● ⁶
Ghana	E, P	●	●	●	●	●	●	○		●		●
Honduras	E(R), P(R)	●	●	●	●			●		●	●	●
India	E(R), P, P*(R), HC, T(R)	●	●	●	●	●	●	●, ○, ○		●	●	● ⁶ , ★ ⁷
Indonesia	E(R), P	●	●	●		★		●		●		●
Kenya	P, HC	●	●	●				●			●	●
Kiribati	P	●										
Kosovo	E, P, HC	●	●									
Kyrgyz Republic		●		●						●		●
Lao PDR	E	●										
Lesotho	P	★			●					★	●	●
Mauritania	E(R), P	●										
Micronesia, Federated States of	P	●			●							
Moldova	E, P, HC, T	★	●		●	●				●		●
Mongolia	E, P	●	●							●		
Morocco	E(R), P(R), HC	●			●			●, ○				● ⁶
Myanmar	P	●								●		
Nicaragua	P	★	●							●		●
Nigeria	P	●	●	●				●, ○		●		●
Pakistan		●	●		●			●		●		●
Palestine, State of ⁵	E, P	●	●		●					●		
Papua New Guinea	P	●										
Philippines	P	●	●	●	●	●				●	●	●, ★ ⁶
São Tomé and Príncipe	P	●										
Solomon Islands	P	●										
Sri Lanka	P, T	●	●	●	●	●				●	●	●
Sudan	E(R), P(R)	●				●						
Timor-Leste	P	●										
Tunisia	E(R), P	●			●			●, ○		●		● ⁶
Ukraine	E, P, HC, T	●	★		●	●				●		● ⁶
Uzbekistan	E, P	★								★		
Vanuatu	E, P	●	●									
Vietnam	E(R), P, T	●	●	●	●	●		●		●		●
Zambia		●	●					●, ○		●		●

Note: Please see key on last page of table.

Table 3. Renewable Energy Targets and Policies, 2019 (continued)

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO ₂ , VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Low Income Countries													
Afghanistan	E, P	●							●				
Benin	E, P	★							●				
Burkina Faso	P	●							●	○	●	●	
Burundi	E, P	★											
Central African Republic		●											
Chad		●											
Comoros	P	●											
Congo, Democratic Republic of the	P	●											
Eritrea	P	★											
Ethiopia	P	●				●			●	○			
Gambia	P	●							○				
Guinea	E, P	●								●			
Guinea-Bissau	P	★							○				
Haiti	E(R), P(R)	●										●	
Korea, Democratic People's Republic		●											
Liberia	E, P, T	★				●				●			
Madagascar	E, P	●							●				
Malawi	E, P, HC	●	●			●	●		●			●	
Mali	E, P	●							○			●	
Mozambique	P, HC	★	●			●				●		●	
Nepal	E, P, T	●	●					●	●		●	●	
Niger	E, P	●							●			●	
Rwanda		●	●						●			●	
Senegal	P	●	●	●	●				●		●	●	
Sierra Leone	P, HC	●											
Somalia		●											
South Sudan	P	●											
Syria	E(R), P(R)	★	●		●				●		●		
Tajikistan	E, P	●	●							●		●	
Tanzania	E, P	★	●		●				●		●	●	
Togo	E, P	●								●			
Uganda		●	●						●			●	
Yemen	E(R), P(R)	●											
Zimbabwe		●				●			○		●	●	

Targets

- E** Energy (final or primary)
P Power
HC Heating or cooling
T Transport
 * Indicates sub-national target
(R) Revised
(N) New

Policies

- ★ New (one or more policies of this type)
 ★★ New subnational
 ★ Revised (from previously existing)
 ★★ Revised sub-national
 ● Removed

- Existing national policy or tender framework (could include sub-national)
 ● Existing sub-national policy or tender framework (but no national)
 ○ National tender held in 2019
 ◻ Sub-national tender held in 2019

¹ Certain Caribbean countries have adopted hybrid net metering and feed-in policies whereby residential consumers can offset power while commercial consumers are obligated to feed 100% of the power generated into the grid. These policies are defined as net metering for the purposes of the GSR.

² FIT support removed for large-scale power plants.

³ Spain removed FIT support for new projects in 2012. Support remains for certain installations linked to this previous scheme.

⁴ State-level targets in the United States include RPS policies.

⁵ The area of the State of Palestine is included in the World Bank country classification as "West Bank and Gaza".

⁶ Includes renewable heating and/or cooling technologies.

⁷ Includes aviation, maritime or rail transport.

⁸ Heat FIT

⁹ Fossil fuel heating ban

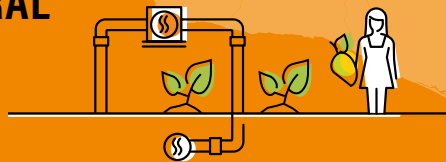
Note: Countries are organised according to annual gross national income (GNI) per capita levels as follows: "high" is USD 12,376 or more, "upper-middle" is USD 3,996 to USD 12,375, "lower-middle" is USD 1,026 to USD 3,995 and "low" is USD 1,025 or less. Per capita income levels and group classifications from World Bank, "Country and lending groups", <http://data.worldbank.org/about/country-and-lending-groups>, viewed May 2020. Only enacted policies are included in the table; however, for some policies shown, implementing regulations may not yet be developed or effective, leading to lack of implementation or impacts. Policies known to be discontinued have been omitted or marked as removed or expired. Many feed-in policies are limited in scope of technology.

Source: See endnote 2 for this chapter.

03



HARVESTING GEOTHERMAL ENERGY IN RURAL COMMUNITIES, EL SALVADOR



In El Salvador, several rural communities located near geothermal fields are involved in projects that use this local renewable energy source to improve livelihoods. Women from these areas grow and sell plants watered with geothermal condensates and harness the waste heat to dehydrate fruits. By the end of 2015, dozens of women from 15 rural communities were participating in these initiatives – indirectly benefiting around 45,570 people.

03 MARKET AND INDUSTRY TRENDS

KEY FACTS

- Modern bioenergy provided around 5.1% of total global final energy demand, accounting for about half of all renewable energy in final energy consumption.
- In industrial process heat, modern bioenergy use has grown around 2% in recent years, while bio-heat demand in buildings has fallen slightly.
- Biofuel production increased 5%, with Indonesia becoming the world's largest biodiesel producer despite a drop in production in the United States.

BIOENERGY



Bioenergy involves the use of a wide range of biological materials for energy purposes. These can be converted into thermal energy, electricity and fuels for transport (biofuels) through a number of different processes. Many well-established bioenergy pathways exist that are technically proven and for which systems are available at a commercial level. In addition, new routes are at the earlier stages of development, demonstration and commercialisation.¹ Given the potential environmental, social and economic implications of using biomass materials for energy, the sustainable production and use of bioenergy is a key issue.²

BIOENERGY MARKETS

Biomass contributes the highest share to the global energy supply of all renewable energy resources. It provides energy not only for heating and transport, but also to produce electricity.³ Including the traditional use of biomassⁱ, bioenergy contributed an estimated 12%, or 45.2 exajoules (EJ), to total final energy consumption in 2018.⁴

Modern bioenergyⁱⁱ, which excludes the traditional use of biomass, provided an estimated 19.3 EJ – or 5.1% of total global final energy demand – in 2018, accounting for about half of all renewable energy in final energy consumption.⁵ (→ See Figure 20.) Modern bioenergy provided around 13.9 EJ for heating (8.6% of the global energy

i The traditional use of biomass for heat involves the burning of woody biomass or charcoal as well as dung and other agricultural residues in simple and inefficient devices in developing and emerging economies.

ii Modern bioenergy is any production and use of bioenergy that is not classed as “traditional use of biomass”.

supply used for heating), 3.7 EJ in transport (3.1% of transport energy needs) and 1.7 EJ to the global electricity supply (2.1% of the total).⁶ Modern bioenergy use has grown most rapidly in the electricity sector – at around 6.7% per year over the last five years – compared to around 4.4% in transport and only around 1.1% for bio-heat.⁷

Bio-heat Markets

Biomass can be used to provide heat in a number of different markets. Traditional use of biomass is still the largest sector, but biomass also is an important source of energy for industry and buildings, with the heat either provided directly at the site where it is to be used, or distributed via district heating systems. The patterns of use have changed relatively slowly in recent years.⁸ (→ See Figure 21.)

The **traditional use of biomass** in developing and emerging economies supplies energy for cooking and heating in simple and usually inefficient fires or stoves.⁹ (→ See *Distributed Renewables chapter*.) The amount of biomass used in traditional applications has decreased slightly in recent years, from 27.2 EJ in 2010 to an estimated 26 EJ in 2018.¹⁰ The decline is due in part to efforts to reduce traditional biomass use and to improve access to clean fuels, given the negative effects of biomass burning on local air quality, the associated health impacts and the unsustainable nature of much of the biomass supply for these uses.¹¹

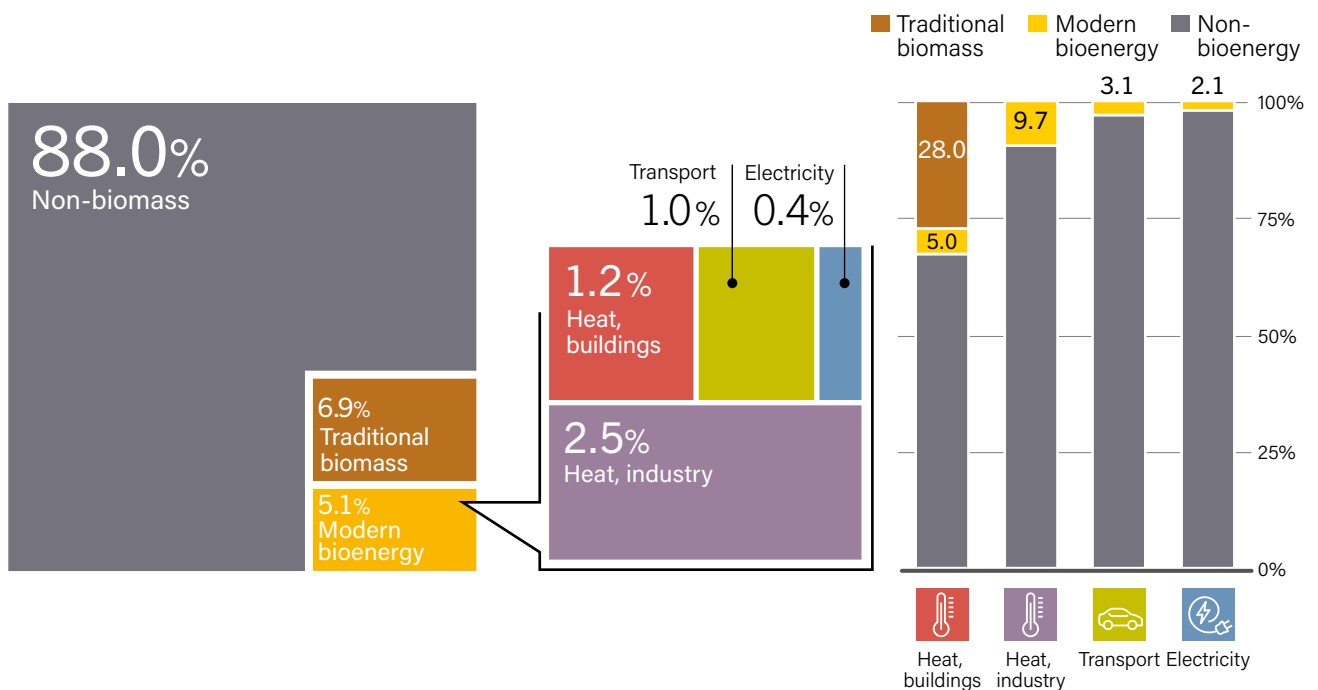
Modern bioenergy can provide heat more efficiently and cleanly for industry and for residential, public and commercial buildings. Bio-heat can be produced and used directly where it is produced,

including through the co-generation of electricity and heat using combined heat and power (CHP) systems. Most of the biomass used for heating is wood-based fuel, but liquid and gaseous biofuels also are used – including biomethane, which can be injected into natural gas distribution systems.¹² In 2018, modern bioenergy applications provided an estimated 13.2 EJ of heat directly – up 9.5% from 2010 – and a further 0.7 EJ via district heating.¹³

Of this total, 8.9 EJ was used directly to provide heat for **industry and agriculture**.¹⁴ Bio-heat demand in these sectors grew 1.8% annually on average between 2013 and 2018, and bio-heat met 9.3% of the sectors' heat requirements in 2018.¹⁵ Industries that handle biomass – notably paper and board, sugar and other food products, and wood-based industries – often use their residues for energy purposes. In the paper and board sector, for example, 40% of energy use is derived from biomass sources, including the “black liquor” produced in paper manufacture.¹⁶ Bioenergy is not yet widely used in other industries. However, biomass and waste fuels met around 6% of the cement industry's energy needs in 2017, mainly in Europe where they provided around 25% of the energy used in cement making.¹⁷

Bio-heat demand in industry grew 1.8% annually between 2013 and 2018, while bio-heat in buildings declined over the same period.

FIGURE 20. Estimated Shares of Bioenergy in Total Final Energy Consumption, Overall and by End-Use Sector, 2018



Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Buildings and industry categories include bioenergy supplied by district energy networks. Totals may not add up due to rounding.

Source: Based on IEA. See endnote 5 for this section.

Bioenergy use for industrial heating has occurred mainly in countries that have large bio-based industries. Brazil, the largest user of biomass for industrial heat in 2018 (1.6 EJ), relies on sugarcane residue (bagasse) from sugar production to generate heat in CHP systems.¹⁸ India (1.4 EJ), also a major sugar producer, was the second largest user of bioenergy for industrial heat in 2018, followed by the United States (1.3 EJ), which has an important pulp and paper industry.¹⁹

In the European Union (EU), industry used some 0.96 EJ of bioenergy directly for heat in 2018, with around 86% of this in the paper and pulp, timber and food industries.²⁰ The EU market continued to grow in 2019; for example, a biomass CHP plant, completed at a paper mill in Venizel, France aimed to generate all of the energy for the mill's operations using 75,000 tonnes of discarded wood and 26,000 tonnes of by-products from paper and pulp production annually.²¹

In the **buildings**ⁱ sector, modern bioenergy provided 4.3 EJ of heat directly in 2018, or around 4.6% of total heat demand.²² The amount of bio-heat provided fell by around 1% annually on average between 2013 and 2018, and biomass' share of heat in buildings also declined during that period.²³ Consistent data for 2019 were not yet available, but the change for that year was expected to be small given recent trends.

Biomass can produce heat for residential building use through the burning of wood logs, chips or pellets produced from wood or

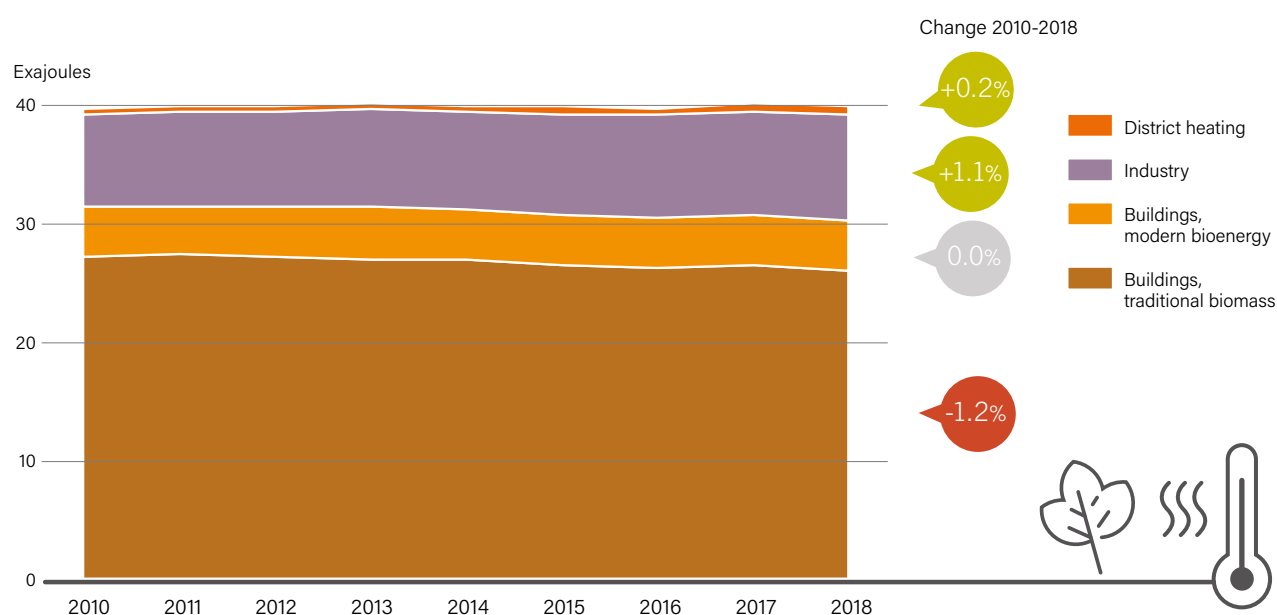
agricultural residues. The informal use of wood and other biomass to heat individual residences is prevalent in developing and emerging economies as well as in more developed economies, and can be a source of local air pollution if inefficient appliances and/or poor-quality fuels are used.²⁴ New technologies that allow for high reductions in emissions from biomass combustion are commercially available, triggered by stringent national regulations for small combustion facilities in some countries.²⁵ Generally, it is easier to meet efficiency and air quality goals economically at larger scales of operation.²⁶

Modern use of bio-heat in buildings has been concentrated in the EU, which accounted for 47% of this total use in 2018.²⁷ France, Italy, Germany and Sweden accounted for around half of the EU's bio-heat demand.²⁸ Most bio-heat demand in the EU (as elsewhere) is residential, although this has not increased much since 2010 and varies greatly by year depending on climatic conditions.²⁹ Systematic country data on biomass heating for 2019 were available for only a few European countries.³⁰

Logs and wood chips accounted for most of the biomass fuel used to heat buildings in the EU in 2018; however, wood pellet use has been growing rapidly and increased 5% in 2018, to around 15.8 million tonnes.³¹ Italy remained the world's largest market for pellet heating, using 4.3 million tonnes (mostly for residential use), followed by Denmark (2.4 million), Germany (2.2 million), Sweden (1.6 million) and France (1.6 million).³² Although the European pellet market varies annually depending

i Excluding the contribution to building heating from district heating; see discussion later in this section.

FIGURE 21. Global Bioenergy Use for Heating, by End-Use, 2010-2018





on weather conditions and heating needs, it generally has expanded as installations of pellet stoves and boilers have risen in response to policy measures that aim to promote low-carbon alternatives and to reduce the role of oil in heating markets.³³

Despite growth in the use of biogas for heating, and particularly in the production of biomethane and its introduction into gas grids, biogas provided only 4% of bio-heat in European buildings in 2018.³⁴ North America followed the EU for bioenergy use in buildings. In 2018, more than 2 million US households (2% of the total) relied on wood or wood pellets as their primary heating fuel – using a total of 0.4 EJ – and a further 8% of households used wood as a secondary heat source.³⁵ Wood use was concentrated in rural areas, with one in four rural households combusting wood for primary or secondary space heating.³⁶ In Canada, the residential heating sector used some 0.13 EJ of bio-heat from wood fuels in 2018.³⁷ Pellet sales in North America totalled around 2.7 million tonnes.³⁸

In addition to direct use of bio-heat in industry and buildings, bioenergy provided some 0.7 EJ to **district heating systems** in 2018; of this total, 51% was used in industry and agriculture, and the rest in buildings.³⁹ Bioenergy use in district heating grew 5.7% annually on average during 2013–2018, and bio-heat accounted for 95% of the heat supplied by renewable sources to district systems in 2018.⁴⁰

The use of bioenergy in district heating has been concentrated in Europe, where district heating networks supplied around 10% of EU heat demand in 2018 and provide an important market opportunity for biomass.⁴¹ Although Sweden, Denmark and Finland continued to lead in this area, bioenergy use for district heating also spread in Estonia, France and Lithuania.⁴²

Expansion continued in several countries during 2019. In Denmark, Ørsted’s Asnæs Power Station, with a capacity of 25 MW of power and 129 MW of process steam and district heating, started operation following the plant’s conversion from coal to wood chips sourced from sustainably managed forests.⁴³ Other plants scheduled to come online in Europe included the Hürth biomass CHP plant in Germany, which aimed to produce 20 MW of electricity and supply heat to a nearby paper mill, and a 18 MW biomass plant in Finland fed primarily by local wood chips, which would provide district heating for the town of Kemi.⁴⁴

Transport Biofuel Markets

Global productionⁱ of liquid biofuels increased 5% in 2019 to 161 billion litres (equivalent to 4 EJ).⁴⁵ The United States remained the leading producer, with a 41% share, despite declines in US production of both ethanol and biodiesel.⁴⁶ The next largest producers were Brazil (26%) and, more distantly, Indonesia (4.5%), China (2.9%) and Germany (2.8%).⁴⁷

The main biofuels are ethanol (produced mostly from cornⁱⁱ, sugar cane and other crops) and biodiesel (fatty acid methyl ester, or FAME, fuels produced from vegetable oils and fats, including wastes such as used cooking oil).⁴⁸ In addition, production capacity has increased for other diesel substitute fuels, made by treating animal and vegetable oils and fats with hydrogen (hydrotreated vegetable oil, or HVO) and hydrotreated esters and fatty acids (HEFA).⁴⁹

In 2019, ethanol accounted for around 59% of biofuel production (in energy terms), FAME biodiesel for 35% and HVO/HEFA for 6%.⁵⁰ (→ See Figure 22.) Other biofuels included biomethane and a range of advanced biofuels, but their production remained low, estimated at less than 1% of total biofuels production.⁵¹

Global **ethanol** production increased 2% to 114 billion litres in 2019, up from 111 billion litres in 2018.⁵² Large increases in several countries more than made up for a drop in production in the United States, the major producer.⁵³ The United States and Brazil, the two leading producers, accounted for 50% and 33% of global production, respectively, followed by China, India, Canada and Thailand.⁵⁴

US ethanol production fell 2% in 2019 to 59.7 billion litres.⁵⁵ Key factors behind the decline were reduced domestic demand for ethanol as blending limits were approached and the US Environmental Protection Agency’s continued support for small refinery exemptions, both of which reduced domestic demand, lowered prices and led to a scale-back in production.⁵⁶ In addition, ongoing US-China trade negotiations (among other factors) restricted the opportunities for ethanol export, leading US exports of the fuel to decline 14% in 2019, to 5.6 billion litres.⁵⁷ In response to the reduction in overall demand, several ethanol production plants cut back production.⁵⁸

In Brazil, ethanol production increased 7% to a record 35.3 billion litres.⁵⁹ Higher ethanol prices encouraged production ahead of the introduction of the RenovaBioⁱⁱⁱ system at the start of 2020.⁶⁰ Most Brazilian ethanol comes from sugar cane, and as of the end of 2019 some 370 sugar ethanol mills were operating across the country.⁶¹ Brazil also produced around 1.4 billion litres of ethanol from corn (up 75% from 2018), with 10 production plants in operation and more corn-based capacity under construction to take advantage of the expected rise in ethanol demand under RenovaBio.⁶²

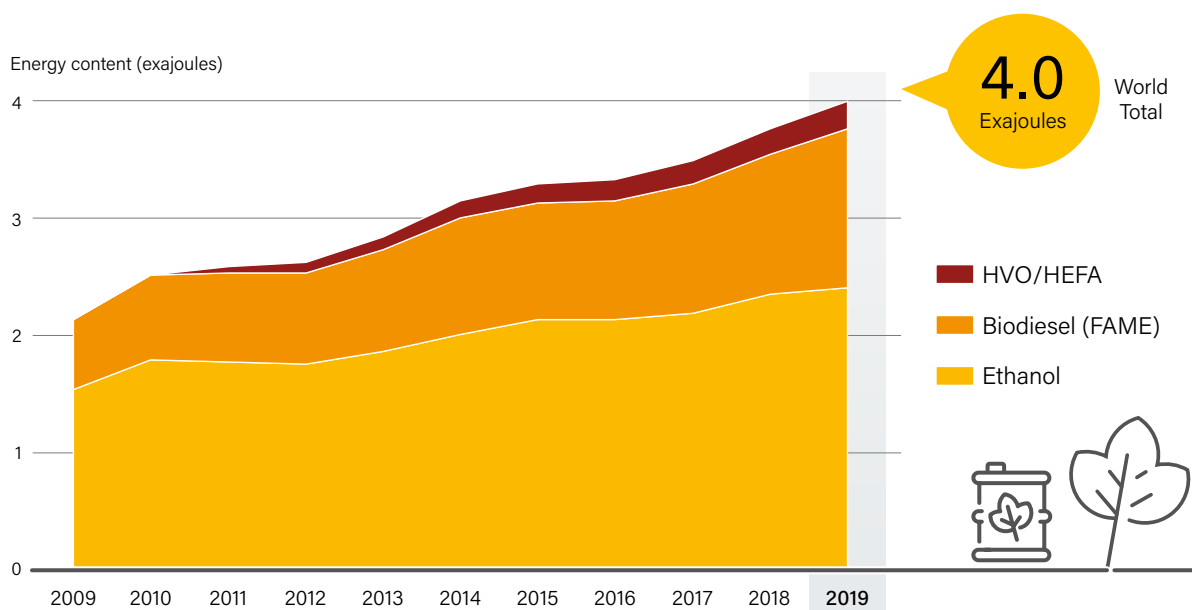
China’s ethanol production increased to 4 billion litres in 2019, up from 3.3 billion litres in 2018, to meet growing domestic demand.⁶³

i This section concentrates on biofuel production, rather than use, because the available data on production are more consistent and up-to-date. Global production and use are very similar, and much of the world’s biofuel is used in the countries where it is produced, although significant export/import flows exist, particularly for biodiesel.

ii The word “corn” has various meanings depending on the geographical region. In Europe, it includes wheat, barley and other locally produced cereals, whereas in the United States and Canada it generally refers to maize. See endnote 48 for this section.

iii The RenovaBio initiative introduces emissions reduction targets for fuel distributors, who can demonstrate compliance by buying traded emissions reductions certificates awarded to biofuel producers.

FIGURE 22. Global Production of Ethanol, Biodiesel and HVO/HEFA Fuel, by Energy Content, 2009-2019



Note: HVO = hydrotreated vegetable oil; HEFA = hydrotreated esters and fatty acids; FAME = fatty acid methyl esters

Source: See endnote 50 for this section.

China aims to progressively extend a 10% ethanol blend mandate to all provinces.⁶⁴ However, growth in the country's ethanol production capacity has been lower than anticipated, and the national roll-out of the mandate has been delayed to avoid the need for high levels of ethanol imports.⁶⁵

In India, where the government has given greater policy priority to biofuels as a way to reduce oil imports, production of ethanol from molasses and other by-products of the sugar industry has increased.⁶⁶ The country's ethanol production surged 70% in 2019, to 2 billion litres, leading India to overtake Canada and Thailand to become the world's fourth largest producer.⁶⁷ In Canada, ethanol production increased 2% to 1.9 billion litres, and in Thailand it increased 23% to 1.6 billion litres.⁶⁸

In the EU, changes to the Renewable Energy Directive limiting the role of "food-based biofuels", along with increased price competition from imports, have led to uncertainties about future markets for the region's ethanol industry.⁶⁹ Even so, a number of countries have increased ethanol blending levels, which helped maintain demand in 2019, and production was at around 70% of capacity by year's end.⁷⁰ Ethanol production fell in the region's top two producing countries, France (down 29% to 0.8 billion litres) and Germany (down 7% to 0.8 million litres).⁷¹

Global production of **biodiesel** increased 13% in 2019 to 47.4 billion litres.⁷² Biodiesel production is more geographically diverse than ethanol production, and the top five countries in 2019 accounted for 57% of global production.⁷³ Indonesia took the lead as the largest country producer (17% of global production), overtaking the United States (14%) and Brazil (12%).⁷⁴ The next largest producers were Germany (8%), France (6.3%) and Argentina (5.3%).⁷⁵

Indonesia's biodiesel production nearly doubled in 2019 to 7.9 billion litres, up from 4 billion litres in 2018.⁷⁶ Excess production capacity and new production plants came online in response to a new policy emphasis on meeting the country's B20 (20% biodiesel) blending target in transport, which was established in 2016 but had not yet been achieved; the expansion of production resulted in higher domestic biodiesel use.⁷⁷

Biodiesel production in the United States fell 7% to 6.5 billion litres, down from 7 billion litres in 2018, and several production plants either closed or were operating at reduced capacity.⁷⁸ This was mainly because the removal of the national biodiesel blending credit made production less profitable (although the credit was later restored retroactively).⁷⁹

In Brazil, biodiesel production continued to rise in 2019, up 11% to a record 5.9 billion litres.⁸⁰ Contributing factors included an increase in the required biodiesel blend in diesel fuel to 11%, and the need to meet expected higher demand with the introduction of the RenovaBio system.⁸¹

In Argentina, biodiesel production decreased 9% to 2.5 billion litres, as the weaker US market and ongoing US duties on biodiesel imports discouraged trade.⁸² Argentine biodiesel exports fell from 1.6 billion litres in 2018 to 1.2 billion litres in 2019.⁸³

Global production of biodiesel increased

13% in 2019, with Indonesia overtaking the United States as the largest producer.

The production of **HVO/HEFA** continued its robust growth of recent years, rising 12% from 6 billion litres in 2018 to 6.5 billion litres in 2019.⁸⁴ Production was concentrated in Finland, the Netherlands and Singapore, although US capacity also grew strongly.⁸⁵

Biomethane is used as a transport fuel mainly in Europe and the United States, which is the largest producer and user of biomethane for transport.⁸⁶ US production has accelerated since 2015, when biomethane was first included in the advanced cellulosic biofuels category of the US Renewable Fuel Standard (RFS) and in state initiatives such as California's Low Carbon Fuel Standard, thereby qualifying for a premium.⁸⁷ US biomethane use under the RFS increased 20% in 2019 to around 30 petajoules (PJ).⁸⁸

In Europe, the use of biomethane for transport increased 20% in 2018 (latest data available) to 8.2 PJ.⁸⁹ Sweden remained the region's largest biomethane consumer, using nearly 60% of the total, followed by Germany, Norway and the United Kingdom, where use of the fuel grew by a factor of four to 0.6 PJ in 2018.⁹⁰

The demand for biomethane for use in commercial vehicles – as well as investments in filling stations to provide the fuel – also grew. In the United Kingdom, a nationwide network of public refuelling stations for heavy goods vehicles was being installed on major routes to reach fleet operators across the country, serving major trunk roads and cities.⁹¹ Similar networks were being developed in Finland and Sweden.⁹²

Interest in biomethane as a low-carbon fuel in public transport increased. In France, the Public Transport Central Purchasing Office (CATP) and Ile-de-France Mobilités ordered 409 biogas buses, supplied by Iveco, to operate in the inner and outer suburbs of the Paris metropolitan area.⁹³ Trondheim, the third largest city in Norway, introduced 189 buses powered by biomethane.⁹⁴ In the UK, the city of Bristol announced plans to procure 77 biomethane-fuelled buses, which can reduce greenhouse gas emissions 80% and nitrogen oxide emissions 95% when compared to diesel equivalents.⁹⁵

Although efforts to develop other “advanced biofuels” continued, and some new production capacity was installed (→ see *Industry section in this chapter*), so far these fuels have been produced and used only in small quantities. Cellulosic ethanol contributed only around 0.8 PJ under the US RFS scheme in 2019, showing minimal growth over the previous three years.⁹⁶ And despite significant efforts, biofuels provided only around 0.01% of aviation fuel for the year.⁹⁷

Global bioelectricity production increased **9%** in 2019, led by China.

Bio-power Markets

Global bio-power capacity increased an estimated 6% in 2019 to around 139 gigawatts (GW), up from 131 GW in 2018.⁹⁸ China had the largest capacity in operation by the end of 2019, followed by Brazil, India, Germany, the United Kingdom, Sweden and Japan.

Total bioelectricity generation rose some 9%, from 546 terawatt-hours (TWh) in 2018 to around 591 TWh in 2019.⁹⁹ In recent years, growth has been concentrated in the EU and in Asia, particularly in China, Japan and the Republic of Korea. China extended its lead as the largest country producer of bio-power, followed by the United States.¹⁰⁰ The other major producers in 2019 were Brazil, Germany, India, the United Kingdom and Japan.¹⁰¹

Asia was the largest regional producer of bioelectricity, generating 225 TWh in 2019, an increase of 17%.¹⁰² Nearly half of this generation was in China.¹⁰³ The EU remained the second largest regional producer, with generation up 5% to 200 TWh.¹⁰⁴ Bioelectricity generation in North America declined slightly (down 2%) to 76 TWh.¹⁰⁵ (→ See *Figure 23*.)

China's bio-power capacity grew 26% to 22.5 GW in 2019, up from 17.8 GW in 2018, increasing in line with the provisions of the country's 13th Five-Year Plan (2016-2020).¹⁰⁶ Generation rose 23% to more than 111 TWh.¹⁰⁷ Capacity growth was focused on the use of solid biomass and municipal solid wasteⁱ for CHP systems, providing electricity as well as heat in urban areas.¹⁰⁸

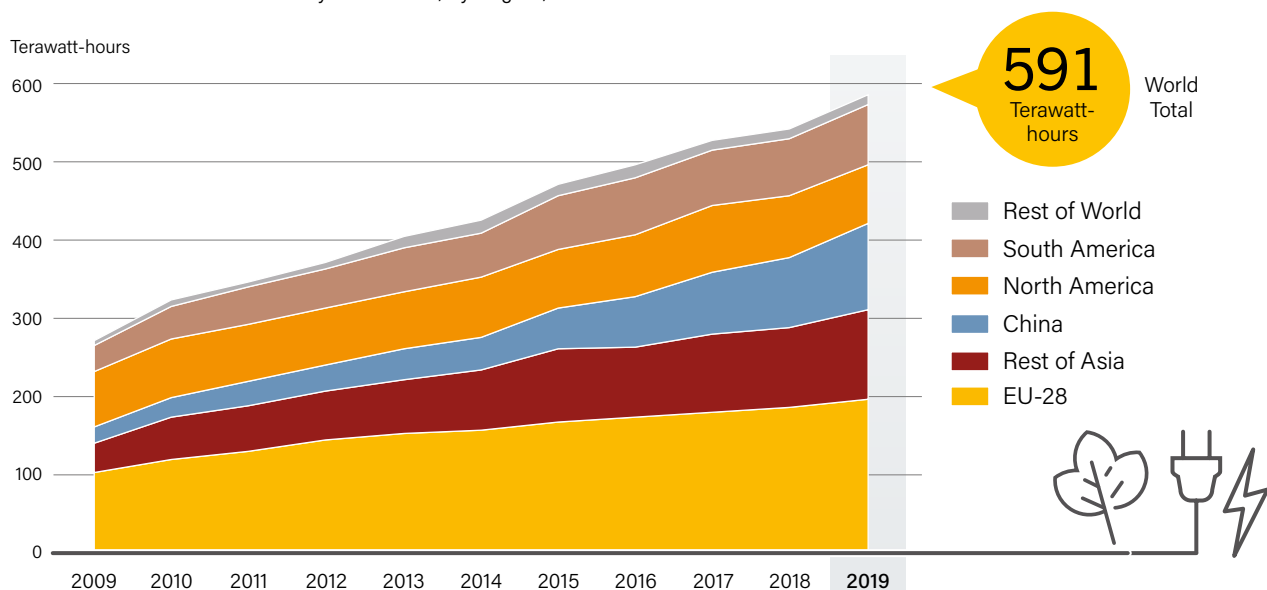
Japan's growth in bio-power capacity and generation remained strong during the year, stimulated by the Feed-in Tariff scheme.¹⁰⁹ The capacity of dedicated bio-power plants increased 8% to 4.3 GW, and generation grew 18% to 24 TWh.¹¹⁰ In the Republic of Korea, bio-power generation rose 50% to 10.9 TWh, stimulated by a generous Renewable Energy Certificate Scheme and feed-in tariffs.¹¹¹ Bio-power growth in both countries was based on rising imports of wood pellets, which are used for co-firing with coal and in new bio-power facilities.¹¹² In India, bio-power capacity increased marginally to 10.2 GW, and generation rose 8% to 51 TWh.¹¹³

In the EU, bio-power capacity and generation continued to rise to meet the national targets for 2020 under the new Renewable Energy Directive.¹¹⁴ Bio-power capacity grew around 4% in 2019 to 44 GW, and generation increased 5% to 200 TWh.¹¹⁵ Germany remained the region's largest producer of bioelectricity, primarily from biogas, but domestic generation did not increase (540 TWh).¹¹⁶ In the United Kingdom, bio-power capacity grew 5% to 7.9 GW, and generation rose more strongly – up 11% to 37 TWh – as new large-scale pellet-fired capacity installed in 2018 came fully online.¹¹⁷ Generation also surged in the Netherlands (up 49%) as bioelectricity projects financed under the SDE feed-in tariff scheme came online.¹¹⁸ In Denmark, bio-power generation rose 21%.¹¹⁹

The United States recorded the second highest national bio-power capacity and generation for the year.¹²⁰ However, the

ⁱ Municipal solid waste consists of waste materials generated by households and similar waste produced by commercial, industrial or institutional entities. The wastes are a mixture of renewable plant- and fossil-based materials, with the proportions varying depending on local circumstances. A default value is often applied that assumes that 50% of the material is “renewable”.

FIGURE 23. Global Bioelectricity Generation, by Region, 2009-2019



country's capacity (16 GW) did not grow, and generation fell 6% to 64 TWh, continuing the trend of recent years (down 9% since 2015).¹²¹ The decline was due to a lack of strong positive policy drivers and to difficulty in competing with wholesale electricity prices as other renewable generation sources and low-cost natural gas became more competitive.¹²²

Brazil was the third largest producer of bioelectricity globally, with most of the country's generation based on sugarcane bagasse.¹²³ Brazil's capacity rose 2% in 2019 to 15 GW, and generation grew 2% to 55 TWh.¹²⁴

The increased use of internationally traded wood pellets in the EU, Japan and the Republic of Korea was part of a significant global trend. Wood pellets can replace coal-based generation either through co-firing with coal in existing facilities or in purpose-built biomass-fired boilers. Globally, pellet use for electricity generation increased 2.5-fold between 2014 and 2018, to 17 million tonnes.¹²⁵

The use of biogas to co-generate electricity and heat has risen as well. By the end of 2019, some 132,000 biogas digesters were



in operation worldwide.¹²⁶ More than 100,000 of the units were in China, followed distantly by Europe (around 18,000) and the United States, where some 2,200 sites in all 50 states were producing biogas.¹²⁷

Electricity generation from biogas expanded to more countries and regions in 2019, including Africa, India, Latin America and the Middle East. In Ghana, a 400 kilowatt (kW) plant fuelled by biogas from waste digestion was under construction as part of a hybrid biogas, solar PV and pyrolysis plant supported by a EUR 5 million (USD 5.6 million) grant from the German government.¹²⁸ In the Indian state of Maharashtra, a new agricultural and municipal waste digester was scheduled to be installed at a biogas plant with 4 MW of power generating capacity; the biogas will be used in solid oxide fuel cells to produce electricity through an electro-chemical rather than a combustion process.¹²⁹

In Latin America, a commercial-scale facility that uses poultry waste to produce organic fertiliser and biogas opened in the state of Jalisco, Mexico.¹³⁰ Brazil's first biogas plant based on pig manure also began operations: the BRL 17 million (USD 4.2 million) project uses the waste from some 18 large local piggeries to run two 240 kW motor-generators that will power 72 public buildings in the municipality of Entre Rios do Oeste.¹³¹

In the Middle East, a new biogas power plant at the Mazoon Dairy Company in Oman, which uses biogas from cattle waste to provide process energy as well as fertiliser, became the first such facility in the region.¹³² In the United Arab Emirates, Dubai Municipality announced plans to build a biogas power plant at the Warsan Sewage Treatment that would reduce some 31,000 tonnes of carbon dioxide (CO₂) emissions annually.¹³³

BIOENERGY INDUSTRY

The bioenergy industry comprises a wide range of different businesses. These are involved in the complex supply chains that turn many potential biomass feedstocks into solid, liquid and gaseous fuels that are then used to produce electricity, heat and transport fuels. The companies involved also reflect the differences in the scale and complexity of these supply chains and the innovation required to respond to new opportunities and challenges.¹³⁴ In 2019, trends and developments varied widely across the solid, liquid and gaseous biomass industries.

Solid Biomass Industry

The entities involved in supplying and using solid biomass fuels range from small, locally based companies that manufacture and supply smaller-scale heating appliances and their fuels; to regional and global players involved in the supply and operations of large-scale district heating and power generation technology; to entities engaged in international trade in wood pellets and other biomass products.

Bioenergy projects that produce electricity and/or heat from solid fuels mostly use feedstocks that are sourced locally, such as residues from agricultural, forestry processes and timber processing, and municipal solid waste. Increasingly, however, solid biomass fuels are being processed and transported (most often in the form of wood pellets) to where markets are available and most profitable. This growth in biomass pellet production to serve international markets for heat and electricity production is an important development in the sector.

In 2018, global production of **biomass pellets** reached an estimated 55 million tonnes.¹³⁵ China contributed around 20 million tonnes – up five-fold from 2014 – produced mainly from wood and agricultural residues and used almost entirely domestically.¹³⁶ The other top producing regions were Europe (17 million tonnes) and North America (11 million tonnes).¹³⁷ Production of pelleted biomass fuels has grown strongly to meet demand in Europe and more recently Asia.

Excluding China (where information on pellet usage is unclear), nearly 17 million tonnes of pellets were used worldwide for power generation and CHP production (and other industrial purposes) in 2018, and 18 million tonnes were used to provide heat in the residential and commercial sectors.¹³⁸ Excluding pellets produced in China, pelleted fuels generated an estimated 90 TWh of electricity, representing around 6% of the biomass used for electricity generation.¹³⁹ Pellets also provided an estimated 7.5% of the biomass used to heat buildings.¹⁴⁰

The global trade in wood pellets initially relied on subsidiary companies established by major users such as Drax (United Kingdom) and RWE (Germany), which, in the absence of alternatives, invested in vertically integrated supply chains to meet their own demand. More recently, however, the market has shifted to third-party supply from major producers such as Enviva (United States), Graanul Invest (Baltic States) and Pinnacle Renewable Energy (Canada), as well as smaller-scale

regional suppliers such as An Viet Phat (Vietnam) and FRAM Renewable Fuels, Highland Pellets and Pacific Bioenergy (all United States).¹⁴¹ These companies have invested in production capacity and logistics to match long-term supply contracts from major power producers in Europe and Asia.¹⁴²

The United States has been the major producer and exporter of wood pellets, with most of the production taking place in the country's south-east.¹⁴³ US pellet production increased 15% in 2019 to around 8.7 million tonnes, and exports rose 9% to 6.1 million tonnes.¹⁴⁴ One US company, Enviva, announced plans to build a facility in the state of Alabama to produce around 1,150,000 metric tonnes of wood pellets annually, which would be transported by river to a planned export terminal in Mississippi and then exported to Europe and Asia.¹⁴⁵

The wood pellet market first developed in the EU, where power producers opted initially to co-fire the pellets with coal and then to convert coal plants to use pellets as a way to prolong the life of these assets.¹⁴⁶ More recently, the wood pellet market has expanded in Japan and the Republic of Korea, stimulated by favourable support schemes.¹⁴⁷

In Japan, where biomass generation is based mainly on new dedicated generation capacity, pellet supply is dependent on long-term contracts and is imported mostly from North America.¹⁴⁸ In 2019, Mitsui (Japan) announced a contract with Pinnacle Renewable Energy to procure 100,000 tonnes of wood pellets.¹⁴⁹

In the Republic of Korea, the market for wood pellets has been based mostly on co-firing. However, dedicated biomass plants are being built as well, with Pinnacle supplying 100,000 tonnes of pellets annually to GS Global, the country's first dedicated independent bio-power producer.¹⁵⁰ Republic of Korea's pellets are sourced in Vietnam and elsewhere in Asia on relatively short-term contracts.¹⁵¹

Debate has continued regarding the carbon savings and other environmental impacts related to pellet production and use.¹⁵² Some countries have introduced stricter and more comprehensive sustainability regulations governing the sources that can be used for wood pellets; in the EU, for example, the sustainability provisions in the Renewable Energy Directive now extend to solid biomass.¹⁵³ In response, the pellet industry has developed more complex and open track-and-trace systems to account for wood sourcing.¹⁵⁴ The leading independent certification body for pellet producers, the Sustainable Biomass Programme, began as an industry initiative but has broadened its governance to include representation from non-governmental and other stakeholders.¹⁵⁵

Most of the pellet supply is produced from wood residues that are dried and compressed, which results in a product with a higher energy density than wood chips. However, work is ongoing to develop and commercialise pellets made by torrefactionⁱ, which have an even higher energy density and can substitute for coal. In 2019, Clean Electricity Generation (United Kingdom) delivered its "BioCoal" pellets for trials at a district heating system in France, ahead of the development of a commercial-scale plant in Estonia that aims to produce 157,000 tonnes of pellets a year.¹⁵⁶

ⁱ Torrefaction of biomass is a mild form of pyrolysis at temperatures typically between 200 and 320 degrees Celsius (°C), which changes biomass properties to provide a better fuel quality for combustion and gasification applications.

In 2019, HVO/HEFA plants in the pipeline were enough to

triple

global production capacity.

Liquid Biofuels Industry

The liquid biofuels industry is concentrated on the production of ethanol, FAME biodiesel and increasingly HVO/HEFA, which together make up the bulk of global biofuels production and use. In 2019, the industry, particularly in the United

States, was negatively affected by trade and other restrictions that constrained production in some markets. Several US ethanol plants, including facilities belonging to the two largest US producers, POET and Archer Daniels Midland, had to cut production because of constraints to domestic demand and export opportunities.¹⁵⁷ In addition, eight US biodiesel plants were closed, and other plants operated at reduced capacity, although several new biodiesel plants also came online or were being planned in the country.¹⁵⁸

To meet rising biofuel demand from both road transport (especially heavy goods vehicles) and aviation, the biofuels industry has increased its investments in facilities that produce **HVO/HEFA** from feedstocks based on waste, residues and virgin vegetable oils.¹⁵⁹ If all HVO/HEFA plants that were under construction or planned in 2019 came online, global production capacity would triple to more than 22 billion litres annually.¹⁶⁰

In North America, nearly 4 billion litres of additional renewable dieselⁱ production capacity was under construction at year's end, and HVO production capacity was rising steadily, mainly in the United States.¹⁶¹ Growth was stimulated by the country's RFS and particularly by the Low Carbon Fuel Standard in California.¹⁶² World Energy (United States) announced a USD 350 million expansion project to complete the conversion of a former oil refinery in Paramount, California to produce up to 1.3 billion litres of renewable diesel, biojet fuel, green gasoline and renewable propane.¹⁶³ Ryze Renewables (United States) was building two projects in the US state of Nevada with a combined capacity of 568 million litres per year, and Marathon Petroleum (United States) was in the process of converting its oil refinery in North Dakota to produce 700 million litres annually by late 2020.¹⁶⁴

In the EU, where the new Renewable Energy Directive is expected to drive up demand for advanced biofuels by 2030, the operational and planned HVO capacity increased in 2019, with more than 3 billion litres of capacity coming online.¹⁶⁵ Total (France) began production at its La Mède site, following an EUR 275 million (USD 308 million) conversion of its oil refinery to produce 640 million litres of HVO annually from vegetable oils (rapeseed, palm, sunflower, etc.) and treated waste (animal fats, cooking oil, residues, etc.).¹⁶⁶

ENI opened a newly converted biorefinery in Gela, Italy that can produce nearly 1 billion litres of HVO per year, and planned to invest another EUR 93 million (USD 104 million) in a plant to

pretreat waste feedstocks.¹⁶⁷ In Sweden, the oil company ST1 invested SEK 1.5 billion (USD 160 million) in a hydrogen plant to produce 250 million litres annually of HVO, due to start operation in 2020.¹⁶⁸ PKN Orlen (Poland) began producing HVO from used cooking oil and vegetable fats at its plants in Plock and Litvinov to help meet rising demand.¹⁶⁹

Elsewhere in the world, Neste (Finland), the world's largest HVO producer, began building a EUR 1.5 billion (USD 1.68 billion) renewable diesel production facility in Singapore, which was expected to add 1.7 billion litres of annual capacity and bring the company's global production to 5.8 billion litres.¹⁷⁰ ECB (Brazil) announced plans to build an HVO plant in Assuncion, Paraguay that would produce HVO from soya for export to Canada, Europe and the United States.¹⁷¹

Industry efforts to demonstrate the production and use of a wider range of **advanced biofuels** continued. Although production has remained limited, the industry aims to increase the development of biofuels that show improved sustainability performance and that benefit from the EU Renewable Energy Directive, the US RFS, RenovaBio and other schemes designed to encourage the uptake of low-carbon fuels.¹⁷² Some advanced biofuels can replace fossil fuels directly in transport systems ("drop-in biofuels"), including in aviation, or can be blended in high shares with conventional fuels in road transport.¹⁷³

Many pathways are under development to produce advanced biofuels, including bio-based fuels (from an array of feedstocks) in the form of ethanol, butanol, diesel jet fuel, gasoline, biomethanol and mixed higher alcohols.¹⁷⁴ The most advanced pathways include the production of ethanol from cellulosic feedstocks (such as cereal residues) by enzymatic processes, and the use of pyrolysis, gasification and other thermal processes. An increasing focus is on producing biofuels for aviation.

So far, few cellulosic ethanol production plants have reached their design output due to ongoing technical and commercial challenges.¹⁷⁵ For example, the POET-DSM plant in Emmetsburg, Iowa in the United States halted routine production in 2019 to concentrate instead on research and development (R&D) to improve plant performance.¹⁷⁶ Meanwhile, VERBIO (Germany) purchased DuPont's commercial-scale cellulosic ethanol plant in Iowa, which ceased operations in 2017, and is converting the plant to produce methane from straw using anaerobic digestion, starting in 2020.¹⁷⁷

More positive trends were observed elsewhere in 2019. In Europe, Clariant (Switzerland), which had been operating a demonstration cellulosic ethanol plant in Germany, announced that it was building a full-scale commercial plant in Romania.¹⁷⁸ The company also licensed its technology for a large-scale plant in the Slovak Republic and negotiated licences in China and Poland.¹⁷⁹ ENI (Italy) took over the Biochemtex cellulosic ethanol plant in Crescentino, Italy – which was closed following the failure of the parent company in 2017 – and planned to restart production in 2020.¹⁸⁰

In Latin America, GranBio (Brazil), which commissioned an 82 million litre per year plant at Alagoas (Brazil) in 2014 but shut

i HVO/HEFA fuels are often referred to as renewable diesel, especially in North America.



it down in 2016 due to technical problems, restarted production with a goal of 30 million litres in 2019 and 50 million litres in 2020.¹⁸¹ Raizen (Brazil) built up production levels at its plant in Costa Pinto, to around 12 million litres in 2017/2018 and an expected 40 million litres (the rated capacity) in 2018/2019.¹⁸²

Commercialisation of thermal advanced biofuel processes, such as pyrolysis and gasification, continued as well. Enerkem (Canada) aimed to add to its portfolio of plants, which gasify waste to produce ethanol, by developing new projects in the US states of Massachusetts and Minnesota.¹⁸³ Construction also was under way at the Red Rock Biofuels LLC biorefinery in Lakeview, Oregon, which will use Fischer-Tropschⁱ technology to convert around 123,000 metric tonnes of wood waste annually into more than 57 million litres of renewable jet diesel and petrol blend-stock fuels.¹⁸⁴

In Europe, Green Fuel Nordic Lieska Oy (Finland) announced plans to invest EUR 100 million (USD 112 million) in BTG's (Netherlands) pyrolysis technology to produce heating oil from wood waste produced by a local sawmill in Lieska.¹⁸⁵ BTG aims to build a plant in Rotterdam, the Netherlands, in partnership with GoodFuels (Netherlands) to produce fuels for shipping.¹⁸⁶

In Sweden, in a joint venture, the timber producer Sodra and the oil company Preem (both Sweden) will produce pyrolysis oil using 35,000 to 40,000 tonnes of wood residues annually, which will be processed at an oil refinery into bio-based gasoline and diesel fuels for use in transport.¹⁸⁷ Shell (Netherlands) announced funding for further development of the company's IH2 process with Biotin (Norway) and Preem to produce biocrude in Norway from 1,000 tonnes of wood residues per day.¹⁸⁸

Although biofuels replaced only 0.1% of aviation fuel in 2018, developments in the sector in 2019 aimed to reduce emissions and to boost collaboration among potential aviation biofuel producers,

airlines and airports, driven by industry carbon reduction targets.¹⁸⁹ SkyNRG announced plans to develop Europe's first dedicated sustainable aviation fuel plant, using regional waste and residue streams in the Netherlands.¹⁹⁰ Amsterdam's Schiphol airport pledged to invest in the facility, and the Dutch airline KLM committed to purchasing 75,000 tonnes annually from the plant for 10 years; in addition, SHV (Netherlands), a leader in distribution of liquefied petroleum gas, said it would buy the bioLPG produced as a by-product.¹⁹¹

Elsewhere in Europe, Lufthansa was collaborating with Neste (Finland) to use sustainable aviation fuel blended with fossil jet fuel on flights from Frankfurt, Germany.¹⁹² Norway's state-owned airport operator Avinor partnered with Quantafuel (Norway) to buy sustainable aviation fuel produced in a pilot plant funded in part by the Norwegian investment bank ENOVA. If successful, the facility, which uses wood chips and sawdust as feedstocks, would be expanded to a full-scale plant producing 7-9 million litres a year.¹⁹³

In the United States, Shell Aviation and HVO producer World Energy agreed to develop a scalable supply of sustainable aviation fuel. World Energy would produce the fuel from agricultural waste fats and oils at its new refinery in Paramount, California and then supply a total of 1 million gallons (3.8 million litres) to Lufthansa Group at San Francisco International Airport for use on flights from San Francisco to Frankfurt, Munich and Zurich.¹⁹⁴ The airline Jet Blue (United States) agreed to purchase sustainable aviation fuel from Neste in New York starting in 2020; the fuel would be shipped via fuel pipeline to the airport, where it would be blended with regular fuel.¹⁹⁵

Also in 2019, Delta Airlines (United States) invested USD 2 million in Northwest Advanced Bio-Fuels (United States) to study the feasibility of a facility to produce sustainable aviation fuel and other biofuel products in Washington state.¹⁹⁶ The company also agreed to purchase 10 million gallons (38 million litres) per year of advanced renewable biofuels from Gevo (United States).¹⁹⁷ United Airlines (United States) agreed to purchase up to 10 million gallons (38 million litres) of sustainable aviation fuel in 2020 and 2021, and committed USD 40 million to a new investment vehicle focused on accelerating the development of sustainable aviation fuels and other decarbonisation technologies.¹⁹⁸

In Canada, the Green Aviation Research and Development Network, Sky NRG, Waterfall Group and Vancouver Airport Authority jointly announced the launch of BioPortYVR, an industry-led project to increase the country's supply of sustainable aviation fuel.¹⁹⁹

Gaseous Biomass Industry

Industry involvement in the gaseous biomass sector relates mainly to the production and use of biogas, which until recently was used mainly for electricity production, stimulated by favourable feed-in tariffs and other support mechanisms.²⁰⁰ The industry, particularly in North America, Europe and China, is diversifying by refining increasing amounts of biogas to biomethane for use as a transport or heating fuel.²⁰¹

i Fischer-Tropsch technologies are used to convert synthesis gas containing hydrogen and carbon monoxide to hydrocarbon products.

Biogas can be upgraded to biomethane by removing the CO₂ and impurities, facilitating its injection into natural gas pipelines when appropriate quality standards can be met.²⁰² Increasingly, policy makers have considered this as an important route to decarbonising the heating and transport sectors.²⁰³ Systems for producing and converting biogas to biomethane were widely deployed in 2019, with the refined biomethane either being injected into natural gas pipelines for use for heating or being used directly for transport.

US biomethane production capacity grew strongly during the year, with several new projects under development by US companies. RNG Energy Solutions was involved in building two new anaerobic digesters in Pennsylvania and New Jersey, each capable of processing 1,100 tonnes of organic waste daily to produce 3.2 terajoules of renewable natural gas (RNG), equivalent to 26,000 gallons (100,000 litres) of petrol.²⁰⁴ The utility Dominion Energy invested USD 500 million to convert methane from pig farms to RNG, as well as USD 200 million in a project with Vanguard Renewables to produce RNG from dairy waste in five states.²⁰⁵ Threemile Canyon Farms and Equilibrium opened a USD 55 million facility in Oregon that produces RNG from dairy waste; the plant uses manure from 33,000 dairy cows to feed an anaerobic digestion system, followed by a biogas clean-up system that injects RNG into the grid for use as transport fuel in California.²⁰⁶

Biomethane installations also have grown rapidly in Europe. Seventy new plants were installed in the region in 2018, bringing the European total to 660 plants producing some 90 PJ (2.3 billion cubic metres) of biomethane.²⁰⁷

Although the United States and Europe are the main centres of biomethane production, India's minister of petroleum and natural gas announced plans to build some 5,000 compressed biogas plants across the country by 2023, using agricultural residues, cattle dung and municipal solid waste to produce 750 PJ (15 million tonnes) of biomethane annually.²⁰⁸

The move to biomethane has stimulated the active interest of large international players. ENGIE (France) had a portfolio of more than 80 biomethane projects in 2019; the company planned to produce some 18 PJ annually by 2020 and to invest EUR 2 billion (USD 2.24 billion) in the technology by 2030.²⁰⁹ The industrial gas supplier Air Liquide (France) has attributed the 30% growth in revenue of its Global Markets and Services Division in 2018 (to USD 494 million) to the company's biogas-related activities in Europe and North America.²¹⁰

Although anaerobic digestion accounted for nearly all of the biogas and biomethane used in 2019, biomethane also can be produced through the thermal gasification of biomass. The technology has been demonstrated technically at scale, but no commercial plants were in operation by year's end.

However, a EUR 175 million (USD 195 million) commercial-scale plant, developed by the clean energy company Progressive Energy (United Kingdom), was approved for Ellesmere Port in the United Kingdom and will use unrecyclable wood and refuse-derived fuel to produce biomethane.²¹¹

Bioenergy with Carbon Capture and Storage or Use

Many low-carbon scenarios depend on the capture and storage of carbon dioxide emitted when bioenergy is used to produce heat, electricity or transport fuels.²¹² Removal from the atmosphere of CO₂ produced in bioenergy production, which is considered part of the carbon cycle, is seen as having a double benefit that leads to "negative emissions".²¹³ Although policy makers and analysts have shown rising interest in such options, in the absence of strong policy drivers that might make projects economically attractive, very few projects demonstrating these technologies have operated at scale so far.²¹⁴

Examples exist of CO₂ from bioenergy projects being separated and used for various industrial applications, but only around five commercial-scale projects using bioenergy with carbon capture and storage (BECCS) were in operation at the end of 2019.²¹⁵ These included a large-scale project at an Archer Daniels Midland (United States) ethanol distillery in the US state of Illinois, which captured around 1 million tonnes of CO₂ per year, and four other projects that were linked to ethanol distilleries in Canada and the United States.²¹⁶

Additional pilot-scale projects demonstrating carbon capture were pursued during the year. Drax Power, working with C-Capture (United Kingdom), invested GBP 400,000 (USD 525,000) in a pilot carbon capture project at its large-scale bio-power plant in the United Kingdom – the first such project in Europe.²¹⁷ CO₂ Solutions (Canada) installed a carbon capture unit at the Saint Félicien pulp mill in Quebec, Canada; the unit uses an enzymatic technology to capture 30 tonnes of CO₂ per day, which is then reused at an adjacent greenhouse complex.²¹⁸



KEY FACTS

- An estimated 0.7 GW of new geothermal power generating capacity came online, with Turkey, Indonesia and Kenya leading new installations.
- Direct use of geothermal energy for thermal applications grew most rapidly in space heating, with China, Turkey, Iceland and Japan representing 75% of direct geothermal use.
- As in previous years, the geothermal industry was inhibited by challenges of high project costs and lack of adequate funding. Research into new and innovative technologies and processes helped fuel optimism for the future.

GEOHERMAL POWER AND HEAT



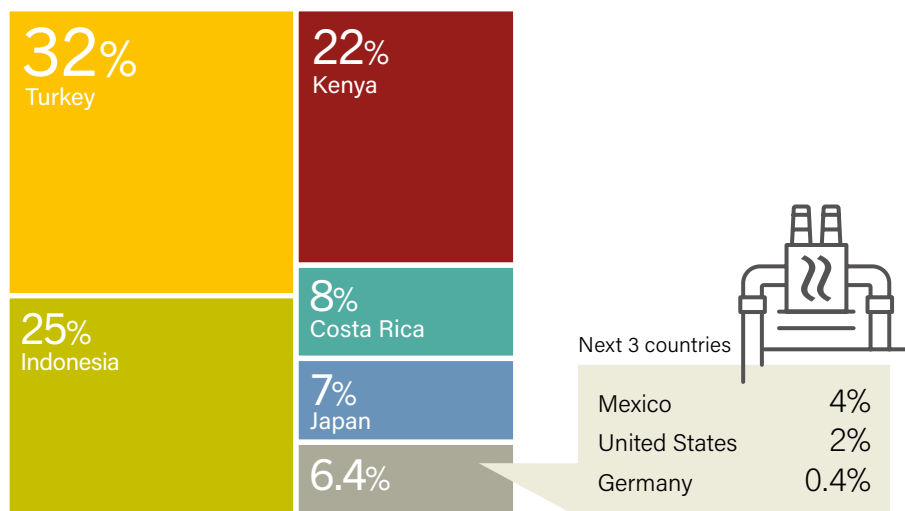
GEOHERMAL MARKETS

Geothermal resources are utilised for energy applications through two primary pathways, either through the generation of electricity or through various “direct use” thermal applications (without conversion to electricity), such as space heating and industrial heat input. In 2019, geothermal electricity output was approximately 95 TWh while direct useful thermal output was around 117 TWh (421 PJ)ⁱ.¹ Some geothermal plants produce both electricity and heat for various thermal applications (co-generation), but this is contingent on thermal demand being relatively near the resource.

An estimated 0.7 GWⁱⁱⁱ of new **geothermal power** generating capacity came online in 2019, bringing the global total to around 13.9 GW.² As in 2018, Turkey and Indonesia remained in the lead for new installations, followed closely by Kenya. Together, these three countries represented three-quarters of new installations globally.³ Other countries that added new geothermal power facilities in 2019 (or added capacity at existing facilities) were Costa Rica, Japan, Mexico, the United States and Germany.⁴ (→ See Figure 24.)

i When geothermal resources are used for electricity generation, a portion of the electricity is used for “indirect” thermal applications, such as cooling (air conditioning) and heating (via heat pumps or through electric resistance).
 ii This does not include the renewable final energy output of ground-source heat pumps. See Systems Integration chapter.
 iii Net additions were somewhat lower due to decommissioning or derating of existing capacity.

FIGURE 24. Geothermal Power Capacity Global Additions, Share by Country, 2019



Source: See endnote 4 for this section.

The top 10 countries with the largest stock of geothermal power capacity at the end of 2019 were the United States, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Kenya, Italy, Iceland and Japan.⁵ (→ See Figure 25.) In some instances, effective generating capacity (running capacity) may be lower than indicated values, due to gradual degradation of the steam-generating capability of geothermal fields or to insufficient drilling of make-upⁱ wells to replenish steam flow over time (see later discussion on Mexico and Japan). For example, the effective netⁱⁱ generation capacity in the United States was 2.5 GW at the end of 2019, whereas the gross nameplate generator capacity was 3.7 GW.⁶

Turkey and Indonesia have been, by far, the most active geothermal markets in the world in recent years. Since 2016, each country has added more than 0.8 GW of capacity, with no other market coming close in that time frame.⁷

Following capacity expansion of 219 MW in 2018, Turkey brought online a net additional capacity of 232 MW in 2019.⁸ Among the units entering operation was the 32 MW Unit 6 at the Pamukören complex.⁹ A 30 MW unit also was added to Maspo Energy's existing 10 MW facility, and the company was continuing feasibility studies for a third unit.¹⁰ In 2019, Turkey ranked fourth globally for total geothermal power capacity, with 1.5 GW.¹¹

The bulk of Turkey's geothermal capacity has been built over the last decade in response to a technology-specific feed-in tariff (FIT) in place since 2011.¹² In 2019, the country's geothermal industry leadership awaited new subsidy schemes to replace the expiring FIT, suggesting that uncertainty about renewal of the

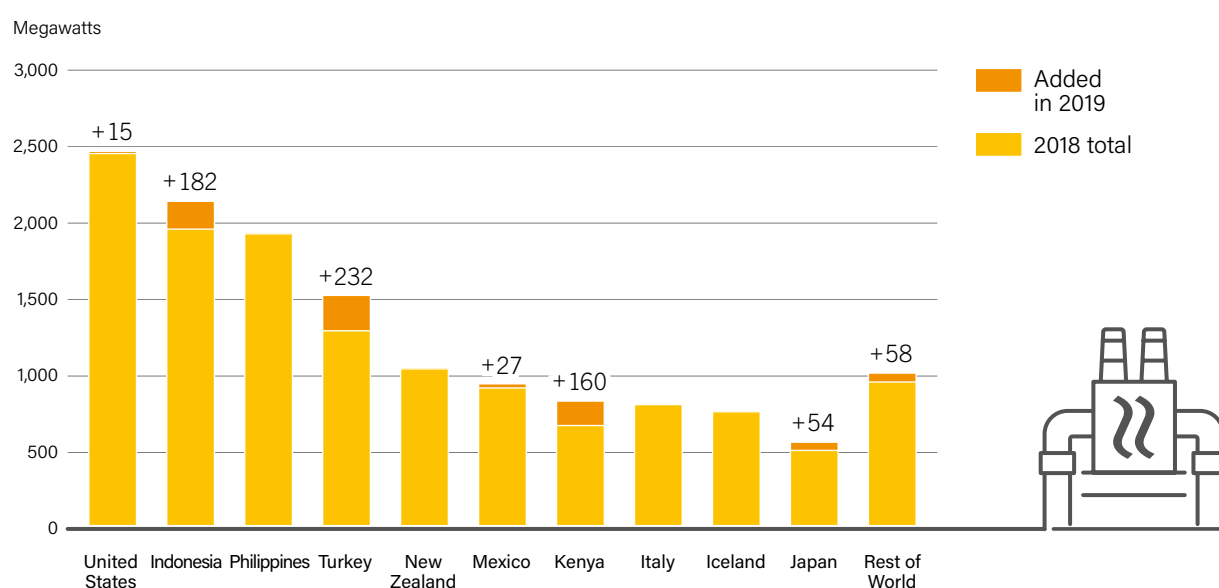
FIT may have been holding back financing and investments in new projects.¹³ At an average project cost of USD 4 million per megawatt, the current growth of 200-250 MW per year represents USD 1 billion in annual investment going forward.¹⁴ In early 2020, with its subsidy scheme under review, the Turkish government indicated that its support for renewables would continue.¹⁵

Turkey's geothermal sector also faced mounting community concern about the potential adverse impacts of air emissions (mainly hydrogen sulphide) and groundwater contamination (heavy metals) from existing geothermal power plants on public health, wildlife and agricultural output (primarily olives and figs).¹⁶ (→ See Feature chapter.) Most of the country's geothermal plants are located in the agricultural regions of western Anatolia, bordering the Aegean Sea.¹⁷ Also of concern, carbon dioxide emissions from Turkey's geothermal operations, which range from 1.0 to 1.3 kilograms of CO₂ per kWh at the time of plant commissioning, are nearly 10 times above the global average.¹⁸ Recent observations suggest that CO₂ emission rates at the country's geothermal fields decline over time, although outcomes vary by facility.¹⁹

Indonesia added 182 MW of geothermal capacity in 2019, following the 140 MW added in 2018, for a year-end operating total of 2.1 GW.²⁰ Construction was completed on three units: the 42.3 MW Sorik Marapi Unit 1 in North Sumatra, and the 55 MW Lumut Balai and the 85 MW first stage of the Muara Laboh facility, both in South Sumatra.²¹ The Sorik Marapi is expected to expand to five generating units and a total of 240 MW by 2023, with the second unit to be ready by the end of 2020.²²

- i If a geothermal power plant extracts heat and steam from the reservoir at a rate that exceeds the rate of replenishment across all its boreholes, additional wells may be drilled over time to tap additional steam flow, provided that the geothermal field overall is capable of supporting additional steam flow.
- ii In general, a power plant's net capacity equals gross capacity less the plant's own power requirements and any seasonal derating. In the case of geothermal plants, net capacity also would reflect the effective power capability of the plant as determined by the current steam production of the field. This defines its running capacity, as opposed to the total nameplate capacity of its generator(s). For the United States, most of the difference between nameplate and running capacity (about 800 MW) results from plant derating at the Geysers geothermal field in California, which is not able to produce enough steam, due to productivity decline, to operate at nameplate capacity. See endnote 6 for this section.

FIGURE 25. Geothermal Power Capacity and Additions, Top 10 Countries for Capacity Added and Rest of World, 2019



Source: See endnote 5 for this section.

The Indonesian government's target for 23% renewables in the energy mix by 2025 assumes that geothermal power capacity will reach 7 GW (supplying 7% of the energy mix).²³ In an effort to mitigate geothermal project risk and to stimulate investment to achieve its target, the government pursued exploratory drilling in three separate locations during 2019.²⁴ The World Bank is spearheading the financing of this drilling, and in 2019 the Bank approved a USD 150 million loan to Indonesia accompanied by USD 127.5 million in grants from the Green Climate Fund and the Clean Technology Fund.²⁵

Geothermal power supplied 14 TWh to Indonesia in 2018, or 4.9% of the country's electricity that year.²⁶ The government anticipates that geothermal production will peak within the next decade (at around 74 TWh), after which it will be dwarfed by more abundant and cost-competitive solar energy.²⁷



Elsewhere in Asia, most geothermal power capacity is located in Japan and the Philippines. Japan's geothermal capacity has expanded very little in recent years despite plentiful resources, which made 2019 relatively eventful. The 7.5 MW Matsuo Hachimantai geothermal power plant was completed in Iwate Prefecture in the north-eastern part of Honshu. As is common for geothermal projects, the development timeline was lengthy: initial research for the single-flash plant began in 2011, exploration started in 2015, and resource development began in 2017.²⁸ At the time of completion, Hachimantai was the largest geothermal plant to be built in Japan in more than 20 years.²⁹ By mid-2019, the double-flash 46.2 MW Waisabizawa plant began operation in neighbouring Akita Prefecture.³⁰

These Japanese projects benefited from government support of surface surveys and exploratory drilling, designed to advance Japan's geothermal resource development efforts. To mitigate the risk and the large upfront cost of further development,

in 2019 the Japanese government announced geothermal exploration grants to support 7 new projects in addition to 17 projects already under way.³¹

Although Japan has some 550 MW of installed generating capacity, the country's actual effective (running) capacity may be around 330 MW.³² The average capacity factor (in this case, generation relative to nameplate capacity rating) of geothermal power plants in the country has been declining since the 1970s. This is in part because developers installed generators that were too large relative to the long-term steam generating capability of the geothermal fields, resulting in gradual degradation of steam output.³³ Over the last decade, some older power units at these declining fields have been decommissioned and replaced with new units with a smaller rated capacity.³⁴

At the end of 2019, the Philippines continued to rank third for total installed capacity, at 1.9 GW, although no new capacity came online during the year.³⁵ The country has large untapped potential for geothermal energy, but the leading local developer does not foresee much new development.³⁶ Reasons include a lack of financial incentives, a challenging permitting process and a lack of investors willing to absorb the development risk that is endemic to the industry.³⁷ Permitting is complicated in the Philippines because most areas with geothermal potential are protected as environmentally critical under existing law.³⁸

Kenya closely followed Turkey and Indonesia for new installations (160 MW), and ended the year with 0.8 GW of total capacity.³⁹ The country is Africa's most active market for geothermal power and the only one on the continent to add capacity in 2019. Units 1 and 2 of the Olkaria V project came online with better-than-expected results, delivering more than 160 MW of power to the national grid.⁴⁰ Also of note in Kenya was the African Development Bank's issuance of a partial risk guarantee in support of the long-delayed Menengai geothermal project.⁴¹ With the requisite drilling already complete, the guarantee was expected to hasten construction of the initial three 35 MW units.⁴² In addition, the Geothermal Risk Mitigation Facility, a regional organisation focused on the funding and acceleration of geothermal energy in East Africa, provided a grant for Kenya's Baringo-Silali project (anticipated initial capacity of 300 MW), where the first well was drilled successfully in late 2019.⁴³

Costa Rica ranked fourth globally for newly installed capacity. The 55 MW Las Pailas II geothermal plant was completed, finalising the complex that also includes the 35 MW Las Pailas I, which came online in 2011.⁴⁴ The Las Pailas II production field encompasses 21 wells with an average depth of 2,200 metres.⁴⁵ During 2019, Costa Rica's national utility indicated that the plant was an important step towards national goals to decarbonise the economy, as well as a welcome diversification from hydropower during a dry period and partial relief from resultant electricity imports.⁴⁶ The country's capacity reached 262 MW by year's end, second only to Mexico in Latin America.⁴⁷

i Flash steam units are the most common type of geothermal power plants in operation, where high-pressure steam is vaporised (flashed) in a low-pressure vessel to remove geothermal fluid before the remaining vapor drives a turbine. Double- or triple-flash plants incorporate sequential flashes to remove remaining liquid for greater energy extraction. See, for example, US Department of Energy, "Geothermal: electricity generation", <https://www.energy.gov/eere/geothermal/electricity-generation>.

Mexico also added new operating capacity, inaugurating a 27 MW unit in the state of Michoacán at the los Azufres power plant, and bringing the plant's total to 10 generating units and 252 MW of capacity.⁴⁸ Also in 2019, the government issued a tender for additional drilling at the Los Azufres geothermal field.⁴⁹ Although great efforts were made to advance Mexico's geothermal industry in years past, that momentum appeared to be slipping in 2019 with changing government priorities.⁵⁰ Even existing projects suffered: for example, due to resource depletion (declining enthalpy) and lack of maintenance, the country's largest geothermal field, Cerro Prieto, can generate only half of its installed capacity of 0.7 GW, calling into doubt Mexico's year-end presumed geothermal power capacity total of 0.9 GW.⁵¹

Also in Latin America, construction began on Chile's 33 MW expansion of the Cerro Pabellón geothermal power plant.⁵² Combined with two high-enthalpy binary-cycleⁱ units already in place, the plant is expected to reach a total capacity of 81 MW when completed.⁵³ Cerro Pabellón is the only geothermal plant in South America and the highest of its kind in the world, located at 4,500 metres above sea level on a plateau of the Atacama Desert.⁵⁴

The United States remains the global leader for installed geothermal power capacity despite very little capacity growth in recent years. In 2019, the country's net geothermal capacity expanded by only 14.8 MW, bringing total net operating capacity to 2.5 GW.⁵⁵ Geothermal power in the United States generated 16 TWh in 2019, virtually unchanged from 2018, representing less than 0.4% of US net electricity generation.⁵⁶

Only a few countries in Europe have geothermal power plants, and most of the region's operating capacity is in Italy and Iceland, although neither country added capacity in 2019. Croatia officially unveiled its first geothermal power plant, the 16.5 MW Velika Ciglana, late in the year, having completed the construction in 2018ⁱⁱ.⁵⁷ Since Croatia does not have the high-temperature geothermal fields found in larger markets, this plant generates electricity from a medium-enthalpyⁱⁱⁱ resource (about 170 °C) using a binary-cycle technology.⁵⁸ The country intends to rely on further geothermal development to boost the share of renewables in its energy mix.⁵⁹ Plans for a second 19.9 MW unit of similar configuration were announced during the year.⁶⁰

New capacity was brought online in Germany as well. Following the start of operations for district heating in late 2018, the town of Holzkirchen initiated power generation from its 3.2 MW geothermal combined heat and power plant.⁶¹ The plant uses binary-cycle technology to generate electricity from geothermal fluid of around 150 °C before supplying the residual energy to the local district heat network.⁶²

Around the world, the capacity for **geothermal direct use**^{iv} – direct extraction of geothermal energy for thermal applications – increased by an estimated 2.2 GW in 2019, or nearly 8%, to an estimated 30 GW_{th}.⁶³ Geothermal energy use for thermal applications grew an estimated 10 TWh during the year to an estimated 117 TWh (421 PJ)^v.⁶⁴

The largest category of direct use was bathing and swimming, comprising around 44% of total use in 2019 and growing about 9% annually. Second was space heating (around 39% of direct use), the fastest growing category with around 13% annual growth. The remaining 17% of direct use was allocated to greenhouse heating (8.5%), industrial applications (3.9%), aquaculture (3.2%), agricultural drying (0.8%), snow melting (0.6%) and other uses (0.5%).⁶⁵

The top countries for geothermal direct use (in descending order) in 2019 were China, Turkey, Iceland and Japan, which together represented roughly 75% of the global total.⁶⁶ China is both the largest user of geothermal heat (47% of the total) and the fastest growing market, having grown more than 20% annually on average over the last five years.⁶⁷ That period of growth coincides with the government's first geothermal industry plan, issued in 2017, for rapid expansion of geothermal energy use, especially for heat applications.⁶⁸

Turkey, Iceland and Japan have experienced more moderate growth of around 3-5% annually.⁶⁹ Other countries that rely on geothermal heat, each representing less than 3% of direct use, include (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil.⁷⁰

The United States

remains the global leader for installed geothermal power capacity, despite little recent growth.

i In a binary-cycle plant, the geothermal fluid heats and vaporises a separate working fluid (with a lower boiling point than water) that drives a turbine to generate electricity. Each fluid cycle is closed, and the geothermal fluid is re-injected into the heat reservoir. The binary cycle allows an effective and efficient extraction of heat for power generation from relatively low-temperature geothermal fluids. Organic Rankine Cycle (ORC) binary geothermal plants use an organic working fluid, and the Kalina Cycle uses a non-organic working fluid. In conventional geothermal power plants, geothermal steam is used directly to drive the turbine.

ii Since the unit was completed and started operation in 2018, its capacity was recorded for 2018 in GSR 2019.

iii Enthalpy refers to the energy potential of the geothermal resource, which is determined by three characteristics: heat, fluid (water) and flow (the last made possible by relative permeability of the sub-surface rock). Harnessing geothermal energy for electricity generation depends on the presence of both heat and water in sufficient quantities. A low-to-medium-enthalpy resource is characterised by temperatures below approximately 200 °C. See, for example, US Department of Energy, "Geothermal: electricity generation", <https://www.energy.gov/eere/geothermal/electricity-generation>.

iv Direct use refers here to deep geothermal resources, irrespective of scale, that use geothermal fluid directly (i.e., direct use) or by direct transfer via heat exchangers. It does not include the use of shallow geothermal resources, specifically ground-source heat pumps. See Heat Pumps section in Systems Integration chapter.

v The estimates of annual growth in capacity and output, and totals for 2019, are based on a survey report published in early 2020 that updated previous survey results for 2014, with no updates available for the intervening years. The annual growth estimate for 2019 is based on the annualised growth rate in the five-year period since 2014. See endnote 64 for this section.

Turkey has devoted more of its geothermal development effort to electricity generation than to direct use, with direct use investment contracting somewhat over the last decade while investment in geothermal power expanded significantly.⁷¹ Iceland has drilled around five high-temperature wells annually in recent years and expects to continue limited drilling of reinjection and make-up wells for existing power plants as well as existing district heating systems.⁷² Relatively little is known about the trajectory of geothermal direct use in Japan due to a lack of recent surveys. More than 80% of direct use in Japan is believed to be associated with bathing facilities located near geothermal springs.⁷³

Expansion of direct use also occurs in areas without access to the high-enthalpy resources enjoyed by top markets, but often at a higher cost and with somewhat greater effort. Several examples are found in continental Europe where low-to-medium enthalpy resources are used mainly for district heating and greenhouse cultivation. This market remained active in 2019 with new development in France, Germany, Hungary and the Netherlands. Based on currently available geological data, more than 25% of the population of the EU lies in areas that are suitable for geothermal district heating.⁷⁴

In the German city of Munich, drilling continued in preparation for what will be the country's largest geothermal plant, exceeding 50 MW_{th}, joining a fleet of five other geothermal heat plants when completed.⁷⁵ The facility is expected to provide heat for more than 80,000 city residents.⁷⁶ With all six boreholes drilled by early 2020, the project was showing higher than expected thermal output.⁷⁷ The local utility, which hopes to make district heating in Munich fully carbon neutral by 2040, announced a co-operative agreement with neighbouring municipalities in 2019 to further expand geothermal use in interconnected district heating systems.⁷⁸

Two regions in France have seen notable expansion of local geothermal resources, mostly for district heating. In the Paris

region, district heating systems have gradually increased their geothermal heating capacity in recent years, with more progress made in 2019 and new future plans announced. In December, the community of Champs-sur-Marne (eastern suburbs of Paris) launched a EUR 40 million (USD 44.8 million) district heating project that will supply heat to the equivalent of 10,000 homes; the renewable energy component of the supply is expected to be 82%.⁷⁹ With drilling under way, the local community was invited to invest in the project to allow residents to take a direct financial stake in its benefits.⁸⁰ (→ See *Feature chapter*.) For the nearby communities of Drancy and Bobigny, drilling of four boreholes commenced in 2019, with project completion expected by 2021.⁸¹

After demonstrating notable success in 2018, producing one of the hottest geothermal wells in continental Europe, geothermal prospects in the Alsace region of France dimmed over the course of 2019.⁸² Early in the year, the French government indicated a likely curtailment to its support (still in question as of early 2020), which is critical for deep geothermal projects in the country.⁸³ Later in 2019, scientists suspected that two strong earthquakes in the Strasbourg area were linked to local drilling and associated well stimulation activity (→ see *Industry section in this chapter*), although the correlation was refuted by a project developer.⁸⁴

In the Netherlands, geothermal heat is used only in greenhouse horticulture, but interest in use for heating homes and industry is growing.⁸⁵ In 2019, 21 deep geothermal projects were completed, representing 3.6 PJ of heat annually, with another 10 projects under development.⁸⁶ Further expansion is said to hinge on the expansion of heat networks, but also on political, financial and social barriers to use beyond horticulture.⁸⁷

In Hungary, work continued on the expansion of geothermal district heating in the city of Szeged, where staged introduction of new capacity is designed to displace fossil fuel use for heat.⁸⁸ As of 2019, direct use of geothermal energy contributed to heating 23 towns in Hungary, in some instances supplementing heat from natural gas on existing district heat networks.⁸⁹



The top countries for geothermal direct use were China, Turkey, Iceland and Japan, together representing roughly **75%** of the global total.

GEOHERMAL INDUSTRY

The global geothermal industry had mixed results in 2019, as in many previous years. Construction activity during the year and cautious optimism for future growth, predicated on government support, remained intact in some key markets. Elsewhere, the industry was inhibited by the weight of the industry-specific challenges of high project costs and front-loaded project risks and by the corresponding lack of adequate funding and risk mitigation. Continued research into new technologies and innovative processes and techniques, often supported by government programmes, helped fuel optimism for a path forward.

The use of geothermal energy remains concentrated in the relatively few geographic locations around the world that exhibit medium-to-high enthalpy resources – the combination of heat, permeability and flow that is required to make extraction economical for heat and electricity generation. In an effort to expand the use of geothermal energy beyond these areas – or to make it more economical in marginal locations – considerable research has gone into developing enhanced geothermal systems (EGS), which continued in 2019. EGS encompasses the use of hydraulic fracturing of hot rock to create the conditions for a geothermal reservoir. Unfortunately, this process is prone to induce seismic activity (earthquakes) – notorious for causing setbacks for EGS programmes in Basel (2006) and St. Gallen (2013) in Switzerland – and is alleged to have been the cause of the 2019 earthquakes in Alsace, France.⁹⁰

In 2019, Swiss researchers found that, depending on the stresses present in the geothermal reservoir, a gradual “training” of the reservoir through cold fluid injection over many months can reduce stress and make earthquakes less likely.⁹¹ Another study on the relationships between seismic activity and the application of hydraulic energy indicated a somewhat predictive but varied relationship, suggesting that monitoring of the injection process and its effects may allow timely modulation of the injection strategy to manage seismic impacts.⁹²

The importance of EGS technology to expand the opportunities for the geothermal industry – along with the need to lower project risk, capital cost and cost of capital – was underscored by an extensive US government study published in 2019.⁹³ The study revealed that geothermal power capacity in the United States might grow to a range of 6-13 GW with current methods and technology, whereas significant further expansion would require extensive use of deep-EGS resources and would entail drilling on a scale rivalling the country's oil and gas industry.⁹⁴

In 2019, the US Department of Energy announced that USD 25 million would be allocated to advancing EGS technologies and techniques.⁹⁵ A further USD 5.5 million was awarded to research on applying machine learning to geothermal exploration.⁹⁶

Notable innovations in geothermal energy during the year included completion of a demonstration facility by the Canadian company Eavor.⁹⁷ The technology takes advantage of directional drilling techniques developed in the oil and gas industry to create a closed-loop system that circulates a working fluid to siphon heat from hot sub-surface rock (several kilometres deep) without bringing any geothermal fluid (brine) to the surface. In addition to eliminating surface emissions of CO₂ and hydrogen sulphide, the continuous closed loop of the working fluid reportedly creates a thermosiphon effect (bringing hot fluid up on one side as cold fluid descends on the other) that mitigates the energy demand from pumping that is associated with other geothermal techniques.⁹⁸

Major technology providers in the geothermal industry in 2019 included power unit (turbine) manufacturers Atlas Copco (Sweden), Exergy (Italy), Fuji Electric (Japan), Mitsubishi and its subsidiary Turboden (Japan/Italy), Ormat (United States) and Toshiba (Japan).⁹⁹ In some key markets, such as Turkey, the suppliers of binary-cycle technology are prominent (for example, Atlas Copco, Exergy and Ormat), while other suppliers specialise in more conventional flash turbines (for example, Toshiba and Fuji).¹⁰⁰



KEY FACTS

- The global hydropower market contracted in 2019, continuing a multi-year trend of deceleration.
- Hydropower generation increased, reflecting new capacity as well as shifting weather patterns and other operational conditions.
- Brazil took the lead in new hydropower capacity, marking the first year since 2004 that China did not maintain a wide lead over other countries for new installations.
- The hydropower industry is grappling with a web of challenges, ranging from technical and economic aspects of the industry to hydropower's relationship with other renewable energy sources.

HYDROPOWER



HYDROPOWER MARKETS

The global hydropower market, as measured in annual capacity installations, contracted in 2018, continuing a multi-year trend of deceleration. New capacity was an estimated 15.6 GW, raising total global installed capacity to around 1,150 GW.¹ The ranking of the top 10 countries for total capacity shifts only over long time frames and remained (in order) China, Brazil, Canada, the United States, the Russian Federation, India, Norway, Turkey, Japan and France, which together represented more than two-thirds of global capacity at year's end.² (→ See Figure 26 and **Reference Table R15.**)

Hydropower generation around the world varies from year to year, affected not only by changes in installed capacity but even more by shifts in weather patterns and other local operating conditionsⁱⁱ. In 2019, global generation was an estimated 4,306 TWh, an increase of 2.3% from 2018, or around 15.9% of the world's total electricity generation.³

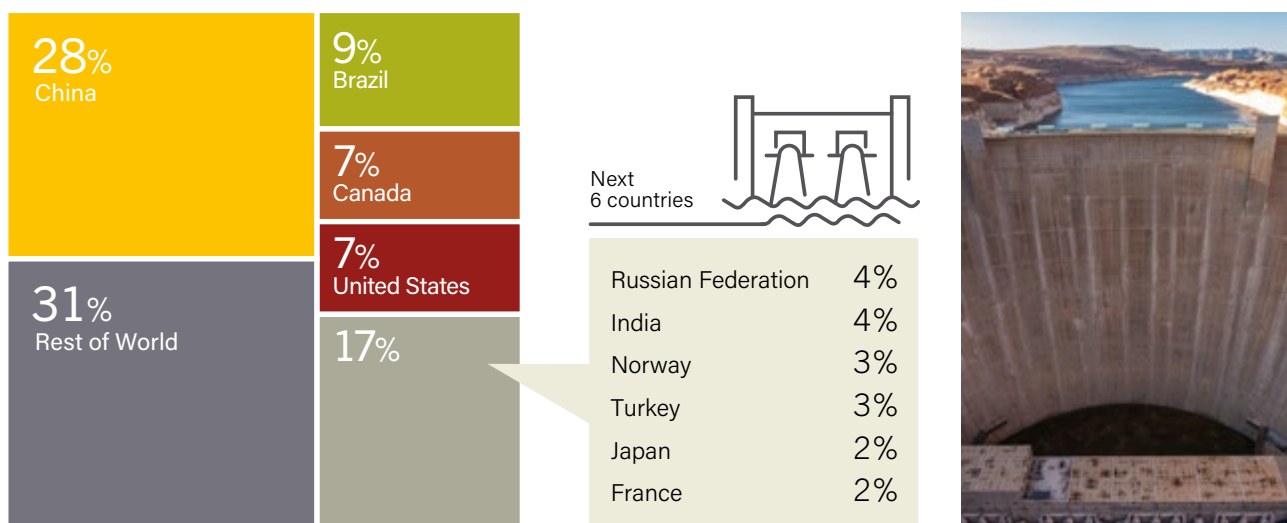
Brazil took the lead in commissioning new hydropower capacity in 2019, followed by four countries in Asia: China, Lao PDR, Bhutan and Tajikistan.⁴ (→ See Figure 27) This marked the first year since at least 2004ⁱⁱⁱ in which China did not maintain a wide-margin lead over all other countries for new hydropower completions.⁵ Global pumped storage capacity (which is counted separately from hydropower capacity) increased about 0.2% (0.3 GW) during the year, with almost all of this in a single installation in China.⁶

i Where possible, all capacity numbers exclude pure pumped storage capacity unless otherwise specified. Pure pumped storage plants are not energy sources but means of energy storage. As such, they involve conversion losses and are powered by renewable and/or non-renewable electricity. Pumped storage plays an important role in balancing grid power and in the integration of variable renewable energy resources.

ii In addition to hydrological conditions, hydropower output also may vary with other local priorities, such as the use of storage capacity (reservoirs) to balance variable renewable electricity generation and to manage water supply, as well as with market conditions, such as the price of competing sources of energy.

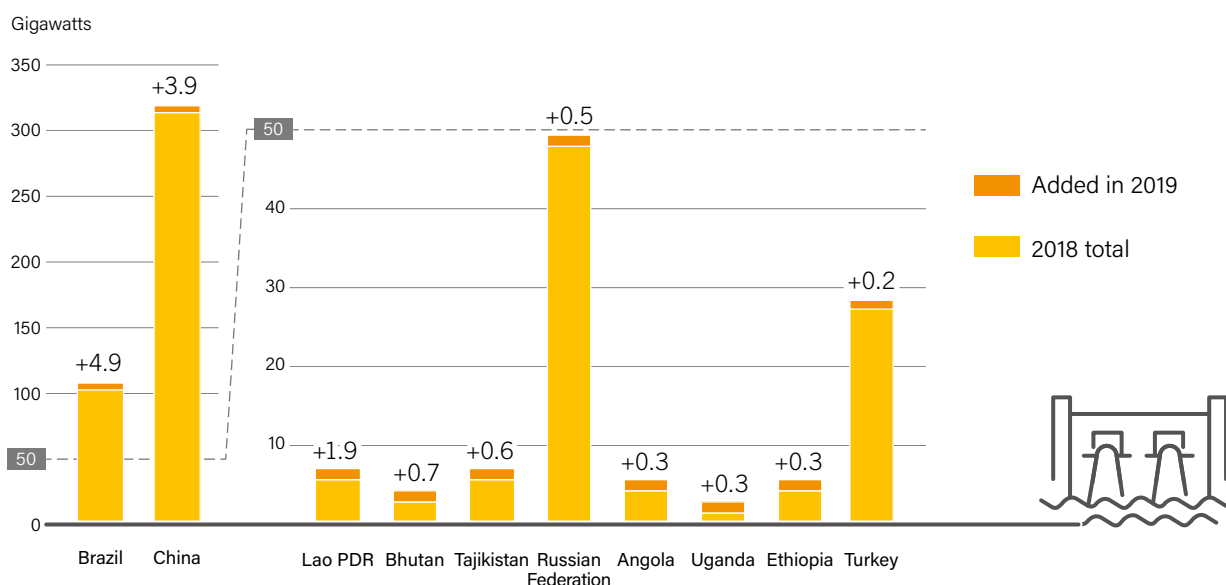
iii Based on data from previous editions of the GSR, first published in 2005 with data for 2004.

FIGURE 26. Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2019



Note: Totals may not add up due to rounding.

Source: Global total from IHA. See endnote 2 for this section.

FIGURE 27. Hydropower Capacity and Additions, Top 10 Countries for Capacity Added, 2019


Source: See endnote 4 for this section.

Brazil's project completions totalled 4.95 GW – nearly one-third of global additions and the largest annual increment since 2016 – for a year-end installed capacity of 109 GW.⁷ The lion's share of the additions was the final six 611 MW turbines added to the Belo Monte plant, completing this 11.2 GW facility.⁸ By year's end, Belo Monte was the fourth largest hydropower plant in the world and represented 7% of Brazil's generation capacity.⁹ At 418 TWh, Brazil's hydropower output was essentially unchanged from 2018, providing 70.5% of electricity supply in the country.¹⁰

Despite Brazil's apparently robust market in 2019, the country's incremental hydropower development is increasingly constrained by available resources. Only around 12 GW (23%) of the remaining greenfield capacity potential (of unit size larger than 30 MW) lies in areas that are not restricted for ecological or social reasons.¹¹ That remaining potential is further constrained by socio-political limitations as well as the environmental costs associated with development, which are estimated to be about an order of magnitude larger than what is typical for wind power and solar PV in Brazil.¹² While hydropower's still-dominant contribution to Brazil's electricity mix is in gradual decline, the combined contribution of wind energy and solar PV is growing rapidly, rising from 8.8% in 2018 to 10.3% in 2019.¹³

A number of projects were completed across other parts of Latin America. For example, Chile completed three small facilities in 2019, adding 38 MW, for a year-end total of 6.7 GW.¹⁴ Another nine projects totalling 0.8 GW were expected to reach completion by the end of 2020, including the 531 MW Alto Maipo complex.¹⁵ Chile's generation from hydropower contracted more than 11% in 2019, providing around 27% of the electricity supply.¹⁶

Peru added 132 MW of hydropower to its grid, mostly in the form of recommissioned capacity such as the 82 MW Callahuanca plant.¹⁷ The Callahuanca plant dates back to 1938, but the structure

was damaged by landslides in 2017 and became inoperable.¹⁸ In 2019, Peru generated 30.2 TWh from hydropower, or around 57% of its total electricity supply.¹⁹

In Bolivia, the second unit (69 MW) at the San Jose complex was completed, following the commissioning of the plant's first (55 MW) unit in 2018.²⁰ The country is experiencing a relative oversupply of capacity (3 GW against a peak demand of 1.8 GW in 2019), which the current government blames on a lack of system planning in years past.²¹ Nonetheless, portions of the country do not have adequate electricity supply due to lack of transmission capability.²² At the end of 2019, Bolivia had 735 MW of hydropower capacity, providing 34% of its electricity supply.²³

More hydropower capacity was added across Asia than in any other region during 2019, with several countries bringing plants online. China led the region for newly installed capacity, but for the first time in many years the country did not lead the world by a wide margin; instead, it trailed Brazil to rank second globally. China added 3.87 GW (excluding pumped storage) in 2019, about half the additions of 2018, for a year-end total of 326.1 GW.²⁴ China's total completed hydropower projects during the year represented investment of CNY 81.4 billion (USD 11.6 billion), an increase of 16.3% over 2018.²⁵

While China's hydropower capacity grew 1.2%, generation increased 5.7% to 1,302 TWh in 2019.²⁶ Even so, hydropower is having trouble keeping up with rising demand. Annual capacity additions have declined somewhat in recent years, both in absolute terms and as a share of overall electricity demand. During the five-year period 2014-2019, China's hydropower capacity grew 15%, and due to higher capacity utilisation hydropower generation grew nearly 23%.²⁷ Meanwhile, overall electricity demand rose over 30%.²⁸



As with Brazil, China foresees growing challenges to incremental hydropower development. At the end of 2019, an additional 52 GW was under development, with estimated further potential of 110-120 GW.²⁹ However, the bulk of that potential lies in Tibet in the far south-west (as well as in Sichuan and Yunnan), far from major load centres in the country's east.³⁰ A shortage of transmission capacity, increasingly complex environmental limitations and rising relative costs (both absolute and relative to other renewables) all converge as major challenges to further hydropower development in China.³¹

To the south, landlocked Lao PDR is harnessing its hydropower resources for both local demand and export to neighbours. In 2019, the country ranked third globally for newly installed capacity. Several large projects were completed, representing 1.9 GW of generating capacity, bringing the country's year-end total to 7.2 GW.³² The largest of the new plants is the 1.3 GW Xayaburi facility.³³ Other Lao PDR projects completed in 2019 included the 260 MW Don Sahong and the 290 MW Nam Ngiep 1 hydropower plants, both of which are intended to generate electricity for export.³⁴ Nam Ngiep's main dam site of 272 MW will produce electricity for export to Thailand, while a secondary 18 MW power station will generate electricity for local use.³⁵

In Lao PDR and other countries downstream along the Mekong River, the extremely low water flows – with parts of the river drying to a trickle even during the wettest season – have raised questions about the impacts of hydropower projects on the water economy of the Mekong delta.³⁶ In the case of the Xayaburi plant, operators have maintained that because the facility's run-of-the-river barrage design does not rely on a large reservoir, it permits natural river flows and therefore does not contribute to the conditions downstream.³⁷ In early 2020, the Mekong River Commission launched a multi-national pilot project to monitor transboundary environmental impacts from the Xayaburi and Don Sahong projects – including effects on hydrology, sedimentation, water quality, aquatic ecology and fisheries – to inform potential measures to mitigate impacts from existing and future hydropower projects on the river.³⁸

Hydropower output in neighbouring Vietnam also was constrained by dry conditions during the year. With reservoir flows declining 20-50%, generation fell more than 18% from January through October relative to the same period in 2018.³⁹ With no immediate

relief in sight and rapidly growing electricity demand, the country's priority is to balance the need for electricity generation against other demands on the limited supply of water.⁴⁰ As part of this effort, Vietnam signed an agreement for the output of another Lao PDR hydropower plant that is scheduled to be completed by 2022.⁴¹ Vietnam also added 80 MW of its own hydropower capacity in 2019, for a total of 16.8 GW.⁴²

In the Kingdom of Bhutan, another landlocked country, an additional 720 MW of hydropower came online in 2019, bringing the country to rank fourth for new installations.⁴³ The four 180 MW units of the Mangdechhu project commissioned during the year increased the total capacity 45%, to 2.3 GW.⁴⁴ In addition, further renovation work was completed at the 336 MW Chhukha plant in southwestern Bhutan.⁴⁵

Tajikistan followed for annual additions with completion of the second of six 600 MW turbines planned at the Rogun facility, bringing total hydropower capacity to 6.4 GW.⁴⁶ The country hopes the plant will generate substantial revenues from electricity exports to neighbouring countries while also helping to alleviate local power shortages.⁴⁷ However, the costly project is believed to place significant strain on state resources during construction.⁴⁸ If the dam rises to the planned 335 metres, it will be one of the world's tallest, breaking the record of the neighbouring 300-metre Nurek dam, also in Tajikistan and along the Vakhsh River.⁴⁹

To the west, Turkey added 0.2 GW of capacity in 2019, for a year-end total of 28.5 GW, which is a little less than one-third of the country's overall generating capacity.⁵⁰ Due to improved hydrological conditions, hydropower generation increased by nearly half to 88.8 TWh – a new record – providing around 30% of the country's total electricity supply.⁵¹ Filling of the 1.2 GW Ilisu dam on the Tigris River resumed in mid-2019 despite unresolved concerns about potential water shortages in downstream Iran and Iraq and the imminent submersion of Turkey's ancient city of Hasankeyf.⁵²

India saw only modest expansion of its hydropower assets in 2019 (15.8 MW), with all added capacity from units less than 25 MW in size, raising the total to 45.3 GW.⁵³ India's electricity generation from hydropower surged 15.9% during 2019 to nearly 162 TWh.⁵⁴

In March 2019, India finalised a decision to re-designate all hydropower assets larger than 25 MW as being renewable energy capacity, a change in accounting rules that advances India towards its commitment under the Paris climate agreement to meet 40% of its electricity from renewable sources by 2030.⁵⁵ The change also may improve prospects for new large projects that now could qualify for certain renewable energy incentives and preferential financing terms (green bonds).⁵⁶ In July, after years of delays and being rejected by a government advisory committee on the grounds of excessive ecological and social costs, the proposed 2.88 GW Dibang hydropower project in Arunachal Pradesh received renewed government support.⁵⁷

Japan (which added no new capacity in 2019), Europe and North America together represent a significant portion of existing global hydropower capacity, but these are relatively mature markets that have shown limited capacity growth in recent years, especially compared to other Asian and Latin American markets. Across Europe, a number of small plants came online in several countries, with the Russian Federation accounting for the region's largest increase in capacity.⁵⁸

The Russian Federation added 0.5 GW of hydropower capacity in 2019, through new construction and rehabilitation of existing facilities, for a total of 48.5 GW.⁵⁹ Among notable projects completed were the 320 MW Nizhe-Bureyskaya plant in the eastern Amur region and a 143 MW unit at the Ust-Srednekanskaya facility, which will provide much-needed electricity to the Magadan region of the Russian Far East, where demand grew 13% in 2018.⁶⁰ The latter project has suffered long delays since its conception decades ago.⁶¹ Total hydropower generation in the Russian Federation in 2019 was over 190 TWh, representing 17.6% of all supply.⁶²

The United States continued to rank fourth in hydropower capacity in 2019, even as net installed capacity contracted by 126 MW to 79.7 GW.⁶³ Two small hydropower units were added in 2019 (totalling less than 10 MW), while several units were retired.⁶⁴ At year's end, the country had a little over 100 MW of capacity under construction, all in small units of 18 MW or less.⁶⁵ US hydropower generation contracted (down 6.4%) for the second year running, to 274 TWh.⁶⁶

Across the African continent, several countries completed projects for a total of 0.9 GW added in 2019.⁶⁷ Most of this came online in Angola, Ethiopia and Uganda. Angola's plans for rapid expansion of hydropower capacity advanced during the year with the completion of the fifth 338 MW turbine at the Laúca station, bringing the country's total to 3.4 GW.⁶⁸ The 2.07 GW facility was expected to be completed and in commercial operation in 2020.⁶⁹

In Ethiopia, the 254 MW Genale Dawa 3 hydropower plant was completed after 10 years of construction, having been delayed by problems arising from resettlement of residents living near the dam.⁷⁰ Majority financed and built by Chinese firms, the project completion coincided with the Ethiopian government affirming its commitment to energy sector partnerships with Chinese entities, including a major transmission interconnection with Kenya that is under way, funded by the African Development Bank (AfDB) and the World Bank.⁷¹



Uganda's total power capacity increased more than 18% (and hydropower rose 33%) with the commissioning of the 183 MW Isimba hydropower station on the Victoria Nile (Upper White Nile).⁷² The government-sponsored project, which received 85% of its funding from the Export-Import Bank of China, aims to increase electrification, spur industrial activity, accelerate economic growth and allow for the export of electricity to neighbouring countries.⁷³ Meanwhile, completion of the 600 MW Karuma project downstream was delayed again on account of transmission constraints and other problems, including alleged cost overruns by the developer, Sinohydro.⁷⁴ In total, Uganda added 260 MW in 2019, bringing total capacity to just over 1 GW.⁷⁵

Several small hydropower projects also contributed to Africa's hydropower capacity. These include the 8.2 MW Ruo-Ndiza plant in Malawi, the 0.64 MW Kasanjiku plant in Zambia (the first mini-hydropower station of the local rural electrification authority) and the 0.45 MW Rubagabaga plant in Rwanda.⁷⁶ The Rwandan facility aimed not only to power the local mini-grid, but to improve local livelihoods more broadly.⁷⁷

Ghana also plans to utilise small hydropower plants to reinforce electricity supply. In 2019, the country completed the first 45 kW phase of its Tsatsadu micro-hydro project.⁷⁸ This run-of-river facility requires no impoundmentⁱ but diverts a portion of the river through a penstockⁱⁱⁱ for electricity generation.⁷⁹ In Uganda, development funds were secured for a 14 MW run-of-river facility on the Kagera River, and in Burundi the AfDB issued a grant in support of a 9 MW solar-hydro hybrid project.⁸⁰ Burundi's planned hybrid system is expected to modulate energy supply between dry and wet seasons and to mitigate power shortfalls caused by climate change.⁸¹

Pumped storage capacity did not increase much in 2019, with a single 300 MW facility completed in China and a 3 MW facility built in Greece.⁸² Total installed capacity at year's end was 158 GW^{iv}.⁸³ However, significant new capacity was being planned, in part to support growth in variable renewable electricity (VRE) from solar PV and wind power. Projects under development in 2019 aimed directly at facilitating the integration of VRE included facilities in Australia, the United Arab Emirates, the United States and Zimbabwe.⁸⁴

Australian projects that advanced in 2019 included the 2 GW Snowy 2.0 project in New South Wales and the 250 MW Kidston project in Queensland. The Snowy 2.0 project, which will be among the largest pumped storage facilities in the world, will provide 350 GWh (175 hours at full capacity) of electricity storage, or enough to supply 500,000 homes during peak demand.⁸⁵ The Kidston project will be co-located with a solar PV facility (up to 320 MW) and will use two abandoned mining pits for upper and lower reservoirs.⁸⁶

i This excludes 22.9 GW of US pumped storage capacity.

ii A reservoir created by a dam.

iii A pipe or open channel that carries the diverted water to the turbine(s) at the power house.

iv This total may include some "mixed" plants that incorporate pumping capability alongside net incremental generation from natural inflows (open loop) and, as such, are counted as hydropower capacity. This does also reflect a downwards revision of existing stock of about 2 GW relative to values reported for 2018.

HYDROPOWER INDUSTRY

The hydropower industry continued to face a wide, interconnected web of challenges and opportunities that are evolving in a world of changing energy systems and priorities. Some are specific to the technical workings and economic considerations of the industry itself, while others pertain to hydropower's relationship with other renewable energy sources, as well as environmental, social, climate and other sustainability imperatives.⁸⁷

Several inter-related themes of recent years continued to engage the industry in 2019, including the need for modernisation of ageing plants, market design that reflects the system benefits of hydropower and pumped storage, climate impact and resilience of hydropower facilities, and water resource management.

Refurbishment and **modernisation (including digitalisation) of ageing hydropower facilities** (mainly in Europe and North America) improves the efficiency of resource utilisation, plant operations and maintenance, and resource planning and management.⁸⁸ In turn, such efforts help the hydropower infrastructure to support wider energy systems and, specifically, the integration of rising shares of VRE.⁸⁹

In the Russian Federation, modernisation of the hydropower fleet continues to be a priority. In addition to building new facilities, RusHydro (the country's largest hydropower operator and the fourth largest in the world) has emphasised rehabilitation and upgrades of its older plants.⁹⁰ Since the start of its modernisation and rehabilitation programme in 2011, RusHydro has added over 400 MW of capacity at existing facilities.⁹¹ In addition to capacity improvement, such efforts aim to increase operational efficiency, reliability and safety, in part through plant digitalisation.⁹²

The industry also is focused on encouraging electricity market design that reflects the **value of hydropower and pumped storage for system flexibility** to ensure that investment continues.⁹³ In some markets, particularly those without compensation for capacity reserves or ancillary services, the narrowing spread between peak and off-peak energy prices (due in part to growth in zero marginal cost VRE) is undermining the profitability of both hydropower and pumped storage assets.⁹⁴ Pumped storage plants in particular can break evenⁱ only if the energy produced carries a sufficient premium relative to energy consumed.⁹⁵ Long-term stability of policies and market structures is particularly important for the hydropower industry due to long project timelines and high upfront capital costs of projects.⁹⁶

Climate change also is posing increased risk to the industry, which is working to reduce both the **impacts of a changing climate** on hydropower output and the potential impacts of hydropower development on the global climate. Increasingly, the industry is incorporating climate variability and its impacts on hydrological conditions into project planning, design and operational plans.⁹⁷ Incorporating other renewable energy technologies – such as solar PV and wind power – with hydropower projects is one option that the industry is adopting to reduce risk and support system resilience.⁹⁸ At the same time, the industry is working to consider and manage the greenhouse gas impacts of hydropower projects, which are location dependent.⁹⁹

In 2019, industry leaders published guidelines to provide a practical approach to identify, assess and manage climate risks to hydropower projects and to provide international industry good practice on how to incorporate climate resilience into hydropower project planning, design and operation.¹⁰⁰

Another global focus of the industry is on sustainability in a broader sense, which requires an **integrated approach to resource management** that balances several priorities, including electricity generation, maintaining water quality, supply of water for non-energy needs such as irrigation, flood control, sediment management and other impacts on communities and natural resources, all while maximising project benefits equitably.¹⁰¹ As part of this effort, industry documents released in 2019 aimed to guide hydropower developers and operators to improve outcomes for their projects and other stakeholders on two additional topics: the sharing of socio-economic benefits of hydropower projects, and the management of potential impacts arising from associated erosion and sedimentation upstream and downstream of a hydropower project site.¹⁰²

Major hydropower technology providers in the world included Andritz Hydro (Austria), Bharat Heavy Electricals (India), Dongfang Electric (China), GE (United States), Harbin Electric (China), Hitachi Mitsubishi Hydro (Japan), Impsa (Argentina), Power Machines (Russian Federation), Toshiba (Japan) and Voith (Germany).

Operating results and outlook for some industry leadersⁱⁱ remained mixed in 2019. GE reported losses in its hydropower segment, due in part to continued competitive pressure from other turbine manufacturers and other renewable energy technologies, and further reinforced by the global trend towards electricity auction mechanisms.¹⁰³ The company's hydropower operations continued to experience declines in the growth of orders and increased project costs.¹⁰⁴ Andritz Hydro also reported a "subdued" global market and a decline in sales for the fourth year running (down 3% for the year), in line with a perennial decline in order intakes.¹⁰⁵

Voith Hydro reported a moderate recovery in the hydropower market during 2019. Modernisation projects and service on existing facilities dominated business in the Americas and Europe, while predominantly new construction was being planned and tendered in Asia and Africa.¹⁰⁶ Voith advanced the development of a high-performance pump turbine during the year, which led to securing a contract for six reversible turbines for the 2 GW Snowy 2.0 project in Australia.¹⁰⁷

In 2019, the European Commission and 19 partners in industry, academia and research launched an EUR 18 million (USD 20.2 million) initiative to demonstrate how modern hydropower systems can provide the flexibility and power grid services required to integrate larger shares of variable solar and wind power into the electricity supply.¹⁰⁸ The project will test enhanced variable- and fixed-speed hydropower turbine systems and other related solutions, concluding in 2023 with a roadmap and recommendations for governments, regulators and industry.¹⁰⁹

i A roughly 80% cycle efficiency means that energy sold needs to carry a 25% premium over energy consumed (1/0.8 = 1.25).

ii Provider-specific information noted based on availability of reports on operations.

KEY FACTS

- Ocean power generation rose substantially in 2019, surpassing 45 GWh.
- The industry began moving from small-scale demonstration and pilot projects towards semi-permanent installations and arrays of devices.
- Maintaining revenue support to ocean power technologies is considered paramount for allowing the industry to achieve greater maturity.

OCEAN POWER



OCEAN POWER MARKETS

Ocean powerⁱ represents the smallest share of the renewable energy market. Although the resource potential of ocean energy is enormous, the technologies are still in the early stages of development.¹ (→ See *Sidebar 4*.) Net additionsⁱⁱ in 2019 were around 3 MW, bringing the total operating installed capacity to an estimated 535 MW at year's end.²

Two tidal barrages using mature turbine technologiesⁱⁱⁱ – the 240 MW La Rance station in France (installed in 1966) and the 254 MW Sihwa plant in the Republic of Korea (2011) – represent more than 90% of total installed capacity.³

Tidal stream and wave power are the main focus of development efforts. Advancements in these technologies have been concentrated largely in Europe, especially the United Kingdom. However, generous revenue support and ambitious R&D programmes in Canada, the United States and China have spurred increased development and deployment.⁴

Tidal stream devices are approaching maturity, with design converging on horizontal-axis turbines mounted on the sea floor or attached to a floating platform.⁵ These devices have demonstrated considerable reliability in performance, and electricity generation rose substantially in 2019, owing to an increase in operating hours.⁶ Total generation surpassed 45 GWh, with tidal stream devices in European waters alone generating 15 GWh in 2019 (up 50% from 2018).⁷

Wave power devices have not yet seen convergence on design, owing to the complexity of extracting wave energy from a variety of wave conditions and the wide range of possible operating principles.⁸ Developers generally have chosen one of two distinct pathways for wave energy development: devices above 100 kW target utility-scale electricity markets, whereas smaller devices, usually below 50 kW, are intended primarily for specialist applications (oil and gas, aquaculture, maritime monitoring and defence).⁹

Although the potential of ocean power is enormous, the technologies are still in the early stages of development.



i Ocean power technologies harness the energy potential of ocean waves, tides, currents and temperature and salinity gradients. In this report, ocean power does not include offshore wind, marine biomass or floating solar.

ii A proportion of current installed capacity is removed or redeployed each year as demonstration projects reach their term or advance to a subsequent phase of testing. In Europe, for example, 10.3 MW of wave energy capacity had been decommissioned as of end-2019, following the successful completion of testing programmes.

iii The same in-stream technologies used in some types of hydropower plants.

SIDEBAR 4. The History of Ocean Power

Modern ocean power devices are the product of highly advanced industrial and technological systems, yet their earliest antecedents date back over 200 years. The first patent for an ocean energy device was filed in Paris by French mathematician Pierre-Simon Girard in 1799; the first operational plant was built in 1910 and was used to light and power a home. From 1855 to 1973, the United Kingdom alone granted over 300 patents for wave energy devices. Attempts to develop ocean thermal energy conversion (OTEC) started in the 1880s, and the first plant was built in Cuba in 1930, generating 22 kW of electricity before being destroyed in a storm.

The first large-scale ocean power facility, the La Rance tidal barrage in France, was built in the 1960s using proven hydropower turbine technologies. However, other methods for generating electricity from the ocean did not attract significant interest until the oil crisis of the 1970s. The US government invested USD 260 million in research and committed to producing 10 GW of electricity from OTEC systems by 1999, but ultimately no plants were commissionedⁱ. The UK Department of Energy commissioned studies and ran a wave energy programme aimed at upscaling prospective devices, and the University of Edinburgh developed a device prototype and installed the first wave tank. As the oil crisis eased, interest waned and ocean power was largely abandoned, receiving very little funding in the 1980s and 1990s.

From the early 2000s onwards, ocean power experienced a resurgence, spurred by concerns about climate change and by the adoption of ambitious renewable energy objectives and policies. International co-operation was strengthened in 2001 with the establishment of the Ocean Energy Systems technology collaboration programme under the auspices of the International Energy Agency. The European Marine Energy Centre (EMEC) was established in 2003, providing an essential proving ground for devices by allowing for grid-connected testing in harsh weather conditions. More than 20 developers have since tested devices at EMEC.

In 2016, MeyGen deployed the first turbine of a planned 86 MW tidal stream array in the Pentland Firth, Scotland, marking a key milestone on the path to commercialisation. Progress has also been made in developing novel applications for ocean power technologies. In 2017, for example, EMEC began harnessing the excess electricity generated at one of its tidal testing sites to produce hydrogen, which is then used in a variety of fuel, power and heat applications. In 2018, Naval Group deployed a 450 kW Microsoft data centre at an EMEC wave test site, using wave energy to power the device and seawater for cooling.

The trajectory of ocean power has been volatile. On the one hand, a number of countries have invested considerable public funds into R&D, and large companies and private investors have become increasingly involved in device and project development. The EU turned its attention to ocean power for its potential to increase energy security and lower greenhouse gas emissions, while also creating jobs amid an economic downturn. On the other hand, government funding has been inconsistent, while the industry, in a bid to entice investors, overpromised what it could deliver in the near term and underestimated the technical challenges and costs. A number of bankruptcies ensued, large investors and energy companies withdrew, and the momentum generated by past public support slowed as private sector investors lost confidence.

Overall, the outlook for ocean power is positive. Costs are declining, and capital expenditure is lower than expected at this stage of development. Ongoing technological progress and development activity are encouraging, with the industry moving beyond pilot projects towards semi-permanent installations and arrays of devices exporting electricity to the grid, and significant investments and deployments were planned for 2020 and beyond.

ⁱ A 50 kW plant was tested for three months in 1979. The Department of Energy was poised to award a contract for a 40 MW pilot plant in 1982, but this did not come to fruition because of a change in the administration.

Source: See endnote 1 for this section.



OCEAN POWER INDUSTRY

Following a turbulent 2018, during which one industry leader ceased operations amid discouraging forecasts and limited development opportunities, the ocean power industry regrouped in 2019 and continued its gradual advance towards commercialisation.¹⁰

Tidal stream benefited from significant new investments of public funds and policy measures to support development. Three full-scale devices based on novel design principles were deployed for testing, although overall capacity additions were limited as developers prepared for large deployments totalling 9 MW in 2020.¹¹

In Canada, the government of Nova Scotia offered a feed-in tariff of between CAD 385 and CAD 530 (USD 295 and USD 405) per MWh for demonstration projects, and as of the end of 2019 five developers were approved for a total of up to 22 MW.¹² During the year, two permits were awarded under Nova Scotia's demonstration permits programme: 2 MW to Jupiter Hydro and 1.5 MW to Nova Innovation.¹³ A total of 7 MW (of the 10 MW maximum) was permitted under the programme.¹⁴

DP Energy and Sustainable Marine Energy continued to advance the Uisce Tapa project under development at the Fundy Ocean Research Centre for Energy (FORCE) in Nova Scotia. The CAD 117 million (USD 85.8 million) project aims to install a 9 MW array of six Andritz Hammerfest turbines and is supported by a Canadian government grant of CAD 29.8 million (USD 21.9 million).¹⁵ Other provinces also are making progress on ocean power, particularly as a means to provide electricity to remote communities in Canada.

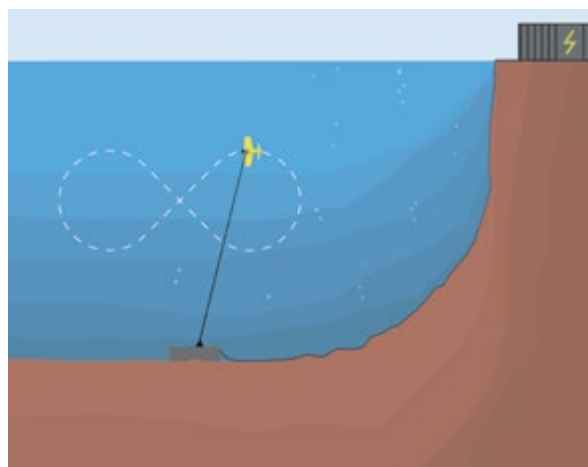
In the United Kingdom, a number of innovative cross-border collaborations and test deployments occurred in 2019, and some tidal devices demonstrated their reliability by generating electricity continuously throughout the year. In a large boost for the sector, Interreg France (Channel) Englandⁱ announced that it would contribute EUR 28 million (USD 31 million) to the Tidal Stream Industry Energiser (TIGER) project – 70% of the project's

EUR 47 million (USD 52 million) budget.¹⁶ Led by the UK's Offshore Renewable Energy Catapult, TIGER brings together 19 partners from the United Kingdom and France to install 8 MW of capacity in and around the English Channel region.¹⁷ The long-term objective is to cut generating costs from the current EUR 300 (USD 336) per MWh to around EUR 150 (USD 168) per MWh by 2025.¹⁸

Having entered its 25-year operational phase in 2018, Scotland's MeyGen tidal stream array (the world's largest at 6 MW) generated continuously in 2019, the longest period of uninterrupted generation to date from a commercial-scale tidal array.¹⁹ The developer, SIMEC Atlantis Energy Ltd (United Kingdom), holds a seabed lease that would allow it to build the project out to 398 MW.²⁰ In 2019, SIMEC announced development of the next phase of the project, which will add a further 80 MW of capacity.²¹ The company also was awarded a GBP 1.5 million (USD 1.8 million) government grant to develop a subsea connection hub for the next phase of the project.²²

Also in Scotland, Nova Innovation's three-turbine 0.3 MW array in the Bluemull Sound of the Shetland Islands continued to generate consistently, with the turbines accumulating more than 20,000 operational hours as of December 2019.²³ Orbital Marine Power (formerly Scotrenewables Tidal Power) began building an optimised model of its SR2000 twin-turbine floating tidal power device, the Orbital O2, which it planned to deploy at EMEC in 2020.²⁴ Orbital also raised GBP 7 million (USD 9 million) through a crowdfunding campaign.²⁵

Minesto (Sweden), which in 2018 successfully demonstrated the ability of its "energy kite"ⁱⁱ to harness relatively low-energy tidal streams and ocean currents, signed a power purchase agreement with the Faroe Islands utility for up to 2.2 MW of installed tidal capacity and obtained the required consents.²⁶ In May 2019, the Welsh government announced its continued support for Minesto's commercial development in Wales, awarding EUR 14.9 million (USD 16.7 million) of EU funding through the Welsh European Funding Office.²⁷ Minesto's long-term plan is to



ⁱ Interreg is a series of programmes to stimulate co-operation between regions in and out of the European Union, funded by the European Regional Development Fund. Interreg France (Channel) England was set up to foster economic development in the south of the United Kingdom and north of France by funding innovative projects that have a sustainable cross-border benefit. See Interreg, "About the programme", <https://www.channelmanche.com/en/programme/about-the-programme>.

ⁱⁱ Minesto's Deep Green device comprises a turbine integrated with a wing, which is tethered to the seabed and operates in a manner similar to an airborne kite.

deploy a commercial tidal energy array of up to 80 MW capacity at its Holyhead Deep site, eight kilometres off the coast of north-west Wales.²⁸ Minesto also was awarded a EUR 2.4 million (USD 2.7 million) grant as part of the TIGER project to install and operate a device at a grid-connected test site off the French coast.²⁹

France remains an attractive location for tidal stream development, owing to its competitive grid-connected test centres, active support from regional and local governments, and the potential for scaling up projects in the future.³⁰ Two turbines were deployed in 2019: a 1 MW vertical-axis turbine at Paimpol-Bréhat (HydroQuest Ocean), which has already surpassed six months of continuous operation, and a short-term test deployment of a 20 kW horizontal-axis turbine at Ria d'Étel (Guinard Energies).³¹

Wave power advanced steadily in 2019, with a range of test deployments hitting the water in Europe and China, the announcement of significant new public funding and a number of developers pursuing novel device designs. More than 4 MW of deployments were planned in 2020, mostly of full-scale, high-capacity devices in Europe.³²

In Europe, 0.6 MW was added through six individual units in 2019. Ocean Power Technologies (OPT) deployed a 3 kW device in the North Sea, where it supports an autonomous communications and remote monitoring platform used by Premier Oil.³³ The deployment began a nine-month lease that includes a purchase option. Another OPT device in the Adriatic Sea marked a full year of maintenance-free continuous operation in 2019.³⁴ In Portugal, AW-Energy deployed its 350 kW WaveRoller device, and commissioning work is under way to connect the device to the local electricity network.³⁵ Deployments also took place in Belgium, France and Italy.³⁶ In the United Kingdom, Wave Energy Scotland (WES) awarded GBP 9 million (USD 12 million) to 11 wave projects.³⁷



In the United States, a 1.25 MW wave energy device was transported to the state of Hawaii for testing.³⁸ The country continued to provide funding for ocean power, with a focus on wave power devices and associated technology. In 2019, the US Department of Energy's Water Power Technologies Office awarded USD 25 million in research projects with the aim of reducing capital costs and shortening project development times.³⁹ The three topic areas for funding were early-stage device

design, advancement of new power take-off (PTO) devices and control systems, and the consolidation of scientific knowledge and understanding of potential environmental impacts.

In China, the government supported its first megawatt-level test site (the Wanshan Wave Energy Demonstration Project) with an overall budget of RMB 151 million (USD 22 million), and a consortium began building two 500 kW test units.⁴⁰ The Guangzhou Institute of Energy Conversion completed the first open-sea test of a floating wave energy platform, which was successfully connected to the power grid of a remote island.

Carnegie Clean Energy (Australia) resumed construction of its CETO 6 device, having entered into voluntary administration in 2018 after a net loss of some AUD 45 million (USD 31 million) in 2018-19.⁴¹ Carnegie continued to operate its Garden Island Microgrid in Western Australia, delivering more than 1,000 MWh to the country's largest naval base.⁴² Wave Swell Energy also began construction of its 250 kW wave energy device.⁴³

Bombora (United Kingdom) was on schedule to deploy its mWave device in mid-2020 and was progressing through the consenting phase of a proposed 2 MW project in Lanzarote, Spain, which it aimed to commission in 2022.⁴⁴ The novel device sits below the water surface and harnesses the pressure of overhead waves, an approach that the company hopes will allow it to overcome the survivability challenges facing wave energy devices.

Other ocean power technologies, such as **ocean thermal energy conversion** (OTEC) and **salinity gradient**, remain well short of commercial deployment, and only a handful of pilot projects have been launched. Nonetheless, novel applications continue to be developed. In 2019, for example, the Indian government approved the construction of a new OTEC-powered desalination plant.⁴⁵

Technology improvements and steep cost reductions are still needed for ocean power to become competitive, and the industry is yet to receive the clear market signals it needs to take the final steps to commercialisation.⁴⁶ The lack of consistent support schemes for demonstration projects has proven especially challenging for developers, who have struggled to build a compelling business case, and the sector remains highly dependent on public funding to leverage private investment.⁴⁷

Uncertainty regarding environmental interactions has often led regulators to require significant data collection and strict impact assessments, which can be costly and threaten the financial viability of projects and developers.⁴⁸ Current scientific knowledge suggests that the deployment of single devices poses little risk to the marine environment, but the impacts of multi-device arrays are not well understood.⁴⁹

Continuing revenue support is considered paramount for increasing investment certainty by providing predictable returns until the industry achieves greater maturity.⁵⁰ As of 2018, more than EUR 6 billion (USD 6.9 billion) had been invested in ocean power projects worldwide, of which 75% was from private finance.⁵¹ A 2018 European Commission implementation plan estimates that EUR 1.2 billion (USD 1.4 billion) in funding is needed by 2030 to commercialise ocean power technologies in Europe, requiring equal input from private sources, national and regional programmes, and EU funds.⁵²

KEY FACTS

- Solar PV markets saw more capacity installed than ever before, with the strong demand in Europe, the United States and emerging markets making up for a substantial decline in China.
- Corporate purchasing expanded considerably, and self-consumption (increasingly with battery storage) was an important driver for new distributed systems in some countries.
- The industry continued to face strong competition which, coupled with policy uncertainties, resulted in extremely low bids at some auctions and thin margins for developers and manufacturers; at the same time, competition and price pressures encouraged more efficient manufacturing and ongoing innovation.
- Solar PV accounted for high shares of electricity generation in countries including Honduras (10.7%), Italy (8.6%), Greece (8.3%), Germany (8.2%) and Chile (8.1%).

SOLAR PHOTOVOLTAICS (PV)



SOLAR PV MARKETS

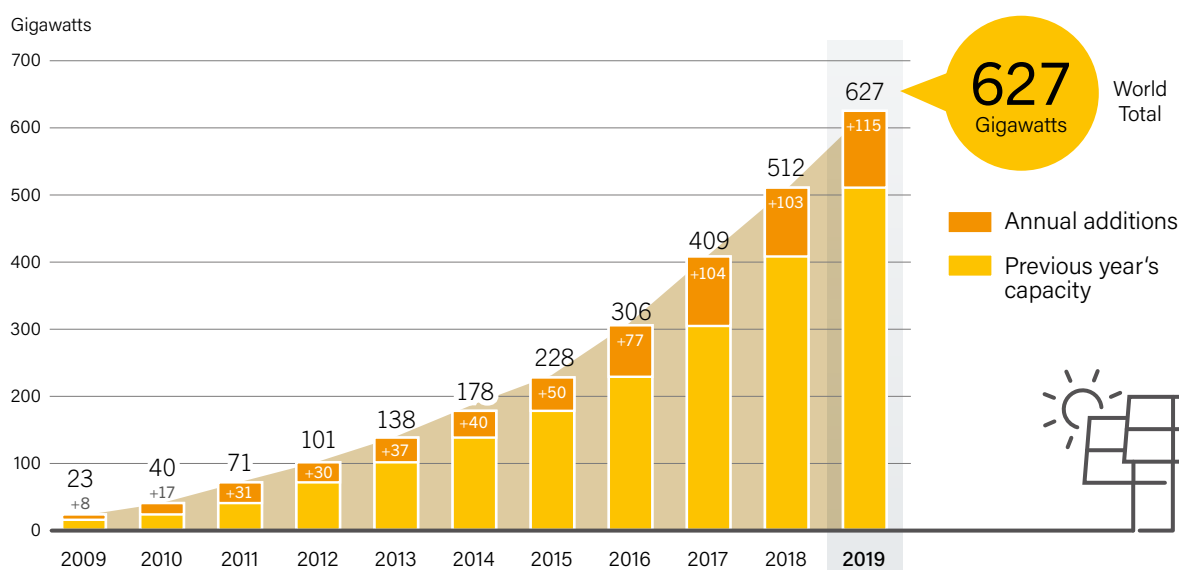
Following a year in which global solar photovoltaics (PV) additions were stable or even contracted slightly, in 2019 the solar PV market increased an estimated 12% to around 115 GW.¹ The decade ended with strong demand in Europe, the United States and emerging markets around the world, more than making up for a substantial decline in China, the single largest market.² Not including China, the global market for solar PV grew about 44% in 2019.³ The global total of 627 GW, which includes on- and off-grid capacity, compares to a total of less than 23 GW only 10 years earlier.⁴ (→ See Figure 28.)

Demand for solar PV is spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of locations – for residential and commercial applications and increasingly for utility-scale projects – even without accounting for the external costs of fossil fuels.⁵ In some markets, this is becoming the case for solar-plus-storage as well.⁶ In 2019, an estimated 18 countries added at least 1 GW of new capacity, up from 11 countries in 2018, and all continents contributed significantly to global growth.⁷ By the end of 2019, at least 39 countries had a cumulative capacity of 1 GW or more, up from 31 countries one year earlier.⁸

In several countries, solar PV already plays a significant role in electricity generation.⁹ By the end of 2019, 22 countries had enough capacity in operation to meet at least 3% of their electricity demand with solar PV, and 12 countries had enough

i For the sake of consistency, the GSR endeavours to report all solar PV capacity data in direct current (DC); where data are known to be in AC, that is specified in the text and endnotes. See endnotes and Methodological Notes for further details.

FIGURE 28. Solar PV Global Capacity and Annual Additions, 2009-2019



Note: Data are provided in direct current (DC). Totals may not add up due to rounding.

Source: Becquerel Institute and IEA PVPS. See endnote 4 for this section.

for at least 5%.¹⁰ For the full year, solar PV accounted for around 10.7% of total generation in Honduras and substantial shares also in Italy (8.6%), Greece (8.3%), Germany (8.2%), Chile (8.1%), Australia (7.8%) and Japan (7.4%), among others.¹¹ Enough capacity was in operation worldwide by year's end to produce around 2.8% of global electricity generation.¹²

There are still challenges to address in order for solar PV to become a major electricity source worldwide, including policy and regulatory instability in many countries, and financial and bankability challenges.¹³ As the level of penetration rises, solar PV is having an increasing effect on electricity systems, raising the importance of effectively integrating solar energy under varying technical and market conditions in a fair and sustainable manner.¹⁴ Opposition from incumbents is generally lower than a decade ago, and many utilities are actively engaging in solar PV deployment and operations, including distributed generation; however, challenges remain in several countries and among some actors, particularly some in the fossil and nuclear industries.¹⁵

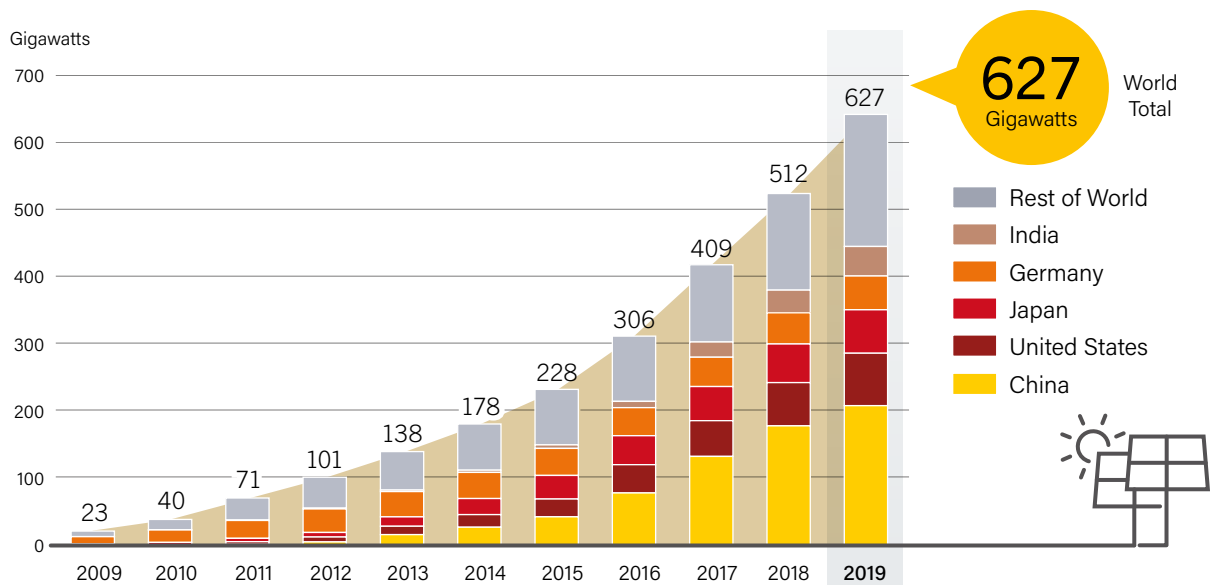
In most countries, the need still exists for support schemes for solar PV, as well as for adequate regulatory frameworks and policies governing grid connections.¹⁶ Government policies – particularly traditional feed-in tariffs (FITs), feed-in premiums and tenders – continued to drive most of the global market in 2019.¹⁷ Corporate purchasing of solar PV expanded considerably, and self-consumption was an important driver of the market for new distributed systems in several countries.¹⁸ Although still a small share of the annual market, a number of purely competitive (without direct government support) large-scale systems were being constructed in 2019; interest in this segment is significant and growing quickly.¹⁹



For the seventh consecutive year, Asia eclipsed all other regions for new installations, accounting for half of global additions, despite declines in the region's top three markets (China, India and Japan).²⁰ Asia was followed by Europe (17%) and the Americas (15%).²¹ China continued to dominate the global market (and solar PV manufacturing), accounting for around 26% of the year's capacity additions, but this compares with 44% in 2018.²² The top five national markets – China, the United States, India, Japan and Vietnam – were responsible for around 56% of newly installed capacity, down from around three-quarters in 2018 as the global market becomes less concentrated; the next five markets were Spain, Germany, Australia, Ukraine and the Republic of Korea.²³ The annual market size required to rank among the top 10 countries more than doubled in 2019, reaching 3.1 GW.²⁴ At year's end, the leading countries for cumulative solar PV capacity remained China, the United States, Japan, Germany and India, and the leaders for capacity per inhabitant were Germany, Australia and Japan.²⁵ (→ See Figure 29.)

i This is the capacity additions of the country that ranked tenth for annual installations, the Republic of Korea.

FIGURE 29. Solar PV Global Capacity, by Country and Region, 2009-2019



Note: Data are provided in direct current (DC).

Source: See endnote 25 for this section.

Despite China's year-end rally with more than 12 GW brought online in December alone, the country's annual solar PV market declined almost 32% (following a 15% drop in 2018), to 30.1 GW newly installed (including 17.9 GW of utility-scale and 12.2 GW of distributedⁱ solar PV).²⁶ Although installations fell for the second consecutive year and were down in almost every region of China, 12 provinces added more than 1 GW each and the country's total additions were more than double those of the next largest national market, the United States.²⁷ (→ See Figure 30 and **Reference Table R16**.) The leading provincial installer in 2019 was Guizhou (3.4 GW), one of China's poorest provinces, followed by Shandong (2.6 GW) and Hebei (2.4 GW).²⁸ By year's end, China's cumulative grid-connected capacity of around 204.7 GW was almost twice the national solar PV target (105 GW by 2020) that was established in 2016.²⁹

China's market decline in 2019 was due largely to policy uncertainty. The country is in the process of restructuring its renewable energy market – shifting from high-speed capacity growth and dependence on direct financial support through uncapped FITs, to deployment of high-quality technologies and systems through auctions and subsidy-free deployment to reduce costs and improve overall performance.³⁰ The national government ceased approvals for new subsidised projects at

the end of May 2018, and took more than a year to provide clarity on a revised FIT policy.³¹ Multiple delays in publication of policy implementation rules pushed back completion dates for several large solar PV projects.³² The market also was tempered by ongoing delays in FIT payments for existing facilities; challenges related to grid connections, land availability and access to finance; an increase in module exports, which curbed expected domestic price reductions and left developers waiting for prices to come more in line with their bids; and more positive and clear guidance for wind power projects, which led some developers to prioritise wind deployment.³³

As part of China's transition to a market without direct policy support by 2021, a bidding scheme was launched to select solar PV projects for FIT support as well as those for "grid-parity"ⁱⁱ, and by July the government approved 22.8 GW and 14.8 GW of capacity respectively.³⁴ For a variety of reasons, however, less than

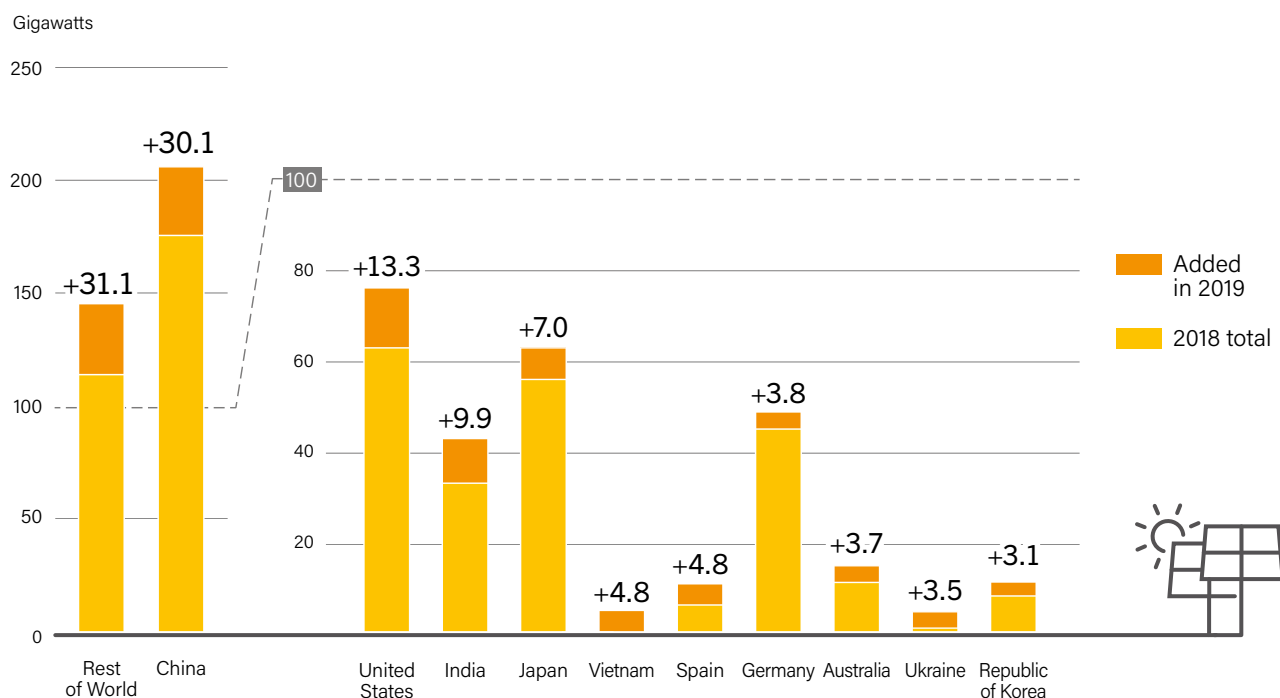
Countries that ranked among the top 10 for new solar PV installations added

3.1 GW
or more.

i "Distributed" solar PV in China includes ground-mounted systems of up to 20 MW that comply with various conditions, in addition to commercial, industrial and residential rooftop systems. Distributed generation consists largely of commercial and industrial systems and, increasingly, residential and floating projects. See endnote 26 for this section.

ii Grid parity in China refers to market-driven with no FIT support, but with priority off-taking. See endnote 34 for this section.

FIGURE 30. Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2019



Note: Data are provided in direct current (DC).

Source: See endnote 27 for this section.

10 GW of FIT-supported projects were executed and only about 2 GW of grid-parity projects became operational during the year.³⁵

China's market for large ground-mounted systems declined around 23% in 2019, and distributed installations (which include residential) were down 41%, but annual installations of residential systems (at 4.2 GW) increased 74% relative to 2018 and exceeded the official full-year target of 3.5 GW.³⁶ Centralised utility power plants (>20 MW) accounted for more than 59% of annual grid-connected installations (and 69% of the year-end total), with distributed systems making up the remainder.³⁷

Curtailment of solar energy in China continued to fall, down 1 percentage point from 2018 to average 2% (or a total of 4.6 TWh) for the year.³⁸ Most curtailment (87%) occurred in the north-west region, and the curtailment rate was highest in Tibet (24.1%, down 19.5 percentage points), but it declined in every province except Qinghai, which saw a large increase in renewable power capacity and a decline in load.³⁹ Reduced curtailment and rising capacity helped increase China's solar PV output from grid-connected systems more than 26% relative to 2018, to 224 TWh.⁴⁰ As a result, solar PV's share of total electricity generation (from grid-connected sources) in the country rose to 3% in 2019 (2.6% in 2018).⁴¹

The second largest market in Asia and the third largest globally was India, which added an estimated 9.9 GW in 2019 for a total of 42.8 GW.⁴² India targets 100 GW of installed solar PV, including 40 GW of rooftop solar capacity, by the end of 2022.⁴³

India's annual installations were down in 2019, following significant growth in 2018.⁴⁴ Reasons for the decline were many: India's economic slowdown, tariff caps and higher costs associated with tender participation, payment delays, renegotiation of power purchase agreements (PPAs) in Andhra Pradesh, challenges related to land acquisition, lack of transmission infrastructure and of access to grid connections, liquidity issues and lack of financing (due in many cases to delays in tariff adoption).⁴⁵ Curtailment also acted as a deterrent to new installations, and the severity was worsened by a decline in power demand due to the slowing economy.⁴⁶ In August, the national government called for "must run" status for solar and wind power projects, but lacked the ability to strictly enforce the rules.⁴⁷ Even so, generation from solar power for the year was up 27% relative to 2018.⁴⁸

Large-scale projects accounted for more than 85% of India's newly installed capacity and represented the vast majority of total solar PV operating capacity.⁴⁹ Around 35 GW of tenders was announced in India during 2019, down 8% relative to 2018, with more than 15.8 GW of projects auctioned (up 2%).⁵⁰ But several tenders were undersubscribed and, as in 2018, many auctions were cancelled retroactively.⁵¹ Nonetheless, by the end of 2019 nearly 24 GW of large-scale capacity was reportedly in the pipeline.⁵²

India's rooftop market declined in 2019 for the first time in five years.⁵³ The contraction was due largely to the economic slowdown combined with liquidity issues, as well as challenges to net metering and lengthy approval processes in some states.⁵⁴ An estimated 1.1 GW of distributed and off-grid capacity was installed during the year.⁵⁵ The rooftop market continued to consist mainly of large commercial and industrial companies (which together account for more than 70% of total capacity), as well as government

entities (including Indian Railways) and educational institutions, all seeking to reduce their electricity bills; comparatively few residential customers can afford the upfront costs.⁵⁶

The market in Japan also contracted, for the fourth consecutive year, and was down significantly from the peak year (2015).⁵⁷ Japan's market continued to suffer from grid constraints, lack of available land and of low-cost financial resources, high prices of solar generation (Japan's prices are some of the world's highest) and high labour costs.⁵⁸ Even so, Japan progressed towards the national target of 82 GW by 2030: around 7 GW was added during 2019, for a total of 63 GW.⁵⁹ For the year, solar PV accounted for an estimated 7.4% of Japan's total electricity generation, up from 6.5% in 2018.⁶⁰

By late 2019, 530,000 residential solar PV systems in Japan, totalling some 2 GW of capacity, reached the end of their 10-year contract period and exited the country's FIT scheme; as a result, and to increase resilience of supply, many system owners increased their focus on self-consumption and on achieving net-zero energy use by combining solar PV with energy storage.⁶¹ Power companies, home builders and others introduced new programmes for post-FIT residential systems, offering to purchase surplus solar electricity and renewable energy credits for their own use or resale to achieve corporate renewable energy targets.⁶²

In contrast to other large markets in Asia, Vietnam saw a surge in installations as developers rushed to win attractive FIT rates before they expired mid-year, rocketing the country to fifth place globally for additions.⁶³ More than 8.9 GW of large projects had been approved by year's end, including around 4.5 GW of capacity that came online at the end of June.⁶⁴ During all of 2019, an estimated 4.8 GW was added (up from 106 MW in 2018 and 8 MW in 2017) for a total of 4.9 GW.⁶⁵ Vietnam's interest in solar PV is largely to meet rising electricity demand, which has grown an average of 10% annually in recent years due to population growth and economic expansion.⁶⁶ Post-June, increasing concerns about grid congestion in the sunniest regions led the government to incentivise new projects in provinces with lower solar resources; in December, the national government urged a suspension of authorisations for all new solar facilities until further notice.⁶⁷

Other Asian countries that added substantial capacity in 2019 included the Republic of Korea, which installed an estimated 3.1 GW for a total of 11.2 GW, followed by Chinese Taipei, Pakistan, Turkey, Malaysia (approaching 0.6 GW) and Kazakhstan (0.5 GW).⁶⁸ Chinese Taipei (added 1.4 GW) aims for 20 GW by 2025, but faces several challenges including policy uncertainty, a struggling manufacturing sector and difficulties securing needed land.⁶⁹ Pakistan had another strong year, adding 1.3 GW for a total of 3.4 GW.⁷⁰

Turkey's annual installations declined significantly for the second consecutive year, due to an economic downturn, lack of available financing and other challenges; the country installed 0.9 GW for a

In 2019, 26 countries in the EU-28 added more capacity than they installed in 2018.



total of 8 GW.⁷¹ In its first attempt to support small-scale systems, Turkey introduced net metering in 2019.⁷² Numerous additional countries in Asia brought projects online or held tenders during the year, including Cambodia, which held its first solar PV tender.⁷³

Europe moved ahead of the Americas to rank second for additions (nearly 20.4 GW), and maintained its second-place regional ranking for total operating capacity.⁷⁴ Demand rose significantly in the EU and beyond: Ukraine, for example, installed a record 3.5 GW (surpassing 1 GW for the first time), thanks to a generous FIT and a scheduled reduction, to place third in all of Europe and ninth globally, while the Russian Federation brought online its largest solar PV plant (75 MW) to date, part of a pipeline of projects allocated in a 2016 auction.⁷⁵

The EU-28ⁱ added around 16 GW of grid-connected solar PV, nearly double the 8.2 GW installed in 2018, bringing total capacity close to 131.7 GW.⁷⁶ Most markets in the region have moved beyond FITs and were driven in 2019 by the competitiveness of solar generation – which is increasing interest in self-consumption (particularly combined with digital technologies and storage) and in corporate renewable power sourcing (including via direct bilateral PPAs) – as well as by governments looking to meet national renewable energy targets through tenders.⁷⁷ At the same time, new challenges are emerging, including access to grid connections, land availability and planning permission (particularly in some areas that already have a large installed base), and a shortening of PPA time periods with the shift towards merchant deals.^{ii 78}

In 2019, 26 of 28 countries in the EU added more capacity than they installed in 2018; even so, around three-fourths of new capacity came online in only five countries.⁷⁹ Spain (4.8 GW) was the top installer for the first time in 11 years, followed by Germany (3.8 GW), the Netherlands (2.4 GW), France (0.9 GW) and Poland (0.8 MW).⁸⁰ The Netherlands' installations were up an estimated

66%, led by the country's rooftop market, and Poland saw its installations quadruple in response to rising incentives for rooftop systems and the extension of net metering.⁸¹ For cumulative capacity, Bulgaria, Denmark and Hungary each exceeded 1 GW for the first time in 2019.⁸² The leaders Germany and Italy together were home to more than half of the EU's cumulative capacity at year's end, but their shares are declining as markets expand elsewhere.⁸³

Spain added nearly 4.8 GW in 2019, up from less than 0.3 GW in 2018, for a total exceeding 9.9 GW.⁸⁴ The high level of installations was due mostly to the commissioning of projects tendered in 2017 to meet the country's EU obligations, as well as to Spain's first PPA- and wholesale-based plants, and rooftop installations for self-consumption.⁸⁵ Installation of rooftop systems picked up considerably following the elimination of Spain's "Sun Tax" in November 2018 and the streamlining of the permitting process.⁸⁶ By year's end, grid constraints were the primary barriers to large-scale project implementation.⁸⁷ In response to an influx of applications for grid connection that far exceed Spain's expected demand growth, the government tightened grid connection rules as of 2020.⁸⁸

Annual demand in Germany was up almost 33% relative to 2018, with more than 3.8 GW added in 2019 for a total exceeding 49 GW.⁸⁹ The market was driven primarily by self-consumption and FIT premiums; limited volume tenders for large (>750 kW) ground-mounted systems accounted for less than 20% of added capacity.⁹⁰ The number of prosumersⁱⁱⁱ in Germany increased by almost 100,000 between February 2019 and January 2020.⁹¹ An estimated one of every two rooftop installations was sold with a battery storage system.⁹² In late 2019, the German government announced a new goal of 98 GW of solar PV by 2030, and removal of the 52 GW feed-in tariff cap was under discussion.⁹³ Solar PV generated an estimated 8.2% of Germany's electricity during the year.⁹⁴

i EU throughout this text refers to the EU-28, including the United Kingdom. Not including the UK, EU additions in 2019 were over 15.7 GW for a year-end total of more than 118 GW. See endnote 76 for this section.

ii Merchant deals (or projects) are those with no regulated or contracted income. The electricity generated is sold into competitive wholesale markets.

iii Individuals, families, commercial enterprises and energy co-operatives that produce electricity with solar PV and consume at least some of it locally.

The United Kingdom's FIT, a key policy for supporting rooftop solar, closed to new applicants at the end of March 2019.⁹⁵ In response, new residential installations fell 94% in May.⁹⁶ Paralysis caused by uncertainty over Brexit as well as policy changes also resulted in reduced investment in community solar projects.⁹⁷ The country had its slowest year since at least 2010, with an estimated 0.3 GW added, well below the 2015 peak (4.2 GW), bringing total capacity to 13.4 GW.⁹⁸ By year's end, however, the pipeline of large-scale projects was reportedly more than 6 GW.⁹⁹

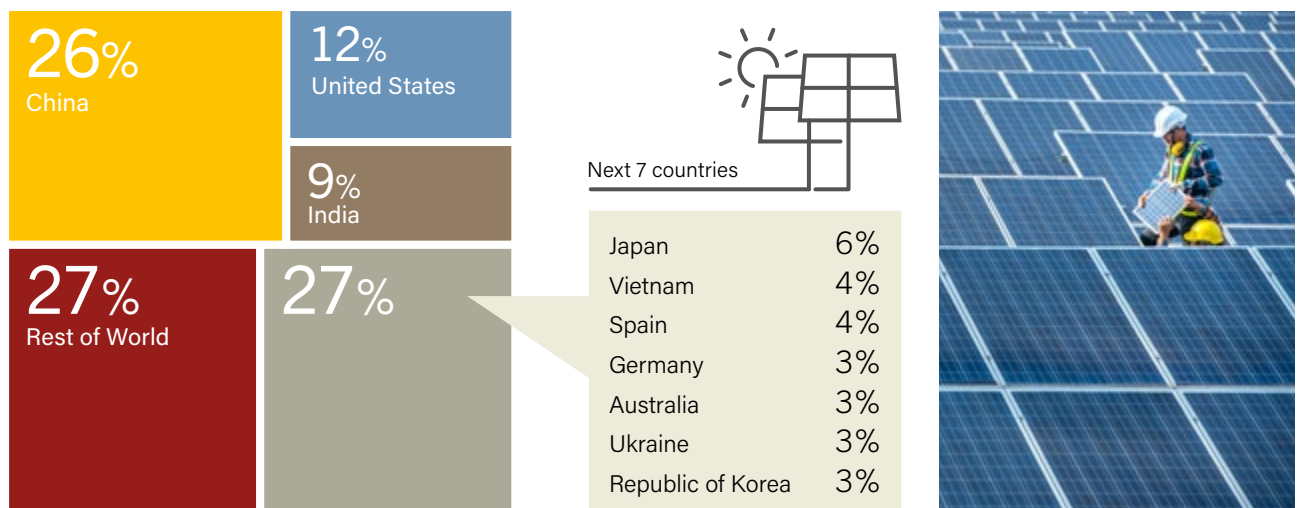
Across Europe, the number of direct bilateral PPAs continued to climb, and solar PPAs are becoming increasingly competitive with wholesale power markets in some countries.¹⁰⁰ Europe's largest PPA was signed in 2019 for a 708 MW solar PV project portfolio in Spain and Portugal.¹⁰¹ The year also saw the region's first large-scale PPA for a crowdfunded project; this financing approach represents one of the many innovations taking place in Europe, the United States and elsewhere to aggregate risk and enable the spread of PPAs beyond utilities and large energy-consuming corporations to smaller offtakers and to new countries.¹⁰² By early 2020, around 8.4 GW of solar PV capacity was operating or planned under PPAs in Europe, with the largest portion in Spain (4.4 GW), followed by Italy (1.9 GW) and Germany (over 1 GW).¹⁰³

The Americas represented around 15% of the global market in 2019, due largely to the United States, which ranked second globally for both new installations and cumulative capacity.¹⁰⁴ (→ See Figure 31.) The country added 13.3 GW for a total exceeding 76 GW.¹⁰⁵ Solar PV accounted for nearly 40% of all new US power capacity additions in 2019, the largest share to date.¹⁰⁶ California again led all states in added capacity (3.1 GW), followed by Texas (1.4 GW) and Florida (1.4 GW).¹⁰⁷ Hawaii led in the adoption of rooftop solar per capita, followed by California and Arizona.¹⁰⁸ Utility-scale solar PV generated 69 TWh, or 1.7% of US utility-scale generation in 2019; small-scale systems generated an additional estimated 35 TWh.¹⁰⁹

The US market as a whole grew 23% in 2019.¹¹⁰ It was led by the utility-scale sector, which expanded 37%, to 8.4 GW, and accounted for 63% of US additions.¹¹¹ Non-residentialⁱ installations declined for the second consecutive year (down 7%), due to policy changes and interconnection delays in some key states.¹¹² But the residential sector had a record year, up 15% to 2.8 GW, driven by ever more attractive economics in many emerging states, as well as by power shutoffs (associated with wild fires) and new-build homes in California.¹¹³ California achieved a target of 1 million solar roofs in late 2019, and the state's mandate to install solar on most new homes entered into force at the start

i Includes commercial, government, non-profit and community solar PV systems.

FIGURE 31. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2019



Source: See endnote 104 for this section.

of 2020.¹¹⁴ Also towards the end of 2019, the National Community Solar Partnership was relaunched with the aim of expanding affordable access to solar energy for all US households by 2025.¹¹⁵

The US rush to complete projects, large and small, and to contract for new ones during 2019 was driven in part by impending cuts in the federal investment tax credit (ITC).¹¹⁶ Project developers and small commercial installers stockpiled modules and other equipment to take advantage of the 30% ITC, and installers were at capacity during the second half of the year.¹¹⁷ Falling technology costs and rising renewable energy commitments also drove demand, including in the US Midwest, which historically has favoured wind energy.¹¹⁸ A record high of new solar PPAs (30.6 GW) was signed or announced, bringing the cumulative contracted project pipeline to 48.1 GW.¹¹⁹ Voluntary purchasing accounted for 57% of new procurement in 2019, with an estimated 14% driven by state renewable portfolio standards.¹²⁰ Innovations such as aggregationⁱ continued to open the market for smaller businesses as well as large corporations.¹²¹

Rapidly falling costs of solar PV and battery installations have led to a surge in solar PV-plus-storage projects across the United States by enabling them to begin competing with natural gas-fired generation.¹²² In 2019, the number of US solar-plus-storage projects announced or already online increased from 16 to 38, and in California most new utility-scale solar was being proposed with some storage capacity.¹²³ Interest in solar-plus-storage is rising in the residential market as well, particularly in Hawaii and in California, where consumers seek energy resiliency and reliability.¹²⁴ (→ See *Systems Integration chapter*.)

To the south, several countries in Latin America and the Caribbean continued their rapid expansion, despite challenging economic conditions in some countries, thanks largely to an abundance of solar resources, falling prices and favourable political climates until 2019.¹²⁵ The region's top installers were Brazil (adding 2 GW), Mexico (nearly 2 GW) and Argentina (0.5 GW).¹²⁶ Several other countries brought online significant capacity, including Colombia, which commissioned a 86 MW plant, and Jamaica, which completed the Caribbean's largest solar PV facility (51 MW) – the plant is expected to provide the island's lowest-cost electricity.¹²⁷ Numerous countries called for public bids for future solar PV projects.¹²⁸

Brazil added more than 2 GW in 2019 and ended the year with nearly 4.5 GW.¹²⁹ An estimated 650 MW of large-scale capacity was brought online, including the first solar PV plant in Latin America to be built with a digital sub-station.¹³⁰ By year's end, around 5.7 GW of additional permitted solar PV projects was in advanced stages of development, and there was a growing interest in new opportunities for bilateral PPAs.¹³¹ Several large-scale projects reached record-setting low bid prices in government auctions, with plans to sell at least 30% of their electricity into the wholesale market.¹³² Brazil's distributed solar PV segment (defined as <5 MW) saw the most growth during 2019 in terms of capacity added (1.4 GW), investments and jobs, driven by net metering and rising energy prices.¹³³ The segment was led by residential systems but saw growing shares of commercial and rural systems.¹³⁴ An end-of-year push to install distributed systems resulted from proposed policy changes, including a debate under way regarding revisions to the national net metering mechanism.¹³⁵



Innovations

such as crowdfunding and aggregation are opening PPA markets to more participants.

- i The ITC provided a 30% investment tax credit for projects that began construction by the end of 2019. The credit steps down to 26% in 2020, 22% in 2021 and 10% from 2022 onwards for commercial and utility projects, and for residential systems owned by companies; it falls to zero in 2022 for residential installations owned by homeowners. See endnote 116 for this section.
- ii For example, a large corporation acts as "anchor tenant", providing a strong credit rating to support project financing, and enabling the developer to build a larger project than the corporation requires. The developer then negotiates separate PPAs for the additional capacity with smaller purchasers, who have differing credit ratings, and who benefit from lower transaction costs and reduced complexity. Alternatively, a number of companies jointly negotiate an agreement, aggregating their individual capacity requirements in order to organise a larger deal and, thereby, to more cost-effectively acquire a PPA. See endnote 121 for this section.

Mexico continued to lead the region for its cumulative capacity, which rose an estimated 62% compared with 2018 to more than 5 GW.¹³⁶ Several large plants came online, including a 220 MW facility that will sell electricity into the wholesale market.¹³⁷ The country also completed what was reportedly the first large-scale project in Latin America to combine solar PV and battery storage.¹³⁸ However, the Mexican government cancelled all plans for renewable energy auctions, raising concerns about the impact on solar PV deployment after 2020.¹³⁹ Mexico also had substantial rooftop capacity, totalling 818 MW at the end of 2019.¹⁴⁰

Across the Pacific, Australia saw record additions in the small, medium and large-scale segments, and ranked eighth globally for installations.¹⁴¹ Around 3.7 GW was added during 2019, increasing the country's total capacity to 14.7 GW.¹⁴² Although output from solar PV was affected by haze and fallout from the bushfires across much of the country, generation rose 55% in 2019, to 18.1 TWh, or 7.8% of Australia's total.¹⁴³ Deployment has been driven by several factors, including falling system prices, increasing awareness of the benefits of solar PV to businesses and households, and the corporate market for PPAs.¹⁴⁴

Corporate solar PPAs continued to be announced in Australia, although at a slower pace than in 2018, with solar PV accounting for 82% of the 400 MW that was newly contracted in 2019.¹⁴⁵ An important innovation in Australia during the year was the development of retail PPAs, in which buyers (particularly a growing number of mid-scale buyers) contract for power via a retailer.¹⁴⁶ Among the new smaller agreements was a seven-year PPA signed by the Sydney Opera House for solar and wind power projects and a residential solar PPA for home buyers in a Western Australia housing development.¹⁴⁷ The number of merchant projects (selling on the spot market) rose as well.¹⁴⁸

Australia's capacity in large-scale (>5 MW) solar PV projects saw record increases.¹⁴⁹ Yet small-scale (<100 kW) household and commercial rooftop solar PV continued to be the largest sector in Australia by far, as both the number and average size of new systems continued to rise.¹⁵⁰ Annual installations increased 35% over 2018, to nearly 2.2 GW added (287,504 new systems), for a year-end total approaching 10.4 GW (2.3 million systems).¹⁵¹ During the year, small-scale systems powered the equivalent of more than 2.6 million households, accounting for 5.3% of the country's total electricity generation.¹⁵² In addition, 22,000 small-scale batteries were installed in 2019, bringing Australia's household storage capacity to more than 1 GWh.¹⁵³

Rapid growth in solar (and wind) generation is transforming Australia's electricity landscape, reducing electricity prices and air emissions while pushing out coal-fired power plants (which are increasingly unreliable and expensive to operate).¹⁵⁴ The vast scale of installations in 2018 and 2019 – well beyond expectations – resulted in an overcrowded grid and connection delays as transmission investment failed to keep up with the growth in renewable energy.¹⁵⁵ By mid-year, grid connections for large projects were increasingly time-consuming and costly (reducing revenue for projects once they were online); this challenge – combined with a lack of clarity about state and federal policies and targets, and the increase in regulatory risks as well as curtailment – led to delayed and cancelled projects, and raised barriers to investment.¹⁵⁶ The rooftop sector also has experienced

problems related to the ability of distribution networks to integrate high penetration rates of solar energy with battery technology.¹⁵⁷

The Australian Energy Market Operator (AEMO) responded by starting to upgrade grids in key regions and by creating renewable energy zones.¹⁵⁸ AEMO also is working on an integrated roadmap for efficient development of the country's national electricity market over the coming decades.¹⁵⁹ By early 2020, frustration over grid congestion led Victoria to break away from national electricity rules to fast-track transmission upgrades and ensure grid-connection for large projects.¹⁶⁰

The Middle East and Africa also saw substantial solar PV installations in 2019. An estimated 6.7 GW was added for a year-end total of 15.1 GW, an 80% increase in cumulative capacity across these two regions.¹⁶¹ As in 2018, the largest installer in the Middle East was the United Arab Emirates, which aims to achieve 50% renewable energy by 2050.¹⁶² Commercial operations began at the 1,177 MW Sweihan facility in Abu Dhabi, the world's largest single-site solar project at the time of completion, expected to cover the electricity requirements of 90,000 people.¹⁶³ In addition, Dubai allocated the fifth phase (0.9 GW) of its 5 GW Mohammed bin Rashid Al Maktoum Solar Park.¹⁶⁴ At year's end, the United Arab Emirates had more than 1.7 GW of solar PV in operation, including at least 125 MW of rooftop capacity under Dubai's Shams initiative.¹⁶⁵

Other noteworthy installers in the Middle East included Saudi Arabia, where production began at the country's first grid-connected solar PV plant (0.3 GW Sakaka) in late 2019; Jordan (added 0.6 GW), where at least two large plants were completed and efforts continued towards the goal to install solar PV on all of the nation's 7,000 mosques; and Israel, which completed its largest solar PV park (120 MW) and added a total of 0.8 GW.¹⁶⁶ Kuwait and Oman added large projects to their pipelines, and Iraq launched a tender for 755 MW of capacity.¹⁶⁷ Policy makers in several countries – including Jordan, Oman, Saudi Arabia and the United Arab Emirates – have reduced electricity tariffs and are



starting to prioritise distributed solar PV, particularly in Dubai, but many countries are still struggling to find the right mix of policy, financing and procurement options.¹⁶⁸

Across Africa, as costs fall, solar PV is viewed increasingly as a means to diversify the energy mix, to meet rising demand while limiting the growth of CO₂ emissions and to provide energy access.¹⁶⁹ But considerable challenges remain, including a lack of suitable financing tools, ongoing subsidies to fossil fuels in many countries as well as social and political unrest in some, a reliance on tenders for new capacity and a race to the bottom in bid prices.¹⁷⁰ Even so, several countries brought projects online during 2019, including the first large plants in Kenya (50 MW), Mozambique (40 MW), Namibia (45 MW) and Zambia (54 MW), among many others.¹⁷¹ The largest solar PV plant in all of Africa, Egypt's Benban solar complex, became fully operational in late 2019; the facility, covering more than 37 square kilometres of desert and with a capacity of nearly 1.5 GW, is expected to provide electricity to 1 million people.¹⁷² At the other end of the spectrum of scale, several countries saw numerous rooftop and other small-scale systems come into operation during the year. South Africa, for example, had more than 100 MW of rooftop systems by the end of 2019.¹⁷³ (→ See *Distributed Renewables chapter for more on access and small-scale solar PV*.)

Many other countries on the African continent held solar PV tenders or had large plants being planned, under construction or commissioned, including Morocco, which had several solar PV-concentrating solar thermal power (CSP) complexes under way.¹⁷⁴ Also in 2019, a plan was unveiled to dramatically expand solar PV (and CSP) capacity in Botswana and Namibia to reduce reliance on energy imports and enable the export of surplus electricity to surrounding countries.¹⁷⁵ Regional efforts also were under way to expand the use of solar PV across the continent.¹⁷⁶ At year's end, Africa's top countries for cumulative solar PV capacity were South Africa with 3.4 GW (added 1 GW), Egypt with nearly 2.3 GW (added 1.65 GW), Algeria with 0.5 GW (no additions) and Kenya (added 0.2 GW for a total of 0.3 GW).¹⁷⁷

Around the world, even as favourable economics are raising interest in distributedⁱ systems, especially for commercial and industrial uses (as well as off-grid), large utility-scale projects continued to dominate the global market for newly installed capacity.¹⁷⁸ (Even the size of distributed systems is trending larger in many countries.¹⁷⁹) The move towards ground-mounted large-scale systems is due at least in part to the growing use of tenders and auctions, and increasingly also to PPAs, whether in Europe, Australia or new markets such as Vietnam.¹⁸⁰

Solar PV plants are approaching the scale of fossil-fired power plants as developers aim to drive down the price of solar electricity.¹⁸¹ The size and number of large projects continued to grow during 2019, with more than 50 solar PV plants of 50 MW and larger completed, and such plants were operating in at least 44 countriesⁱⁱ by year's end.¹⁸² Developers commissioned

at least 35 projects that were 200 MW or larger.¹⁸³ In addition to those mentioned previously, new facilities included a 420 MW solar complex in Vietnam; Spain's 494 MW Mula plant (reportedly Europe's largest solar PV project at year's end); China's largest (500 MW) project without direct financial support (which will compete against coal- and natural gas-fired plants); and India's 2 GW Pavagada Solar Park, which began development in 2016 and was completed in 2019.¹⁸⁴

Large-scale ground-mounted plants can cover vast areas, raising concerns about potential environmental impacts, grid-connection challenges and the use of agricultural lands.¹⁸⁵ The potential for rooftop solar systems remains enormous, and many countries, such as India, have established large rooftop programmes and targets.¹⁸⁶ The relatively small market for floating solar also continues its rapid expansion, driven by the limited availability and high costs of land in many places.¹⁸⁷ Floating projects bring new risks and generally higher costs than ground-mounted facilities, but economies of scale in project sizes are helping to reduce associated costs.¹⁸⁸ (→ See *Sidebar 3 in GSR 2019*.)

Most floating solar PV projects are sited in Asia, but they can be found from Africa to Europe to the Americas.¹⁸⁹ During 2019, China completed several large plants, including a 70 MW project at a former coal mining area in Anhui Province; India held a tender for a floating solar PV project (70 MW); Portugal held a tender to seek engineering, procurement and construction contractors for 10 floating solar PV plants (50 MW total) and, in early 2020, Vietnam announced pilot auctions for an eventual 400 MW.¹⁹⁰ Floating projects also are being constructed



Operating capacities
of many new

solar PV

plants are approaching the level of fossil-fired power plants as developers aim to drive down the price of solar electricity.

i Distributed refers to systems that provide power to grid-connected consumers, or to the grid, but on distribution networks rather than bulk transmission, or off-grid systems. See endnote 178 for this section.

ii Countries that added their first 50-plus MW plants in 2019 include Argentina, Belgium, Colombia, Jamaica, the Russian Federation, Saudi Arabia and Vietnam. See endnote 182 for this section.

offshore, with a pilot project completed off the Dutch coast in the North Sea, and plans were announced for projects off the coasts of the United Arab Emirates, the Republic of Korea and Singapore.¹⁹¹ A total floating capacity of at least 2.4 GW was expected to be operating in 35 countries by year's end, with projects completed or under way in almost every region.¹⁹²

Other niche markets that minimise land requirements include building-integrated PV, which is progressing only slowly (a highlight in 2019 being a new high-rise building in China with a 460 kW façade), and the emergence of plans among mainstream auto manufacturers, particularly in Asia, to incorporate solar cells into electric vehicles.¹⁹³ Agricultural PVⁱ also is an emerging sector that can address concerns associated with land use, especially with the growing availability of bifacial systems (see later discussion).¹⁹⁴ Several studies have highlighted the advantages, including improved crop yields, reduced evaporation, rainwater harvesting (with modules), provision of shade for livestock and prevention of wind and soil erosion, as well as additional income for farmers from electricity production.¹⁹⁵ In 2019, a total of more than 2.9 GW of capacity was operating in Japan and elsewhere, and plans were announced for new projects, including a 1 GW agricultural PV livestock farming project in Malaysia.¹⁹⁶



SOLAR PV INDUSTRY

The year reflected a dichotomy of perspectives on the health and prosperity of the solar PV industry. On the one hand, competition drove declining prices, which in turn opened new markets, while the pressure of lower prices and expectations of rising global demand encouraged expanded and more efficient manufacturing, the entrance of new companies into the sector and ongoing pursuit of innovation. On the other hand, the relentless competition, coupled with policy vagaries and uncertainty, prompted highly competitive bids at some auctions – resulting in razor-thin margins for some developers and manufacturers – and contributed to ongoing consolidation.

Globally, solar PV prices continued to decline in 2019.¹⁹⁷ The price of modules fell around 12% during the year, to a world average of USD 0.36 per watt, but with significant variations in price from country to country.¹⁹⁸ A ramp-up in manufacturing along the supply chain in recent years, due to overly optimistic expectations about global demand growth (particularly in China), held down prices for polysilicon, wafers, cells and modules.¹⁹⁹ Innovations and improvements in design and operation also helped to reduce operations and maintenance (O&M) costs.²⁰⁰ By one estimate, the global benchmark levelised cost of electricity (LCOE) from solar PV declined 17% relative to 2018.²⁰¹

Tenders and auctions saw bid pricesⁱⁱ drop to new lows in 2019, and in some countries they fell below the average price of wholesale electricity.²⁰² The average bid price across all markets was close to USD 30 per MWh, but bids below USD 20 per MWh became more common towards year's end.²⁰³

The lowest bid prices were seen in Brazil, Dubai (United Arab Emirates) and Portugal. In Brazil's A-6 auction, solar PV came in with the most competitive final average electricity price among all competing technologies (including wind power and natural gas) at BRL 67.48 (USD 16.48) per MWh.²⁰⁴ Dubai allocated 0.9 GW of capacity at a price of USD 16.95 per MWh, and Portugal awarded 1.29 GW with a world-record low bid of EUR 14.76 (USD 16.53) per MWh.²⁰⁵

Time will tell if the lowest bids will be viable. Outside of locations with a low cost of finance, open desert and excellent solar resources, such as Dubai, a broad range of experts believe that very low bids, such as Portugal's winning price, are possible only because firms made overly optimistic assumptions about future cost reductions (ahead of project construction) or plan for merchant sales at the end of the contract period, betting on the merchant price (until the end of project lifetime) to supplement revenues.²⁰⁶ Several record-setting low bid prices in Brazil's auctions were made by developers planning to sell at least some of their electricity into the wholesale market.²⁰⁷

Direct bilateral PPA prices also reached new lows in 2019 and in early 2020.²⁰⁸ In the United States, PPA prices were in the range of USD 16 to USD 35 per MWh, and solar PV-plus-storage achieved

i Agricultural PV is defined as use of the same site for both energy and crop production. See endnote 194 for this section.

ii Bid prices do not necessarily equate with energy costs. Also, energy costs vary widely according to solar resource, project size, regulatory and fiscal framework, customer type, the cost of capital and other local influences. Distributed rooftop solar PV remains more expensive than large-scale solar PV but has followed similar price trajectories, and is competitive with (or less expensive than) retail electricity prices in many locations. See endnote 202 for this section.

a new record low in the country of USD 40 per MWh for the Eland projectⁱ in California's Mojave Desert, which should be operational by 2023.²⁰⁹ In January 2020, a PPA was signed in Qatar for 800 MW at QAR 57.1 (USD 15.8) per MWh, one of the lowest prices ever recorded.²¹⁰ Agreement periods are shortening in Australia, Germany, the United States and elsewhere, with price trajectories flattening (at least in Australia and the United States), and several markets have begun shifting towards the merchant model.²¹¹

New lows in auction prices, resulting from intense competition (with some instances of bidding below marginal costs to win tenders) – in some cases driven by policy design – constrained margins and brought further consolidation in the industry.²¹² Among the casualties in 2019: China-based module manufacturer Hareon Solar was forced into bankruptcy liquidation; Suntech (China), once the leading global manufacturer, again came up for sale or liquidation; another former world leader, Yingli (China), continued to lose money, following several difficult years; Panasonic (Japan) transferred a solar module manufacturing subsidiary in Malaysia to GS-Solar (China), as part of an effort to return its solar business to profitability; Moser Baer Solar (India) began liquidating its assets; and several solar-related companies in Chinese Taipei consolidated to survive through economies of scale.²¹³

By contrast, many Chinese cell and module manufacturers benefited from record-low prices for polysilicon, solar wafers and cells, as well as from strong demand from most regions around the world.²¹⁴ LONGi, for example, saw both its revenues and net profit rise in 2019, with further improvements in the first quarter of 2020.²¹⁵ LONGi and other top-tier vertically integrated companies were able to cope with price declines by expanding production to take advantage of lower costs of new equipment and economies of scale, in some cases through joint partnerships.²¹⁶ For example, LONGi and Tongwei signed a strategic co-operation agreement to support each other's supply chains, following on earlier joint ventures and agreements; and GCL-Poly and Zhonghuan Semiconductor announced a plan to further their co-operation by increasing joint manufacturing capacity.²¹⁷

Many companies achieved or announced significant increases in production capacity in 2019, reflecting optimism about future market growth, efforts to maintain market share, as well as policies to promote local manufacturing.²¹⁸ By the end of 2019, global crystalline and thin-film cell production and module assembly capacitiesⁱⁱ were estimated to be 153.1 GW (cell) and 185 GW (module), respectively, up 35% and 29% over 2018.²¹⁹

Much of the expansion occurred in China.²²⁰ China has dominated production and global shipments of solar PV cells and modules since 2011, which means the country also has dominated the prices of cells and modules, influencing the margins that other

manufacturers receive.²²¹

This continued to be the case in 2019. During the year, 123.5 GW of cells and modules were shipped worldwide (up 39% over 2018), mostly from manufacturers in Asia, and particularly China.²²² Of the estimated 78 GW of cell/module

volume shipped by the top 10 suppliers, over 80% was shipped by Chinese firms, with the others representing equal shares of the remaining volume and hailing from the Republic of Korea (Hanwha Q-Cells), Chinese Taipei (UREC) and the United States (First Solar).²²³

The solar PV industry remained vulnerable to turbulence in some countries (the list of countries changing annually), and particularly in China.²²⁴ In China and elsewhere, policy uncertainty as well as policies that are stop-go or poorly designed – including cancelled or postponed auctions – hampered the industry.²²⁵ The industry also was challenged by unreliable or insufficient grid infrastructure (often the reason for revisions to policies and targets), particularly in emerging markets.²²⁶

Trade policies also continued to affect the solar PV industry in 2019.²²⁷ (→ See *Sidebar 3 in Policy Landscape chapter*.) India imposed new duties on product imports from several other Asian countries and from Saudi Arabia as part of the push towards domestic manufacturing.²²⁸ US tariffs imposed in 2018 on nearly all major sources of solar PV imports, as well as on steel and aluminiumⁱⁱⁱ, were in place throughout 2019.²²⁹ The United States added tariffs on Chinese solar inverters, and removed India from duty-free status for many products, including solar cells and modules.²³⁰ In addition to tariffs on imports, several countries had measures in place to encourage local production or to penalise the use of foreign-made products.²³¹

During the year, the US International Trade Commission found that US tariffs had boosted module manufacturing in the country – including new module plants set up by Hanwha Q-Cells and LG (both Republic of Korea), and by China's Jinko Solar – but had failed to halt the decline of domestic cell makers.²³² The Commission also found that tariffs had softened solar price declines in the United States compared to those experienced globally.²³³ Bifacial panels were granted exemption from US import tariffs in June (with a temporary reversal in October^{iv}), and US demand for bifacial panels soared in an effort to evade tariffs and improve project efficiency, as well as to stockpile modules to qualify for the 30% federal investment tax credit^v.²³⁴

The solar PV industry

remained
vulnerable

to turbulence in some
countries, and
particularly in China.

i The project includes 400 MW of solar PV capacity and 300 MW/12,000 MWh of energy storage capacity. See endnote 209 for this section.

ii Cell capacity is MW or GW of semiconductor (cell) capacity available to a manufacturer; module assembly capacity is that available to assemble cells into modules.

iii Tariffs on imports of these metals are significant because they are used to manufacture balance-of-systems equipment.

iv In April 2020, a decision was made to remove the exemption again, effective as of 18 May 2020; the tariffs are due to end in 2022.

v The US solar "safe harbor agreement" governs when a solar PV project qualifies for the ITC. Projects that began construction before the end of 2019 qualify for the full 30% credit, which started to step down in 2020. To qualify, one option was to incur 5% of the total cost of a project before the end of 2019, and the easiest way for developers to do that was to buy up panels and inverters.

In spite of the challenges faced by some actors in the solar PV industry, new companies continued to enter in.²³⁵ For example, most of the largest wind power developers in the United States have expanded into solar PV and energy storage, and similar trends are seen in China, India and elsewhere.²³⁶ Oil and gas giants, particularly Europe-based companies, are moving into solar project development and operation, and using solar PV to power their operations around the world.²³⁷

Competition
and price pressures have encouraged investment in solar PV technologies, particularly in cells and modules.



In addition to driving the construction of new, more-efficient manufacturing facilities, competition and price pressures have encouraged investment in solar PV technologies across the entire value chain, and particularly in solar cells and modules, to further improve efficiencies and reduce the LCOE.²³⁸ New record cell and module efficiencies were achieved during 2019.²³⁹ Monocrystallineⁱ cell technology, which lost its lead to multicrystalline in 2002, raced ahead for the majority share of global shipments.²⁴⁰

Demand for higher-efficiency modules has steered a shift towards Passivated Emitter Rear Cell (PERC)ⁱⁱ technology and the next generation of technologies.²⁴¹ PERC has become the new standard for the monocrystalline silicon solar cell variety because it increases efficiencies, making it an economically attractive option for many projects.²⁴² Manufacturers of PERC (particularly China’s LONGi) have invested heavily in its commercialisation.²⁴³

While monocrystalline PERC is the focus of most capacity expansions, and substantial commercial capacity came online in 2019, the industry is already looking beyond PERC.²⁴⁴ In 2019, several manufacturers were converting or building new factories to produce heterojunction cell technologyⁱⁱⁱ (HJT), which offers higher efficiencies and occurs at low temperatures and with fewer production steps than other high-efficiency cell technologies.²⁴⁵ A number of China-based companies were actively looking into HJT, and some had small production lines in operation.²⁴⁶ European manufacturers were considering HJT (and other technologies) as an option to regain market share.²⁴⁷ In late 2019, REC (Norway) started production at a HJT cell and module facility in Singapore.²⁴⁸

Researchers also were working to overcome the theoretical efficiency limits of silicon-based solar cells by stacking cells of different types and developing new, more efficient cell technologies.²⁴⁹ Perovskites^{iv}, in tandem with crystalline silicon or a thin-film base, are attracting substantial research dollars and seeing increasing efficiencies.²⁵⁰ Researchers continued to focus on the long-term stability of perovskites, lead content and other challenges during the year.²⁵¹ By one estimate, more than a dozen companies worldwide were working on perovskites in 2019 with aims to sell panels soon (although some also pulled out of the market).²⁵²

Improvements in cell technology and module design have enabled the development of modules with higher power ratings.²⁵³ In 2019, for example, SunPower (United States) launched the industry’s most powerful residential panel, at 400-plus watts, and Canadian Solar unveiled what it claimed was the first poly bifacial module of 400-plus watts for large projects.²⁵⁴ Raising the power rating increases electricity output per module, thereby reducing the number needed for a project, meaning that less space is required and associated land, installation and other costs are reduced.²⁵⁵

Bifacial modules, which can capture light on both sides, also offer potential gains in output (and thus a lower LCOE) – with even greater performance gains if used in installations with trackers^v – although there are ongoing uncertainties about real-world performance.²⁵⁶ The scale of bifacial exports from China (the largest manufacturer of and market for bifacial panels) and the geographical distribution of demand increased considerably

i Crystalline technologies account for nearly all cell production. Historically, monocrystalline cells have been more expensive but also more efficient (more power per unit of space) than multi- or poly-crystalline cells, which are made of multi-faceted or multiple crystals. See endnote 240 for this section.

ii PERC is a technique that reflects solar rays to the rear of the solar cell (rather than being absorbed into the module), thereby ensuring increased efficiency as well as improved performance in low-light environments.

iii HJT combines advantages of conventional crystalline silicon solar cells with good absorption and other benefits of amorphous silicon thin film technology.

iv Perovskite solar cells include perovskite (crystal) structured compounds that are simple to manufacture and are expected to be relatively inexpensive to produce. They have achieved considerable efficiency improvements in laboratories, with reports of about 3% in 2006 to more than 24% in 2019, and 28% was achieved in a silicon-based tandem cell in 2018. See endnote 250 for this section.

v Trackers enable panels to track the movement of the sun. More and more large ground-mounted projects are using trackers because they flatten the production curve and increase yield. See endnote 256 for this section.



in 2019 thanks to improvements in cell technology.²⁵⁷ Several manufacturers announced plans to ramp up bifacial production or launched new products in 2019.²⁵⁸

Operators are playing a growing role in project development, working to maximise generation and to reduce the LCOE as direct government support declines and solar assets become exposed to market prices.²⁵⁹ Plant operations are increasingly digital and automated as rising competition pushes companies to further reduce costs, improve system performance and integrate energy storage.²⁶⁰ Digitalisation, thanks in large part to advances in inverterⁱ technology, is helping to improve performance (for example, through predictive maintenance, remote sensing and control, satellite and ground-based as well as numerical solar forecasting schemes) and to provide grid services such as ramping capability and frequency regulation in order to support grid reliability.²⁶¹ (→ See *Systems Integration chapter*.)

Remote maintenance and control technologies are improving efficiency and reducing O&M costs as well as outage times.²⁶² Drone technologies are allowing operators to access and analyse performance data via remote thermographic imaging of facilities.²⁶³ Interest in robotic cleaning is increasing in India, Israel and elsewhere to reduce labour and other costs, save water and improve efficiency.²⁶⁴ In addition, research is under way to develop surface coverings that can reduce dust deposition on solar panels, an advance that improves system performance and lowers cleaning costs in dusty environments.²⁶⁵

Even as solar PV technologies and operations continue to advance, there is concern that low tender bidding and resulting low margins have negatively affected quality along the entire value chain.²⁶⁶ Poor quality – from product manufacturing and shipping, to project design and construction, to the commissioning and O&M stages – is a concern in a number of countries, as manufacturers feel pressure to cut corners in production or quality control and as developers seek the lowest-cost products.²⁶⁷ There are many areas where problems can enter

in – particularly in emerging markets with rapid deployment as well as political and policy uncertainty.²⁶⁸ Although the volume of related literature is increasing, there is still limited understanding of the issues involved, and several countries continue to lack quality standards and regulations.²⁶⁹

To address some of these quality-related concerns, in 2019 India's Ministry for New and Renewable Energy approved a series of guidelines for solar inverters under a quality control order that was first introduced in 2017.²⁷⁰ In Bangladesh, concerns about imports of sub-standard products that are threatening sustainability of the domestic market led the national government to introduce minimum quality standards on solar modules, inverters, charge controllers and batteries.²⁷¹ Australia made significant progress on a new consumer code to establish minimum standards for consumer protection and good practice for solar PV, batteries and other emerging products and services.²⁷² Also in 2019, global standards-making organisations continued working to establish rigorous standards for improving the quality of module production and system installation.²⁷³

Industry efforts to further advance environmental sustainability also continued in 2019. While the technical lifetimes of solar panels can be up to 25-40 years, the volume of decommissioned panels in the coming decade is expected to be large, and research into second-life (reuse) and end-of-life (recycling) options was ongoing in many countries during the year.²⁷⁴ PV Cycle (France) collected more than 280,000 solar PV panels for recycling.²⁷⁵ Also in 2019, Jinko Solar, the world's top module manufacturer, became the first solar PV manufacturer to join RE100, pledging to source all of its energy from renewable sources, aiming for 70% by 2023 and 100% by 2025.²⁷⁶ It was followed, in early 2020, by LONGi, which committed to 100% renewable electricity across its operations by 2028.²⁷⁷

i Inverters convert direct current electricity from solar panels to alternating current for the electric grid.

KEY FACTS

- Global CSP capacity in operation again grew exclusively in emerging markets and spread to new countries including Israel, Kuwait and France.
- An estimated 21 GWh of thermal energy storage was operating in conjunction with CSP plants across five continents.
- Levelised costs of energy from CSP continued to decline, with CSP being built increasingly alongside both solar PV and wind power to lower costs and raise capacity value.



CONCENTRATING SOLAR THERMAL POWER (CSP)



CSP MARKETS

Global CSPⁱ capacity grew 11% in 2019 to 6.2 GWⁱⁱ, with 600 MW of capacity coming online.¹ This was down from the 700 MW commissioned in 2018 and well below the average annual increase (24%) of the past decade.² (→ See *Figure 32 and Reference Table R17.*) However, CSP continued to spread to new markets, and more than 1.1 GW of additional capacity was under construction at year's end.³

Five countries brought new CSP plants into operation during the year: Israel led the market in new additions, followed by China, South Africa, Kuwait and France.⁴ Israel, Kuwait and France saw the implementation of their first commercial CSP capacity.⁵ For the fourth consecutive year, all new CSP capacity came online outside of Spain and the United States, the two leading countries for cumulative capacity since the technology was first commercialised in the 1980s.⁶

For the first time, as much tower capacity as parabolic trough capacity was completed in 2019.⁷ Each of these technologies represented around 45% of total additions, and linear Fresnel plants accounted for the remaining 10%.⁸ However, parabolic trough plants continue to represent the majority of total global installed capacity. At year's end, the plants under construction worldwide included just under 0.9 GW of trough systems, just under 0.3 GW of tower systems and a 14 MW Fresnel system.⁹ With the exception of two hybrid CSP-natural gas plantsⁱⁱⁱ, all of these plants will include thermal energy storage (TES).¹⁰

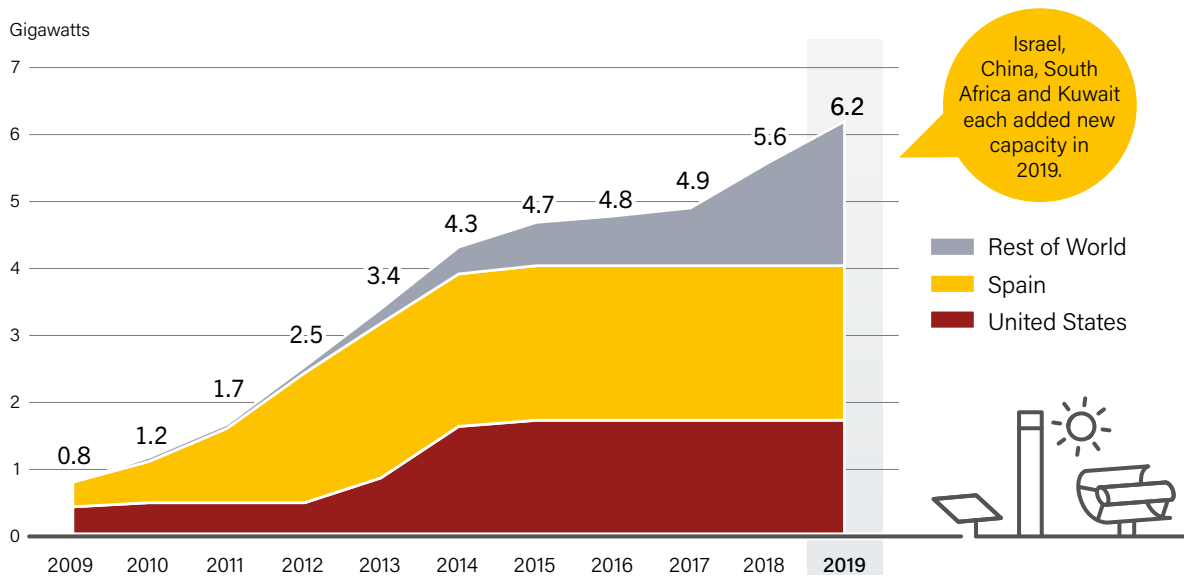


i CSP is also known as solar thermal electricity (STE).

ii GSR 2019 reported that the 150 MW Noor III CSP plant in Morocco entered operations in early 2019. Subsequent reports have indicated that the plant is considered to have begun commercial operations in late 2018. This edition of the GSR has revised CSP market data accordingly. See endnote 1 for this section.

iii The two plants without TES are integrated solar combined-cycle (ISCC) facilities, hybrid plants that use both solar energy and natural gas to produce electricity.

FIGURE 32. Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2009-2019



Source: See endnote 2 for this section.

Israel added more CSP capacity than any other country in 2019, bringing online 242 MW, including the 121 MW Megalim tower plant (no TES) and the 121 MW Negev parabolic trough plant with molten salt storage (4.5 hours; 495 MWh).¹¹ The projects are Israel's first two commercial CSP facilities and the country's largest renewable energy plants of any type.¹² The Megalim project also includes the world's tallest solar tower, at 240 metres high.¹³

China followed with a total of 200 MW of capacity completed in four CSP plants of 50 MW each, all with molten salt TES.¹⁴ The projects include the Dacheng Dunhuang Fresnel plant (13 hours; 650 MWh), the Power Qinghai Gonghe tower plant (6 hours; 300 MWh), the CPECC Hami tower plant (8 hours; 400 MWh) and the Luneng Haixi tower plant (12 hours; 600 MWh).¹⁵ The first three of the new plants are among 20 CSP "demonstration"ⁱ plants that were announced by China's National Energy Administration in 2017; 5 of the plants were operational at the end of 2019.¹⁶ The plants completed during the year brought the country's total CSP capacity to 420 MW.¹⁷ At year's end, China had an additional 250 MW of both parabolic trough and tower capacity under construction, in parallel with 2.4 GWh of TES.¹⁸

In South Africa, the 100 MW Kathu parabolic trough plant (4.5 hours; 450 MWh) entered commercial operations, bringing the country's total installed CSP capacity to 500 MW.¹⁹ An additional 100 MW of tower capacity was approaching construction during 2019.²⁰ However, further development of the South African CSP sector was in doubt following the release in late 2019 of the country's Integrated Resource Plan (IRP), which makes no capacity allocations for CSP before 2030.²¹

Kuwait brought its first CSP capacity online with the opening of the 50 MW Shagaya parabolic trough plant (9 hours; 450 MWh).²² This is the first phase of a planned 3 GW renewable energy park that will incorporate multiple renewable energy technologies, including wind power and solar PV.²³

The Shagaya plant is part of a growing market in the Middle East and North Africa (MENA) region, where 15 plants totalling almost 1.8 GW accounted for nearly 30% of global capacity in operation at the end of 2019.²⁴ Capacity in the region is expected to increase significantly with completion of the Noor 1 Energy project under construction in the United Arab Emirates.²⁵ The Noor 1 project will include 700 MW of CSP capacity, consisting of three 200 MW parabolic trough plants and a 100 MW tower plant, coupled with 15 hours of storage capacity.²⁶

The smallest CSP plant to reach commercial operations in 2019 was the 9 MW eLLO Fresnel plant (4 hours; 36 MWh), the first commercial CSP facility in France.²⁷ Although no other commercial CSP projects were being built in Europe during the year, a Chinese consortium was selected for the engineering, procurement and construction of a 52 MW (5 hours; 260 MWh) tower project on the Greek island of Crete; the project is planned for operation in 2020.²⁸

In addition, construction continued on the 110 MW Cerro Dominador project in Chile (17.5 hours TES).²⁹ Construction began in 2014 and has been hampered by delays, but the plant was expected to be operational in 2020.³⁰ Despite significant past CSP development activity, Cerro Dominador remains the only CSP plant in Chile to have passed the development phase and entered construction.³¹

ⁱ While the GSR generally excludes pilot and demonstration facilities from the CSP market data, the Chinese demonstration plants are included due to their scale and the fact that they are being grid connected.

For cumulative capacity in operation, Spain remained the global leader with 2.3 GW at the end of 2019, followed by the United States with just over 1.7 GW.³² With no new capacity additions in six years, Spain's share of global CSP capacity in operation declined from a high of nearly 80% in 2012 to just under 40% by the end of 2019.³³ The United States, which has added no new CSP capacity since 2015, was home to just under 30% of global CSP capacity by the end of 2019.³⁴ Neither country had new facilities under construction at year's end, although the Spanish government announced plans to increase installed capacity 5 GW by 2030.³⁵

All of the commercial CSP capacity under construction by the end of 2019 was in Asia (China and India), the Middle East (United Arab Emirates and Saudi Arabia) and Latin America (Chile).³⁶ The pipeline of CSP projects under construction reached around 1.1 GW, with the United Arab Emirates accounting for more than 60% of this capacity.³⁷

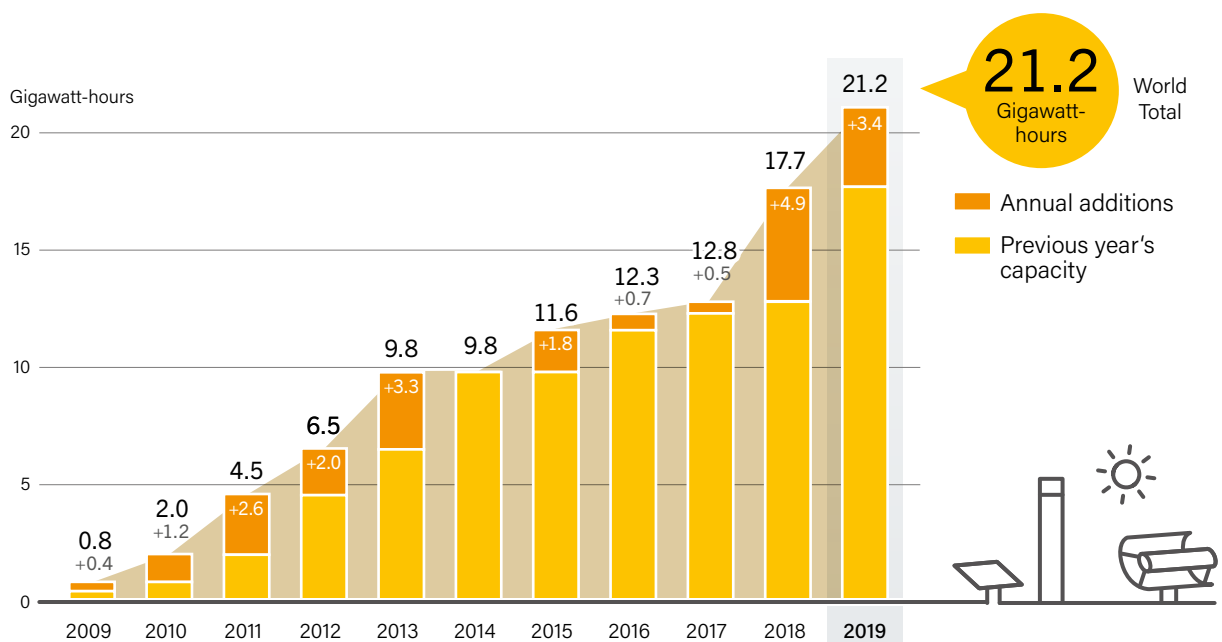
Nearly all of these projects will include thermal energy storage, which improves plant economics and increases system benefits – such as providing relatively dispatchable electricity and grid flexibility – which can support the integration of higher shares of variable renewable electricity in power systems.³⁸ (→ See *Systems Integration* chapter.)

At the end of 2019, an estimated 21 GWhⁱ of TES, based almost entirely on molten saltsⁱⁱ, was operating in conjunction with CSP plants across five continents.³⁹ (→ See *Figure 33*.) Of the 23 CSP plants completed globally since the end of 2014, only two do not incorporate TES: an ISCC facility in Saudi Arabia and the Megalim plant in Israel.⁴⁰



i The total TES capacity in MWh is derived from the sum of the individual storage capacities of each CSP facility with TES operational at the end of 2019. Individual TES capacities are calculated by multiplying the reported hours of storage for each facility by their corresponding rated (or net) power capacity in MW.
 ii More than 95% of global TES capacity in operation on CSP plants is based on molten salt technology. The remainder use steam-based storage.

FIGURE 33. CSP Thermal Energy Storage Global Capacity and Annual Additions, 2009-2019



Note: Totals may not add up due to rounding.

Source: See endnote 39 for this section.

CSP INDUSTRY

The CSP industry has become increasingly diverse geographically, in terms of the location of commercial plants as well as the origins of developers, investors and contractors involved in project implementation. CSP projects that either entered operations or were under construction during 2019 involved lead developers and investors from at least eight countries including China, France, Israel, Kuwait, Saudi Arabia, Spain, the United Arab Emirates and the United States.⁴¹ Contractors were based in China, Denmark, Israel, Spain and the United States, with Chinese companies involved in almost half of the completed or active projects.⁴² By contrast, before 2015 most CSP companies hailed from the United States and Spain.⁴³

The Saudi company ACWA Power remained the leading CSP project developer in 2019, with around 700 MW of projects under construction.⁴⁴ Other notable developers, investors or owners of CSP plants that either entered operations or were under construction during the year included EIG Global Partners (United States), ENGIE (France), Royal Tech (China), Noy Fund and Shikun & Binui (both Israel), as well as at least 13 other developers from around the world.⁴⁵

The leading companies involved in the engineering, procurement and construction of CSP facilities (ranked in terms of megawatts completed and/or under construction) included Abengoa (Spain), Shanghai Electric (China), Acciona (Spain), General Electric (United States), Sener (Spain), Brightsource (Israel) and China Shipbuilding New Power Company (China).⁴⁶

With the spread of markets around the world, the broadening of supply chains and increasing experiences in the industry, costs have continued to fall.⁴⁷ Lower total installed costs combined with longer or more flexible power purchase agreements and higher capacity factors (thanks largely to including TES and the shift towards locations with better resource conditions for CSP) have reduced the cost of electricity from CSP.⁴⁸

A 2019 study estimated that the global weighted average levelised cost of electricity (LCOE) of CSP in 2018 (USD 18.5 per MWh) was 26% lower than it was in 2017, and 46% lower than in 2010.⁴⁹ Another study from 2019 estimated that the average LCOE of new CSP capacity with storage was lower than the average LCOE of new natural gas peaking plants under certain circumstances.⁵⁰ Despite these advances, developers of CSP with TES faced strong competition from projects coupling solar PV and wind power with battery storage, which were increasingly prevalent in 2019.⁵¹ (→ See *Systems Integration chapter*.)

In many cases CSP and TES capacity are being combined with solar PV and/or wind power capacity in hybrid facilities to lower costs and increase capacity value. For example, Israel's Megalim and Negev CSP plants each are located alongside solar PV plants, and China's new 50 MW Luneng Haixi plant forms part of a 650 MW renewable energy complex that also includes 200 MW of solar PV and 400 MW of wind power capacity, plus 50 MW of storage capacity.⁵² The 110 MW Cerro Dominador plant in Chile will incorporate 17.5 hours of TES alongside an existing 100 MW solar PV plant.⁵³

In 2019, a hybridised project in Morocco that will combine CSP, solar PV and energy storage was awarded by the Moroccan Agency for Sustainable Energy at a tariff of MAD 680 (USD 68) per MWh.⁵⁴ Contractual agreements for the United Arab Emirates' Noor Energy 1 project, which will combine 700 MW of CSP capacity with 8.1 GWh of TES and 250 MW of solar PV capacity, were finalised in early 2019 based on a CSP tariff of USD 73 per MWh in parallel with a solar PV tariff of USD 24 per MWh.⁵⁵

Also in 2019, a range of R&D activities were under way that aimed to further reduce the costs of CSP. Some of this work focused on increasing system operating temperatures in order to unlock greater thermal energy efficienciesⁱ. For example, a partnership between the French utility EDF and Chinese CSP technology company Shouhang aimed to convert an existing CSP demonstration project from using a steam cycle for thermal power generation to using a closed-loop supercritical CO₂ cycle, which is capable of higher operating temperatures.⁵⁶

In the United States, a government-backed programme at Sandia National Laboratories was focused on developing a CSP central receiver that is capable of operating at temperatures above 1,000 °C, allowing for greater heat concentration.⁵⁷ Also in 2019, the US Department of Energy announced USD 30 million in support for 13 research projects, with the goal of improving CSP economics by reducing manufacturing costs, developing new storage technologies and allowing for more autonomous system operations.⁵⁸

R&D attention during the year also was focused on addressing the environmental impacts of CSP. In Europe, for example, researchers were evaluating novel ways to reduce water consumption for heliostat cleaning through the development of ultrasonic cleaning systems and hydrophobicⁱⁱ coatings.⁵⁹

CSP capacity

has been combined with solar PV and/or wind power capacity in hybrid facilities to lower electricity generation costs.



i Higher operating temperatures can enable greater thermodynamic efficiency in the heat transfer processes that are involved in steam-based power generation.

ii Hydrophobic coatings repel water that otherwise might collect on the surface of the heliostat and absorb dust particles from the surrounding air.

KEY FACTS

- China remained the world's largest national market for solar thermal systems, followed distantly by the United States, Turkey, Germany and Brazil.
- Outside China, new additions in the largest solar heating and cooling markets were stable, with growth in some markets balancing declines in others.
- The year saw record-high additions of solar industrial heat capacity, led by Oman, China and Mexico.
- The largest collector manufacturers stabilised their production volumes on average, but small and medium-sized collectors faced increased pressure.

SOLAR THERMAL HEATING AND COOLING



SOLAR THERMAL HEATING AND COOLING MARKETS

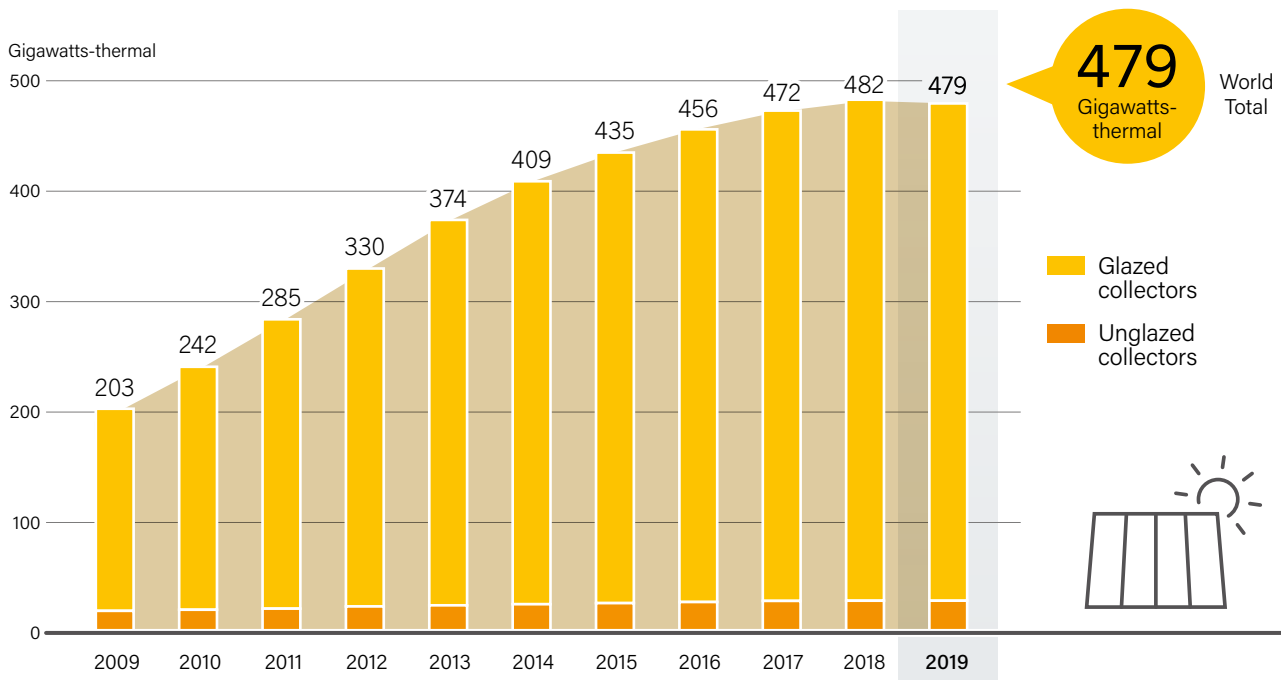
Solar thermal heating and cooling systems served millions of residential, commercial, industrial and public clients in 2019. By year's end, the systems had been sold in at least 134 countries for use in a wide range of applications including hot water, space heating and cooling, product drying and water desalination.¹

An estimated 31.3 gigawatts-thermal (GW_{th}) of glazed (including flat plate and vacuum tube technology) and unglazed solar collectors was added globally in 2019, and by year's end a total of an estimated 479 GW_{th} was in operation.² These three types of solar thermal collectors provided around 389 terawatt-hours (TWh) (1,402 petajoules, PJ) of heat annually by the end of 2019 – equivalent to the energy content of 229 million barrels of oil.³

For the first time ever, the estimated cumulative global operating solar thermal capacity declined in 2019, down 1% from the previous year's total of 482 GW_{th}.⁴ (→ See Figure 34 and Reference Table R18.) The drop is attributed to insufficient new additions in China to meet or exceed the capacity of systems that were retired during the year.⁵ China remained the world's largest national market for solar thermal systems, accounting for 69% of cumulative world capacity, followed distantly by the United States, Turkey, Germany and Brazil.⁶ Not including China, global capacity increased 3% to an estimated 148 GW_{th} in 2019, up from 144 GW_{th} in 2018.⁷

i The service life of systems operating in China is assumed to be 10 years. In 2019, the new capacity installed in the country (22.8 GW_{th}) was less than the capacity added 10 years earlier, in 2009, when 29.4 GW_{th} was put in operation.

FIGURE 34. Solar Water Heating Collectors Global Capacity, 2009-2019



Note: Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors.

Source: IEA SHC. See endnote 4 for this section.

In addition to the three main collector types, other technologies such as hybrid, concentrating and air collectors are available to meet specific heat needs. Because annual additions of these technologies are small, they are not yet included in global and national capacity statistics. As of the end of 2019, hybrid or solar PV-thermal technologies provided 608 MW_{th} of thermal capacity (as well as 208 MW of electric power capacity) for space and water heating.⁸ In addition, around 554 MW_{th} of concentrating solar thermal capacity provided hot water or steam for commercial and industrial customers.⁹ An estimated 1.1 GW_{th} of air collectors for drying and space heating was in operation at the end of 2018 (latest data available).¹⁰

China again led the world for new installations of glazed and unglazed collectors – accounting for 73% of the total – followed by Turkey, India, Brazil and the United States.¹¹ The top 20 countries accounted for 94% of global additions in 2019.¹² Global newly commissioned capacity in 2019 (31.3 GW_{th}) was down 7% from 2018, due mainly to an 8% contraction in China.¹³ Outside China, new additions in the largest solar heating and cooling markets remained stable in 2019, with growth in Brazil, Cyprus, Denmark, Greece, South Africa and Tunisia balancing declines in Australia, Austria, Germany, Israel, Italy, Poland and Switzerland.¹⁴ (→ See Figure 35.)

Among glazed collectors, the transition from vacuum tube to flat plate accelerated in 2019, driven by high demand for flat plate

units in China's building industry. Flat plate collectors dominated in the largest European markets and reached a 28% market share in the world's 20 largest solar thermal markets (up from 24% in 2018).¹⁵ The share of vacuum tube collectors among new additions in the 20 largest markets fell to 67% in 2019, from 72% in 2018, although vacuum tube units still represented more than 75% of new installations in China and India and about 50% in Turkey.¹⁶

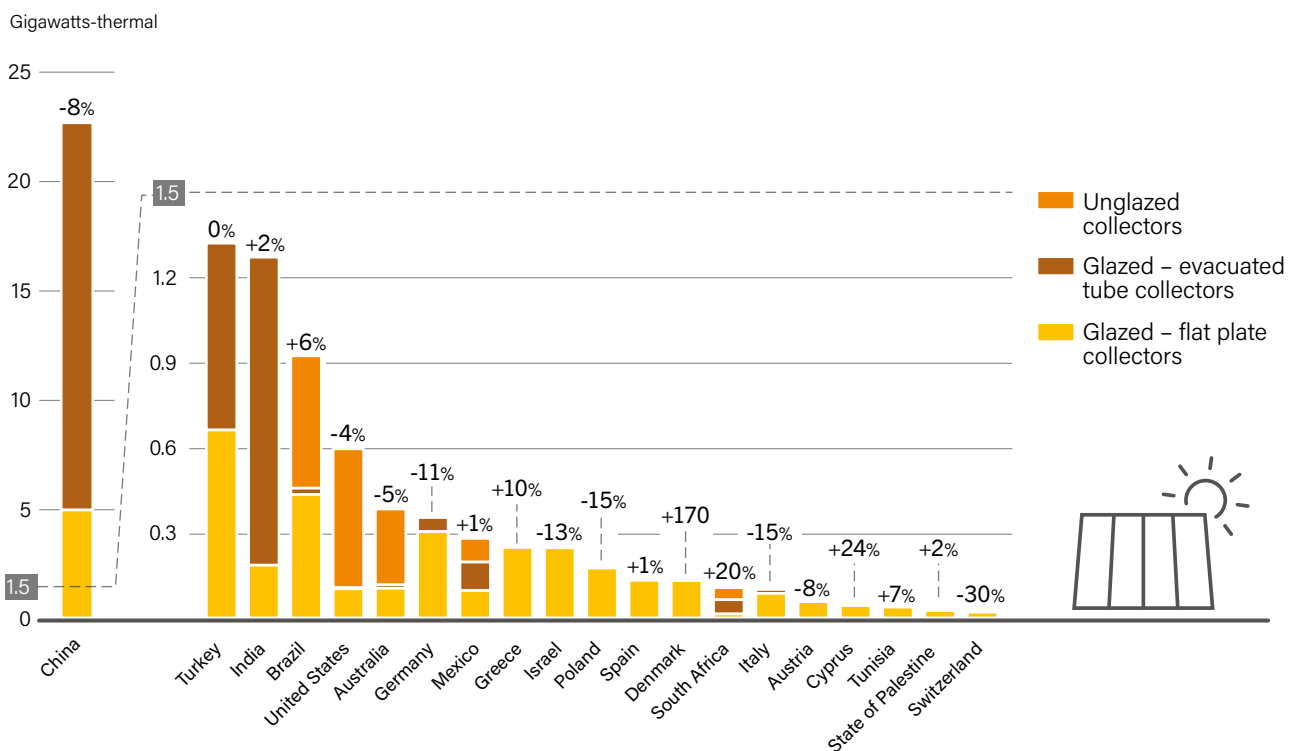
The market share of unglazed collectors, commonly used to heat swimming pools, increased slightly in 2019, to 5%.¹⁷ Unglazed collectors accounted for more than half of all new installations in Australia, Brazil and the United States.¹⁸

Despite remaining the world's largest installer of solar thermal technologies, China's market has declined 8% annually on average since its record year of 2013.¹⁹ New installations in China in 2019 totalled 22.8 GW_{th}ⁱ, 17 times more than those in Turkey, the second largest market.²⁰ Shandong was the top Chinese province for both production and installation of solar collectors for the eighth year in a row, followed by Zhejiang and Yunnan.²¹ Although sales of vacuum tube collectors fell 13% in China in 2019, demand for flat plate collectors rose 15%, for use on high-rise balconies and for large central hot water systems.²²

The transition continued in China from small residential solar thermal units to large projects for multi-family residences, tourism and the public sector, with large projects accounting for 74% of Chinese capacity additions in 2019, up from 61% in 2015.²³

i New additions in China were based on produced collector area, and included export volumes in the national statistics for 2019 and earlier years. The export volumes for previous years were not known at the time of publication, and to the extent possible GSR 2021 will reflect corrected statistics.

FIGURE 35. Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2019



Note: Additions represent gross capacity added.

Source: See endnote 14 for this section.

In many provinces and cities, authorities called on businesses and industry to abide by existing solar building codes by installing solar hot water systems in new and refurbished buildings.²⁴ Tenders for solar thermal in the construction business represented three-quarters of China's total market volume in 2019.²⁵

China saw only limited progress in the use of solar thermal systems for space heating and for industrial and agricultural processes, with 282 MW_{th} installed in the first half of 2019.²⁶ A key reason for the slow growth was the preference in "green" heating policies for stand-alone heat pumps rather than solar thermal systems to replace coal boilers in the northern provinces. Concerns have arisen around overheating associated with large solar space heating fields during the summer months, as well as the need for an auxiliary heating device and the limited experience of users in operating solar space heating systems.²⁷

Turkey's market remained stable in 2019, and the country's 1.32 GW_{th} of new installations was divided roughly equally among flat plate and vacuum tube collectors.²⁸ Flat plate sales were buoyed by public orders for central hot water systems in hospitals, prisons and refugee camps. Vacuum tube collectors were sold in the residential market and mainly in the colder regions of Turkey (such as middle and eastern Anatolia), as well as for replacement of existing solar water heaters.²⁹

Following two years of double-digit expansion (18% in 2018 and 26% in 2017), India's market grew 2% in 2019, with 1.27 GW_{th} of new installations.³⁰ Vacuum tube collectors again dominated sales – representing 85% of additions – but their share of the market declined relative to 2018 as sales remained stable.³¹ Meanwhile, sales of flat plate collectors increased as several tenders prioritised certified collectors, which according to Indian standards apply only to flat plate units.³²

Three Indian states – Karnataka, Gujarat and Maharashtra – accounted for nearly 90% of the country's additions in 2019.³³ Karnataka remained the leading state, with almost half of newly installed solar thermal systems, and Gujarat overtook Maharashtra to account for around 20% of total sales in 2019.³⁴ Gujarat's strong growth is attributed to high awareness of solar energy across the state in cities as well as increasingly in semi-urban areas and villages.³⁵

Brazil added 0.93 GW_{th} of solar thermal capacity in 2019, up 6% from the previous year.³⁶ The growing construction industry and increasing demand from new commercial customer groups with high hot water demand – such as restaurants, spas and laundries – contributed to this surge, which followed four years of continuously declining sales in the country.³⁷

The United States was the fifth largest market for the three main types of solar thermal collectors in 2019 (600 MW_{th}) and was the largest market for unglazed collectors (487 MW_{th}).³⁸ The unglazed segment, used mainly to heat swimming pools, accounted for 81% of US additions.³⁹ The smaller glazed segment remained stable in 2019, following an 8% decline in 2018, despite continuing low oil and natural gas prices and an increasing domestic focus on solar PV.⁴⁰ Hawaii's solar obligation and the California Solar Initiative's solar thermal rebate programme, which is set to expire in July 2020, helped to stabilise sales.⁴¹

The European Union (EU-28) remained the second largest regional market after Asia, with estimated gross additions of 1.5 GW_{th} in 2019, down 1.8% from 2018.⁴² More than 10 million solar thermal systems were in operation by year's end.⁴³ The decline in sales is attributed to the low rate of refurbishment of old heating systems, the low interest in solar thermal systems among installers and the still relatively high cost of residential solar thermal systems in most European countries.⁴⁴ In addition, continued discussion about the electrification of residential heat demand generated interest in heat pump solutions among private homeowners and public and commercial clients, which reduced the demand for solar thermal systems.⁴⁵

Annual additions in the two leading EU countries for solar thermal installations – Germany (358 MW_{th}) and Greece (253 MW_{th}) – converged in 2019 due to opposing national trends.⁴⁶ The German market continued its decade-long decline (down 11% in 2019), whereas additions in Greece grew 10% for the fifth year in a row due to cost-competitive products, a regulation stipulating a minimum 60% solar hot water share in new buildings and the Energy Savings in Households grant programme.⁴⁷ Germany's situation changed in early 2020, however, following a ruling in December 2019 that enabled the provision of grants that cover 40% of the costs of replacing an outdated oil boiler with a natural gas condensing boiler supported by a solar space heating unit.⁴⁸

The globalisation of solar thermal technologies continued in 2019, with sales picking up for example in the Middle East's Gulf region as users in some countries found it financially attractive to use solar thermal rather than electricity to provide domestic hot water.⁴⁹ In Saudi Arabia, a gradual reduction in subsidies for electricity (commonly used to heat water) led to greater demand for solar hot water solutions among hotels and the construction industry.⁵⁰ Imports of solar thermal systems to the United Arab Emirates reached a record high in 2019 in response to a building regulation in Dubai that requires solar thermal systems on new construction.⁵¹

In Kuwait, where imported natural gas generates half of all electricity, the government began using solar water heating in public buildings to reduce electricity use and natural gas imports.⁵² The country's Sabah Al Ahmed University installed a 0.5 MW_{th} rooftop system on its buildings, and the Kuwaiti Public Authority for Housing Welfare announced plans to install solar water heaters on all new villas that it builds in the coming years.⁵³

The year 2019 was a bright period for **solar district heating** in Denmark, China and Germany. Denmark had a record year for new installations, bringing online 10 new solar district heating plants and expanding 5 existing plants, for a total of 134 MW_{th} added (compared to only 6 new plants and 4 expanded plants totalling 47 MW_{th} added in 2018).⁵⁴ Denmark consolidated its lead in the global solar district heating market as capacity topped 1 GW_{th} in August 2019, when as many as 113 Danish villages, towns and cities were using solar energy for space heating.⁵⁵

Denmark's strong market was supported by good framework conditions, including high taxes on fossil fuels, sufficient land for cost-effective ground-mounted collector fields and low-cost financing for the non-profit, user-owned utilities that operate the district heating networks.⁵⁶ Flat plate collectors were the dominant technology for new solar district heating systems in both Denmark and Germany.

In China, under the state-financed solar district heating programme for Tibet, three solar district heating systems were commissioned in the last quarter of 2019.⁵⁷ In October, 1,800 households in the Tibetan town of Shenzha were connected to a district heating system that was designed to cover 75% of its demand with heat from a 14 MW_{th} parabolic trough collector field.⁵⁸ An even higher annual solar share of around 90% may be achieved at a new solar district heating plant in the town of Zhongba, where since 2019 a 24.5 MW_{th} flat plate collector field with 15,000 m³ of seasonal storage has provided households with a total heated floor area of 118,000 m².⁵⁹ A second 13.4 MW_{th} flat plate collector field began operation in the town of Saga to supply public buildings with 80,000 m² of heated floor space.⁶⁰

Outside Tibet, no new large solar space heating systems were reported in China in 2019, as coal boilers were replaced mostly with heat pumps under the green heating policies in the northern provinces.⁶¹

Germany again saw an increase in its solar district heating installed capacity, as a growing number of municipal utilities discovered large solar thermal systems to be an economically feasible solution. Six new systems totalling 9.9 MW_{th} were added in 2019, compared to a total of 5.8 MW_{th} for five smaller solar fields completed in 2018.⁶² Three additional systems were under construction as of the end of 2019, including a 10.4 MW_{th} field in Ludwigsburg, which will be Germany's largest solar district heating plant when it comes online in 2020.⁶³

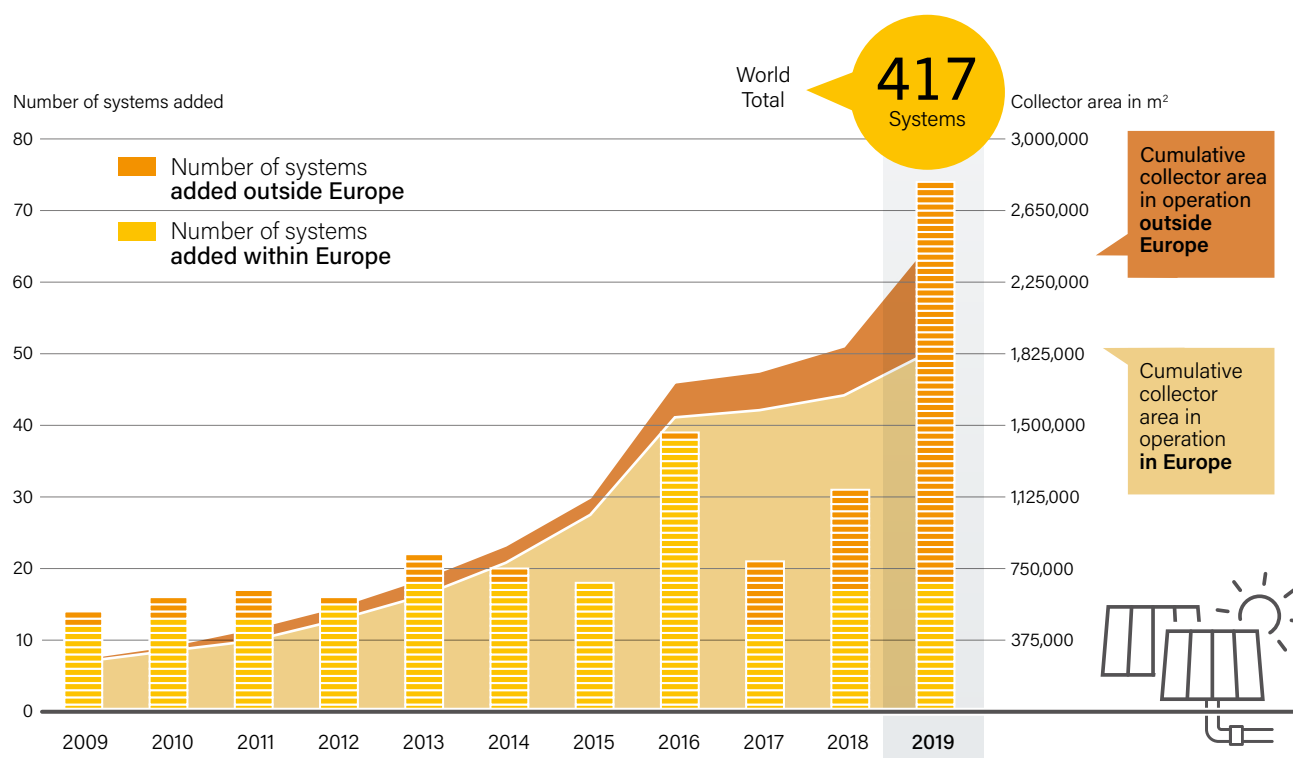
The successful development of solar district heating in Denmark, China and Germany has generated interest beyond these countries. In September 2019, the district heating operator in

Salaspils, Latvia inaugurated a 15 MW_{th} solar field paired with a wood chip boiler to meet 90% of demand from the local heat network.⁶⁴ Solar district heating also attracted interest in Serbia and Kosovo after the European Bank for Reconstruction and Development provided funding for (pre-)feasibility studies. As of early 2020, a feasibility study was completed for the Serbian town of Pancevo, with promising results, and pre-feasibility analyses had been conducted for Belgrade, Bor and Novi Sad in Serbia and Pristina in Kosovo.⁶⁵

Two very large solar district heating projects were delayed in 2019. In China, a 51 MW_{th} solar field intended to meet heating and cooling needs in Turpan (Xinjiang province), one of the country's energy demonstration cities, was put on hold because of funding challenges.⁶⁶ The Big Solar Graz project, a planned 154 MW_{th} solar field with 0.9 million m³ of seasonal storage for district heating in Graz, Austria did not develop further due to conflicts with the project's Danish major financing institution.⁶⁷

In addition to solar district heating, **central solar hot water systems** for large residential buildings, hospitals and prisons sold well in China and Turkey in 2019. In China, 44 such projects were commissioned during the year, each with collector fields of at least 350 kilowatts-thermal (kW_{th}) (500 m²), for a combined total of 175 MW_{th}.⁶⁸ In Turkey, the government ordered central hot water systems for three prisons and three hospitals, for a total of 4.8 MW_{th}.⁶⁹ By the end of 2019, at least 417 district heating and central hot water systems were in operation around the world (up from 345 systems in 2018), with a cumulative capacity of 1.73 GW_{th} (including glazed and concentrating solar thermal collectors).⁷⁰ (→ See Figure 36.)

FIGURE 36. Solar District Heating Systems, Global Annual Additions and Total Area in Operation, 2009-2019



Note: Includes large-scale solar thermal installations for residential, commercial and public buildings. Data are for solar water collectors and concentrating collectors.

Source: IEA SHC. See endnote 70 for this section.

In addition to the growing interest in new water heating installations for public and residential buildings, solar thermal technologies are used increasingly to provide heat for industry around the world. Industry accounts for a large share of global heat demand, and solar energy is suitable for meeting needs in the low-to-medium temperature range (below 400 °C), which account for around 50% of industrial heat demand.⁷¹

In 2019, global additions of **solar industrial heat capacity** reached a record high of 251 MW_{th}, up from 39 MW_{th} in 2018 and 153 MW_{th} in 2017.⁷² The top country for newly installed capacity was Oman – where the Miraah solar steam project developed by Glasspoint (United States) added 180 MW_{th} – followed by China (53 MW_{th}), Mexico (3 MW_{th}), India (2 MW_{th}) and Germany (1 MW_{th}).⁷³ China and Mexico led in the number of new solar heat for industrial processes (SHIP) systems, with 26 systems each, followed by Germany with 11 new installations.⁷⁴ By year's end, at least 817 SHIP systems totalling more than 700 MW_{th} were supplying process heat to factories worldwide.⁷⁵

Solar industrial heat plants in Mexico, Oman and Spain were cost-competitive with fossil fuels, suggesting the potential for further market growth.⁷⁶ In many other countries, however, achieving competitiveness against oil and natural gas remained challenging.⁷⁷ Consequently, a growing number of governments supplied funding for solar industrial heat installations in 2019, including Austria, China, France, Germany and the Netherlands. Supported by grants, several new large installations were built, including a 3.4 MW_{th} flat plate collector system supplying heat to a French paper mill and a 6.5 MW_{th} field providing heat for floral greenhouses in the Netherlands.⁷⁸ As of early 2020, a 10 MW_{th} plant was under construction in France to deliver process heat to a malting plant.⁷⁹

Potential new markets were discovered in 2019 with the installation of the first industrial solar heat plants in Malaysia, Portugal, Saudi Arabia and Senegal.⁸⁰ Financed by the World Bank, feasibility studies for selected industry sectors also were conducted in the Middle East and North Africa region, and construction of the first plant within the World Bank's support programme in Morocco was expected to begin in 2020.⁸¹

SOLAR THERMAL HEATING AND COOLING INDUSTRY

Manufacturers are producing and delivering a wide range of solar heating and cooling solutions to meet customer needs in the residential, public, commercial and industrial sectors. In 2019, significant consolidation occurred – with large players expanding their market shares mostly through contracts for large capacities or high numbers of systems, and smaller manufacturers (particularly in Europe) struggling because of declining demand.

Although the worldwide solar thermal market declined in 2019, Chinese manufacturers of flat plate collectors expanded their production volume by 21% in response to increased demand from the national construction industry for both façade integration and central collector fields.⁸² However, some large manufacturers competed against one another with low-price bids and sacrificed margins to utilise their greatly expanded production capacities.⁸³ Industry consolidation occurred in Europe in 2019, with the largest flat plate collector manufacturers stabilising their production volumes on average, but small and medium-sized collectors facing increased pressure as demand contracted in several major markets.⁸⁴ Consequently, a number of companies in the region's small and medium-sized manufacturer group became insolvent or ceased production during the year.⁸⁵

Two long-time European solar brands, KBB Kollektorbau (Germany) and Kingspan Renewables (Ireland), closed their collector factories, with Kingspan halting completely its manufacturing of solar thermal products.⁸⁶ KBB, citing the lack of effective support measures in the renewable heating market as well as falling prices and dwindling margins, announced that it would sell its machinery to an independent business outside Europe and maintain only a sales and engineering team in Berlin.⁸⁷

The insolvencies of manufacturers Aventa Solar (Norway) and Fresnex (Austria) were caused by their inability to secure the necessary funding to increase business volumes and maintain financial health.⁸⁸ Investors took over the technologies of both companies: 3 Norske AS purchased the assets of Aventa Solar's polymeric collector technology in 2019, and in early 2020 it announced plans to build up collector production in Jevnaker, Norway under the new name Inaventa Solar.⁸⁹ Ecotherm, the former business partner of Fresnex, took over that company's collector technology.⁹⁰

The top markets for solar district heating in 2019 were

China, Denmark and Germany.



After filing for bankruptcy in May 2019, Austria's turnkey solar heating and cooling system developer S.O.L.I.D. successfully restructured its business with a new investor under the name Solid Solar Energy Systems.⁹¹ S.O.L.I.D. had suffered after its former project partner VKR Holding (Denmark) failed to deliver milestones related to the delayed Big Solar Graz project, a large solar district heating plant that was expected to cover a double-digit share of heat demand in the district heating network of Graz, Austria.⁹²

Fluctuations in the volume of contracted projects affected some of the world's larger collector manufacturers in 2019, with some seeing growth and others seeing contractions.⁹³ Linuo Paradigma, one of the largest collector manufacturers in China, recorded strong sales of large solar hot water systems in the national market.⁹⁴ Working with local partners, the company's domestic engineering team designed and installed 6 central solar hot water projects with a capacity of more than 7 MW_{th} each and listed 21 projects with collector areas between 3.5 MW_{th} and 7 MW_{th}, for a total of 154 MW_{th} – the second largest project volume of any company in 2019 after Glasspoint.⁹⁵

On the negative side, a major Turkish flat plate collector manufacturer, Solimpeks, recorded a severe drop in production volumes due to the postponement of a large project that was to have been finalised in 2019.⁹⁶ In early 2020, Arcon-Sunmark, the Danish market leader in solar district heating, announced that it would sell its collector factories due to a large financial deficit in recent years.⁹⁷ The heavy losses were because of high fluctuations in turnover and low margins in contracted projects. For example, the company had commissioned 10 solar district heating fields in Denmark during the first half of 2019, but business dried up for the rest of the year after an energy savings schemeⁱ for utilities expired.⁹⁸ Greenonetec (Austria) acquired Arcon-Sunmark's key assets in Denmark, and Solareast Group (China) bought the shares in the company's Asian business.⁹⁹

Technology suppliers of **solar heat for industrial processes** also had a difficult year. Only 30% of the around 80 companies listed in the world database of turnkey SHIP suppliers commissioned a project in 2019, mainly because of low fossil fuel prices, lack of awareness of SHIP technology and a consumer focus on the high upfront costs.¹⁰⁰ A growing number of technology suppliers responded to the challenges of signing contracts with industrial clients by using new manufacturing strategies to reduce costs.

For example, rather than offering solar heat solutions for individual projects, the parabolic trough collector manufacturer Absolicon Solar Collector (Sweden) took the approach of selling complete production lines, with a typical annual capacity of 100,000 m².¹⁰¹ After commissioning its first production line in China in 2018, the company signed agreements in 2019 with Greenline Africa (South Africa) and Ariya Finergy (Kenya) to sell lines for construction in those countries.¹⁰² With this strategy, Absolicon aims to reduce

technology costs by producing solar collector fields close to large numbers of potential heat customers, such as the tea industry in Kenya. The company expects to achieve benchmark costs of EUR 250 (USD 280) per kW_{th} to be cost competitive in the target countries.¹⁰³ Also in 2019, Trivelli Energia (Italy) signed an agreement with Yaoguo (China) to build a parabolic trough collector production line in China.¹⁰⁴

Other solar technology suppliers created new, mutually beneficial partnerships with conventional energy technology providers to overcome some of the challenges of developing SHIP projects. These partnerships enable the collaborating companies to offer solutions that meet the heat, steam and/or cooling demands of their customers while minimising the use of fossil fuels.¹⁰⁵ For example, the linear Fresnel collector manufacturer Industrial Solar (Germany) and the boiler producer Gasco (Australia) agreed to collaborate on hybrid solar-fossil systems to expand solar process heat markets in Australia and neighbouring countries.¹⁰⁶

Several solar collector manufacturers tapped into the wastewater treatment market to widen their sales activities, and joined forces with water separation and purification experts.¹⁰⁷ In early 2019, Rioglass Solar (Belgium), a manufacturer of linear Fresnel collectors, partnered with Condorchem Envitech (Spain), a specialist in multi-effect evaporators, to form Solarvap, a solar-powered wastewater evaporation system.¹⁰⁸ Financed by the issuance of new shares, in early 2020 Industrial Solar (Germany) announced the acquisition of Solarspring (Germany), a manufacturer of membrane-based water treatment systems, to offer clean energy and clean water for industrial customers.¹⁰⁹

Concentrating collector technologies have been used increasingly for heat and steam production. As with glazed collectors, consolidation occurred in 2019 for manufacturers of concentrating collectors that provide systems for heat and steam at temperatures above 100 °C for boiling, sterilising and cleaning. Glasspoint, which focuses on large deals with oil producers to provide solar steam for enhanced oil recovery, added 180 MW_{th} of parabolic trough collector capacity at the Miraah project in Oman – the largest single project capacity commissioned as of the end of 2019.¹¹⁰ By contrast, small and medium-sized manufacturers of concentrating solar solutions in Europe, India and Mexico recorded lower sales figures in 2019 than in 2018.¹¹¹

Third-party financiers discovered new opportunities in the commercial solar heat market in 2019. Third-party financing avoids the high upfront costs for the clients and in most cases is combined with an operation and maintenance contract with solar thermal specialists over the contractual or repayment period, which reduces the client risk associated with a new technology.¹¹² For example, the crowdfunding platform ecoligo.investments (Germany), which until 2019 focused on solar electricity projects, funded three solar hot water systems for hotels in Costa Rica and Kenya during the year.¹¹³

ⁱ The energy savings scheme allowed district heating utilities to fulfil their energy-saving mandates by extending existing solar district heating plants or by initiating the construction of new facilities by mid-2019. See endnote 98 for this section.



Third-party financiers
discovered new opportunities in the commercial solar heat market in 2019.

Another model of third-party financing is a heat supply contract, or energy service company (ESCO). Kyotherm (France), which specialises in financing renewable heat projects, played a pioneering role in setting up ESCOs in 2019 by developing and financing what is anticipated to be Europe's largest solar industrial heat plant, a 10 MW_{th} system for a malting plant in France.¹¹⁴ The malt producer profits from a price below the average price it would pay for heat produced from natural gas combustion. Kyotherm, together with its network of solar thermal project developers, also started contractual negotiations with 11 commercial heat consumers outside France, with plans to sign some project contracts in the first half of 2020.¹¹⁵

A few solar heat project developers signed their first heat supply contracts in 2019. NewHeat (France) financed a 3.4 MW_{th} single-axis tracked flat plate collector system to sell heat to the Condat paper mill in southwest France.¹¹⁶ Azteq (Belgium) signed a solar steam delivery contract with a chemical producer in Antwerp and contracted with Solarlite (Germany) for a parabolic collector field at the client's factory.¹¹⁷

Other project developers faced difficulties in developing their ESCOs because some clients have slow decision-making processes or have been reluctant to commit to medium- or long-term contracts. For example, after Millennium Energy Industries (Jordan) signed its first solar heat delivery contract in mid-2019, the client asked for a delay in the installation, and the project had not been realised as of early 2020.¹¹⁸ SWA Solar Wärme (Austria), established in 2018, completed only one project in 2019 after clients delayed decisions because of a temporary halt in national funding for large-scale projects.¹¹⁹

SHIP project developers in Asia shifted their ESCO businesses away from solar thermal technology, finding it more economical to design heat delivery contracts based on heat pumps. Linuo Paradigma's newly founded subsidiary for developing heat supply contracts realised its first two projects in 2019, both with air-source heat pumps.¹²⁰ Aspiration Energy (India), which announced big plans for solar industrial heat supply contracts in 2017, did not close a single deal with solar heat in 2019 and focused only on heat pump solutions.¹²¹

Solar thermal air conditioning and cooling remained a niche market in 2019. A handful of sorption chiller manufacturers promoted solar thermal cooling systems in southern Europe and the Middle East.¹²² After realising publicly effective reference projects in 2018, Fahrenheit (Germany) contracted seven new solar thermal cooling projects in 2019: two smaller projects in Europe – in an office building in the Netherlands and a family residence in Germany – which were commissioned by the end of the year, and five projects across Australia, Dubai (United Arab Emirates), India, Morocco and Pakistan, which were still under construction at year's end.¹²³

In Italy, despite high investment subsidies under the national Conto Termico 2.0, the solar thermal cooling market did not pick up in 2019. Maya (Italy), a joint venture with Yazaki (Japan) installed only one solar air conditioning system in the country (at a hospital), with a second system under construction at year's end.¹²⁴ Customer demand failed to materialise because in many cases solar heat-driven cooling systems were not cost-effective compared to gas-driven heat pumps or electricity-driven compression chillers, both of which are established air conditioning technologies.¹²⁵

The German-Indian joint venture VSM Solar increased sales efforts for its solar cooling technology, mainly among hospitals and corporate buildings.¹²⁶ The company refurbished a solar air conditioning system with 225 tonnes of refrigeration at an IBM building in Bangalore, India and signed a strategic alliance with Blue Star, a large HVAC manufacturer in India, promoting the large power-saving potential compared to electricity-driven cooling units.¹²⁷ Newly founded Solid Solar Energy Systems (Austria) finished the design phase for an industrial cooling system for the engine manufacturer AVL in Graz, Austria.¹²⁸

Although Thermax (India) was no longer actively promoting solar thermal cooling solutions in 2019, its competitors – other sorption chiller manufacturers such as Energy Concepts (United States) and Shuangliang (China) – redirected their thermal cooling solutions to utilise waste heat (rather than a solar collector field) to drive the cooling machines, as a way to lower investment costs.¹²⁹

In an important step towards the standardisation of solar cooling systems, the world's first standard for space cooling and ventilation systems was published in Australia following seven years of preparation.¹³⁰ The standard includes methods for calculating energy consumption and determining the thermal comfort of space heating and cooling devices and ventilation systems for five different solar air conditioning technologies.¹³¹

KEY FACTS

- The global wind power market saw its second largest annual increase, with offshore wind accounting for a record 10% of new installations.
- Market growth reflected surges in China and the United States in advance of policy changes, and a significant increase in Europe despite continued market contraction in Germany.
- At least 102 countries had some level of commercial wind power capacity, enough to provide an estimated 5.9% of global power generation; the highest shares of generation were in Denmark (57%), Ireland (32%), Uruguay (29.5%) and Portugal (26.4%).
- Falling prices are opening new markets, but the global transition to auctions and tenders has resulted in intense price competition, reducing the number and diversity of participants and leading to further attrition among turbine manufacturers.

WIND POWER

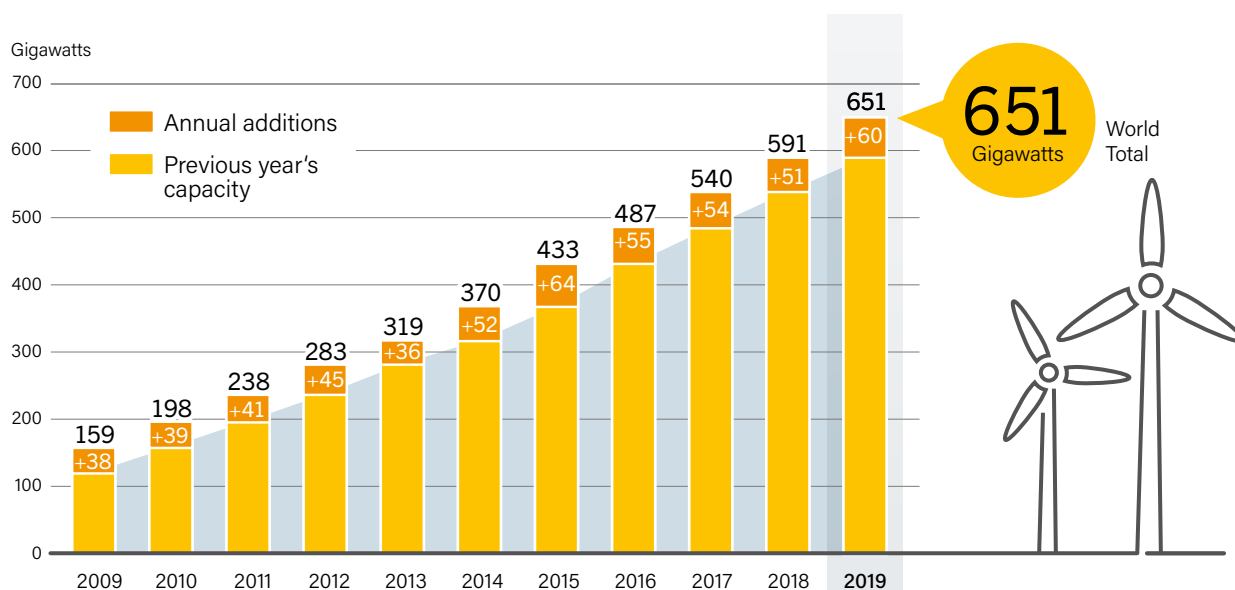


WIND POWER MARKETS

The global wind power market expanded 19% in 2019, with around 60 GW of new capacity added to the world's electric grids (including more than 54 GW onshore and over 6 GW offshore).¹ This was the second largest annual increase in capacity ever, and followed three consecutive years of decline after the peak in 2015 (63.8 GW).² Offshore wind power plays an increasingly important role in the global market, accounting for a record one-tenth of additions in 2019.³ The year's newly installed wind power capacity increased the global total by 10% to around 651 GW overall (621 GW onshore and the rest offshore).⁴ (→ See Figure 37.)

The rapid growth in 2019 was due largely to surges in China and the United States in advance of policy changes and to a significant increase in Europe, despite continued market contraction in Germany.⁵ Some emerging markets experienced slowdowns due to delays in public tenders and stop-and-go policies, which have deterred investment, although several markets in Africa, Latin America, the Middle East and Southeast Asia saw notable growth relative to 2018.⁶ New wind farms reached full commercial operation in at least 55 countries during 2019, up from 47 in 2018, and at least one country, Senegal, brought online its first commercial project.⁷ By year's end, the number of countries with some level of commercial wind power capacity exceeded 102, and 35 countries – representing every region – had more than 1 GW in operation.⁸

FIGURE 37. Wind Power Global Capacity and Annual Additions, 2009-2019



Note: Totals may not add up due to rounding.

Source: GWEC. See endnote 4 for this section.

Rapidly falling costs per kilowatt-hour (both onshore and offshore) have made wind energy ever more competitive and allowed onshore wind power to compete head-to-head with fossil fuel generation in a large and growing number of markets around the world, often without financial support.⁹ The economics of wind energy have become the primary driver for new installations.¹⁰ Outside of China (which has a feed-in tariff, or FIT, for wind power) and the United States (which offers tax credits and state renewable portfolio standards, or RPS), global demand for wind power in 2019 was driven largely by other policy mechanisms including auctions (or tendering), which have exerted a downward pressure on prices.¹¹ In some mature markets – such as in North America (around 80% of the global market) and northern Europe – corporate power purchase agreements (PPAs) are playing an ever more important role; worldwide, newly signed PPAs during 2019 were up an estimated 30% compared with 2018.¹²

Wind power provides a substantial share of electricity in a growing number of countries.

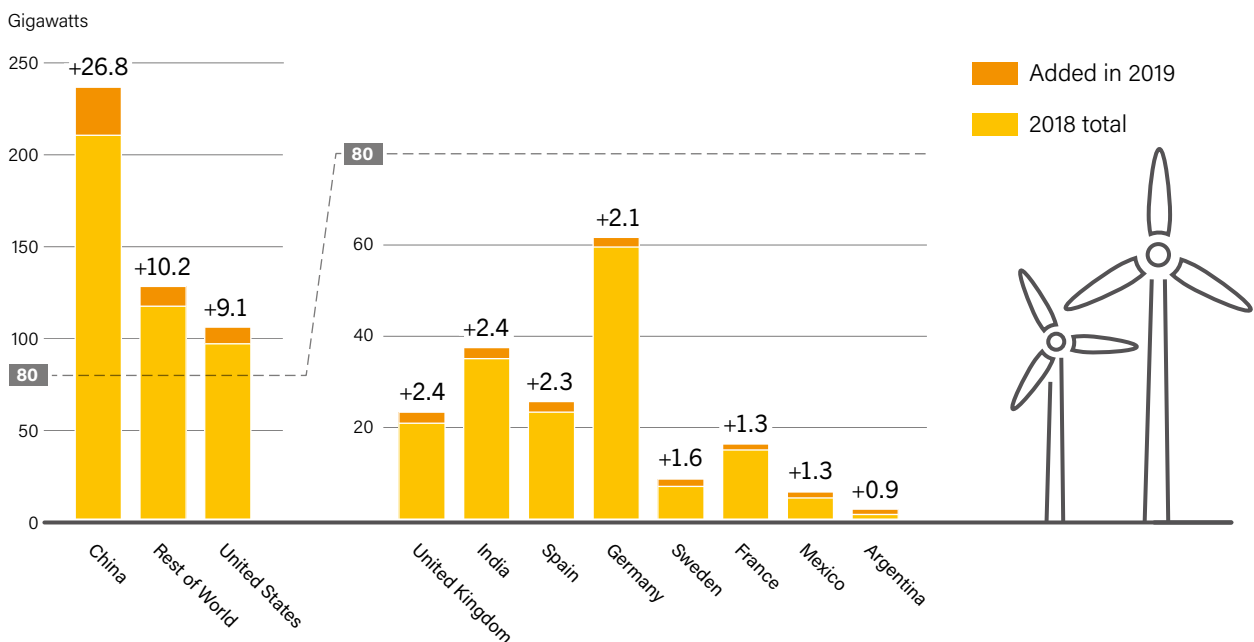
Wind power provides a substantial share of electricity in a growing number of countries. In 2019, wind energy generated

enough to provide an estimated 15% of the EU’s annual electricity consumption, and equal or higher shares in at least seven individual Member States.¹³ Wind energy met an estimated 47% of Denmark’s electricity demand in 2019 and accounted for nearly 57%ⁱ of the country’s total generation.¹⁴ Other countries in Europe with wind generation shares above 20% for all of 2019 included Ireland (32%), Portugal (26.4%), Germany (21.8%) and Spain (20.9%).¹⁵ Uruguay (29.5%), Nicaragua (17.4%) and Costa Rica (15.8%) also achieved high shares of generation from wind energy in 2019, and shares were high at the sub-national level in several countries.¹⁶ By year’s end, wind power capacity in operation worldwide was enough to provide an estimated 5.9% of total global electricity generation.¹⁷

For the 11th consecutive year, Asia was the largest regional market, representing more than 50% (down from 52% in 2018) of added capacity, with a total exceeding 292 GW by the end of 2019.¹⁸ Europe (24%), North America (16%) and Latin America and the Caribbean (6%) accounted for most of the rest of the year’s installations.¹⁹ China retained its lead for new capacity (both onshore and offshore) and was followed distantly by the United States, the United Kingdom and India (both adding almost equal amounts) and Spain; together, these five countries accounted for 70% of annual installations.²⁰ Other countries in the top 10 for total capacity additions were Germany, Sweden, France, Mexico and Argentina.²¹ For cumulative capacity, the top 10 countries were unchanged from 2018.²² (→ See Figure 38 and **Reference Table R19**.)

i The difference between generation (electricity produced within a country’s borders) and consumption is due to imports and exports of electricity and to transmission losses.

FIGURE 38. Wind Power Capacity and Additions, Top 10 Countries, 2019



Note: Additions are net of decommissioning.

Source: See endnote 22 for this section.

China again saw an increase in new installations (up 22%) during 2019, adding around 26.8 GW (24.3 GW onshore and 2.5 GW offshore) for a total of 236.3 GW installed.²³ More than 25.7 GW (23.8 GW onshore and nearly 2 GW offshore) of wind power capacity was integrated into the national grid in 2019, with just over 210 GWⁱ considered officially grid-connected by year's end.²⁴

China's support through the FIT (and its looming expiration), as well as the country's first wind power auction, drove the domestic market in 2019.²⁵ In May, the national government announced that, starting in 2021, FITs for onshore wind generation will no longer exceed those provided for coal-fired generation.²⁶ The government also published an initial list of approved projects (totalling 5.7 GW) to be built without direct financial support.²⁷ The policy changes result from a belief that the wind energy sector is mature enough to proceed without direct government support, as well as the need to clear a backlog of outstanding FIT payments for existing projects.²⁸

Although the northern and western provinces were still home to the majority of China's cumulative capacity by year's end, the top provinces for official grid-connected additions in 2019 were Henan (nearly 3.3 GW), Hebei (2.5 GW), and Shanxi and Shandong (2.1 GW each), with Jiangsu in the lead for offshore installations – all of which are relatively close to demand centres and where curtailment rates were relatively low.²⁹ Overall, an estimated 16.9 TWh of potential wind energy was curtailed in China – a national average of 4% for the year, down from 7% (27.7 TWh) in 2018, and below the national government's targeted cap (10%) for 2019.³⁰ Curtailment remained concentrated mainly in Xinjiang, Gansu and Inner Mongolia, but all three provinces saw substantial reductions relative to 2018.³¹ China's generation from wind energy was up nearly 11% (to 405.7 TWh), and wind energy's share of total generation continued its steady rise, reaching 5.5% in 2019 (up from 5.2% in 2018).³²

India was the only other Asian country to rank among the top 10 for installations of wind power capacity in 2019, placing fourth globally for additions and for total capacity.³³ The country's additions increased 8.5% over 2018, when installations fell nearly 50% from their record high in 2017, as India shifted from FITs to reverse auctions.³⁴ India added 2.4 GW in 2019, bringing the year-end total to 37.5 GW.³⁵ Another 8.6 GW was in the active pipeline at year's end, but many wind (and other) power projects have been delayed by problems obtaining land and accessing transmission lines.³⁶

Although the issuance of tenders remained strong in India during 2019, many were cancelled or undersubscribed, and projects that were already tendered faced delays (due to efforts to renegotiate for lower tariffs or to outright withdrawal of existing PPAs), which have held up turbine deliveries and put significant pressure on the domestic manufacturing industry.³⁷ Among the many challenges deterring investment have been policy uncertainties, India's slowing economy, aggressive bidding, low ceiling tariffs

for auctions, curtailment and infrastructure constraints, delayed payments for generation, lack of low-cost financial resources, lack of available land in good wind areas (where developers want to be, due to low wind energy tariffs) and duties and tariffs on imports.³⁸ The number and diversity of local investors has declined since the shift to auctions, while installations have become more concentrated geographically.³⁹

Elsewhere in Asia, Turkey's annual installations increased relative to 2018, with nearly 0.7 GW added for a total exceeding 8.1 GW.⁴⁰ Wind energy accounted for 7.4% of Turkey's electricity generation in 2019.⁴¹ Thailand placed fourth in the region (added 0.3 GW for a total of 1.5 GW), although its market contracted after a significant drop in FIT rates dampened investor confidence.⁴² Other Asian countries that added capacity included Japan (adding nearly 0.3 GW for a total of 3.9 GW), the Republic of Korea, Pakistan and Vietnam.⁴³ Vietnam's capacity increased 70% (to 388 MW) in a rush to complete projects before generous FIT rates were reduced, and wind power projects competed with solar PV and conventional power projects for space on the country's grid networks.⁴⁴ In much of Southeast Asia, policy uncertainty and subsidies to fossil fuels continued to curb deployment.⁴⁵



After Asia, Europe installed the most capacity of any region during 2019. All of Europe added nearly 14.7 GW of new wind power capacity, bringing the total to 196.8 GW.⁴⁶ Most of this was in the EU-28ⁱⁱ, which installed roughly 13.2 GW (9.6 GW onshore and 3.6 GW offshore), or net additions of 13 GW (accounting for decommissioning), for a year-end total of 192.2 GW (170.2 GW onshore and 22.1 GW offshoreⁱⁱⁱ).⁴⁷

Net EU additions, although below the all-time high in 2017, were up 34% over 2018.⁴⁸ The sharp increase was due mainly to strong growth in Greece (added a record 0.7 GW), Spain and Sweden – which more than doubled its additions relative to 2018, installing 1.6 GW for a total of 9 GW.⁴⁹ In total, 19 EU countries added capacity during 2019, up from 16 countries in 2018.⁵⁰

i Statistics differ among Chinese organisations and agencies as a result of what they count and when. For more details, see endnote 24 for this section.

ii Here, the EU refers to the EU-28, including the United Kingdom. The EU-27 added nearly 10.8 GW during the year and had 169 GW of capacity at end-2019. See endnote 47 for this section.

iii Numbers do not add up to total of 192.2 GW due to rounding.

However, the market was again fairly concentrated, with the top five countries – the United Kingdom, Spain, Germany, Sweden and France – accounting for almost 75% of net additions, even though markets in France and Germany contracted for the second consecutive year.⁵¹ The leading EU countries for cumulative capacity were Germany, Spain, the United Kingdom, France and Italy.⁵²

Net installations of wind power capacity in the EU-28 were up **34%** over 2018.

The United Kingdom was the region's top installer in 2019, adding 2.4 GW, three-quarters of which is operating offshore, for a total of 23.5 GW.⁵³ Most new onshore capacity (0.6 GW) was added in Scotland and Wales, and was awarded under Contracts for Differenceⁱ (CfD) in 2015.⁵⁴ Elsewhere in the United Kingdom, wind energy projects rely on merchant options such as PPAs.⁵⁵ The country saw historic lows for generation from coal (less than 1% for the second quarter of 2019), due largely to the rise of wind power, which accounted for nearly 20% of domestic electricity generation during the year.⁵⁶

Spain, which ranked second in the region and fifth globally for installations, had its best year in a decade. The country added 2.3 GW (all onshore) – more than five times its 2018 installations – to end 2019 with 25.8 GW.⁵⁷ While most of this capacity was awarded in auctions held in 2016 and 2017, Spain also led the region for investments in new onshore capacity.⁵⁸ In late 2019, to mitigate regulatory uncertainty regarding future revenue from renewable power plants, the national government introduced a series of measures in an effort to guarantee a stable economic and regulatory framework to encourage further investment in renewable energy projects.⁵⁹

Although still among the EU's top installers, Germany saw a sharp decline in annual additions (as well as in investment in new projects), ceding its first-place ranking in Europe, held since 2011.⁶⁰ Germany added 2.2 GW (nearly 2.1 GW net, including almost 1 GW onshore and 1.1 GW offshore) in 2019 for a cumulative 61.4 GW (53.9 GW onshore and more than 7.4 GW offshore).⁶¹ Onshore installations have declined markedly since the 2014-2017 period (to 16% of the volume in 2017, when the auction model was introduced), due mainly to long, complex permitting processes and policy uncertainty.⁶²

As of late 2019, more than 10 GW of wind power projects was stuck in Germany's permitting process, which has lengthened from around 10 months just a few years ago to more than two years.⁶³ The largest permitting barriers relate to aviation and the military; in addition, rising public opposition and a proposed

setback distance of 1,000 metres for wind turbines have ruled out several prime locations.⁶⁴ (→ See *Feature chapter*.)

Growing economic risk, the increased complexity associated with tenders, permitting challenges and the threat of legal action have deterred potential investors, including community wind energy actors, and the removal of some privileges for community projects has reduced the number and diversity of participants in auctions.⁶⁵ Of the total 3.7 GW of onshore capacity auctioned in 2019, only 1.8 GW was awarded – far below the volume envisioned in Germany's expansion plan.⁶⁶ The number of companies active in the domestic wind power industry has declined with new installations, affecting the entire local value chain.⁶⁷

Germany's gross generation from wind energy was up 12% onshore and 27% offshore, reaching a total of 126 TWh, or 21.8% of electricity generation in 2019.⁶⁸ Much of this electricity is produced in northern Germany, and a lack of grid capability hinders the transmission of excess electricity to load centres in the country's south, resulting in curtailment of wind energy and challenges for neighbouring countries due to electricity exports.⁶⁹ Curtailment in Germany has declined since 2017, however, as have exports, and the country has completed the first 1,300 kilometres of 7,700 kilometres of new transmission lines planned by 2030.⁷⁰ In Germany and elsewhere, interest in the use of excess renewable generation for electric heating, cooling and transport as well as for hydrogen production is quickly gaining ground.⁷¹ (→ See *Systems Integration chapter*.)

For the EU as a whole, onshore wind energy met around 12.2% of total electricity demand, and offshore wind energy met 2.3%, with an estimated total of 417 TWh of wind generated electricity.⁷² The one percentage point share increase relative to 2018 resulted from additional capacity and from windy conditions during the year throughout the region.⁷³

Outside the EU-28, Norway was again the largest installer in Europe (adding 0.8 GW) in 2019.⁷⁴ However, Norway's plans for future installations were put on hold due to local opposition across the country sparked by environment and tourism concerns.⁷⁵ Ukraine saw a nearly 10-fold increase in installations relative to 2018 (adding 0.6 GW), more than doubling its capacity to 1.2 GW in advance of a transition from attractive FITs to auctions in 2020.⁷⁶ Throughout all of Europe, 2.1 GW of wind power PPAs were signed, and 10 countries held auctions in which wind energy secured contracts, including 8.6 GW onshore and 6.8 GW offshore.⁷⁷

Across the Atlantic, the Americas added 13.4 GW (up 13% over 2018) and accounted for more than one-fifth of the world's newly installed capacity in 2019.⁷⁸ The United States installed 68% of the region's total and had its third biggest yearⁱⁱ.⁷⁹ US additions were up 20% over 2018, to 9.1 GW, for a total of 105.6 GW across

i The CfD is the UK government's primary mechanism for supporting renewable electricity generation. Developers that win contracts at auction are paid the difference between the strike price (which reflects the cost of investing in the particular technology) and the reference price (a measure of the average market price for electricity).
 ii The year 2019 saw the third highest installations of new capacity after 2009 and 2012, when the US production tax credit was due to expire and then was extended retroactively.

41 states and 2 territories.⁸⁰ At year's end, another 22.1 GW was under construction.⁸¹ The rush of new installations was driven mainly by the phase-out of the federal production tax credit (PTC), which was granted a one-year extensionⁱ in late 2019.⁸² Demand from utilities to meet customer preferences, sustainability goals and mandates under state RPS laws as well as demand from corporations also played a role.⁸³ Wind power PPAs achieved a new record (8.7 GW) in 2019, with utilities contracting 5.1 GW; at year's end, almost half of the project pipeline had a PPA in place, with 27% of these owned by utilities.⁸⁴

The state of Texas (nearly 4 GW) again led for annual installations and, along with Iowa (1.7 GW), set new records for capacity additions.⁸⁵ Six US states ended the year with more than 5 GW in operation – including Texas, with more than 28.8 GW.⁸⁶ In Texas and much of the rest of the country, wind power set short-term generation records, exceeding 66% in the US central region, and grid operators were reliably managing such high penetration levels.⁸⁷ Tests by the California Independent System Operator during 2019 found that wind turbines equipped with inverter-based smart controllers can provide grid services similar to those provided by natural gas power plants.⁸⁸ (→ See *Systems Integration chapter*.)

For the full year, utility-scale wind power facilities accounted for more than 30% of electricity generation in 3 US states – with Iowa (in the lead at 42%) passing Kansas (41.4%) – and accounted for more than 16% of annual generation in 13 states.⁸⁹ In total, wind power accounted for 7.3% of US utility-scale electricity generation (up from 6.5% in 2018).⁹⁰ As an indication of how big wind power has become in the United States, it exceeded



hydropower for generation in 2019, having already surpassed it for capacity three years earlier.⁹¹

Latin America and the Caribbean added 3.7 GW of capacity in 2019, with two countries – Mexico and Argentina – ranking among the top 10 globally.⁹² The slight decline relative to 2018 was due mainly to a significant drop in Brazil that was nearly offset by increases elsewhere.⁹³ The region ended the year with around 29.2 GW of wind power capacity operating in at least 26 countries.⁹⁴ The top installers were Mexico (nearly 1.3 GW) and Argentina (0.9 GW), which both surpassed Brazil (0.7 GW) in annual additions for the first time, followed by Chile (0.5 GW).⁹⁵ Colombia held its first successful renewable energy auction, in which wind power was awarded nearly 1.2 GW.⁹⁶ More than 80% of the non-hydro renewable power capacity operating across the region (mostly wind power) at year's end was driven by public tenders and auctions, and PPAs also were becoming increasingly important.⁹⁷

Mexico was again among the world's top 10 installers, ranking ninth for additions ahead of Argentina, and ending the year with 6.2 GW.⁹⁸ The country cancelled planned auctions and revised its renewable energy support scheme, and annual installations (up 38% over 2018) were due mainly to bilateral PPAs.⁹⁹ Argentina's market also has been affected by on-and-off policies but, thanks to awarded capacity from auctions launched between 2016 and 2018, the country more than doubled its capacity to end the year with 1.6 GW.¹⁰⁰ Argentina's largest wind farm (220 MW) was completed in 2019; the project has an average capacity factor of 51%, and is expected to supply enough electricity for more than 330,000 homes.¹⁰¹

Brazil added its lowest amount of wind power capacity since 2011, due to a break in the country's auction schedule during the recent national economic crisis; even so, by one account, more wind power than thermal power capacity was installed in 2019.¹⁰² Brazil's free marketⁱⁱ has expanded in recent years, and in 2019 more than 2 GW of new wind power capacity was sold into the free market compared to 1.1 GW via public auctions.¹⁰³ At year's end, with almost 15.5 GW of capacity in operation, Brazil remained home to more than half of the total capacity operating in Latin America and the Caribbean.¹⁰⁴ Wind power accounted for 9.4% of Brazil's electricity generation (up from 8.3% in 2018).¹⁰⁵

Canada again added a modest 0.6 GW, bringing total capacity to 13.4 GW.¹⁰⁶ Wind power has been the country's largest source of new electricity generation over the past decade, driven by environmental concerns and by the relatively low price of wind-generated electricity.¹⁰⁷ The leading provinces for cumulative capacity were Ontario (5.4 GW), Quebec (3.9 GW) and Alberta (1.7 GW).¹⁰⁸ Wind power accounted for 6.5% of Canada's electricity generation in 2019, up from 5.8% in 2018.¹⁰⁹

i The PTC gives wind energy generators a tax credit of roughly USD 0.02 per kWh for electricity fed into the grid. Starting in 2021, the credit will decline steadily until it ends in 2025.

ii Brazil's power sector is undergoing a transition that encourages the development of a free market, in which power buyers, sellers and traders can negotiate PPAs directly. See endnote 103 for this section.

Wind energy is also playing a growing role in Australia, which again saw records for both installations and output in 2019.¹¹⁰ The country brought online more than 0.8 GW of capacity for a total approaching 6.3 GW.¹¹¹ Wind power surpassed hydropower in 2019 to become Australia's largest renewable source of electricity, producing 19.5 TWh, or 8.5% of the country's total generation.¹¹² Far higher shares were achieved in several states, including in South Australia (29%), Victoria (28%) and New South Wales (22.6%).¹¹³ The rapid increase in the number and capacity of large wind (and solar) power projects in Australia continued to challenge the grid, resulting in project delays.¹¹⁴ (→ See Solar PV section in this chapter.) By year's end, more than 5.5 GW of additional capacity was under construction or financially committed.¹¹⁵ Other parts of Oceania were quiet, with little wind power activity observed in 2019.¹¹⁶

Africa and the Middle East together added about 2.6% less capacity than they did in 2018, with around 0.9 GW brought online in 2019.¹¹⁷ At year's end, 13 countries in Africa and 6 in the Middle East had a cumulative 6.7 GW of wind power capacity (all onshore), with most of it in South Africa (2.1 GW), Egypt (1.5 GW) and Morocco (1.2 GW).¹¹⁸ Challenges in both regions included uncertain or unsupportive policy and power market frameworks, bottlenecks in transmission infrastructure and off-taker risk.¹¹⁹

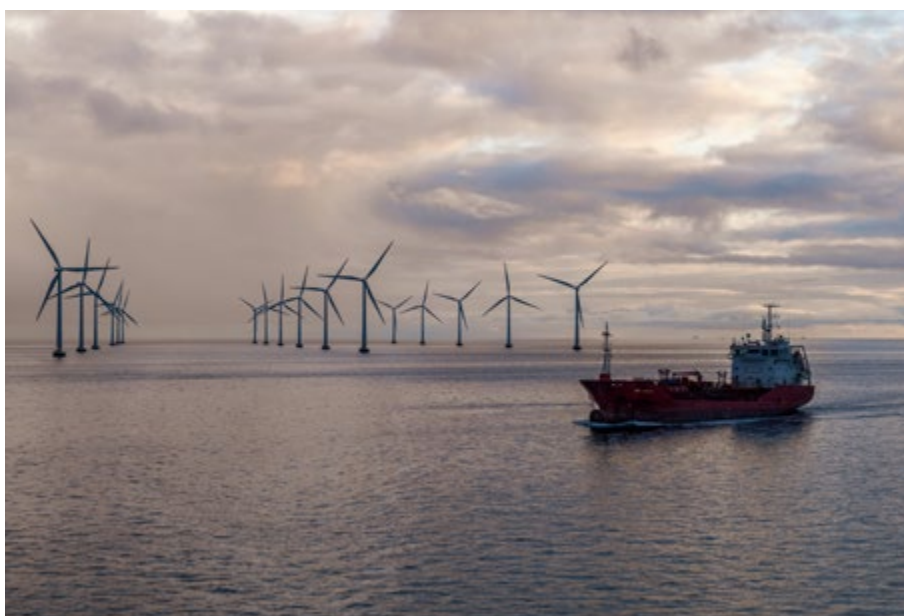
In Africa, the leadersⁱ for new installations were Egypt (262 MW), Morocco (216 MW) and Ethiopia (120 MW).¹²⁰ Egypt's additions were in a single project, the country's largest and first privately owned wind farm.¹²¹ Despite being among the top three on the continent for additions and total capacity, Egypt remained far short of its target of 7 GW by 2022, but the country had a project pipeline of 4 GW as of early 2020.¹²² Senegal also added capacity: its first utility-scale wind farm (159 MW) began delivering electricity to the grid in December, with full commissioning planned for 2020.¹²³

Jordan (0.2 GW) and Iran (50 MW) led the Middle East for new installations during 2019.¹²⁴ Saudi Arabia's government contracted for the country's first large-scale wind power plant, a 0.4 GW facility with an expected operation date of early 2022.¹²⁵ The Saudi government aims to free up for export much of the oil used to generate electricity.¹²⁶

In the **offshore wind power segment**, five countries in Europe and three in Asia connected a record 6.1 GW in 2019 (up 35.5% over 2018), increasing cumulative global capacity to more than 29 GW.¹²⁷ Wind turbines operating offshore represented less than 5% of total global wind power capacity at year's end, but offshore additions accounted for 10% of all newly installed capacity (up from 5% in 2015), and 2019 was a record year for investment in future offshore capacity.¹²⁸ Europe accounted for 59% of new installations and Asia for 41%.¹²⁹

China again led the sector, completing nearly 2.4 GW of capacity for a total of 6.8 GW, and easily surpassing a national target of 5 GW by 2020.¹³⁰ Record installations were driven by policy changes: for the first time, China announced reductions to the FIT for offshore wind power for 2019, and further cuts in 2020, and several new projects were initiated to take advantage of the policy before it expires.¹³¹ Although the country has no long-term targets for offshore capacity, coastal provinces have targets and development plans, including Guangdong (30 GW by 2030), Jiangsu (15 GW) and Zhejiang (6.5 GW).¹³² At year's end, more than 10 GW was under construction and an additional 30 GW had received approval.¹³³

Elsewhere in Asia, Chinese Taipei commissioned its first offshore utility-scale (120 MW) project and announced that, in addition to its target of 5.7 GW by 2025, the country aims for a further 10 GW between 2026 and 2036.¹³⁴ Japan launched 3 MW of floating capacity to end the year with nearly 66 MW of offshore capacity and 14 GW in the pipeline; Vietnam had 0.1 GW of intertidal capacity with several projects under construction; and India launched a tender process for offshore wind power.¹³⁵



Offshore wind power additions accounted for **10%** of all newly installed capacity, up from 5% in 2015.

ⁱ Kenya's 310 MW Lake Turkana wind power project remained the largest in Africa at the end of 2019. Several sources note that it started operations in 2019; however, the project began supplying electricity to the national grid in 2018, and Vestas announced the project's completion that year, so it was included with 2018 data in GSR 2019. See endnote 120 for this section.

Europe continued to be home to most of the world's offshore capacity. In 2019, the region added more than 3.6 GW (up 36% from 2018), a new high, bringing the regional total close to 22.1 GW.¹³⁶ Installations came online in the United Kingdom (1.8 GW), Germany (1.1 GW), Denmark (374 MW), Belgium (370 MW) and Portugal (8 MW); all but Germany set new records.¹³⁷ The United Kingdom accounted for about half of Europe's offshore installations and reached a year-end total of 9.9 GW offshore.¹³⁸ All turbines were grid-connected for the UK's 1.2 GW Hornsea One, making it the world's largest offshore wind farm as well as the farthest from shore.¹³⁹ Germany added more capacity offshore than on land, for the first time, and exceeded the national offshore target for 2020.¹⁴⁰

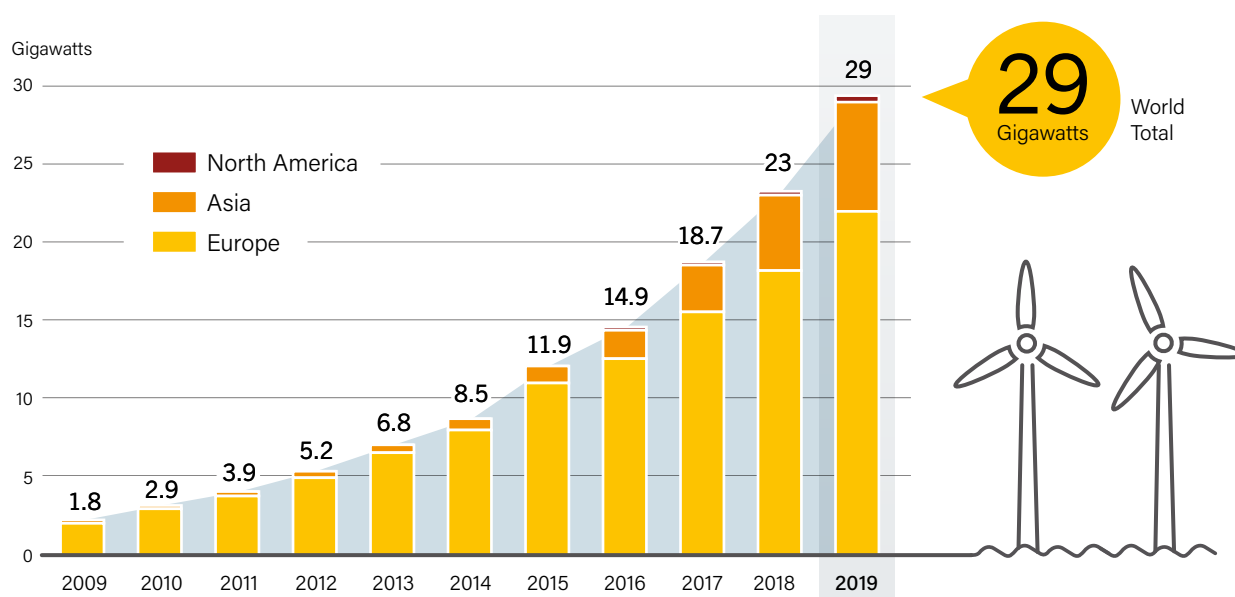
Several European governments also increased targets for offshore wind power, driven at least in part by falling prices, raising the region's total targeted capacity by 2030 from 76 GW to 100 GW.¹⁴¹ France, the Netherlands and the United Kingdom all held auctions for offshore capacity during 2019, including the world's largest-ever offshore auction – 5.5 GW was awarded by the UK government.¹⁴² An additional five offshore corporate PPAs were signed, following the first in 2018, totalling more than 360 MW of future capacity.¹⁴³ In Sweden, however, a proposed 300 MW offshore wind farm that was permitted in 2012 was cancelled after the national military rejected revised plans.¹⁴⁴

The US offshore capacity remained at 30 MW, but targets for state procurement increased from 9.1 GW in 2018 to 25.4 GW in 2019.¹⁴⁵ Vineyard Wind, a 0.8 GW project off the Massachusetts coast, was scheduled to begin construction in 2019, but was delayed repeatedly for further government study of the broader impacts of offshore wind farms' on commercial fisheries.¹⁴⁶ The project is the first in a long pipeline of large wind farms along the country's east coast, and the delay has caused wider uncertainty in the US offshore market.¹⁴⁷ However, construction did begin on a 12 MW project off Virginia's shores, and by year's end an estimated 7.5 GW was in advanced developmentⁱ along the US east coast.¹⁴⁸ During the year, six east coast states procured capacity, approved projects or passed legislationⁱⁱⁱ, and a new coalition was launched to push for at least 10 GW off the California coast by 2040.¹⁴⁹ At year's end, a Maine utility announced that it was the anchor buyer in a PPA for the first US floating wind power project, a 12 MW facility off the state's coast.¹⁵⁰

By the end of 2019, 18 countries (12 in Europe^{iv}, 5 in Asia and 1 in North America) had offshore wind capacity in operation.¹⁵¹ The United Kingdom maintained its lead for total capacity (9.9 GW), followed by Germany (7.5 GW), China (6.8 GW), Denmark (1.7 GW) and Belgium (1.6 GW).¹⁵² Europe was home to about 75% of global offshore capacity (down from 79% in 2018), with Asia accounting for nearly all the rest.¹⁵³ (→ See Figure 39.)

- i Opposition that resulted in the failure of the proposed Cape Wind project in 2017 led developers and regulators to locate leases farther out from shore, pushing them into vessel routes and commercial fishing areas. See endnote 146 for this section.
- ii Advanced development means that projects have a signed PPA, a firm turbine order or are proceeding under utility ownership. See endnote 148 for this section.
- iii Connecticut committed to solicit 2 GW by 2030, enough to meet 30% of the state's electricity demand; Maryland raised its Renewable Portfolio Standard (RPS) to 50% by 2030, with incentives for deployment of 1.2 GW offshore capacity; and New Jersey more than doubled its offshore wind capacity target from 3.5 GW by 2030 to 7.5 GW by 2035. See endnote 149 for this section.
- iv By year's end, all of the offshore capacity in France, Norway and Spain was in demonstration projects; all other European countries with offshore wind power capacity also had demonstration projects in place. See endnote 151 for this section.

FIGURE 39. Wind Power Offshore Global Capacity by Region, 2009-2019



Source: See endnote 153 for this section.

Additional countries were studying the feasibility of offshore wind or starting project development in 2019, and the World Bank Group announced a new programme to speed the deployment of offshore wind power in emerging markets, many of which have strong offshore wind resources.¹⁵⁴

Cost reductions in new wind power projects have resulted from a combination of lower capital costs and improved performance.

Offshore and (mostly) onshore, wind turbines of various sizes, totalling an estimated 0.4 GW of capacity in nine countries, were decommissioned in 2019.¹⁵⁵ The United States took the lead, decommissioning about 195 MW of capacity.¹⁵⁶ In Europe, around 170 MW of capacity was decommissioned (down from 451 MW in 2018), led by Germany (97 MW), with turbines also decommissioned in Austria, Denmark, France and the United Kingdom.¹⁵⁷ Some of the decommissioned projects were repowered. (→ See *Industry section*.)



WIND POWER INDUSTRY

Wind energy has emerged as one of the most economical ways to add new generating capacity.¹⁵⁸ Yet, while falling prices are helping to move wind power into new markets and are pushing up sales, the global transition from FITs to auctions and tenders has resulted in intense price competition in some countries, challenging wind developers and causing attrition among turbine manufacturers.¹⁵⁹ Even as progress is made, new challenges have emerged in some markets, such as poorly designed tenders, permitting delays and lack of available land and grid access, as well as the inherent limitations of power systems and markets that were designed and optimised for centralised, large-scale fossil power.¹⁶⁰ (→ See *Systems Integration chapter*.) Meanwhile, the industry is working to meet each new challenge with improved technologies (including larger and more efficient turbines) and other advances (such as supply chain efficiencies) that are helping to further reduce the cost of energy and to better integrate wind energy with existing electricity grids.¹⁶¹

By one estimate, from 2018 to 2019 the global benchmark levelised cost of energy (LCOE) from new wind power projects declined 10% onshore (to an average USD 48.5 per MWh) and 28% offshore (USD 83.50 per MWh).¹⁶² Cost reductions have resulted from a combination of lower capital costs and improved performance.¹⁶³

Auctioned capacity in 2019 was more than double the 2018 total, with 25 GW auctioned onshore and 15.8 GW offshore in at least 18 countries (including wind-specific and technology-neutral/renewable energy auctions).¹⁶⁴ Auction results vary widely depending on local conditions and costsⁱ, project scale, expected commissioning date and other factors.¹⁶⁵ While declining costs and fierce competition have driven average bid prices down in many markets, bids have been rising in others, such as Germany.¹⁶⁶

Some of the lowest winning bids (excluding China) in 2019 were seen in Brazil (USD 20.8 per MWh) and Denmark (USD 22.8 per MWh).¹⁶⁷ Saudi Arabia's first commercial wind farm, the 400 MW Dumat Al Jandal project, reached financial close in July at USD 19.9 per MWh.¹⁶⁸ In Latin America and the Caribbean, the surge in public auctions helped to drive down the region's average price for wind energy by 46% from 2016 to 2019.¹⁶⁹ Colombia's first successful renewable energy auction brought low average winning prices (for both wind and solar energy) of USD 28 per MWh in 2019.¹⁷⁰

Across Europe, more than 14 GW of new wind power capacity was awarded (about 7.6 GW onshore and 6.8 GW offshore) through auctions in 2019.¹⁷¹ The region's largest onshore auction was held in Poland, where 2.2 GW of capacity was awarded at an average price of EUR 49 (USD 55) per MWh.¹⁷² Europe's winning onshore bids were in the range of EUR 21 to EUR 67.2 (USD 23.5 to USD 75.3) per MWh.¹⁷³ However, while average awarded bid prices continued to fall in Denmark and

i Unless noted otherwise, mentions of auctions and tenders as support mechanisms presume wind technology-specific tenders or those specific to renewables in general. Technology-neutral tenders (open to non-renewables) do not constitute a support mechanism, although such tenders can and do draw successful bids from renewable energy developers.

ii Note that bid levels do not necessarily equate with costs. Also, energy costs vary widely according to wind resource, project and turbine size, regulatory and fiscal framework, the cost of capital and other local influences. Bid levels differ from market to market due to varying auction designs, policies and risks, among other factors. See endnote 165 for this section.



Greece, for example, they increased further in Germany (above the statutory tariffs under the old FIT), where five of the six onshore wind power auctions in 2019 were undersubscribed.¹⁷⁴

Offshore in Europe, prices in auctions (in France, the Netherlands and the United Kingdom) continued to fall due in part to technology innovations and economies of scale.¹⁷⁵ The United Kingdom awarded 5.5 GW of capacity offshore in a single auction, for projects to be commissioned between 2023 and 2026, with strike prices 30% below those of the 2017 auction.¹⁷⁶ The Netherlands held its second offshore wind tender for which the winning project (due online by 2023) will receive only the wholesale price of electricity and will pay an annual rent for seabed rights.¹⁷⁷

In the United States, while average contract lengths shortened, wind PPA pricesⁱ remained level or even rose throughout 2019, following historic lows in 2018, in anticipation of the PTC phase-out and further exacerbated by tariffs.¹⁷⁸ Vestas blamed its rising execution costs and falling margins in the United States (the company's most important market) on trade conflicts and tariffs, which had cascading effects on the global supply chain.¹⁷⁹ US tariffs on steel and aluminium, which make up 70-90% of wind turbines, as well as tariffs on permanent magnets, have put pressure on the US network of suppliers.¹⁸⁰ By one estimate, US tariffs on Chinese imports increased the costs of US wind projects by as much as 20%.¹⁸¹ Several other countries also have introduced new trade barriers on wind-related commodities and components, which affects the flexibility of supply chains, even as local content rules push for localisation of manufacture.¹⁸² (→ See *Sidebar 3*.)

While the shift from FITs to other instruments such as tenders and auctions has helped push down the cost of energy, it also has helped create a race to the bottom on price.¹⁸³ This intense competition (combined with trade tariffs in some cases) has

challenged the sustainability of the entire supply chain, squeezing the margins of turbine manufacturers, developers and operations and maintenance (O&M) suppliers.¹⁸⁴ For a variety of reasons, including tender design and unrelenting competitive pressures, the diversity (in size and geography) and the number of auction participants has dropped sharply in some countries, including Germany and India, with only a handful of large international corporations submitting bids.¹⁸⁵

The wind industry has seen more than 100 turbine suppliers over the years, with a peak of 63 suppliers reporting installations during 2013, but the number has declined rapidly since 2015; in 2019, four companies (three in China and one in India) had no new installations.¹⁸⁶ While 33 manufacturers delivered wind turbines to the global market during the year, the top 10 companies captured 85.5% of the capacity installed (up from 85% in 2018, 80% in 2017 and 75% in 2016).¹⁸⁷ The leading four companies – Vestas (Denmark), Siemens Gamesa (Spain), Goldwind (China) and GE Renewable Energy (United States) – were responsible for about 55% of capacity installed during 2019.¹⁸⁸ Vestas stayed on top but lost the most market share; Siemens Gamesa jumped from fourth to second (and led the offshore market); GE benefited from the healthy US market; and Goldwind continued to dominate in China while also increasing its presence in the Asia-Pacific region and beyond.¹⁸⁹ China-based Envision also remained in the top five globally,¹⁹⁰ Germany's Nordex-Acciona and Enercon (despite a significant decline in market share) took the seventh and eighth spots, and the remaining companies among the top 10 (all Chinese – Ming Yang, Windey and Dongfang) moved up in ranking thanks to a strong domestic market.¹⁹¹

By contrast, Senvion (Germany) and India's Suzlon – both of which were among the top 10 in 2017 – suffered severely as a result of declining home markets, as did Enercon, despite

i Prices in the United States reflect the US production tax credit, which applies to commercial wind power systems.

remaining among the top 10 (80% of the company's installations were outside of Germany).¹⁹² After two years of dramatic decline in the German onshore market, Enercon cut thousands of jobs at home and abroad, ended co-operation with domestic production partners and reported significant losses.¹⁹³ Senvion, once a leading innovator in the global industry, filed for insolvency in 2019; Siemens Gamesa took over some of Senvion's key European assets and businesses.¹⁹⁴ In early 2020, Suzlon disclosed outstanding debt of about USD 1.8 billion and started debt restructuring.¹⁹⁵

Even the top manufacturers suffered losses, closed factories and laid off workers in 2019, despite record turbine orders (globally and for individual companies) and increased revenues, due to rising costs that included trade-related tariffs.¹⁹⁶ But some companies opened new facilities as well, driven by the need to reduce transport costs and to access new revenue sources, as well as by local content requirements.¹⁹⁷ For example, Vestas opened a new turbine factory in Brazil, and MHI Vestas Offshore Wind (Denmark) signed a contract for blade materials in Chinese Taipei; Nordex opened a rotor blade factory in Mexico; Siemens Gamesa completed Turkey's first nacelle factory, a condition of Turkey's first wind tender in 2017, and confirmed plans for a nacelle assembly plant in Chinese Taipei; and GE started constructing a factory in China for its 12 MW Haliade-X.¹⁹⁸

Many wind turbine manufacturers and project developers were pulling together teams to expand into solar PV, and many were developing hybrid projects during 2019.¹⁹⁹ In Australia, China, India, the United States and several European countries, wind power projects have been co-located with solar and/or storage projects to reduce energy prices while mitigating the impacts of variability and expanding revenue opportunities.²⁰⁰ Some companies have taken this a step further. In 2019, Acciona (Spain) was studying the use on its turbine towers of flexible solar PV thin films made of carbon to power auxiliary systems.²⁰¹ Also during the year, a 2 MW hybrid project in Minnesota was the first in the United States to combine solar and wind power at the same interconnection, using a GE turbine that routes solar and wind energy through a shared inverter.²⁰² Pairing technologies not only side-by-side but at the same interconnection reduces costs of equipment, siting, grid connection, financing, and operations and maintenance compared to separate projects, while also increasing capacity factors.²⁰³ The Minnesota project, for example, expects a capacity factor of 65-70%.²⁰⁴

Both the number and size of large projects continued to increase in 2019, especially onshore in China and the United States and offshore in the United Kingdom.²⁰⁵ By year's end, the largest projects in operation were the East Anglia (0.7 GW) and Hornsea One (1.2 GW) off the UK coast.²⁰⁶ Particularly offshore, the rapid increase in project and turbine size has helped to reduce costs through scale and standardisation – as project size increases, the costs of capital and the per MW costs of planning and balance-of-plant all typically decline.²⁰⁷

The trend also continued towards larger machines (including longer blades, larger rotor size and higher hub heights, and therefore higher power rating) for both onshore and offshore use, as turbine manufacturers aimed to boost output and to gain or maintain market share.²⁰⁸ The average size of turbines

delivered to market was 12% larger than in 2018 (2.45 MW), at 2.76 MW (2.6 MW onshore and nearing 5.7 MW offshore) in 2019.²⁰⁹ Onshore, the largest country averages were seen in Morocco (4.2 MW), Finland (almost 4.2 MW) and Norway (3.8 MW), with averages exceeding 2 MW

in all other established markets – including Brazil (2.6 MW), the United States (2.5 MW) and China (nearly 2.4 MW).²¹⁰ Offshore, the highest average power ratings were in Belgium and Portugal (both 8.4 MW), and in Denmark (8.3 MW).²¹¹ Across Europe, the average per unit capacity of newly installed turbines offshore in 2019 was 7.2 MW, up from 6.8 MW in 2018.²¹²

Turbines are set to get only bigger. Siemens Gamesa launched a 10 MW offshore turbine in January 2019 and presented an upgraded 11 MW model late in the year; the company plans to have the machine on the market in 2022.²¹³ MHI Vestas also had a 10 MW turbine under way in 2019.²¹⁴ Chinese manufacturers are in competition to develop machines that match these capacities, and both Dongfang (prototype) and CSIC Haizhuang (plan only) unveiled 10 MW machines in 2019.²¹⁵ GE installed its first Haliade-X (12 MW) prototype at the Port of Rotterdam; the world's largest turbine to date started generating electricity in November, and serial production was scheduled to begin in 2021.²¹⁶ The machines blades are the longest ever made, at 107 metres, about the length of a football pitch (soccer field), and a single turbine is expected to generate enough electricity for 16,000 European homes.²¹⁷ Other turbine and generator companies are working on the next generation, envisioning unit capacities of 20 GW.²¹⁸

Offshore developers are taking advantage of larger turbines as soon as they become available, with several orders placed for these mega-turbines during 2019.²¹⁹ Larger turbines mean that fewer foundations, converters, cables, less labour and other resources are required for the same output, translating into faster project development, reduced risk, lower grid-connection and O&M costs, and overall greater yield.²²⁰

At the same time, increasing machine size (whether for onshore or offshore use), large projects and developments farther out to sea have required that suppliers adapt designs to minimise the logistical challenges of manufacture, transport, installation as well as O&M.²²¹ GE, for example, developed a two-part blade that can be assembled on-site for its largest onshore turbine (5.3 MW).²²² Drones already have been used to inspect blades, reducing outage time from hours to minutes and reducing the required numbers of vessel trips.²²³ In 2019, Vestas unveiled a research partnership to develop drone technology to support blade installation, and Siemens Gamesa, Ørsted (Denmark) and Esvagt (Danish vessels supplier) were exploring how to use drones to transport spare parts to offshore wind projects.²²⁴ Some operators have begun to pool resources at centralised facilities or to expand operations hubs at sea that can house technicians for weeks at a time.²²⁵

The world's largest turbine, at 12 GW, started generating electricity in November, and serial production was scheduled to begin in 2021.

The offshore industry also made advances in the segment of floating turbines, which offer the potential to expand the areas where offshore wind energy is viable and economically attractive because they can be placed where winds are strongest and most consistent, rather than where the sea-floor topography is suitable.²²⁶ Several configurations for floating substructures continue to be developed and demonstrated in Europe and elsewhere, and the technology is becoming increasingly cost-competitive.²²⁷

During 2019, Portugal installed the first platform of WindFloat Atlantic, and the first of three 8.4 MW turbines began feeding the grid, while Spain tested the first multi-turbine floating platform.²²⁸ Innogy SE (Germany), Shell (Netherlands) and Steisdal Offshore Technologies (SOT, Denmark) announced the final investment decision to build a demonstration project off Norway using SOT's modular floating foundation concept, which can be fully industrialised and deployed without installation vessels.²²⁹ By year's end, Europe's floating fleet reached 45 MW, and an estimated 80.5 MW was operating offshore around the world.²³⁰

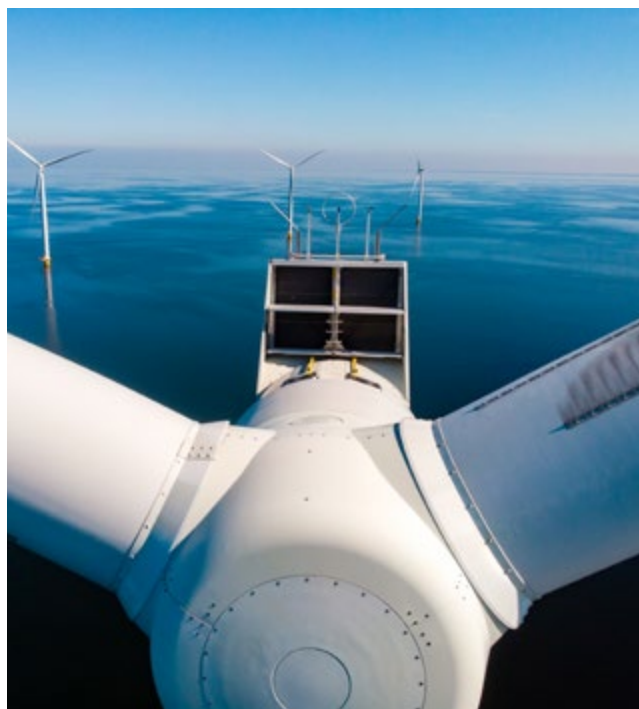
The low centre of mass of vertical-axis wind turbines and their potential for use with a floating platform has revitalised interest in the concept.²³¹ Several attempts, often unsuccessful, have been made in the past to develop these turbines for offshore use.²³² In 2019 and early 2020, Swedish company SeaTwirl, which is developing a floating vertical-axis turbine, announced that it had secured patents in China, Europe and the United States.²³³ In September the firm launched a two-year project with the ultimate aim to commercialise its 1 MW turbine.²³⁴ Vertical-axis designs have the potential to greatly reduce costs by eliminating the need for a number of components, enabling the use of cheaper platforms, improving stability and requiring easier and less costly maintenance compared to horizontal-axis turbines.²³⁵

In Europe, major offshore wind power developers advanced efforts to produce hydrogen from excess wind energy for greater grid flexibility or for use in transport and industry.²³⁶ In 2019, Ørsted (Denmark), the world's largest offshore wind developer, announced plans to use electricity from wind farms being built off the Dutch coast to produce hydrogen for sale to industrial customers.²³⁷ Siemens joined a partnership to develop a hybrid solar PV-wind power project in Australia for hydrogen production, and partnered with Shell (Netherlands) and grid operator TenneT (Netherlands/Germany) to propose a joint offshore wind power and hydrogen tender in Germany.²³⁸ (→ See *Systems Integration* chapter.)

As offshore wind power has advanced, particularly floating technologies, Shell and other major oil companies have become interested in the sector.²³⁹ Developments in 2019 included: Italy's oil and gas contractor Saipem unveiled a new substructure that can be a foundation for a range of turbine sizes; US-based ExxonMobil was researching the use of floating turbines to enhance oil production; and Equinor (Norway), which built the world's first floating offshore wind project (Hywind Scotland), entered the Chinese offshore market and committed to constructing a project to supply oil and gas facilities by 2022, aiming to reduce costs 40% compared to Hywind Scotland.²⁴⁰

New offshore markets still face challenges that Europe and China have addressed, including developing supply chains, a trained workforce and associated infrastructure such as ports, rail links and installation vessels, as well as grid infrastructure and technology for electrical connections.²⁴¹ Much of the Asian market also lacks viable finance solutions and co-operation among the relevant countries.²⁴² However, several countries – including India, Turkey and Vietnam – were collaborating with Denmark in 2019 to develop roadmaps and build technical capacity.²⁴³

In the United States, states are collaborating to establish an efficient supply chain and are investing in grid infrastructure.²⁴⁴



US utilities and project developers are partnering with Europe's largest offshore wind developers to set up manufacturing hubs and build projects, while also working with US government agencies, environmental organisations and the fishing industry to study and address the potential impacts of offshore wind power on fisheries and wildlife.²⁴⁵

Around the world, and particularly onshore, major manufacturers are focused increasingly on the repowering segment.²⁴⁶ Historically, repowering has involved the replacement of old turbines with fewer, larger, taller, and more-efficient and reliable machines at the same site, but increasingly operators are switching even relatively new machines for larger and upgraded turbines (including software improvements) or are replacing specific components, such as blades (partial repowering).²⁴⁷ Such partial repowering can extend turbine lifetime while greatly increasing a wind farm's performance.²⁴⁸ Nearly every major turbine manufacturer offers various upgrading services.²⁴⁹

In the United States, project owners partially repowered a total of 2.8 GW at existing projects, up from 1.2 GW in 2018.²⁵⁰ Despite the rising number of ageing turbines in some European countries, repowering was down relative to 2018 due to permitting challenges, lack of regulatory support and high wholesale electricity prices.²⁵¹ An estimated 185 MW of European capacity was repowered, mostly in Germany but also in Austria, Greece and the United Kingdom.²⁵² Repowering in China has been limited to date.²⁵³

As the earliest fleets of wind turbines reach retirement age, concerns are increasing about what to do with turbines at the end of their life. Although most of a turbine can be used on another

wind farm or recycled, blades are made of materials that are difficult and expensive to recycle.²⁵⁴ Developments in 2019 that were aimed at addressing this challenge included a partnership in Europe among wind power and chemical industries to advance recycling efforts for composite wind turbine blades; plans by the Danish company Miljoskarm to grind blades into small pieces and use them in recycled plastic casing as noise barriers; and the construction by US-based Global Fiberglass Solutions of a recycling plant that will break down blades and turn them into water-resistant pellets or panels for use as flooring and walls.²⁵⁵ In addition, US researchers were working to develop blades from a thermoplastic resin system, which has the potential to reduce the energy, time and cost involved in manufacturing while also allowing for blades to be recycled at the end of their life.²⁵⁶

Also in 2019, GE Renewable Energy announced that it would make its operations 100% carbon neutral by the end of 2020.²⁵⁷ Siemens Gamesa committed to becoming a carbon-neutral company by, for example, switching all operations to renewable energy-based electricity sources, and in early 2020 it turned its attention to its international supply chain.²⁵⁸ Also in early 2020, Vestas (which achieved 100% renewable electricity in 2013) joined RE100 and set a target to become carbon-neutral by 2030 through its own corporate actions. Vestas also announced plans to eliminate non-recyclable waste from manufacturing, operating and decommissioning of its wind turbines by 2040.²⁵⁹

→ See Box 1 for developments in the small-scale wind power sector. Also see Sidebar 5 and Figure 40 on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.²⁶⁰

i Old wind turbines that are no longer receiving FIT payments can operate in the open market or contract under PPAs (with similar prices). As long as wholesale prices are high enough to more than cover rising O&M costs, operators have a business case for continuing to operate the old turbines. See endnote 251 for this section.



Around the world, major manufacturers are focused increasingly on the repowering segment.

BOX 1. Small-scale Wind Power

Small-scaleⁱ (up to 100 kW) wind turbines are used for a variety of on- and off-grid applications, including defence, rural electrification, water pumping and desalination, battery charging, telecommunications and to displace diesel in remote locations. The annual global market continued to shrink in 2018 (latest data available) in response to unfavourable policy changes and ongoing competition from relatively low-cost solar PV.

By one estimate, 47 MW of new small-scale wind power capacity was installed in seven countries during 2018, down from an estimated 114 MWⁱⁱ in 2017. China continued to be the largest market, with an estimated nearly 31 MW installed in 2018, a slight increase from 2017 but a substantial decline relative to previous years. The United States deployed an estimated 1.5 MW (2,661 units) in 2018, a 12% annual reduction that continued the country's downwards trend in small-scale turbines. The UK market also fell further from its 2014 peak, in step with FIT changes.

Japan and Denmark, by contrast, both saw significant increases during 2018. Japan added an estimated 12.9 MW (up from 2.85 MW in 2017) and had another 153 MW in the FIT-approved queue by year's end. Worldwide, more than 1 million small-scale turbines (totalling at least 1.7 GW) were estimated to be operating at the end of 2018.

In response to shrinking markets in recent years, the number of producers of small-scale wind turbines in China and the United States has declined sharply, with manufacturers relying heavily on export markets, which also are in decline. US-manufactured exports, for example, fell from 5.5 MW (USD 42 million) in 2017 to less than 1 MW (USD 4.6 million) in 2018. The

number of small-scale wind turbine manufacturers that reported sales in the United States fell from 31 in 2012 to 8 in 2018, and several manufacturers reported that costs were affected during 2018 by tariffs on materials imported from China.

At least in the United States, however, things were looking up in 2019 with evidence that a 2018 extension of the US investment tax credit for small-scale wind power, combined with public research and development funding, could enable small and distributed wind power technology to turn the corner in the country. In addition, US R&D efforts were under way to make wind power a plug-and-play component in hybrid systems and microgrids, among other options.

Also in 2019, a small-scale turbine made by Hi-VAWT (Chinese Taipei) became the first vertical-axis turbine to achieve certification under the Small Wind Certification Council's Small Wind Turbine Program.

- i Small-scale wind systems generally are considered to include turbines that produce enough power for a single home, farm or small business (keeping in mind that consumption levels vary considerably across countries). The International Electrotechnical Commission sets a limit at approximately 50 kW, and the World Wind Energy Association and the American Wind Energy Association as well as the US government define "small-scale" as up to 100 kW, which is the range also used in the GSR; however, size varies according to the needs and/or laws of a country or state/province, and there is no globally recognised definition or size limit. See endnote 260 for this section.
- ii The significant reduction in reported deployment between 2017 and 2018 could be due in part to differences in data availability, from US Department of Energy, Office of Energy Efficiency and Renewable Energy, *2017 Distributed Wind Market Report* (Washington, DC: 2018), p. 12, <https://www.energy.gov/sites/prod/files/2018/09/f55/2017-DWMR-091918-final.pdf>.

Source: See endnote 260 for this section.



SIDEBAR 5. Renewable Electricity Generation Costs in 2019

Renewable power generation is increasingly becoming the default source of least-cost new power generation. The global weighted average levelised cost of electricity (LCOE)ⁱ from solar and wind power technologies again declined in 2019, with utility-scale solar PV down 13%, onshore and offshore wind both down 9%, and concentrating solar thermal power (CSP) down 1% compared with 2018ⁱⁱ.

The 13% decline in the global weighted average LCOE of solar PV in 2019 – which was slightly below the 15% reduction in 2018 – was driven by declines in module prices and balance-of-system costs. The 9% decline in onshore wind costs was only slightly below the 10% reduction in 2018; however, the LCOE of offshore wind fell by three times the 3% decline of 2018. These cost decreases are due in part to technology improvements and to reductions in total installed costs, but also to increasing market competition. For example, major suppliers of turbines and associated technology for solar PV noted strong and increasing competition in the global marketplace, contracting sales, and declining or even negative margins. (→ See *Market and Industry chapter*.)

Because the LCOE of different technologies can vary greatly by country and region, the global weighted average LCOE is an imperfect measure; however, trends in this metric give a sense of overall movement and comparison with costs of generation from conventional fuels. In 2019, mature renewable electricity generation technologies – hydropower, bio-power and geothermal power – remained cost competitive with fossil-fuelled power technologies. The global weighted average LCOEs of solar and wind power technologies show that they continue to become more cost competitive with fossil fuels.

In particular, costs for solar PV and CSP as well as onshore and offshore wind have fallen sharply over the past decade. (→ See *Figure 40*.) Global average hydropower costs have risen since 2010 as more challenging sites are exploited, but nine-tenths of the new hydropower capacity added in 2019 still had lower costs than the cheapest fossil fuel-fired source of new electricity.



i All references to LCOE in this sidebar exclude the impact of any financial support policies, so the cost to final consumers will be lower than quoted here in markets where this support is material. The other key assumption is that the weighted average cost of capital is 7.5% in member countries of the Organisation for Economic Co-operation and Development (OECD) and in China, compared with 10% (adjusting for inflation) elsewhere. LCOE numbers presented here are therefore conservative given the low interest rate environment in 2019. Note also that costs are very location- and project-specific, and cost ranges can be substantial; the LCOEs presented here should be considered in the context of the country- and region-specific project cost ranges provided in International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2019* (Abu Dhabi: 2020), which also provides further details on the LCOE methodology.

ii All data in this sidebar are from the IRENA Renewable Cost Database 2020, which contains cost data on more than 17,000 renewable power generation projects, accounting for around half of all deployment to 2019. All cost data are expressed in USD₂₀₁₉.

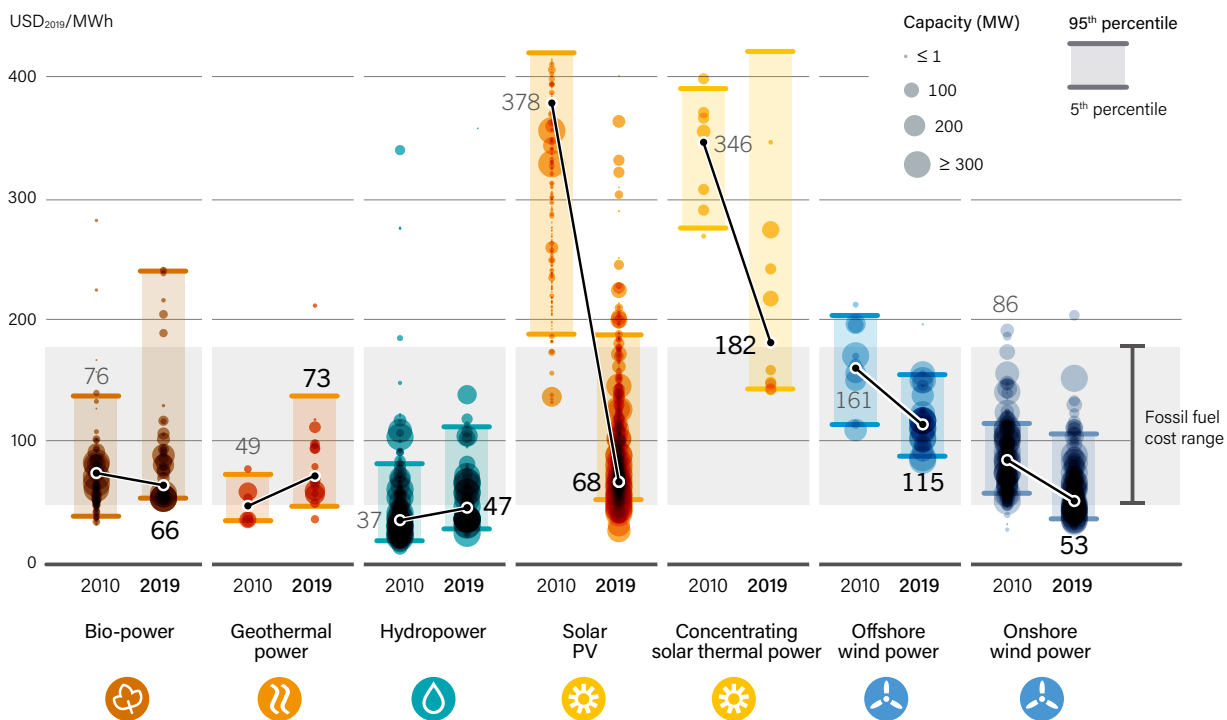
Source: IRENA. See endnote 260 of Wind Power section in this chapter.

Between 2010 and 2019, the global weighted average LCOE of commissioned projects fell 13% for bio-power, 29% for offshore wind power, 39% for onshore wind power, 47% for CSP and a precipitous 82% for solar PV. The global weighted average LCOE of geothermal projects increased to USD 73 per MWh in 2019, reflecting the higher volatility of the thin geothermal market.

The global weighted average LCOE of utility-scale solar PV for newly commissioned projects fell from USD 378 per MWh in 2010 to USD 68 per MWh in 2019. This reduction was driven mainly by the decline in module prices – which have fallen around 90% since 2010 – and by the reduction in balance-of-system costs, which together resulted in a nearly four-fifths decrease in the total installed costs of utility-scale solar PV between 2010 and 2019.

The global weighted average cost of electricity from onshore wind power projects fell 39% between 2010 and 2019, from USD 86 per MWh to USD 53 per MWh. This decline was driven by reductions in total installed costs, technology improvements in wind turbines (which increased capacity factors) and lower operations and maintenance costs. Wind turbine prices have fallen around 55-60% since 2010, with the global weighted average total installed cost declining more slowly at 24%. For onshore wind power, the key cost reductions from technology improvements have been through larger turbines, as their higher hub heights and swept areas collect more energy than older turbines.

FIGURE 40. Global Levelised Cost of Electricity from Newly Commissioned, Utility-scale Renewable Power Generation Technologies, 2010 and 2019



Note: These data are for the year of commissioning. The diameter of the circle represents the size of the project, with its centre being the value for the cost of each project on the y-axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

Source: IRENA.
See endnote 260 of Wind Power section in this chapter.



WORKING WITH COMMUNITIES TO REDUCE ENERGY POVERTY, HAITI



The social enterprise EarthSpark International is reducing energy poverty in Haiti by scaling and multiplying the delivery of clean energy technology, ranging from mini-grids to solar lanterns and energy-efficient cook stoves. EarthSpark began by helping a community organisation in the rural town of Les Anglais develop a store to supply clean energy technologies, education and training. In 2019, Earthspark worked with community members in the small fishing town of Tiburon to launch a community power solar mini-grid, which will serve 500 homes and businesses with 24/7 electricity.



04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

KEY FACTS

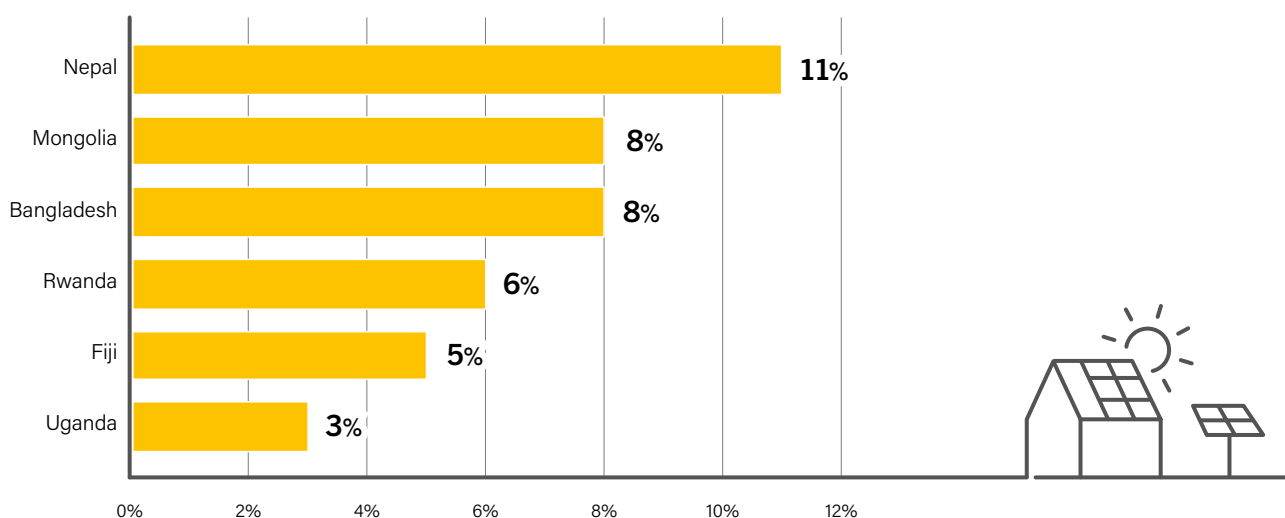
- By the end of 2018, the global population without access to electricity fell to 860 million, while 2.65 billion people lived without access to clean cooking facilities.
- The market for solar lighting systems and solar home systems grew 13% in 2019 – the highest growth of the past five years – with sales totalling some 35 million units.
- Solar PV and solar hybrid mini-grids, which accounted for just under 10% of the total installed mini-grids, continued to gain momentum and were increasingly positioned as the technology of choice.
- With a smaller number of advanced start-ups, investment in the off-grid solar sector dropped 42%, highlighting a shift from equity to debt financing.
- Investments in mini-grid start-ups more than doubled to a record USD 113 million. Clean cooking attracted less than 1% of the USD 4.4 billion investment required annually to achieve universal access in the sector.

Distributed renewables for energy access (DREA) systems are renewable-based systems (stand-alone off-grid systems as well as mini-grids) that can generate and distribute energy independently of a centralised electricity grid. DREA systems provide a wide range of services – including for lighting, consumer and productive appliances, cooking, space heating and cooling – in both urban and rural areas of the developing world. They represent a key solution for fulfilling modern energy needs and improving the livelihoods of hundreds of millions of people presently lacking access to electricity or clean cooking solutions. For example, mini-grids and stand-alone systems are considered to be the least-cost option for providing electricity access to nearly half of the population in sub-Saharan Africa by 2030.¹

DREA systems already provide electricity access to more than 14% of the combined populations of Bangladesh, Cambodia, Ethiopia, Kenya, Myanmar and Rwanda.² In 2017, the countries with the highest rates of electricity access from off-grid solar were Nepal (at around 11%), Mongolia (8%), Bangladesh (8%) and Rwanda (6%).³ (→ See Figure 41.) Around 60% of the population in Papua New Guinea, and 35% in Vanuatu, relied on off-grid solar lighting systems that year.⁴

ⁱ See Sidebar 9 in GSR 2014 for more on the definition and conceptualisation of DREA. Note that since 2018 the GSR has used the acronym DREA to distinguish from distributed renewable energy (DRE) that has no link to providing energy access.

FIGURE 41. Top 6 Countries with Highest Electricity Access Rate from Off-grid Solar Solutions (Tier 1+), 2017



Note: Data in figure include solar home systems and mini-grids but exclude solar lights. Data are rounded to the nearest ones. Tier 1+ access technologies include small solar home systems (11-50 W), large solar home systems (>50 W) and mini-grids.

Source: World Bank. See endnote 3 for this chapter.

Because of their improved reliability, lower technology costs and the emergence of innovative financial schemes that improve accessibility, DREA systems are increasingly being considered as either a complement to, or in some situations a substitute for, traditional centralised approaches. Several countries, such as Ethiopia, Kenya and Rwanda, have developed integrated electrification strategies around both grid-based and DREA systems in their efforts to reach universal access in a cost-effective and timely manner.⁵ Similarly, many countries, such as India, Indonesia and Nepal, are adopting key policy measures to accelerate the transition to clean cooking fuels and technologies.⁶

Beyond the opportunity to accelerate energy access in many regions of the world, DREA systems offer social, environmental and economic co-benefits, such as:

- reduced chronic and acute health effects, especially for women and children;
- improved lighting quality for households;
- increased income and resilience for rural livelihood enterprises, including small and medium-sized businesses;
- improved delivery of public services such as health care and education; and
- reduced negative impacts on forests.⁷

In South Asia, 94% of off-grid solar customers reported improvements in their quality of life, and 11% of households using the systems saw about a 10% increase in their monthly incomes.⁸ In East Africa, 89% of off-grid solar customers reported improved health, and for 28% of customers their monthly incomes increased (by 14% on average).⁹ Among students using off-grid solar lighting in East Africa, the majority reported having much more time to dedicate to their education after the school day, as a result of longer and more reliable lighting hours.¹⁰

The rapid deployment of DREA systems has had a positive effect on job creation in many countries. The DREA sector accounted for some 95,000 formal jobs in India, 10,000 in Kenya and 4,000 in Nigeria.¹¹ Overall, in East, West and Central Africa, as well as in South Asia, an estimated 370,000 people work full-time in the off-grid solar sector.¹² (→ See Sidebar 2.)

This chapter reviews the current status of and trends in the DREA sector in developing countries and presents an overview of the major programmes and initiatives launched or operational in 2019.

The DREA sector is a **significant employer** in emerging economies and has wide, positive impact through formal, informal and productive use jobs.

i See Sidebar 9 in GSR 2015 on women and distributed renewables for energy access.

OVERVIEW OF ENERGY ACCESS

Worldwide, the number of people lacking access to electricity dropped to 860 million (11% of the population) in 2018, down from a reported 1 billion (13%) in 2017.¹³ Meanwhile, an estimated 2.65 billion people (35% of the global population and 44% of the population in developing countries) were living without cleanⁱ cooking facilities in 2018, down from 2.7 billion in 2017 (36% of the global population and 46% of the population in developing countries).¹⁴ (→ See Figure 42.)

With 153 million additional people gaining **access to electricity** every year, significant progress has been made in many regions.¹⁵ However, this progress remains uneven. Around 80% of the 800 million people who gained access to electricity between 2010 and 2018 were in developing Asia, while more than two-thirds of

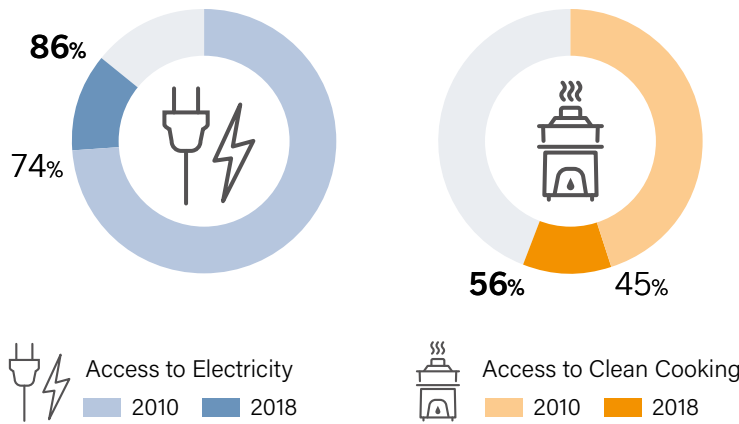
the people without electricity access in 2018 were living in sub-Saharan Africa.¹⁶ (→ See Figure 42 and **Reference Table R20**.)

Some 20 million people in sub-Saharan Africa gained access to electricity between 2014 and 2018, and the region's electrification rate increased from 49% in 2015 to 54% in 2018.¹⁷ Progress has been notable in East Africa, where Kenya, Ethiopia and Tanzania together accounted for more than half of the increase in the number of people with electricity access in the region.¹⁸ In North Africa, access rates have neared 100%.¹⁹ However, in 10 countries across the African continent more than 80% of the population still lacked access to electricity in 2018, with the highest shares in South Sudan (more than 99%, or 12.3 million people), the Central African Republic (more than 95%; 4.6 million), Chad (91%; 13.9 million) and the Democratic Republic of the Congo (91%; 76.9 million).²⁰

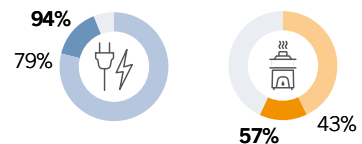
i As per the methodology of the World Bank (Multi-Tier Framework), access to clean cooking facilities means access to (and primary use of) modern fuels and technologies, including natural gas, liquefied petroleum gas (LPG), electricity and biogas, or improved biomass cook stoves that have considerably lower emissions and higher efficiencies than traditional three-stone fires for cooking.

FIGURE 42. Access to Electricity and Clean Cooking by Region, 2010 and 2018

All Developing and Emerging Countries



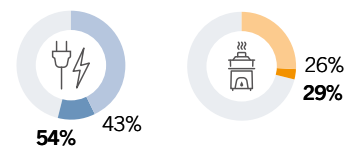
All Developing and Emerging Asian Countries



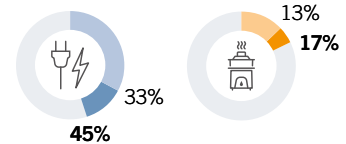
India



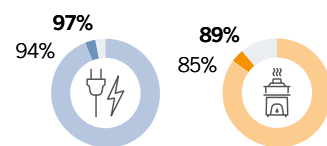
All Africa



Sub-Saharan Africa



Central and South America



Source: IEA. See endnote 14 for this chapter.

In developing Asia, 94% of the population had electricity access in 2018.²¹ For specific countries, the rates reached 95% in India and Indonesia and 85% in Bangladesh (up from only 47% in 2010).²² Even so, a large number of people, mainly in rural and remote areas of developing Asia, still lacked electricity access in 2018, including 73.7 million in India (5% of the population), 46.3 million in Pakistan (23%), 30.6 million in Myanmar (57%) and 25.1 million in Bangladesh (15%).²³

In Central and South America, 97% of the population had access to grid electricity in 2018.²⁴ However, several countries still had high shares of people without access, including Haiti (61% of the population; 6.8 million people), Honduras (21%; 2 million) and Guatemala (7%; less than 1.2 million).²⁵ In the Middle East, 93% of the population had electricity access in 2018.²⁶ Yemen continued to lag, however, with 53% of its population (15.4 million people) lacking access to electricity.²⁷

In the area of **clean cooking**, although millions of people have gained access to clean cooking facilities in recent years (including 450 million in India and China since 2010), progress continued to be uneven both within and across regions, and was often outpaced by population growth.²⁸ In 2018, 63.1% of people without access to clean cooking energy lived in developing Asia, and 34.1% lived in sub-Saharan Africa.²⁹ (→ See **Reference Table R21**.)

Across Africa, nearly 910 million people (71% of the population) lacked access to clean cooking facilities in 2018, with 853 million of them (83%) living in the sub-Saharan region.³⁰ Only 25 million people in sub-Saharan Africa gained access to clean cooking facilities between 2015 and 2018, and in about 22 countries in the region more than 90% of the population still relies on the traditional use of biomassⁱ, coal or kerosene for cooking.³¹ These countries include Nigeria (142 million people without access to clean cooking), Ethiopia (99 million) and the Democratic Republic of the Congo (81 million).³²



In Asia, where most of the progress in clean cooking has occurred, some 1.7 billion people (43% of the population) still lacked access to clean cooking facilities in 2018.³³ In China and India, the share of the population without access dropped 15 points on average between 2010 and 2018 (falling from 45% to 28% in China and from 66% to 51% in India).³⁴ The number of people relying on the traditional use of biomass, coal or kerosene to meet household cooking needs in 2018 totalled more than 688 million (51% of the population) in India, 242 million (28%) in China, 135 million (81%) in Bangladesh, 108 million (54%) in Pakistan and 785 million (32%) in Indonesia.³⁵

Around 57 million people in Central and South America (11% of the population) did not have access to clean forms of cooking in 2018.³⁶ In Haiti, 94% of the population (10 million people) depended on traditional cooking fuels and devices, and in Guatemala, Honduras and Nicaragua less than 60% of the population had access to clean cooking (9 million, 4 million and 3 million people, respectively).³⁷

In the Middle East, where 96% of the population had access to clean cooking facilities in 2018, Yemen lagged with an estimated 34% of its population (10 million people) lacking access to modern cooking fuels and technologies.³⁸

TECHNOLOGIES AND MARKETS

DREA solutions are an effective, established solution for providing energy access and served some 150 million people around the world in 2019.³⁹ The number of people obtaining electricity access through DREA systems increased an estimated three-fold between 2010 and 2017.⁴⁰ In 2017, DREA systems provided electricity access to more than 60% of the rural populations in both Ethiopia and Myanmar.⁴¹

Depending on a country's infrastructure and market readiness, a range of DREA technologies are being deployed to provide energy access. Populations that are not served through grid connections or extensions can obtain access to electricity through DREA solutions such as solar PV, bio-power, and hydropower mini-grids and stand-alone solar PV systems. DREA systems also are increasingly being used in grid-connected areas to address the unreliability of existing electricity infrastructure. For clean cooking, DREA systems use biomass, biogas, solar and ethanol.

150
million people
worldwide benefited from
energy access through
DREA systems in 2019.

i India announced in 2019 that it had provided access to all willing households after connecting 26 million households since October 2017 through its Saubhagya scheme. Efforts are being undertaken to provide a reliable, 24/7 supply of electricity to these populations.

ii See Glossary.

ACCESS TO ELECTRICITY

Off-grid solar solutions (solar lighting systems and solar home systems) accounted for nearly 85% of DREA systems worldwide in 2019, and since 2010 more than 180 million off-grid solar units have been sold, including 150 million pico solar productsⁱ and 30 million solar home systems.⁴² In at least 10 countries or territories – Benin, Burkina Faso, Fiji, Jordan, Kenya, Papua New Guinea, Rwanda, Samoa, Tanzania and Vanuatu – at least 9% of the population has benefited from off-grid solar lighting systems.⁴³

The market for off-grid solar systems grew 13% in 2019 – the highest growth of the past five years – with sales totalling some 35 million units, up from 31 million units in 2018.⁴⁴ (→ See Figure 43.) This increase is attributed mainly to a higher-than-expected decline in solar PV prices and to gains in the efficiency and commercial viability of off-grid systems, which have made them more economically attractive.⁴⁵ In addition, the availability of proven, viable and affordable consumer financing models, specifically the “pay-as-you-go” (PAYGo) model, has been instrumental in expanding the off-grid solar market.⁴⁶

A record 8.5 million units of affiliatedⁱⁱ off-grid solar products were sold in 2019, up 12% from 2018.⁴⁷ (→ See Figure 43.) Pico solar systems continued to dominate, with around 7 million units sold in 2019 and 4.5% growth in sales (by volume) compared to the previous year.⁴⁸ However, the market share of solar home systemsⁱⁱⁱ

expanded – from 13% in 2018 to 18% in 2019 – due to the greater affordability of these systems and the rising demand for off-grid appliances – and sales jumped 66.6% to 1.5 million units.⁴⁹ (→ See Box 1.) The total installed capacity of off-grid solar products grew to 94.1 MW in 2019, up from 58.8 MW in 2018.⁵⁰

The main regional markets for affiliated off-grid solar systems – together accounting for nearly three-quarters of the total sales volume – continued to be East Africa (49% of total sales in 2019; led by Kenya) and South Asia (23%; led by India).⁵¹ After declining in 2018, sales of affiliated products in the East African market recovered in 2019, increasing 41%, whereas sales in South Asia fell 28%.⁵² Sales also continued to grow in the Middle East and North Africa (up 57%, with the products used mainly to meet humanitarian needs) as well as in Central Africa (up 32%) and West Africa (up 27%).⁵³

The top five markets for affiliated off-grid solar systems in 2019 (by sales volume) were Kenya, India, Ethiopia, Uganda and Nigeria.⁵⁴ Sales expanded the most in Ethiopia (up 108% to 1.01 million units) and Kenya (up 55% to 1.97 million units).⁵⁵ (→ See Figure 44.) The growth in Kenya is attributed mainly to rising customer demand for solar home systems and to the country’s conducive sales environment, resulting from an adequate regulatory framework and from the impetus provided by the ongoing World Bank-funded Kenya Off-Grid Solar Access Project (KOSAP).⁵⁶

- i Pico solar systems/products refer to off-grid solar systems rated up to 10 watts-peak (W_p), that are used primarily for lighting and mobile charging purposes.
- ii Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members, companies selling products that meet Lighting Global Quality Standards, and appliance companies that participated in the Global LEAP Awards, or are engaging with the Low Energy Inclusive Appliances (LEIA) programme.
- iii Solar home systems are off-grid solar systems, rated at 11 W_p and above, that can be used for lighting purposes and to power electrical appliances.

BOX 1. Energy-Efficient Appliances

The adoption of energy-efficient appliances continues to expand with the growth of distributed renewable solutions for energy access and increasing focus on productive uses of energy.

Global sales of off-grid consumer appliances, such as fans, televisions and refrigerators, have increased 50% to 80% annually since 2014. In 2019, an estimated 1.2 million off-grid appliances were sold, with the majority being televisions and fans. In addition, the demand for packaged off-grid solar solutions and appliances has grown, and up to 80% of solar home systems now include an appliance such as a fan, radio or television. Electric cooking also is increasingly in demand, and the 2020 Global LEAP Awards administered by CLASP provided grants to appliance manufacturers and off-grid solar distributors for efficient electric pressure cookers for use in off-grid and weak-grid settings.

Interest in productive end-use appliances powered by distributed renewables is rising as well. Existing applications include water pumps, cold storage and agro-processing.

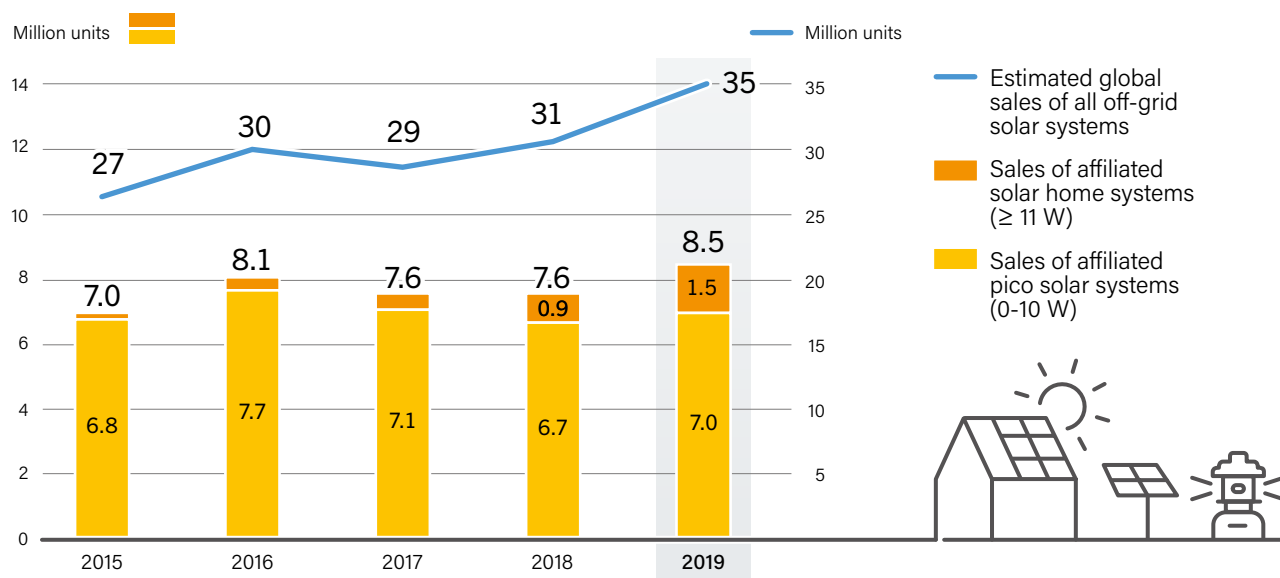
However, the market remains in its infancy, and appropriate delivery models continue to be tested to reach commercial viability and scale.

High-risk funding is required to support research and development, pilot initiatives, consumer research and capacity building. Some of the programmes that have supported the development of appliances and ecosystems for productive uses of energy include the 2019 Global LEAP Awards (with a focus on solar water pumps and off-grid refrigerators), the Efficiency for Access Research and Development Fund and the CEEW-Villgro Powering Livelihoods initiative.

Unlocking the market for off-grid appliances requires wider availability of products for consumers and improved access to financing. In some contexts, service-based delivery models allow consumers to access products on a pay-per-use basis.

Source: See endnote 49 for this chapter.

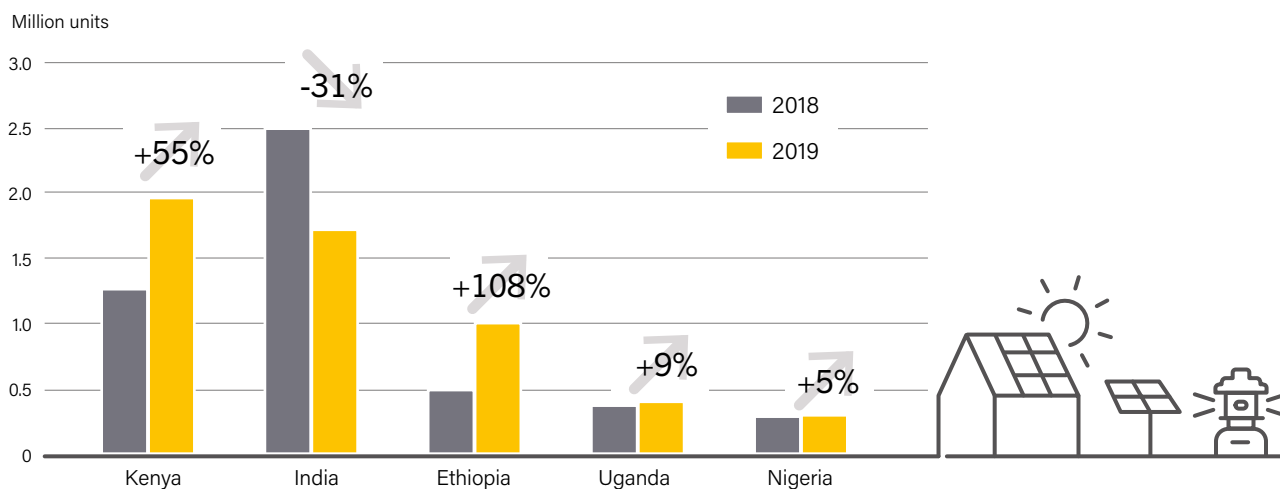
FIGURE 43. Global Sales Volumes of Off-Grid Solar Systems, 2015-2019



Note: Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members and companies selling products that meet Lighting Global Quality Standards.

Source: IFC and GOGLA. See endnote 44 for this chapter.

FIGURE 44. Sales Volumes of Affiliated Off-Grid Solar Systems in Top 5 Countries, 2018 and 2019



Note: Figure includes only countries that provided data for more than three companies. Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members and companies selling products that meet Lighting Global Quality Standards.

Source: GOGLA. See endnote 55 for this chapter.

In Ethiopia, three key policy interventions catalysed the boost in sales in 2019: the provision of adequate foreign currency to facilitate imports of off-grid solar products, implementation of quality standards for these products and the development of an appropriate ecosystem for PAYGo companies to operate.⁵⁷ Sales also increased in Uganda (up 9%) and Nigeria (up 5%).⁵⁸ In contrast, the sales volume in India fell nearly 31% due to policy uncertainties, the limited funding availability of microfinance institutions, and rising imports and sales of non-solar portable lanterns in the country.⁵⁹

Cash-based sales continued to dominate the market for affiliated off-grid solar products. Of the total volume of affiliated products sold in 2019, 75% of the transactions were made in cash and 25% through the PAYGo model.⁶⁰ Cash sales of affiliated off-grid solar products were more prominent in South Asia than in the African sub-regions – representing nearly 99% of sales in South Asia but just over 60% in sub-Saharan Africa.⁶¹

A key driver of sales in East, West and Central Africa has been the availability of the PAYGo model for the commercialisation of off-grid solar products. In 2019, PAYGo sales accounted for 39%,

47% and 22% of the total sales of affiliated products in these regions, respectively.⁶² For affiliated solar home systems, nearly 70% of the sales were completed using the PAYGo model, whereas for pico solar products, 81% of sales were conducted on a cash basis.⁶³

Renewable energy-based mini-grids continued to gain momentum as more projects were developed across Africa and Asia. Worldwide, an estimated 19,000 mini-grids had been installed by the end of 2019, serving some 47 million people.⁶⁴ Around half of these mini-grids were based entirely or partially on renewables, with most supplied by hydropower. Solar PV and solar hybrid systems, which accounted for just under 10% of the installed mini-grids, are increasingly being positioned as the technology of choice, with solar installations growing 100% between the 2009-2013 period and the 2014-2018 period.⁶⁵ The shift to solar PV has been enabled by the drop in prices for PV technologies and the emergence of innovations such as smart meters and remote monitoring.

An estimated 354 MW of solar mini-grid capacity was added globally in 2018, providing more than 3 million people with electricity access.⁶⁶ Around 77% of the systems were in Africa and only 16% in Asia.⁶⁷ (→ See Figure 45.) In 2019, some 150 mini-grid projects were completed, another 1,600 projects were announced, and around 7,500 projects were either in planning or under development, mainly in India, Nigeria and Senegal.⁶⁸

Africa continued to be a major testing ground for mini-grid projects during the year. In Nigeria, one of the most promising markets for mini-grids under a public-private partnership model, projects were commissioned in several states.⁶⁹ As part of Nigeria's national Energizing Education Program, mini-grids with

capacities ranging from 2.8 MW to 7.1 MW were commissioned at four universities.⁷⁰ In Sierra Leone, some 24 solar hybrid mini-grids totalling 1.2 MW were installed across small towns and villages to increase energy access.⁷¹

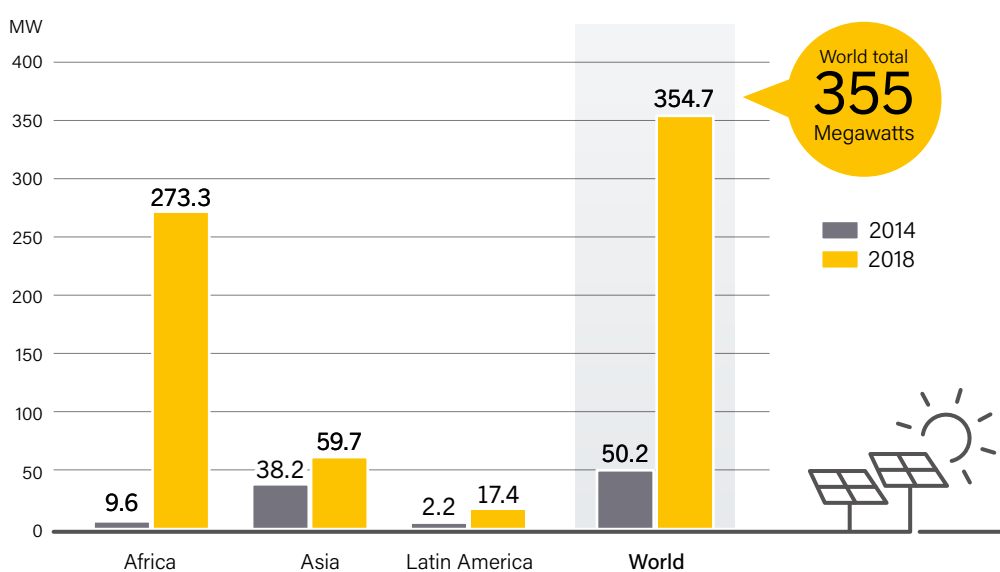
In Tanzania, 11 solar mini-grids were commissioned on 10 different islands on Lake Victoria as part of the first phase of the Micro Power Economy Tanzania Roll-out project, co-funded by the European Union.⁷² Solar mini-grids of 42 kW capacity were deployed in Mali to provide electricity access to 20 villages.⁷³ In Zambia, ENGIE (France) and Huawei (China) completed mini-grid installations in the districts of Chitandika and Mwinilunga, respectively.⁷⁴ Late in the year, Burkina Faso, Ethiopia and Togo all launched tenders for mini-grid deployments.⁷⁵

Countries in Asia – including Afghanistan, Myanmar, India and Nepal – installed the highest numbers of mini-grids in 2019.⁷⁶ Myanmar, which has a long track-record of micro-hydro and biomass-based mini-grids, added around 100 solar hybrid mini-grids during 2017-2019.⁷⁷ Under the Rural Development Department's mini-grid programme, which aims to electrify every household in Myanmar by 2030, the country commissioned its largest solar mini-grid in 2019.⁷⁸ On the Philippine islands of Palawan, WEnergy (Singapore) installed a 2.4 MW solar hybrid mini-grid in Sabang and began building a second (662 kW_p) solar hybrid mini-grid in Panlaitan.⁷⁹

Solar PV mini-grids

are increasingly the preferred technology for providing electricity access across Africa and Asia.

FIGURE 45. Installed Capacity of Solar PV Mini-Grids, Selected Regions and World, 2014 and 2018



Note: World total may not add up due to rounding.

Source: IRENA. See endnote 67 for this chapter.

In addition to meeting basic power needs for lighting, television and mobile charging, the provision of energy access has the potential to catalyse income-generating activities and trigger wider economic development in rural and remote areas.⁸⁰ Activities that generate income, increase productivity, enhance diversity and create economic value in these areas are known as **"productive uses of energy"**.⁸¹ They may include:

- local activities such as agriculture, livestock and fishing;
- light mechanical works such as welding, carpentry and water pumping;
- small retail and commercial activities such as tailoring, printing, catering and entertainment; and
- small and medium-scale production such as agro-processing (grinding, milling and husking), refrigeration and cold storage, drying, preserving and smoking.⁸²

DREA systems can greatly increase the productivity of livelihood activities.⁸³ In India, the use of mini-grids has helped reduce irrigation costs 70% and improved crop productivity 50%.⁸⁴ Through the adoption of specific DREA systems, the average annual revenue of Indian micro-enterprises has increased an estimated 13%.⁸⁵ In Kenya, the uptake of solar-powered water pumps has helped to increase farmers' crop yields 2-5 times and their incomes 5-10 times.⁸⁶

The availability of off-grid solar and mini-grid technologies, coupled with new business models that make productive uses of energy affordable, have accelerated the demand for such applications in recent years.⁸⁷ In sub-Saharan Africa (mainly East Africa), an estimated 10,000 systems for productive uses of energy – including solar-powered irrigation pumps as well as units for agro-processing and cooling/refrigeration – have been

sold.⁸⁸ In India, more than 150,000 units have been sold, and in Bangladesh some 1,500 solar pumps were deployed between 2013 and 2019 under the IDCOL Solar Irrigation Program.⁸⁹

ACCESS TO CLEAN COOKING FACILITIES

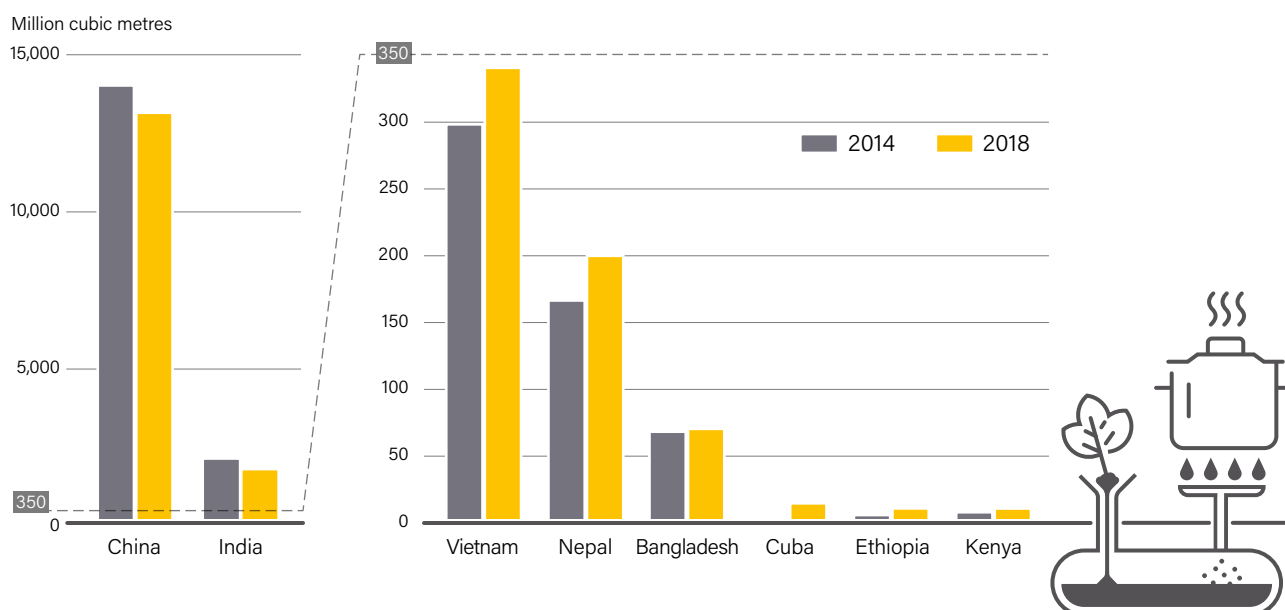
Although liquefied petroleum gas (LPG) continued to dominate the market for clean cooking solutions, other technologies such as biomass cook stoves, biogas and solar cookers, and electric cooking were being deployed and piloted in many developing countries. In Rwanda, an estimated 30,000 biomass improved cook stoves have been distributed under the National Cookstoves Programme.⁹⁰ In South Africa, biomass briquettes and pellets accounted for a reported 33% of the fuels used in clean cookstoves as of 2018.⁹¹

An estimated 125 million people worldwide used biogas for cooking in 2018 (latest data available), most of them in Asia (including 111 million in China and 9 million in India).⁹² In total, around 15.5 billion cubic metres of biogas were produced for cooking purposes during the year, mainly in China (13.1 billion cubic metres) and India (1.6 billion cubic metres).⁹³ However, the demand for biogas for cooking decreased in these two dominant markets between 2014 and 2018, while surging in other Asian countries such as Bangladesh, Nepal and Vietnam.⁹⁴ (→ See Figure 46.) Hivos and Energia distributed around 120,000 biogas digesters through their respective programmes in Cambodia and Indonesia.⁹⁵

Biogas production in Africa increased nearly 40% during 2014-2018 to around 46 million cubic metres, mainly in the five countries engaged in the Africa Biogas Partnership Programme: Burkina Faso, Ethiopia, Kenya, Tanzania and Uganda.⁹⁶ Under the first two phases of this programme, around 70,000 biogas digesters were installed across East Africa, providing clean cooking solutions to some 500,000 people.⁹⁷

i As many as 65 different productive use and livelihood applications enabled by DREA systems have been documented in India. See endnote 83 for this chapter.

FIGURE 46. Production of Biogas for Cooking in Selected Countries, 2014 and 2018



Source: IRENA. See endnote 94 for this chapter.

By the end of 2019, more than 3.9 million concentrating solar cookers were estimated to have been distributed worldwide, providing clean cooking solutions to around 14 million people.⁹⁸ In addition, solar PV electric cooking gained attention after studies showed that electricity from solar PV mini-grids and solar home systems can be cost-competitive with other cooking alternatives.⁹⁹ In 2019, SUNSPOT (United States) partnered with EarthSpark International (United States) to pilot the introduction of solar-powered induction cook stoves in Haiti.¹⁰⁰

BUSINESS MODELS

Innovations in business models have been critical for the successful deployment of DREA systems, mobilising the financing necessary to achieve universal energy access by 2030. DREA-specific business models vary widely in their complexity as well as in their target consumers, delivery approaches, economics and use of digital technologies. Whereas some models are as simple as cash sales of locally manufactured, off-the-shelf products, others rely on outsourced manufacturing and global supply chains, diversified sales channels, complex customer data analytics and digital finance.

One of the most successful business models for the deployment of **off-grid solutions**, and particularly off-grid solar products, in recent years has been “pay-as-you-go”. The PAYGo model allows customers to pay for off-grid solutions in instalments rather than providing capital upfront, an approach that has made DREA systems more affordable to millions of people around the world. In 2019, a quarter of the global sales volume of off-grid solar products was conducted using the PAYGo model.¹⁰¹ In East Africa, one of the main markets for off-grid solar products, PAYGo accounted for around 40% of the total sales volume.¹⁰² In West Africa, also a growing market for off-grid solar, nearly 50% of sales were PAYGo.¹⁰³

As both the off-grid sector and PAYGo mature, off-grid solar start-ups have shifted increasingly from a business development model based on growth to one focused on profitability, in order to sustain their operations over time and also to expand their activities.¹⁰⁴ In 2019, several companies were bundling their energy services with other financial offerings (loans, insurance or microfinance) and consumer products (TV, refrigerators, etc.).¹⁰⁵ These companies aimed to generate other revenue streams through their existing platforms and networks by providing a bundle of energy products and services to populations either off the grid or connected to unreliable grids.¹⁰⁶

In Kenya, the PAYGo start-up Angaza (United States) partnered with JUA Energy (Kenya) to offer customers PAYGo LCD televisions and developed a PAYGo laptop together with Endless Solutions.¹⁰⁷ Azuri Technologies (United Kingdom), a leader in PAYGo solutions, launched a PAYGo bundle in Zambia consisting of a solar home system, a satellite television and a lighting system.¹⁰⁸ In Uganda, the company was promoting a PAYGo solar irrigation solution bundled with an insurance scheme that provides cover for unexpected crop loss.¹⁰⁹ Also in Uganda, Fenix International (Uganda) was providing loans for school fees to more than 40,000 rural families and was experimenting with bundling agricultural loans and

health insurance with the company's solar home systems.¹¹⁰ The PAYGo start-ups Baobab+ (France) and BrightLife (Uganda) also continued to offer microfinance products to their customers in partnership with microfinance institutions.¹¹¹

Continuing a recent trend, some PAYGo companies established partnerships with telecommunications companies to expand their customer base and also penetrate new markets. In Afghanistan, d.light (United States) collaborated with the Afghan Wireless Communications Company to supply small-scale solar PV systems to homeowners.¹¹² In Africa, Greenlight Planet (United States) partnered with the mobile operators Orange in Burkina Faso, Telma in Madagascar and Vodacom in Tanzania to promote its PAYGo solar system.¹¹³

Beyond the PAYGo model, the concept of peer-to-peer electricity trading or “swarm electrification” was being tested among rural households in Bangladesh. Through swarm electrification, households that have a solar home system are able to connect to a low-voltage distribution system and sell their excess electricity to neighbouring households that may or may not have their own solar home system in place.¹¹⁴ The government of Bangladesh, SOLshare (Bangladesh) and the national grid operator kicked off a pilot project in 2019 to trial the concept, which could enable more households to connect to electricity.¹¹⁵

Innovative business models also were being used to boost the deployment of **clean cooking facilities** worldwide, leveraging on mobile payment technologies. Cambodia-based ATEC Biodigesters launched the first PAYGo scheme for biogas, enabling farmers who cannot afford the upfront cost of a biodigester to pay monthly instalments via mobile money schemes.¹¹⁶ By the end of 2019, more than 1,500 of the units had been sold in Cambodia, providing renewable gas for cooking (of which 250 sold through the PAYGo scheme).¹¹⁷ In Rwanda, BBOX (United Kingdom) launched its PAYGo cooking solution, with the goal of providing clean cooking services using biogas and LPG to some 5,000 households by 2020.¹¹⁸

A growing number of solar home system companies and mini-grid developers and operators have adapted their business models to enable **productive uses of energy**. This market segment offers a unique opportunity to provide energy start-ups with a new revenue stream, while also giving rural households the ability to boost their incomes.¹¹⁹ Several companies have structured their business models to offer pay-per-use productive use of energy services – such as solar irrigation, cooling and agro-processing products – to off-grid populations.¹²⁰

This model has helped to address the barrier of the high upfront cost of productive uses of energy products. In 2019, Oorja (India) offered a PAYGo solar irrigation service for small farmers whereby the company installs, operates and maintains the solar pumps for the community, and the farmers pay only for the irrigation services.¹²¹ M-PAYG (Denmark) has engineered a product aimed at reducing food waste by providing local fishermen in Kenya with a solar-powered cooling system that keeps the catch cool while still on the boat.¹²² ColdHubs (Nigeria) was providing solar-powered cold storage facilities to farmers using a pay-as-you-store model whereby farmers pay only a daily fee per crate of food stored.¹²³

INVESTMENT AND FINANCING

ACCESS TO ELECTRICITY

Despite the multiple benefits that access to electricity provides, total investment in the DREA sector is well below the level needed to achieve universal access by 2030. Of the estimated USD 51 billion required annually to achieve universal electricity access in the 20 “high-impact countries”ⁱ by 2030, around USD 36 billion was invested in 2017 – and of this, only one-third, or USD 12.6 billion, is estimated to have provided residential access, and only 1.2% flowed towards DREA systems.¹²⁴

Investment in DREA companies has increased substantially in recent years, with the sector raising a cumulative USD 2.1 billion in corporate-level investmentⁱⁱ since 2010.¹²⁵ In 2019, corporate-level investments in the DREA sector totalled around USD 468 million, down 8.5% from the USD 512 million invested in 2018.¹²⁶ (→ See Figure 47.) This decline is attributed mainly to a strategy of greater

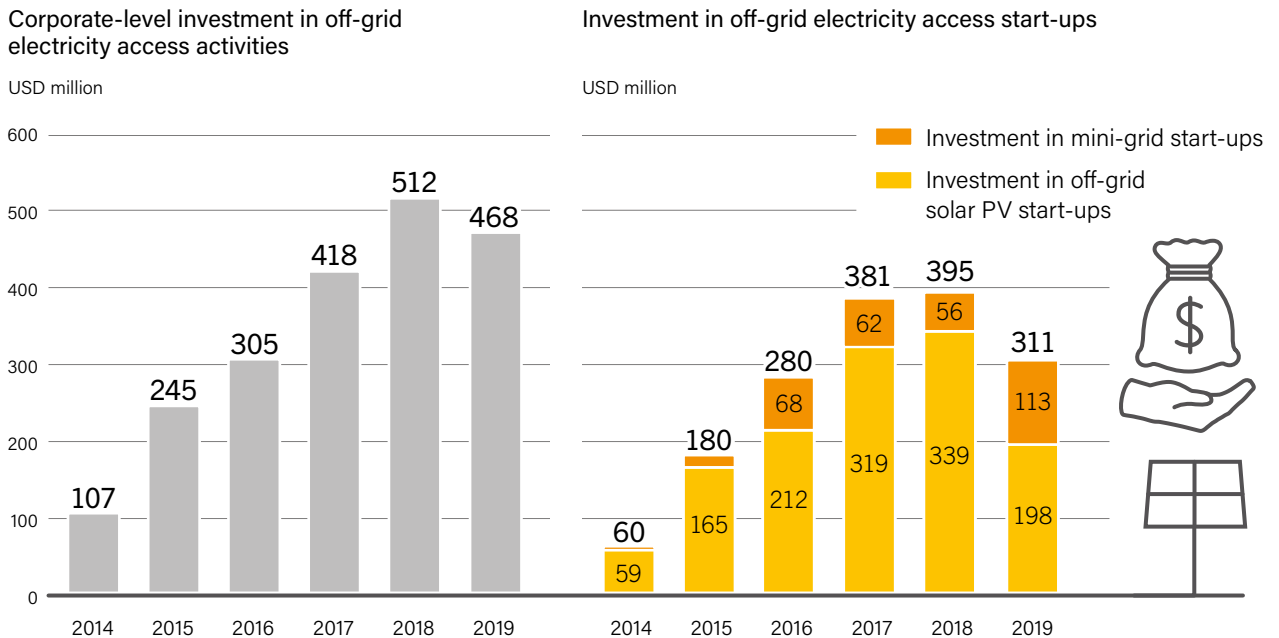
diversification by DREA investors, as they direct more financing towards energy access funds and financial instruments rather than to DREA companies.¹²⁷

Off-grid electricity access start-upsⁱⁱⁱ have been one of the main actors in the deployment of DREA systems in recent years and a major recipient of DREA-related investments. These start-ups attracted an estimated USD 311 million in capital flows in 2019, down 20.1% from the USD 389 million raised in 2018.¹²⁸ (→ See Figure 47.) Investments in off-grid solar start-ups dropped 41.6%, whereas capital flows in mini-grid start-ups more than doubled to a record USD 113 million in 2019.¹²⁹

Investments in mini-grid start-ups more than doubled to a **record USD 113 million** in 2019.

- i These 20 countries account for more than two-thirds of the people living without electricity and four-fifths of the people who rely on traditional biomass for cooking and heating. For electricity access, the high-impact countries, as identified in the IEA and World Bank’s *Global Tracking Framework 2015* report, are Afghanistan, Angola, Bangladesh, Burkina Faso, the Democratic Republic of the Congo, Ethiopia, India, Kenya, the Democratic People’s Republic of Korea, Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, the Philippines, Sudan, Tanzania, Uganda and Yemen.
- ii Corporate-level investments refer to investments in off-grid energy access companies by strategic investors. These include grants, direct investments (debt and equity), mergers and acquisitions, and blended finance, among others.
- iii Off-grid electricity access start-ups refer to start-ups providing electricity access through off-grid systems (off-grid solar systems and mini-grids). Mini-grids refer to systems (100 kW_p or more) that provide energy access to multiple users. Mini-grid systems may be powered by more than one source of energy, with at least one renewable energy source (solar, hydropower or wind) and include energy storage.

FIGURE 47. Global Investment in Off-Grid Electricity Access Activities, 2014-2019



Note: Corporate-level investment encompasses off-grid and off-grid-related energy access activities by strategic investors such as oil and gas majors, utilities and independent power producers, and global original equipment manufacturers (OEMs), as well as by market leaders from the technology, telecommunications and fast-moving consumer goods sectors. This includes direct investment (debt and equity), mergers and acquisitions, commercial partnerships and joint ventures, and investment through funds and financial intermediaries. Investment in energy access start-ups refers to investment through debt and equity mainly in start-ups providing electricity access through off-grid systems. Mini-grids refer to systems of more than 100 kW for energy access activities only. These systems may have more than one source of energy, with at least one renewable energy source.

Source: See endnote 126 for this chapter.

The decline in investment in off-grid solar start-ups may be attributed to the high concentration of investments in a small number of start-ups and to recent acquisitions by large corporations.¹³⁰ Since 2012, just 10 start-upsⁱ have raised 78% of the total investment in the off-grid solar sector.¹³¹ With less of an appetite for equity financing and successful debt financing campaigns in 2017 and 2018, these companies were less involved in mobilising investment in 2019.¹³² In addition, several of the major start-ups – such as d.light, Fenix International, Mobisol (Kenya) and Simpa Networks (India) – have since been acquired by larger corporations and no longer rely heavily on external investment.¹³³

East Africa, and to a lesser extent West Africa, continued to be the main recipients of off-grid solar investment in 2019, due to the high penetration of mobile money services in these regions.¹³⁴ Since 2012, off-grid solar companies in East Africa have attracted an estimated 60% of investments in the sector, and West Africa has mobilised around 17%, as more companies start or expand operations in the region.¹³⁵ In 2019, notable investment deals in East and West Africa included a USD 50 million investment by Mitsubishi (Japan) in BBOXX and a USD 26 million equity investment by Marubeni (Japan) in Azuri Technologies.¹³⁶

In addition, PEG Africa (Ghana) secured USD 46.5 million in debt and equity to develop new markets in West Africa, where it already served some 400,000 people in Côte d'Ivoire, Ghana and Senegal, while d.light mobilised USD 18 million to expand operations on the continent.¹³⁷ Companies operating in Central and Southern Africa also mobilised investments during the year: upOwa (Cameroon) raised USD 2.8 million to support its PAYGo solar home systems operations, and Solarworks (South Africa) mobilised some USD 6 million to expand its off-grid solar operations in Mozambique.¹³⁸

Off-grid solar companies in Asia, traditionally operating on cash sales rather than using the capital-intensive PAYGo

model, mobilised relatively low investment in 2019.¹³⁹ Despite the uncertainty in the Asian off-grid solar market, SolarHome (Singapore), a PAYGo solar start-up, secured USD 1 million to provide off-grid electricity access in Myanmar through its solar home systems solution.¹⁴⁰ Orb Energy (India) obtained equity investments from Shell New Energies to support its growth in India.¹⁴¹

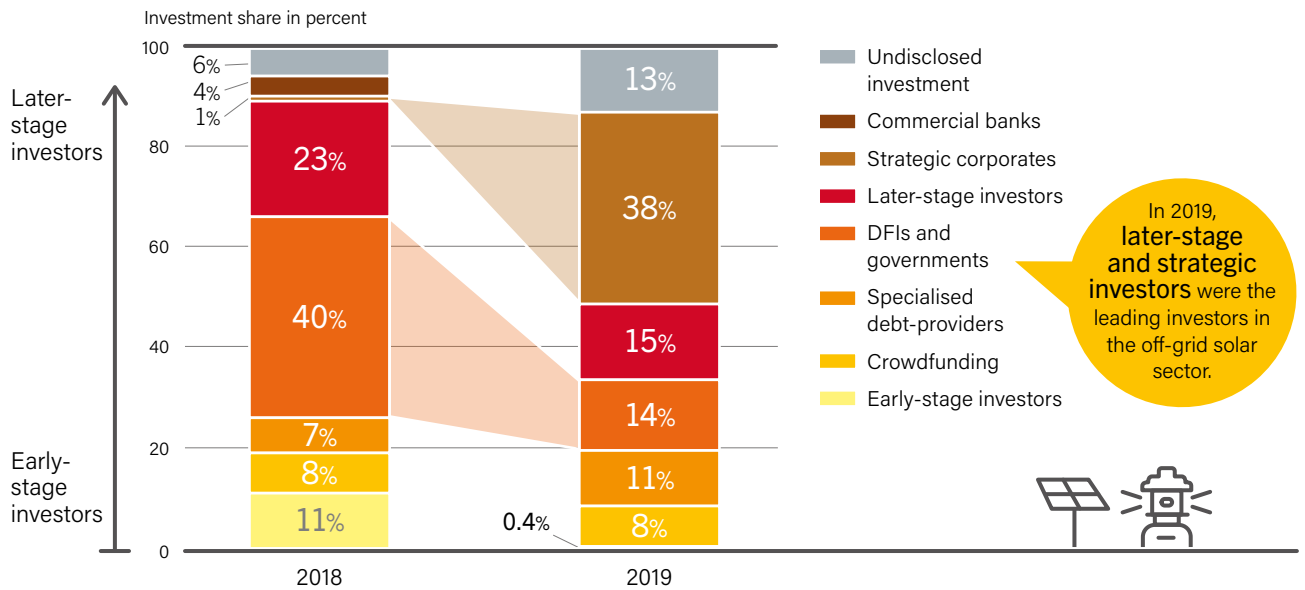
Building on the momentum of recent years and on the emergence of new business and financing models, investments in mini-grid start-ups more than doubled in 2019 to exceed USD 100 million for the first time.¹⁴² Investments continued to flow in Asia, which had the most mini-grids installed by year's end, with Yoma Micro Power (Myanmar) mobilising USD 30 million to develop solar mini-grids in Myanmar.¹⁴³ In Africa, where investment in mini-grid start-ups also continued, Cross-Boundary Energy Access made a first USD 5.5 million investment in PowerGen (Kenya) to deploy 60 mini-grids to provide electricity to some 34,000 people in Tanzania.¹⁴⁴ PowerGen also secured USD 6.9 million from Infracore to deploy mini-grids in Sierra Leone.¹⁴⁵ In addition, Powerhive (United States) raised USD 9.3 million from the clean energy investment company Kouros (United States) to expand rural mini-grid operations in Kenya.¹⁴⁶

The type of investors in DREA markets shifted notably in 2019. Strategic corporate investors accounted for nearly 38% of total capital flows in the sector – up from less than 1% in 2018 – while the share of total investments in off-grid solar companies by development finance institutions (DFIs) and governments fell to 13.5%, down from 40.1% in 2018.¹⁴⁷ (→ See Figure 48.) This shift is attributed mainly to the growing maturity of the sector and to the new growth strategy being adopted by the first generation of off-grid solar start-ups.¹⁴⁸ A major illustration of the rising role of strategic corporate investors was ENGIE's acquisition of Mobisol, a leader in East Africa's PAYGo market.¹⁴⁹ DFIs and governments, however, continued to be the main investors in mini-grid start-ups in 2019.



i The 10 start-ups are Zola Electric, d.light, M-KOPA SOLAR, BBOXX, Mobisol, Nova Lumos, Greenlight Planet, Azuri Technologies, Kingo and SolarNow.

FIGURE 48. Share of Investment in Off-Grid Solar PV Companies, by Type of Investor, 2018 and 2019



Note: Early-stage investors include impact investors, individuals such as business angels, and venture capital funds; later-stage investors include private equity and asset management funds; DFI = development finance institution.

Source: IFC. See endnote 147 for this chapter.

Crowdfunding remained an important source of working capital for off-grid solar companies, with some USD 22 million in investment mobilised in 2019; through the Trine crowdfunding site, BBOXX raised around USD 6.6 million from more than 4,400 investors to finance its off-grid activities in Africa.¹⁵⁰ Greenlight Planet secured some USD 2 million through Trine to finance its growth in India's off-grid solar market.¹⁵¹

ACCESS TO CLEAN COOKING FACILITIES

Despite recent calls for action, less than 1% (USD 32 million) of the USD 4.4 billion required annually to achieve universal access to clean cooking facilities by 2030 is being invested in the sector.¹⁵² In 2019, Sistema.bio (Mexico) secured USD 12 million in investment to expand its biogas activities in India, Kenya, Mexico and South America.¹⁵³ In addition, ATEC Biogas raised USD 1.6 million to roll out the world's first PAYGo model for biogas and to expand its operations from Cambodia to Bangladesh.¹⁵⁴

Clean cooking attracted less than 1% of the USD 4.4 billion investment required annually to achieve universal access in the sector.



POLICY DEVELOPMENTS

With the rapid deployment of off-grid energy solutions in recent years and stronger recognition of the added value and potential of DREA in providing energy access, governments are increasingly prioritising the adoption of policy and regulatory frameworks promoting the uptake of DREA systems.¹⁵⁵ Between 2010 and 2017, four of the top five fast-moving policies for electricity access among countries that have deficits in energy access were DREA related.¹⁵⁶ These included programmes as well as fiscal and financial incentives to promote the development of mini-grids and stand-alone systems.¹⁵⁷ (→ See Tables 4 and 5 at the end of this chapter.)

Although many countries had electricity access targets in 2019 (in line with the goals of the United Nations' Sustainable Development Goal 7 on affordable, reliable, sustainable and modern energy for all), only a few had targets specific to DREA technologies. India, in particular, has introduced various schemes for DREA deployment in recent years, with specific targets for off-grid technologies such as solar home systems, solar streetlights and solar PV pumps.¹⁵⁸ In Africa, the Rural Electrification Agency of Nigeria announced in late 2017 its aim to develop 10,000 mini-grids, and the government of Rwanda, in its 2018 Energy Sector Strategic Plan, outlined a pathway for DREA systems to serve 48% of the population by 2024.¹⁵⁹ The Angolan government announced plans in 2019 to install 30,000 off-grid solar systems with a total capacity of 600 MW by 2022.¹⁶⁰

Governments continued to develop policy frameworks to enable the deployment of DREA systems and the mobilisation of investments in the sector. In 2019, the most common policy-based approaches for accelerating the deployment of DREA included product quality standards for solar systems and cook stoves, as well as regulations for the licensing, tariff setting, grid-interconnection and technical performance of mini-grids. Fiscal and financial instruments such as tax and import duty reductions and waivers, capital subsidies and results-based financing also were widely used. In addition, more countries have been developing integrated electrification plans that consider DREA systems, and several countries have adopted competitive tenders as an instrument for deploying the systems.¹⁶¹

In 2019, Guatemala launched a new electrification policy that aims to extend electricity access to 1.5 million people through alternative sources including off-grid and mini-grid systems.¹⁶² By year's end, five countries – Ethiopia, Kenya, Myanmar, Nepal and Togo – had adopted integrated electrification plans that incorporate approaches and policies that support energy access using grid-based, mini-grid and off-grid solutions, and Namibia and the Republic of the Congo were developing such plans.¹⁶³ In the area of clean cooking, Kenya announced plans to provide clean cooking solutions to 100% of the population by 2028.¹⁶⁴

Competitive processes to deploy DREA systems were launched in several African countries. The government of Togo, through its CIZO programme, launched a tender procedure for the

supply, installation and maintenance of off-grid solar systems on a PAYGo basis.¹⁶⁵ Mali launched a tender procedure for two mini-grid systems totalling 1.3 MW as part of its rural electrification programme.¹⁶⁶ Ethiopia launched its first tender for the deployment of solar mini-grids in 25 villages.¹⁶⁷ In addition, Nigeria began signing grant agreements with companies selected to deploy mini-grids, following a competitive process under the World Bank-backed Nigeria Electrification Project.¹⁶⁸ Algeria launched tenders for the installation of solar-diesel hybrid mini-grids in 2019.¹⁶⁹

Also during the year, policy makers continued to develop regulatory frameworks and to enact policies to attract private sector investment in DREA systems in their countries. Nigeria launched a minimum subsidy tender, a performance-based grant and a mini-grid acceleration scheme to support mini-grid deployment.¹⁷⁰ India announced plans to adopt guidelines for distribution companies on the interconnection of decentralised solar plants with capacities above 2 MW, which will potentially facilitate the development of larger mini-grids.¹⁷¹

Fiscal and financial incentives – including grants, subsidies, and exemptions on value-added tax, import duties and custom tariffs – play an important role in addressing the financial barriers to the deployment of off-grid systems in many countries. India, building on the success of its electrification programme, launched a financing schemeⁱ in 2019 that encourages farmers to replace their diesel and grid-connected water pumps with solar PV pumps.¹⁷² In East Africa, analysis found that a 20% increase in import tariffs (currently at 0%) could reduce sales of off-grid solar systems by an estimated 18-32%, depending on the size of the systems.¹⁷³

With the expansion of DREA markets, a growing number of governments and policy makers have explored approaches for setting up the proper regulatory frameworks needed to ensure the quality of off-grid solutions in their countries. Among the measures that governments have introduced to keep poor-quality products out of the market and to protect customers are the adoption of international standards; the implementation of quality assurance through product testing, inspections and market surveillance; and product bans.

Several countries took steps in 2019 to enhance their policy frameworks around product quality. In the East Africa region, Ethiopia, Kenya, Tanzania and Uganda introduced pre-export verification of compliance to standards for stand-alone solar systems.¹⁷⁴ Under this procedure, DREA systems such as solar lights or solar home systems must be inspected prior to import by an accredited entity in the country of origin. A similar system of pre-inspection was put in place in Pakistan.¹⁷⁵ The Nigerian government started work on a framework to adopt the IEC Global standards for solar energy, and China marked an important milestone by adopting the IEC test methods for stand-alone solar systems.¹⁷⁶ In the areas of cooking and heating, Ethiopia's National Standardisation Council endorsed a clean cook stove and clean cooking solution standard aligned with the International Organization for Standardization's ISO19867-1.¹⁷⁷

i The full name of the subsidy scheme is Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM KUSUM).

NEW PROGRAMMES AND INITIATIVES

A variety of programmes and initiatives were launched in 2019 to support global efforts to advance energy access. These activities, established by international organisations, development partners, philanthropic foundations and non-governmental actors, aimed primarily at creating the right enabling environment, promoting a co-ordinated and integrated approach, and unlocking the level of financing required to achieve the 2030 target of universal energy access.



Several countries have developed **integrated electrification** strategies that include both grid-based and distributed renewable solutions to reach universal access.

ACCESS TO ELECTRICITY

In 2019, development finance institutions continued to provide financial and technical support to the off-grid energy sector through various programmes and mechanisms. DFIs committed an estimated USD 1 billionⁱ to off-grid electricity access programmes and projects during the year (around 12% of total commitments in the energy sector).¹⁷⁸ For example, the World Bank approved the Regional Off-Grid Electrification Project for West Africaⁱⁱ (ROGEP), a USD 200 million programme that aims to improve the policy landscape and the business and investment climate for off-grid energy businesses in the region.¹⁷⁹ The Bank also allocated USD 5.6 million for the development of mini-grids in Nepal.¹⁸⁰

The African Development Bank (AfDB) launched a USD 50 million multinational financing programme to provide guarantees to off-grid energy service companies in sub-Saharan Africa, seeking capital from local banks or financial intermediaries.¹⁸¹ Through its Sustainable Energy Fund for Africa, the AfDB also committed USD 500,000 to support the development and launch of the Nigeria Energy Access Fund, a new private equity fund investing in off-grid and mini-grid projects in the country.¹⁸² The Green Climate Fund approved support of around USD 28 million for the Mali rural electrification programme.¹⁸³

In addition, several donor governments launched bilateral initiatives to support off-grid electricity access in 2019. The Dutch government launched the SDG 7 Results Facility programme to provide grants up to EUR 2.5 million (USD 2.8 million), through a competitive process, for energy access projects in 17 countriesⁱⁱⁱ.¹⁸⁴ The UK government, together with the Shell Foundation, established the Catalysing Agriculture by Scaling Energy Ecosystems initiative to provide energy access to smallholder farms in South Asia and sub-Saharan Africa.¹⁸⁵ The United Kingdom also increased its support to several of its programmes including the Transforming Energy Access programme, the UK Energy Catalyst fund and the Africa Clean Energy programme.¹⁸⁶

Under a joint Papua New Guinea Electrification Partnership, the governments of Australia, Japan, New Zealand and the United States committed USD 25 million to provide electricity access to 70% of the country's population.¹⁸⁷ The US government, through its Power Africa initiative and the US Agency for International Development, also launched a USD 5 million Solar Home System Kick-Starter Programme to provide financing and technical support to solar home system companies in Malawi.¹⁸⁸ The Swedish International Development Cooperation Agency expanded its USD 50 million Beyond the Grid Fund for Africa Facility to provide electricity access to 5-15 million people in Burkina Faso, Liberia and Mozambique.¹⁸⁹ The Italian government signed a USD 9 million extension of its 10-year-long partnership on clean energy access with the International Finance Corporation, which will help support continuation of the Lighting Global programme.¹⁹⁰

ⁱ Includes commitments from the Abu Dhabi Fund for Development, the Asian Development Bank, the Asian Infrastructure Development Bank, the African Development Bank, the European Bank for Reconstruction and Development, FMO, the Green Climate Fund, Proparco and the World Bank Group.

ⁱⁱ Beneficiary countries include the 15 countries in the Economic Community of West African States (ECOWAS) region as well as Cameroon, the Central African Republic, Chad and Mauritania.

ⁱⁱⁱ The 17 countries are: Bangladesh, Burkina Faso, Chad, Ethiopia, the Gambia, India, Kenya, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, South Sudan, Sudan, Tanzania and Uganda.

Also in 2019, several partnerships between philanthropic foundations, corporations and financial intermediaries were established to support energy access activities in Africa and Asia. The Rockefeller Foundation joined forces with Tata Power (India) to create an enterprise to set up 10,000 mini-grids and provide power to 5 million households in India by 2026.¹⁹¹ The Rockefeller Foundation also partnered with All On, a Shell-backed off-grid energy impact investment company, to launch a facility to support off-grid entrepreneurs in Nigeria.¹⁹² Schneider Electric collaborated with Amundi, EDFI and Norfund to create the Schneider Electric Energy Access Asia Impact Fund, which aims to provide energy access to some 350 million people in Bangladesh, India, Indonesia, Myanmar and the Philippines.¹⁹³ In addition to its partnership with the UK government, the Shell Foundation launched the USD 120 million Energy Entrepreneurs Growth Fund (along with the Dutch Development Bank (FMO) and other investment firms), to provide catalytic financing for early- to growth-stage energy access companies in sub-Saharan Africa.¹⁹⁴

Various actors launched initiatives aimed at providing key market, policy and technical information to entrepreneurs, investors and policy markets. For example, building on the experience of the Africa-EU Renewable Energy Cooperation Programme, the European Union launched together with Austria, Germany, the Netherlands and Sweden the GET.invest programme to provide market information and to catalyse financing for sustainable energy and DREA projects, primarily in Africa.¹⁹⁵

Similarly, the World Bank launched the Global Electrification Platform, an open-access, interactive, online platform that offers practitioners and policy makers an overview of electrification investment scenarios and pathways for achieving universal electricity access in selected developing countries.¹⁹⁶

In the same vein, Swedfund, in collaboration with the Alliance for Rural Electrification, the Africa Minigrid Developers Association and Smart Power India, launched a comprehensive set of Consumer Protection Principles for Clean Energy Mini-Grids that are aimed at guaranteeing a minimum standard of service to consumers connected to mini-grids.¹⁹⁷

The Global Commission to End Energy Poverty (GCEEP) also was launched during the year. The GCEEP comprises heads of development banks, utilities, DREA companies, academics and investors, and aims to develop a co-ordinated approach to address energy access challenges.¹⁹⁸

Efforts during 2019 also sought to advance the use of renewables in humanitarian situations. The UN refugee agency UNHCR launched a new Global Strategy for Sustainable Energy that promotes the transition to clean and renewable energy at refugee settlements and other facilities that host migrants, in part as a means to boost energy access for these populations.¹⁹⁹ The strategy builds on, among others, the existing Renewable Energy for Refugees (RE4R) partnership between IKEA Foundation,

UNHCR and Practical Action, which aims to deliver renewable energy solutions to 60,000 people in humanitarian settings in Jordan and Rwanda.²⁰⁰ A key achievement of the partnership in 2019 was the deployment of DREA systems to 1,500 households in refugee settlements in Rwanda.²⁰¹

ACCESS TO CLEAN COOKING FACILITIES

Various development partners established financing programmes and instruments to catalyse investments in the clean cooking sector during 2019. The World Bank launched a USD 500 million Clean Cooking Fundⁱ to scale up public and private investment in the clean cooking sector, in collaboration with United Nations organisations and other DFIs.²⁰² The UK Department for International Development launched the Modern Energy Cooking Services initiative, a USD 50 million research and innovation programme to facilitate the transition from traditional use of biomass to modern cooking solutions.²⁰³

To mobilise the international community and improve co-operation between the health and energy sectors, several organisations (the Clean Cooking Alliance, the International Renewable Energy Agency, Sustainable Energy for All, the United Nations Development Programme (UNDP), the United Nations Foundation, the World Bank and the World Health Organisation (WHO)) launched the Health and Energy Platform of Action in 2019.²⁰⁴ The platform will focus initially on clean cooking and healthcare facilities. In addition, a High-Level Coalition of Leaders for Clean Cooking, Energy and Health was convened by the WHO, UNDP, the UN Department of Economics and Social Affairs and the World Bank to catalyse potential synergies at the ministerial level among the health, energy and finance sectors to address access to clean cooking.²⁰⁵ The Clean Cooking Alliance also launched a global advocacy campaign, "Clean Cooking Is ...", to create awareness and support for clean cooking solutions.²⁰⁶



i The main donors to the Clean Cooking Fund are Denmark, the Netherlands, Norway and the United Kingdom, and the recipient countries to be engaged are Burundi, Ghana, Niger, Rwanda, Uganda and Zambia.

TABLE 4. Distributed Renewables Policies for Electricity Access, Selected Countries, 2019

Country	National Plans and Targets			Regulatory Policies			Non-Regulatory Policies		
	Distributed renewables for energy access targets	Distributed renewables for energy access in INDC or NDC	Integration of distributed renewables in energy access plan/strategy	Grid arrival plan/strategy	Administrative and legal provisions (connection codes, tariff, licensing, etc.)	Tendering, call for proposals or competitive process	Quality/Technical frameworks and standards	Public financing (loans, grants, subsidies, guarantees, etc.)	Fiscal incentives (import duty, VAT, etc.)
Africa									
▲ Angola	★		●		●	●			
Benin	●				●	●	●		●
Botswana						●			
▲ Burkina Faso	●		●	●	●	●		●	●
Burundi									●
Cameroon		●	●						
Central African Republic									
Chad									●
Comoros									
▲ Congo, Democratic Republic of the			●						●
Côte d'Ivoire	●		●	●	●	●			●
Djibouti			●		●				
Equatorial Guinea									
Eritrea			●						
Eswatini		●							
▲ Ethiopia	●		●		●	★, ○	★	●	●
Gabon									
Gambia	●		●		●				
Ghana	●	●	●		●	●			●
Guinea									●
Guinea-Bissau	●								
▲ Kenya	●		●		●	●	★	●	●
Lesotho									
Liberia	●		●						●
▲ Madagascar	●		●		●	●	●	●	●
▲ Malawi	●								●
Mali	●					○		●	●
Mauritania		●							
▲ Mozambique	●		●		●				●
Namibia	●				●			●	
▲ Niger	●	●	●		●				●
▲ Nigeria	●	●	●	●	●	★, ○		●	●
Rwanda	●	●	●	●	●	●	●	●	●
São Tomé and Príncipe		●							
Senegal	●	●	●		●			●	●
Sierra Leone	●			●	●	●			●
Somalia		●							
South Africa									●
South Sudan	●								
▲ Sudan	●	●							
▲ Tanzania			●	●	●		★	●	●
Togo	●		●			★, ○	●	●	●
▲ Uganda	●	●	●		●		★	●	●
Zambia							●		●
Zimbabwe		●			●				●
Asia									
▲ Bangladesh		●	●		●	●	●	●	●
Cambodia		●		●	●		●	●	●
▲ India	●		●	●	●	●	●	●	●
▲ Korea, Democratic People's Republic									
Lao PDR	●	●			●				●
Mongolia	●				●				
▲ Myanmar	●	●	●		●	●	●	●	●
Nepal	●	●			●	●	●	●	●
Pakistan		●					★		●
▲ Philippines			●		●			●	●

Note: Please see key on the next page.

■ TABLE 4. Distributed Renewables Policies for Electricity Access, Selected Countries, 2019 (continued)

Country	National Plans and Targets			Regulatory Policies			Non-Regulatory Policies		
	Distributed renewables for energy access targets	Distributed renewables for energy access in INDC or NDC	Integration of distributed renewables in energy access plan/strategy	Grid arrival plan/strategy	Administrative and legal provisions (connection codes, tariff, licensing, etc.)	Tendering, call for proposals or competitive process	Quality/Technical frameworks and standards	Public financing (loans, grants, subsidies, guarantees, etc.)	Fiscal incentives (import duty, VAT, etc.)
Central and South America									
Bolivia									
Guatemala			★						●
Haiti									●
Honduras									
Nicaragua									
Panama									
Peru			●		●	●		●	
Middle East									
Syria									
▲ Yemen	●	●	●						

Note: The list includes only countries that had an electrification rate below 95% according to the IEA World Economic Outlook 2019 Electricity Access Database. For more on the electrification rates of these countries, see Reference Table R20. High-impact countries are the 20 countries with the highest absolute gaps in access to electricity and/or clean fuels and technologies for cooking, measured by population as identified in the IEA and World Bank's *Global Tracking Framework 2015* report. For electricity access, the countries are: Afghanistan, Angola, Bangladesh, Burkina Faso, the Democratic Republic of the Congo, Ethiopia, India, Kenya, the Democratic People's Republic of Korea, Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, the Philippines, Sudan, Tanzania, Uganda and Yemen. INDC and NDC refers to countries' (Intended) Nationally Determined Contributions to reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: See endnote 157 for this chapter.

- Existing national policy or tender framework
- ★ New (one or more policies of this type)
- National tender held in 2019
- ▲ High-impact countries

■ TABLE 5. Distributed Renewables Policies for Clean Cooking Access, Selected Countries, 2019

Country	National Plans and Targets			Regulatory Policies		Non-Regulatory Policies		
	Clean cooking targets	Clean cooking in INDC or NDC	Integration of clean cooking in energy access plan/strategy	Administrative and legal provisions	Tendering, call for proposals or competitive process	Quality/Technical frameworks and standards	Public financing (loans, grants, subsidies, etc.)	Fiscal incentives (import duty, VAT, etc.)
Africa								
▲ Ethiopia	●	●	●			●		
Ghana	●	●	●			●		
▲ Kenya	●	●	●			●		●
Rwanda	●	●	●					●
▲ Uganda	●	●	●					●
Asia								
▲ Bangladesh	●	●	●			●		●
▲ China	●	●	●					
▲ India	●	●	●				●	
▲ Nepal	●	●	●			●	●	●
Central and South America								
Guatemala		●	●					

Note: High-impact countries are the 20 countries with the highest absolute gaps in access to electricity and/or clean fuels and technologies for cooking, measured by population as identified in the IEA and World Bank's *Global Tracking Framework 2015* report. For clean cooking access, the countries are: Afghanistan, Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, India, Indonesia, Kenya, the Democratic People's Republic of Korea, Madagascar, Mozambique, Myanmar, Nepal, Nigeria, Pakistan, the Philippines, Sudan, Tanzania, Uganda and Vietnam.

INDC and NDC refers to countries' (Intended) Nationally Determined Contributions to reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: Clean Cooking Alliance. See endnote 157 for this chapter.

- Existing national policy or tender framework
- ★ New (one or more policies of this type)
- National tender held in 2019
- ▲ High-impact countries



SOCIO-ECONOMIC BENEFITS OF CSP, SOUTH AFRICA



The KaXu Solar One project in South Africa is the first privately developed large-scale concentrating solar thermal power (CSP) plant with storage to operate in an emerging market. The project has stimulated local economic growth and generated around 1,780 jobs in the Northern Cape, an impoverished province with one of the world's highest rates of youth unemployment. Thanks to a unique ownership structure that includes minority shareholding by the local community, the project can directly support long-term education and economic development initiatives in the area.

05 INVESTMENT FLOWS

KEY FACTS

- Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) totalled USD 301.7 billion, up 5% from 2018.
- Dollar investment in new renewable power capacity (including all hydropower) was three times the total committed to new coal, natural gas and nuclear power generating capacity.
- Developing and emerging economies surpassed developed countries in renewable energy capacity investment for the fifth year running, reaching USD 152 billion.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 megawatts, MW) totalled USD 301.7 billion in 2019, as estimated by BloombergNEFⁱ. This was a 5% increase from 2018, due in part to greater spending on small-scale solar PV systems. Investment in renewable power and fuels has exceeded USD 200 billion annually since 2010.

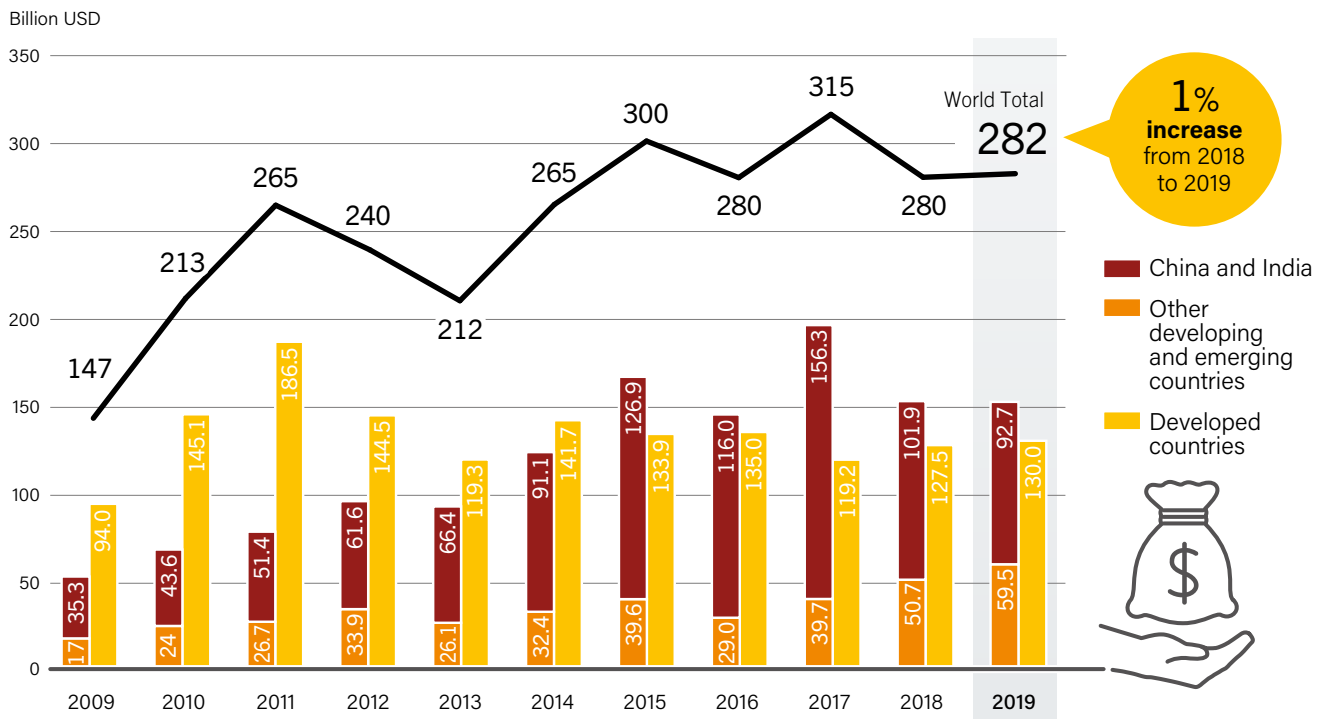
Investment in renewable power and fuel capacity accounted for much of the 2019 total, at USD 282.2 billion, up 1% from 2018. (→ See *Figure 49 and Reference Table 22*.) Investment in hydropower projects larger than 50 MW added an estimated USD 15 billion to the global total in 2019ⁱⁱ.

These estimates do not include investment in renewable heating and cooling technologies, for which data are not collected systematically.

ⁱ This chapter is derived from the United Nations Environment Programme's *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020), the sister publication to the GSR, prepared by the Frankfurt School–UNEP Collaborating Centre for Climate and Sustainable Energy Finance (FS-UNEP Centre) in co-operation with BloombergNEF. Data are based on the output of the Desktop database of BloombergNEF, unless otherwise noted, and reflect the timing of investment decisions. The following renewable energy projects are included: all biomass and waste-to-energy, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with solar PV projects less than 1 MW estimated separately and referred to as small-scale projects or small-scale distributed capacity; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more. For more information, see the FS-UNEP Centre and BloombergNEF *Global Trends* report. Where totals do not add up, the difference is due to rounding. Capacity investment values include asset finance volume adjusted for re-invested equity as well as small distributed capacity investment for solar power. Total investment values include capacity investment values and estimates for undisclosed deals as well as R&D and company investment (venture capital, private equity and public market new equity).

ⁱⁱ Investment in large-scale hydropower (>50 MW) is not included in the overall total for investment in renewable energy. Similarly, investment in large-scale hydropower is not included in the figures throughout this chapter, unless otherwise noted.

FIGURE 49. Global Investment in Renewable Power and Fuel Capacity in Developed, Emerging and Developing Countries, 2009-2019



Note: Figure does not include investment in hydropower projects larger than 50 MW. Investment totals have been rounded to nearest billion.

Source: BloombergNEF.

Investment in new renewable power capacity (excluding large hydropower) was almost three times the level of investment in fossil fuel generating capacity and accounted for a remarkable 71% of the total amount committed to new power generating capacity (including coal, natural gas and nuclear) in 2019.

Investment in renewable energy continued to be dominated by wind power and solar photovoltaics (PV). Asset finance of utility-scaleⁱ projects, such as wind farms and solar parks, dominated investment at USD 230.1 billion worldwide. Small-scale solar PV installations (less than 1 MW in size) accounted for USD 52.1 billion.

Investment in renewable power capacity was **three times** the level of investment in coal, natural gas and nuclear generating capacity combined in 2019.



ⁱ "Utility-scale" here refers to wind farms, solar parks and other renewable power installations of 1 MW or more in size, and to biofuel production facilities with capacity exceeding 1 million litres.

INVESTMENT BY ECONOMY

Developments in renewable energy investment varied by regionⁱ, rising in the Americas, including the United States and Brazil, but falling in all other world regions including China, Europe, India, and the Middle East and Africa. (→ See Figure 50.)

Developing and emerging economies outweighed developed countries in renewable energy capacity investment for the fifth year running, accounting for 54% of the total in 2019, due largely to China. Investment in developing countries (including China and India) totalled USD 152.2 billion for the year, down slightly from 2018. Although renewable energy capacity investment declined in both China and India, outside these two countries it rose 17% in developing countries to a record USD 59.5 billion.

Renewable energy capacity investment in developed countriesⁱⁱ as a group rose 2% in 2019. Sharp increases in the Netherlands, Poland, Spain and the United States were balanced by declines in Australia, Belgium, Germany and the United Kingdom.

China continued to account for the largest share of global investment in renewable energy capacity (excluding hydropower larger than 50 MW), at 30%, followed by the United States (20%), Europe (19%) and Asia-Oceania (excluding China and India; 16%). The Middle East and Africa accounted for 5%, the Americas (excluding Brazil and the United States) 4%, India 3% and Brazil 2%.

The top 10 countries with the most renewable energy capacity investment comprised six developed countries and four developing or emerging countries. In addition to China and the United States, the top five countries were Japan, India and Chinese Taipei, and the next five were Spain, Brazil, Australia, the Netherlands and the United Kingdom.

China's overall investment in renewable power and fuels dropped 6% in 2019 to USD 90.1 billion, continuing the downward trend started in 2018. In capacity only, China invested USD 83.4 billion



– most of it in wind power (USD 55 billion), a 10% increase over 2018. Investments rose in both onshore and offshore wind power capacity. Despite the boom in solar power capacity investment in China in 2017, by 2019 wind investment overshadowed solar PV investment, which fell 33% to USD 25.7 billion. The decline reflected the government's 2018 announcement of its suspension of financial support for solar PV, which caused a so-called market freeze. Biomass and waste-to-energy investment increased 2% to USD 1.5 billion, driven by a string of incineration plants being built in the country.

Investment in European renewable power and fuels totalled USD 58.4 billion in 2019, down 4% from 2018, with a sharp contrast across technologies. In capacity only, Europe invested USD 54.6 billion, with investment in wind energy down 24% to USD 26.4 billion (reflecting the regional trend) but investment in solar PV rising 25% to USD 24.6 billion, a high not seen since 2012. The growth in solar PV resulted from the spread of low-cost projects in Spain and elsewhere, relying on tariffs set in auctions or via private sector power purchase agreements. (→ See *Policy Landscape chapter*.) In 2019, for the first time, Spain led investment in renewable energy capacity in Europe at USD 8.4 billion, up 25% from 2018. The Netherlands (at USD 5.5 billion) and the United Kingdom (at USD 5.3 billion) were in second and third place, due largely to offshore wind projects.

In the United States, which remained the largest individual investor among developed economies, investment increased 25% to USD 59.0 billion in 2019 – its highest value to date. In capacity only, the United States invested 55.5 billion. Developers pushed forward solar PV and wind power projects to enable them to qualify for the soon-to-expire federal tax credits. Investment in wind power projects increased 44% to USD 31.8 billion, and investment in solar PV projects increased 16% to USD 23.3 billion. All other renewable technologies experienced declines or stagnation.

In Asia-Oceania (excluding China and India), overall investment in renewable power and fuels fell 3% to USD 48.2 billion. In capacity only, Asia-Oceania invested USD 45.1 billion. Japan's investment in renewable capacity fell 10% to reach its lowest level since 2011, at only USD 16.5 billion. Reasons for the decline included the lower unit costs of solar PV, which reduced the dollar amount committed per megawatt, as well as grid and land constraints that held back developer activity and auction bidding. However, biomass capacity investment climbed 26% to USD 2.6 billion.

Elsewhere in the region, Chinese Taipei experienced an all-time high in capacity investment of USD 8.8 billion, up 390% from 2018. This was due largely to the financing of three large offshore wind power arrays, together worth USD 7.8 billion. Increases also occurred in Kazakhstan (up 58% to USD 0.8 billion), Pakistan (up 12% to USD 0.6 billion) and Cambodia (rising from almost zero to USD 0.6 billion). Capacity investment declined in Vietnam (down 64% to USD 2.6 billion), Indonesia (down 53% to USD 0.4 billion) and Malaysia (down 44% to USD 0.3 billion).

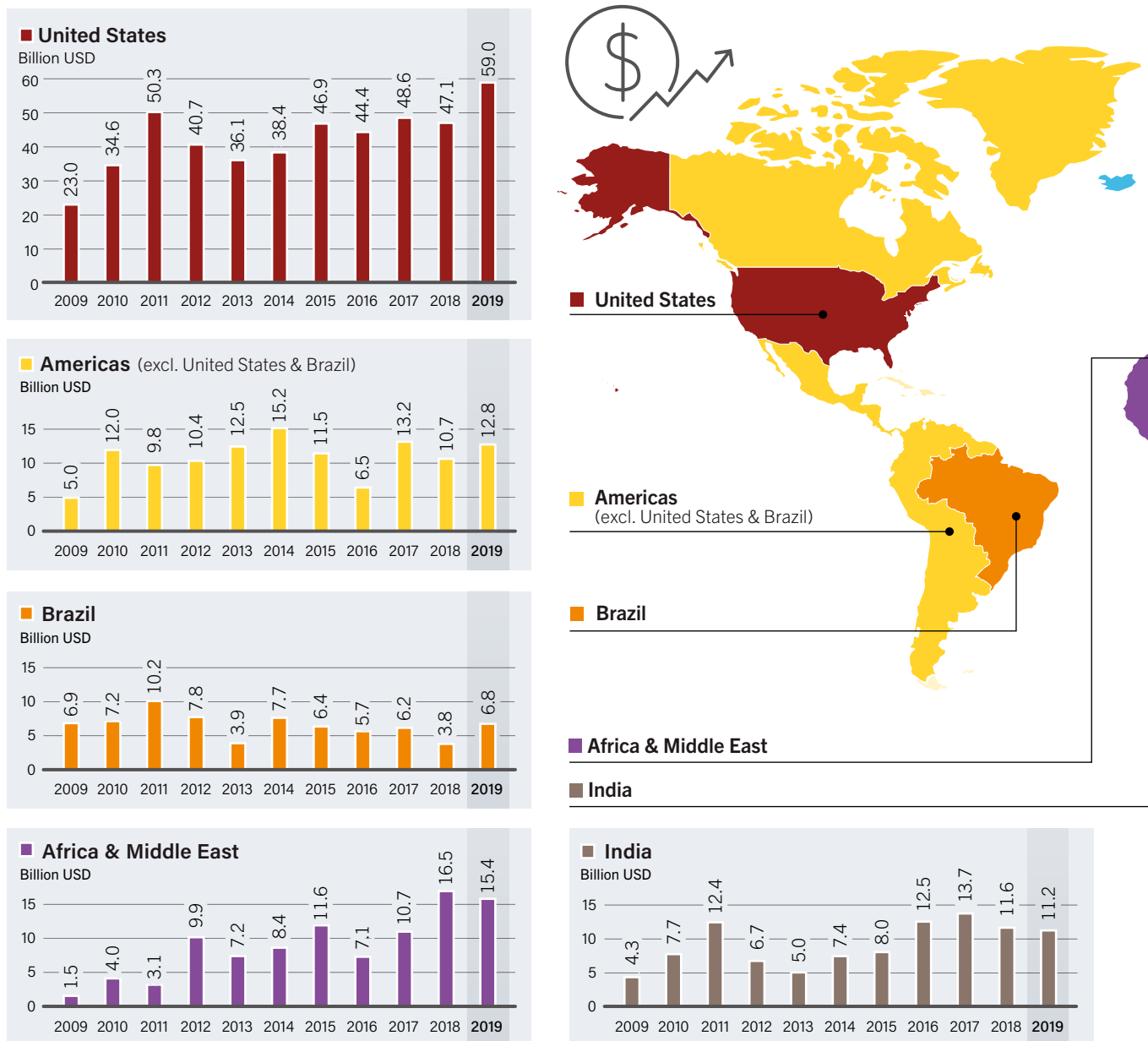
i Regions in this chapter reflect those presented in Frankfurt School-UNEP Centre and BloombergNEF's *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020) and differ from the regional definitions across the rest of the GSR, which can be found at <http://www.ren21.net/GSR-Regions>.

ii Developed-country volumes are based on countries in the Organisation for Economic Co-operation and Development (OECD), excluding Mexico, Chile and Turkey.

In India, total new investment in renewable power and fuels fell 4% in 2019 to USD 11.2 billion, due largely to project financing delays resulting from problems with the electricity distribution companies. In capacity only, India invested USD 9.3 billion. The decline reflected a 48% drop in wind power investment (to USD 2.2 billion) and a 32% drop in biomass and waste-to-energy investment (to USD 0.3 billion). Investment in solar PV capacity increased 8% to USD 6.6 billion.

In the Americas (beyond Brazil and the United States), investment totalled USD 12.8 billion, up 20% from 2018 but still below the 2017 high. In capacity only, investment was USD 12.6 billion. Increases in capacity investment occurred in both Chile (up 302% to USD 4.9 billion, the country's highest value yet) and Mexico (up 17% to USD 4.3 billion). Investment fell 18% in Argentina and also decreased in the Dominican Republic and in Panama (down 66% and 44%, respectively), although these countries remained comparatively small markets.

FIGURE 50. Global Investment in Renewable Power and Fuels, by Country and Region, 2009-2019

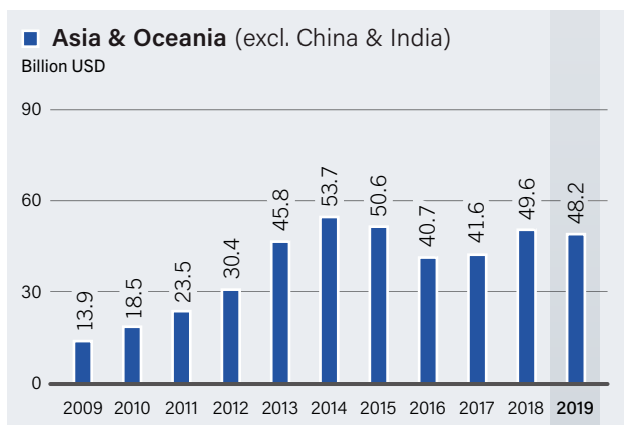
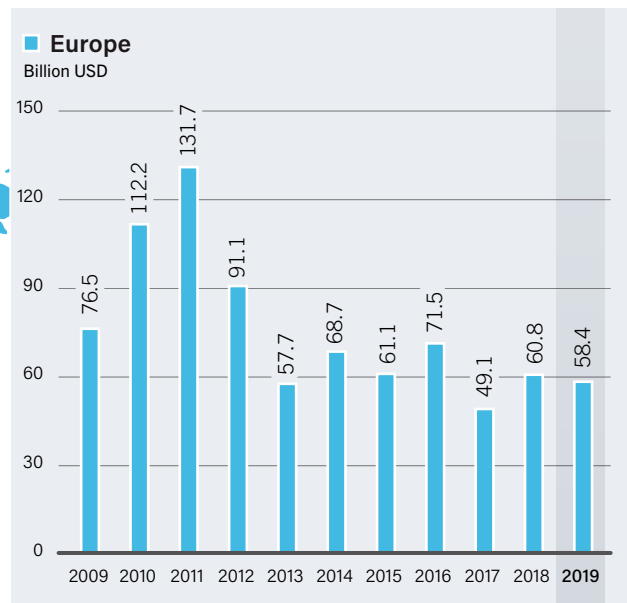
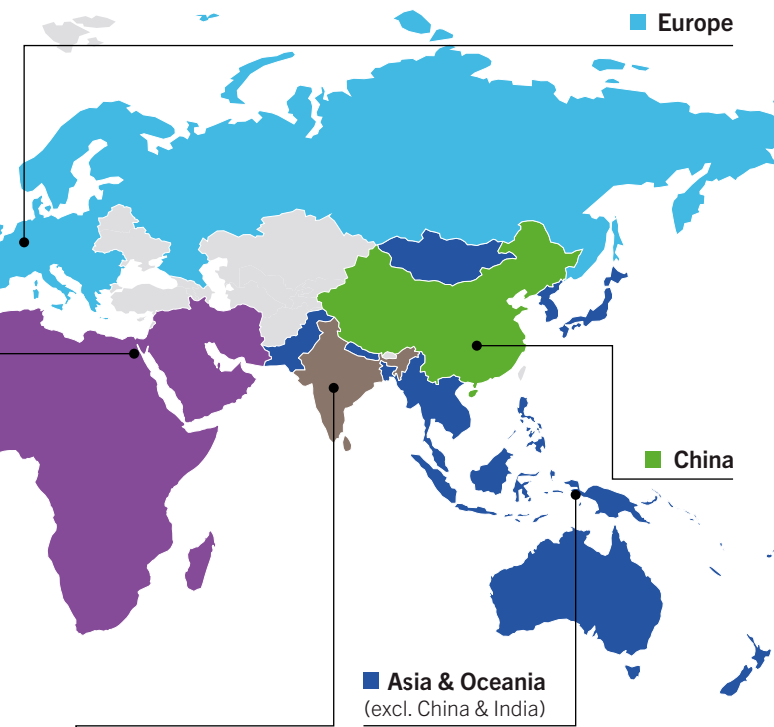


Note: Investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals.

Brazil's total investment in renewable power and fuels was USD 6.8 billion, up 78% from 2018 but still far below the peak of USD 11.1 billion in 2008, when the country's biofuel boom was in full swing. In capacity only, investment was USD 6.5 billion. Most investment was in wind power, at USD 3.4 billion (up 148% from 2018), and in solar power, which rose 30% to USD 2.5 billion.

Total investment in the Middle East and Africa region decreased 7% in 2019 to USD 15.4 billion. In capacity only, investment

was USD 15.2 billion. Gaps in auction programmes were a leading factor behind the declines in capacity investments in many countries that had become prominent renewable energy investors, including South Africa (down 76% to USD 1.0 billion), Kenya (down 45% to USD 0.7 billion) and Morocco (down 83% to USD 0.5 billion). However, in the United Arab Emirates, investment rose a staggering 1,223% to USD 4.5 billion, making it the new regional leader.



Source: BloombergNEF.

INVESTMENT BY TECHNOLOGY

Wind power and solar PV continued to dominate new investment in renewable energy in 2019, each accounting for roughly 47% of the total. Wind power and small hydropower were the only technologies for which investment increased in 2019, with wind power investments rising 8% to USD 142.7 billion. Investment in wind power capacity outweighed that in solar PV for the first time since 2010, and investment in small hydropower technologies grew 6% to USD 2.5 billion. (→ See Figure 51.)

Although overall solar power investment slipped 2% to USD 141 billion, a sharp dichotomy was apparent between utility-scale asset finance of solar PV projects (which fell 19% due mainly to a slowdown in financing of solar PV projects in China) and money committed to small-scale solar PV systems (which jumped 37% to USD 52.1 billion). Investment in concentrating solar thermal power (CSP) capacity totalled USD 4.6 billion, up 256% from 2018.

The other renewable energy technologies struggled to attract capital spending commitments in 2019. Most dramatically, overall investment in geothermal was down 50% to USD 1.2 billion, well below its peak of USD 3.8 billion in 2011.



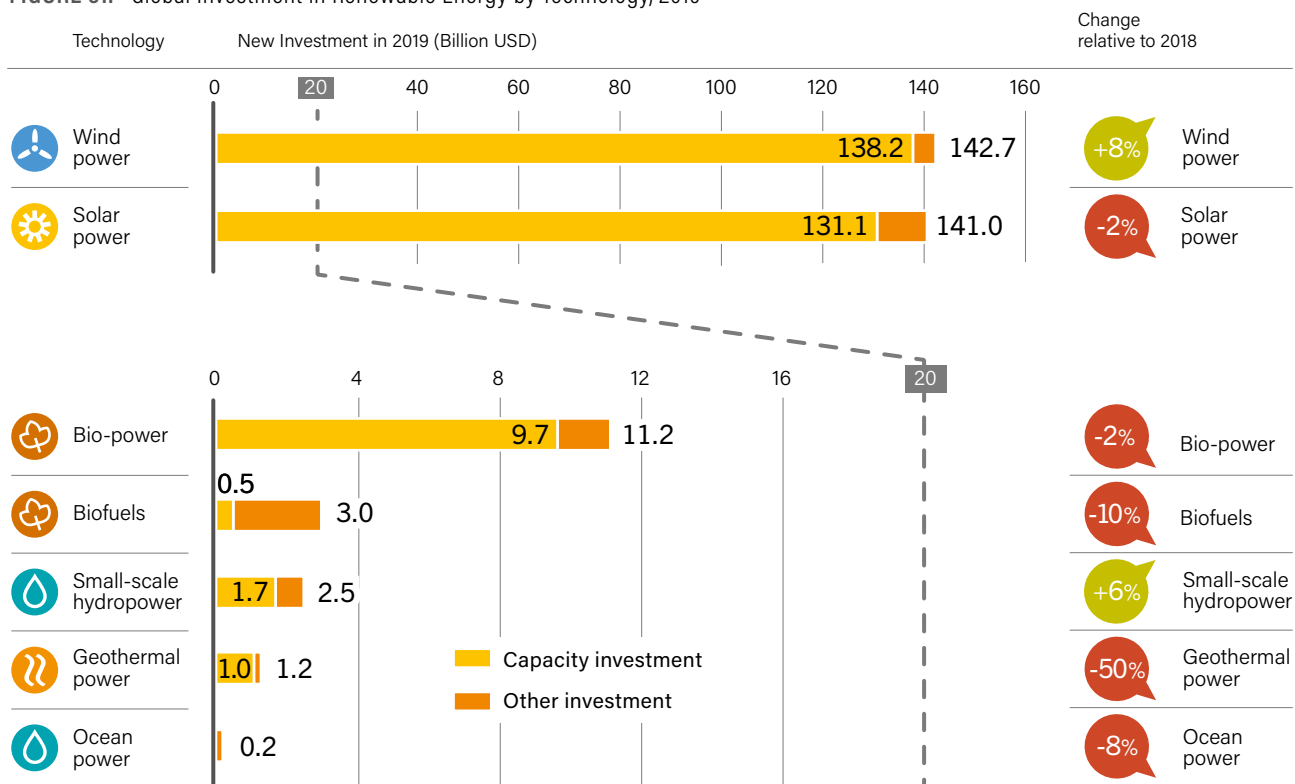
Investment in biofuels fell 10% to 3.0 billion – also far below its peak of USD 26.4 billion in 2007 – as industry stagnated without fresh government purchasing mandates. Investment in biomass and waste-to-energyⁱ technologies also fell slightly (down 2%) to USD 11.2 billion.

Large-scale hydropower projects (over 50 MW) represented the third largest sector (after solar and wind power) for renewable energy investment in 2019, reaching an estimated USD 15 billionⁱⁱ.

i Includes all waste-to-power technologies, but not waste-to-gas.

ii Translating hydropower capacity additions into asset finance dollars per year is not straightforward because the average project takes four years to build. Although BloombergNEF did not track detailed statistics for large-scale hydropower projects, it estimated that asset financing for large-scale hydropower projects reaching financial go-ahead totalled around USD 15 billion in 2019, down 6% from 2018.

FIGURE 51. Global Investment in Renewable Energy by Technology, 2019



Note: Capacity investment values include asset finance volume adjusted for re-invested equity as well as small distributed capacity investment for solar power. Total investment values include estimates for undisclosed deals as well as R&D and company investment (venture capital, private equity and public market new equity).

Source: BloombergNEF.

INVESTMENT BY TYPE

Research and developmentⁱ (R&D) spending rose 1% in 2019 to USD 13.4 billion. Government R&D edged up 4% relative to 2018, to USD 5.7 billion, while corporate R&D slipped 1% to USD 7.7 billion after three years of growth. Trends in total R&D spending were mixed across renewable energy technologies in 2019.

R&D investment in solar power – the largest recipient of such investment – increased 1% to USD 6.7 billion, while R&D spending for biofuels grew 2% to USD 1.8 billion and for geothermal rose 2% to USD 0.2 billion. Small hydropower saw the strongest growth in R&D investment, up 29% to USD 742 million.

Declines occurred in wind power (down 6% to USD 2.7 billion), biomass and waste-to-energy (down 1% to USD 1.0 billion) and ocean power technologies (down 4% to USD 0.2 billion).

Venture capital and private equity investment (VC/PE) in renewable energy increased 22% in 2019, to USD 3 billion, which was the highest level since 2015 but less than a third of its 2008 peak. The main renewable energy technologies, and the companies that manufacture them, are now mature, so there is less need for this earlier-stage financing compared with a decade ago. Solar power companies continued to attract the most VC/PE investment (up 29% to USD 1.8 billion), and wind power VC/PE investment reached USD 529 million.

India was the biggest market for VC/PE spending in 2019 – up 169% to USD 1.4 billion – followed by the United States where VC/PE investment fell 8% to USD 797 million. In the biggest VC/PE deal of the year, worth USD 824 million, India's wind, hydropower and solar developer Greenko Energy Holdings was bought by Singapore's Sovereign Wealth Fund (GIC) and the Abu Dhabi Investment Authority.

Public market investment in renewable energy companies and funds increased 11% to USD 6.6 billion, just a third of the peak reached in 2007. Because solar and wind power – the main sectors – are now dominated by well-established global companies, there is less need to tap investors. Funds raised by initial public offerings (IPOs) increased 47% to USD 2 billion but

remained well below the 2007 peak. In the biggest public market deal in 2019, Greencoat UK Wind raised USD 488 million in a secondary offering.

Asset finance of utility-scale projects again accounted for the bulk of total investment in renewable energy, although it fell 5% in 2019 to USD 230.1 billion, the lowest level since 2014. The largest asset financing of the year was for a combined CSP and PV project in Dubai (United Arab Emirates) that received a USD 3.9 billion equity and debt package.

Small-scale distributed capacity investment, or investment in solar PV systems of less than 1 MW, increased 37% to USD 52.1 billion. Although the increase remained well below the 2011 peak of USD 75.1 billion, it was an encouraging upswing from the declines witnessed since that time. Small-scale investment was highest in China, at USD 9.6 billion (up 8% over 2018), followed by the United States at USD 5.3 billion (up 176%). Large increases also occurred in Brazil (up 337% to USD 2.1 billion), the Netherlands (up 93% to USD 2.9 billion) and India (up 40% to USD 1.5 billion).

Most renewable energy projects rely on balance sheet finance by a utility, an independent power producer or other investor, or on non-recourse project finance comprised mainly of debt from banks. Funds for renewable energy projects also are channelled increasingly through climate finance avenues.² (→ See Box 1.)

Acquisition activity – which is not counted as part of the USD 301.7 billion in new renewable energy investment – dropped 34% in 2019 to USD 100.7 billion, ending five years of strong growth. This was due mainly to a decline in the sale and purchase of assets such as solar farms. Corporate mergers and acquisitions (M&A), the buying and selling of companies, slipped 6% to USD 13.7 billion. Private equity buy-outs fell to USD 3.2 billion, just a fraction of the highs seen in 2017 and 2018. Asset acquisitions and refinancing fell sharply in 2019 after five years of growth, with deals worth USD 83.8 billion. European asset acquisitions and refinancing remained comparatively high at USD 44.2 billion. Activity fell sharply in both the United States (down 49% to USD 23.3 billion) and China (down 32% to USD 3.2 billion).

ⁱ See Sidebar 5 in GSR 2013 for an explanation of investment terms used in this chapter.



BOX 1. Climate Finance and Renewable Energy

Climate finance is any financing that seeks to support either mitigation actions (for example, renewable energy generation, energy efficiency or low-carbon transportⁱ) or adaptation actions (for example, disaster risk management, waste and water, or resilient infrastructure) to address climate change.

Climate finance flows reached a record high of USD 612 billion in 2017 but dropped 11% in 2018 to USD 546 billionⁱⁱ, reflecting regulatory shifts in the East Asia and the Pacific region, decreases in the costs of renewable energy and the global slowdown in economic growth. Mitigation activities represented roughly 93% of the 2018 total, or around USD 508 billion. Renewable energy accounted for the largest share of mitigation-related financing flows, at 63%, with most of the rest going to low-carbon transport (26%) and energy efficiency (6%).

The landscape of climate finance flows is multifaceted, interconnected and evolving. As of 2018, private finance supplied around 56% of climate finance, and public finance – including funds provided by governments, climate funds and development finance institutions (DFIs) – supplied the remaining 44%. Although most public climate finance comes from DFIs, multilateral climate funds are an important source of capital for some of the most challenging sectors and poorest regions, providing around USD 3.2 billion in 2017/2018ⁱⁱⁱ.

The Green Climate Fund (GCF), established in 2010 within the framework of the United Nations Framework Convention on Climate Change, provided 50% of the finance from climate funds in 2018, followed by the Global Environment Facility (GEF) at 32% and the Climate Investment Funds (CIF) at 14%. The shares for renewable energy projects, however, have varied widely across funds over time. Around 37% of the GCF's USD 5.6 billion in project funding has gone to energy access or renewable energy-related projects. The GEF, since its inception in 1992, has provided USD 2.5 billion for renewable energy and energy efficiency projects. Around 69% of the CIF Clean Technology Fund's USD 4.3 billion in projects was for renewable energy.

Most climate finance is channelled as market-rate debt (through project-level or balance sheet finance), although equity and grants also are common instruments. Issuance of one type of debt instrument – climate or green bonds^{iv} – reached a record high of USD 257 billion in 2019, up 51% from 2018. Most green bonds were issued in Europe (45%; led by France), followed by the Asia-Pacific region (25%; led by China) and North America (23%; led by the United States)^v. In 2019, around 31% of green bonds were allocated to the energy sector – down from 51% in 2018 – followed by the buildings (30%) and transport (20%) sectors.

Governments in many regions have established taxonomies of assets and project types that qualify for specific climate finance and/or have the most impact. For example, China's Green Bond Endorsed Project Catalogue, first released in 2015, lists projects eligible for green bond issuance, and India, Japan and Malaysia also include lists of eligible assets in their green bond guidelines. In the European Union, a taxonomy was published in March 2020 that set performance thresholds for different economic activities that contribute to one of six environmental objectives, including climate change mitigation and adaptation. Similar models were being established in Australia and Canada.

i Low-carbon transport includes a wide range of options, from walking and cycling infrastructures to public transport and "low emission" vehicles.

ii Total estimates of climate finance flows vary depending on methodology and data quality. This figure is provided by the Climate Policy Initiative.

iii Total provided is an average of funds supplied in the two-year period 2017/2018, which is the most recent data available.

iv See Glossary for definition. In order for green bonds to qualify as a true climate finance instrument, proceeds must flow to climate beneficial infrastructure or assets, which is not always the case. More recent data (2019) are available for green bonds than for climate finance flows as a whole, which are covered only up to 2018.

v The definition of these regions may differ from the regional definitions used in the rest of the GSR, which can be found at <http://www.ren21.net/GSR-Regions>.

Source: See endnote 2 for this chapter.

INVESTMENT IN PERSPECTIVE

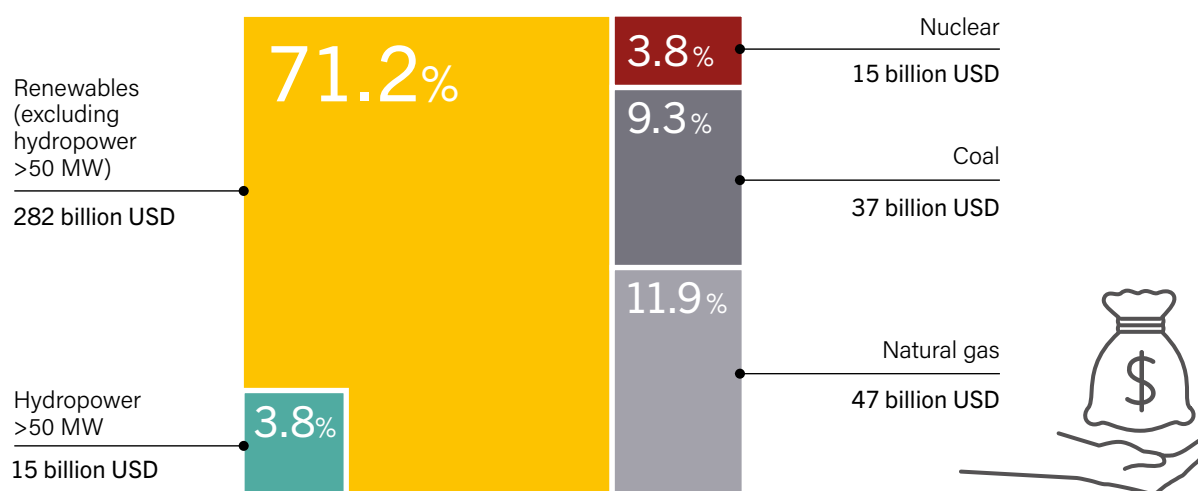
In 2019, renewable power technologies continued to attract far more investment dollars than did coal, natural gas or nuclear power generating plants. An estimated USD 296.7 billion was committed to building new renewable power plants (USD 281.7 billionⁱ without large-scale hydropower, plus an estimated USD 15 billion for hydropower projects above 50 MW). This compares to around USD 84 billion committed to coal and natural gas-fired generating capacity and USD 15 billion for nuclear power capacity. Dollar investment

in new renewable power capacity (including all hydropower) was three times the total committed to new coal, natural gas and nuclear power generating capacity. Overall, renewable energy (including all hydropower) accounted for three times the total amount committed to new power generating capacity (including coal, natural gas and nuclear) in 2019. (→ See Figure 52.)

The number of institutions divesting from fossil fuels has increased globally since 2011, although the funds are not necessarily reinvested in companies associated with renewable energy.³ (→ See Box 2.)

i This number is for renewable power asset finance and small-scale projects. It differs from the overall total for renewable energy investment (USD 301.7 billion) provided elsewhere in this chapter because it excludes biofuels and some types of non-capacity investment, such as equity-raising on public markets and development R&D.

FIGURE 52. Global Investment in New Power Capacity, by Type (Renewables, Coal, Gas and Nuclear Power) 2019



Note: Renewable investment data in figure exclude biofuels and some types of non-capacity investment.

Source: BloombergNEF.

BOX 2. Fossil Fuel Divestment Trends

Since 2011, institutions worldwide have increasingly divested from, or sold off their financial interests in, fossil fuel companies. By 2019, around 1,115 institutions spanning 48 countries had committed to fossil fuel divestmentⁱ, with estimated total asset values of around USD 11 trillion. This is up from an estimated USD 7.9 trillion in 2018, a 39% increase in one calendar year.

The set of institutions committed to divestment is diverse and spans insurance companies (which account for roughly 50% of total assets under management), private and government pension funds (around 30%), banks (around 10%), as well as governments, non-governmental and faith-based organisations, health, cultural and educational institutions, and others.

Insurance companies (including at least 19 major companies worldwide) have increasingly divested from coal company equities and bonds and, in some cases, have ceased to underwrite coal projects. Company divestment policies covered around 37% of the insurance industry's global assets in 2019, up from 20% in 2018 and 13% in 2017. What began as a European phenomenon expanded in 2019 to reach the United States and Australia. Asian insurers remained reluctant to adopt divestment policies during the year.

As of the end of 2019, 158 self-managed public pension funds had committed to divesting from fossil fuels, up from 144 in 2018. This includes the pension funds of major cities such as Berlin (Germany), Copenhagen (Denmark), Dunedin (New Zealand), Paris (France) and Sydney (Australia). Norway's

sovereign wealth fund, worth USD 1.1 trillion, announced that it would divest from companies dedicated solely to oil and gas exploration and production, although it will maintain stakes in refiners and other downstream firms.

Funds divested from fossil fuel companies are not necessarily reinvested in companies associated with renewable energy. However, a global network of individuals and organisations, known as DivestInvest, links the two by providing guidance to organisations and individuals through the divestment process and encouraging them to establish climate-friendly criteria for their investments (for example, in renewable energy companies, low-carbon transportⁱⁱ, or sustainable agriculture and forestry options). In addition, C40 Cities launched the the C40 Divest/Invest Forum in late 2018, forming a network of cities interested in divesting and investing in sustainable options. Further expanding the connection between divesting and investing in renewable energy, in 2019 the first major Global South divest-invest conference was held, the Financing the Future Summit.

i Through fossil fuel divestment, an institution makes a binding commitment to exclude any fossil fuel company (coal, oil and natural gas) from either all or part of its managed asset classes, or to selectively exclude companies that derive a large portion of their revenue from coal and/or tar sands companies. Organisations also may commit to some form of an exclusion policy based on a different criteria, such as whether the company is aligned with the goals of the Paris Agreement.

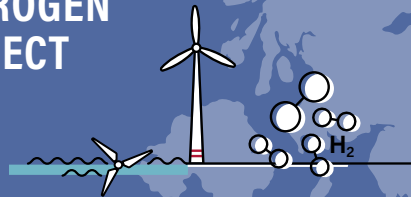
ii Low-carbon transport includes a wide range of options, from walking and cycling infrastructures to public transport and "low emission" vehicles.

Source: See endnote 3 for this chapter.

06



RENEWABLE HYDROGEN COMMUNITY PROJECT IN SCOTLAND, UNITED KINGDOM



The Orkney islands, off the coast of Scotland, have used a combination of private and community investment to develop significant wind, wave and tidal power capacity. The innovative community project Surf 'n' Turf, developed in response to energy curtailment challenges, routes surplus renewable electricity to a 500 kW electrolyser in order to create green hydrogen. The stored renewable energy then can be used for heating, power, transport and other purposes, including agricultural fertiliser.

06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

KEY FACTS

- Rapid growth in the installed capacity and penetration of variable renewable electricity has occurred in many countries. In 2019, at least four countries met more than 30% of electricity generation from solar PV and wind power.
- To integrate higher shares of VRE, countries are drawing on a wide variety of flexibility resources including power market design, grid extension, forecasting and demand response.
- Technologies that support the integration of variable renewable electricity, such as heat pumps, electric vehicles and energy storage, have seen substantial market growth in recent years. However, key national markets for EVs and battery storage slowed in 2019.

Energy systems integration is the removal or reduction of many of the technical, physical, organisational and legal barriers to high penetration of renewable energy – including in power grids, heating and cooling systems, and transport fuelling systems. Integration includes the planning, design and implementation of supply- and demand-side technologies, infrastructure, markets and regulatory frameworks to facilitate greater use of renewables across all end-use sectors, while ensuring sustainable, secure, adequate, reliable and affordable energy services.

Renewable energy can facilitate more efficient, sustainable and economical operation of energy systems.¹ To achieve this, governments, energy utilities and other actors are working to address barriers that may slow or halt the growth of renewables.² As shares of renewable energy grow, energy systems that have evolved or been designed around conventional energy sources may require multifaceted restructuring to ensure that the benefits of renewables are fully realised.³

As such, growth in renewable energy is transforming energy systems around the world.⁴ In the power sector in particular, rapid growth in the installed capacity and penetration of **variable renewable electricity** (VRE) sources – such as solar photovoltaic (PV) and wind powerⁱ – has occurred in many countries.⁵ At the end of 2019, renewables produced an estimated 27.3% of global electricity generation, 8.7% of which was from VRE.⁶ The penetration of modern renewables in the heating, cooling and transport sectors is much lower than in the power sector, however.⁷ (→ See *Global Overview chapter*.)

ⁱ Defined more broadly, VRE also can include some forms of ocean power and hydropower. This chapter focuses mainly on solar PV and wind power, as these are the fastest growing VRE markets and are having the greatest impacts on energy systems. See Glossary for an extended definition of VRE.

Many of the notable advances in renewable energy integration in 2019 involved increased uptake of VRE in power systems and the use of VRE to electrify end-uses in transport, heating and cooling. These advances occurred mainly in countries or regions that have supportive policy environments or where energy markets are adapting to the uptake of VRE, including in Australia, China, Europe and North America. (→ See *Policy Landscape* chapter.)

Several technologies are supporting the integration of renewables by enabling greater flexibility in energy systems or by promoting the linking of energy supply and demand across electricity, thermal and transport applications. Among the more mature or commercialised technologies are heat pumps, electric vehicles (EVs) and certain types of energy storage. Other technologies are still emerging but may help to reach higher shares of renewable energy in all sectors – including renewable hydrogen, non-lithium-ion batteries (such as flow batteries) and novel forms of mechanical storage.⁸

ADVANCES IN THE INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

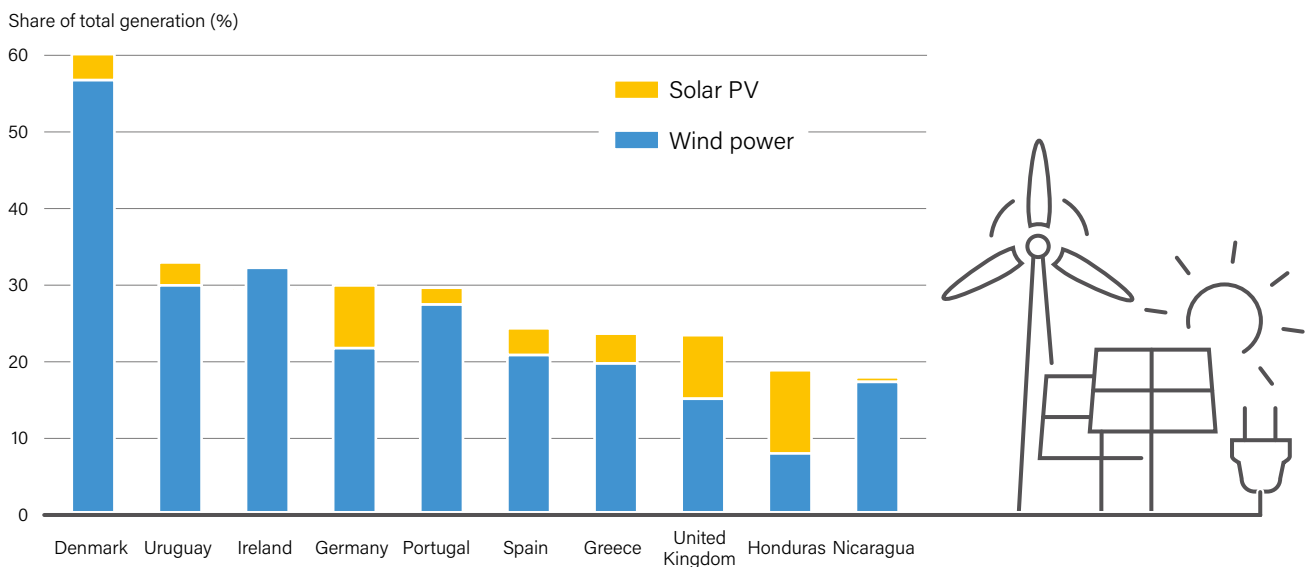
In numerous countries, the power sector has transformed rapidly in recent years, driven by the increased penetration of variable wind and solar power. At least four countries met more than 30% of their electricity generation from VRE in 2019: Denmark, Germany, Ireland and Uruguay.⁹ (→ See *Figure 53*.)

Improving **power system flexibility** is central to advancing the integration of VRE.¹⁰ Flexibility is important in all power systems to ensure uninterrupted services while managing changes in supply and demand, allowing for safe operating conditions and minimisation of generator or transmission outages.¹¹ Some degree of flexibility exists in all power systems, and most systems can accommodate at least moderate shares of VRE in their generation mix before reaching significant physical or capacity-related barriers and experiencing operational challenges, such as grid imbalances and excessive or uneconomic curtailment of generation.¹²

Solar PV and wind power provided **8.7%** of global electricity in 2019, up from around 7.9% in 2018.



FIGURE 53. Share of Electricity Generation from Variable Renewable Energy, Top Countries, 2019



Note: Figure shows countries among the top 10 according to the best available data at the time of publication. However, several small-island countries with low total generation may be excluded from this list.

Source: See endnote 9 for this chapter.

Power system flexibility can be improved through a range of interventions, many of which are supported by and continue to be enhanced through advances in the digitalisation of power systems.

Four key interventions discussed here are:

- strategic market design that rewards or promotes flexibility;
- direct procurement of flexibility services from sources of generation, demand and energy storage;
- improved forecasting of electricity demand and of VRE generation and demand; and
- the implementation of physical linkages – in the form of grid infrastructure – between VRE sources and demand centres, as well as among VRE sources in different geographical locations.

MARKET DESIGN FOR FLEXIBILITY

Effective electricity market design for VRE integration promotes the accurate pricing of energy and the appropriate remuneration of grid balancing services that improve flexibility. This can be achieved by designing or re-designing short-term (day-ahead or intraday) markets to more accurately reflect the real-time value of electricity, and by procuring flexibility services from distributed sources of demand, generation and energy storage.¹³

Market design interventions in 2019 included the California Independent System Operator's (United States) announcement of a day-ahead market for renewables, which will allow utilities to better plan for and optimise the use of VRE on the grid.¹⁴ The Italian grid operator Terna also outlined reforms of its intraday electricity markets to shorten forecast periods for VRE generators feeding into the grid, allowing for more accurate commitments of VRE capacity.¹⁵ In Singapore, liberalisation of the retail electricity market enabled distributed energy resources to start providing flexibility services.¹⁶

INCREASED FLEXIBILITY FROM GENERATION, DEMAND AND STORAGE

Conventional power systems with low VRE shares obtain flexibility primarily by adjusting the output of dispatchable generators to follow demand.¹⁷ As VRE shares increase, power system flexibility is being enhanced not only through better generation flexibility, but also through flexibility from sources of demand and energy storage.¹⁸

VRE generators themselves can contribute essential reliability services to power grids, including frequency control and regulation, inertial response, voltage regulation and reactive power voltage support (also known as power factor correction).¹⁹ Apart from generation, demand flexibility also is an increasingly important enabler of higher shares of VRE, primarily through demand response initiatives that use market signals – such as time-of-use pricing, incentive payments and penalties – to influence the electricity consumption behaviours of end-users.²⁰

Grid operators are increasingly procuring packaged flexibility services that incorporate both demand responseⁱ and flexibility from the embedded generation and energy storage assets of prosumersⁱⁱ. In Canada, the Italian firm Enel X was awarded 210 megawatts

(MW) of demand response capacity to provide flexibility services to the grid by managing the demand of industrial energy users in parallel with energy storage and generation assets.²¹ Several electrical utilities in the United Kingdom undertook tendering for demand and generation flexibility capacity in 2019, from both commercial and residential sources.²² In the United States, a 14 MW contract for behind-the-meter demand response in California was awarded to a firm that aggregates fleets of home batteries.²³

The wider aggregation of generation, demand and storage capacity is being unlocked through innovative trials and digital technologies that can control fleets of assets providing flexibility services. For example, a 2019 virtual power plant trial backed by the Australian Renewable Energy Agency aimed to use up to 50,000 distributed residential solar-plus-storage installations to deliver co-ordinated power dispatch and frequency control services.²⁴

In Finland, the German technology firm Siemens, in partnership with the government, piloted an initiative that combines loads from buildings with renewable energy generators and battery storage.²⁵ Such systems also work in conjunction with forecasting technologies, as in Singapore where a partnership among government, industry and academia aims to complete a virtual power plant by 2022 that responds to demand forecasting based on live market data from the power grid.²⁶

"Smart" digital products are being used to change consumption patterns among grid-connected customers, leading to better grid balancing during high VRE production periods and to reduced curtailment of solar and wind energy.²⁷ In the United Kingdom, consumers who subscribed to a pilot smart metering programme were paid to use electricity during a period of surplus VRE generation in late 2019.²⁸ These prosumers were effectively compensated for providing a grid balancing service.²⁹ Digital technologies, including artificial intelligence, also are being used for predictive maintenance of fleets of VRE generators, leading to increased reliability and reduced downtime.³⁰

Virtual power plants use digital technologies to co-ordinate and control energy demand, distributed generation and energy storage.

i Demand response initiatives or programmes make use of market signals such as time-of-use pricing, incentive payments and penalties to influence end-user electricity consumption behaviours, usually to balance electrical supply and demand within a power system. Modern demand response programmes often also aim to influence or control the behaviour of embedded generators or energy storage capacity to achieve similar ends.

ii A prosumer, in the context of the energy sector, is an individual or entity that both consumes and generates energy.

IMPROVED FORECASTING OF VARIABLE RENEWABLE ELECTRICITY GENERATION

Accurate forecasting of both power system demand and VRE generation allows system operators to anticipate VRE availability and to cost-effectively balance generation and demand in short-term energy market scheduling.³¹ This reduces fuel costs, minimises curtailment of VRE and improves system flexibility and reliability.³² Efforts continued in 2019 to improve forecasting of VRE resources to enable accurate supply and demand planning. In Australia, researchers combined neural networks and pattern sequences – techniques commonly used in artificial intelligence and language translation – to improve solar forecasting.³³ In the United Kingdom, artificial intelligence was used to evaluate up to 80 variables influencing solar generation output and to boost forecasting accuracy by one-third.³⁴ Solar forecasting advanced at numerous US universities and research institutes, and a company on the Indian Ocean island of Reunion (France) was combining multiple data inputs and models to offer enhanced VRE forecasting tools to solar projects around the world.³⁵

For wind power, the Australian Renewable Energy Agency awarded funding to Vestas (Denmark) to develop a new wind forecasting solution for Australia.³⁶ In the United States, DeepMind, a subsidiary of the US multinational Alphabet, used artificial intelligence to more accurately predict generation from wind energy and the periods during which its value can be maximised in the market.³⁷



INFRASTRUCTURAL LINKAGES

Grid infrastructure, including transmission and distribution equipment and technologies, can be a crucial enabler of power system flexibility. Grid infrastructure can connect regions of VRE generation with demand centres; aggregate VRE resources over larger geographic areas to mitigate the effects of variability; and link or expand electricity markets to increase market scope, choice and efficiency.³⁸ Conversely, with the rapid growth of VRE capacity in many markets, grid infrastructure can become a significant bottleneck for integrating rapidly increasing VRE output if power networks are not actively planned and upgraded in line with VRE uptake.³⁹

Grid infrastructure upgrades to directly support VRE growth were under way or planned in most world regions in 2019. In Europe, a subsea transmission line linking Ireland and the United Kingdom to support the uptake of renewables secured private and public funding and advanced through various permitting processes.⁴⁰ In several US states, large transmission projects were under development with the aim of interconnecting regional energy markets with VRE projects.⁴¹ Projects also were planned in Australia, where transmission infrastructure has been a barrier to ongoing deployment of wind and solar power.⁴²

In Asia, the state-owned Power Grid Corporation of India announced plans for USD 1.8 billion of new transmission projects in several Indian states to support 25.4 gigawatts (GW) of planned wind and solar power projects.⁴³ Significant investments in enhanced transmission infrastructure have occurred in China – including the completion of 22 ultra-high-voltage transmission lines in the past decade, motivated in part by the need to accommodate more renewable generation.⁴⁴

South Africa's public utility Eskom secured ZAR 1.5 billion (USD 107 million) in development funding for transmission projects that will couple solar and wind power plants with the national grid.⁴⁵ In Mozambique, the World Bank approved USD 420 million in grants to strengthen the transmission system and support the integration of renewable technologies in power system planning and operation.⁴⁶

In Latin America, the Brazilian Development Bank approved a BRL 1.8 billion (USD 429 million) loan for developing transmission lines that will enable the connection of 6.5 GW of wind power projects.⁴⁷ A 55-kilometre transmission line was completed in Chile to connect 293 MW of solar capacity to the national grid.⁴⁸



ENABLING TECHNOLOGIES FOR SYSTEMS INTEGRATION

Technologies such as heat pumps, electric vehicles and energy storage are supporting the integration of renewable energy by increasing flexibility in energy systems, and in particular power systems. These technologies also are unlocking increased demand for renewable energy, particularly VRE, by coupling renewables with end-uses across the power, transport, and heating and cooling sectors.

In many cases, these enabling technologies have been in use for decades, for applications unrelated to the integration of renewable energy. They have achieved varying levels of commercial maturity: while EVs have relatively low market shares, heat pumps are deeply embedded in many residential and industrial heating and cooling markets.⁴⁹ Important market and industry developments occurred for all of these technologies in 2019.

HEAT PUMPS

Heat pumps are a widely used and mature group of technologies that most commonly employ an electrically driven process to efficiently move heat from one body of air, water or the ground to another. They are used for heating and cooling in buildings and industry. Heat pumps can increase power system flexibility by coupling generation with heating and cooling end-uses that have flexible demand characteristics.

The potential of heat pumps for increasing power system flexibility and for unlocking greater demand for VRE is significant. An estimated 75% of the global potential for demand response lies in the electrification of heat in buildings, and heat pumps could serve as much as 90% of global space and water heating demand.⁵⁰

Heat Pump Markets

Heat pumps form a large part of the broader heating, ventilation and air conditioning (HVAC) market, which has grown rapidly in recent years, driven by rising demand for cooling in emerging economies.⁵¹ However, accurately assessing the scale of the global heat pump market is challenging due to a lack of data and to inconsistencies among datasetsⁱⁱ.

Much of the growth in the heat pump market is due to sales of reversible air conditioning units used for both cooling and heating.⁵² Air-source heat pumps are particularly well suited to use solar electricity to meet large and rising global demand for cooling, since solar generation typically corresponds with increased cooling loads.⁵³ Much of the remaining heat pump market consists of ground-source heat pumps.⁵⁴

As global demand for heating and cooling has expanded, growth in the heat pump market has been consistently strong.⁵⁵ Nearly

18 million households purchased heat pumps for heating and/or cooling applications in 2018 (latest data available), up nearly 30% from 2017.⁵⁶ Around 80% of these units were installed in China, Japan and the United States.⁵⁷

Heat pumps still contribute only a small share to heating applications, servicing around 3% of global heating demand in buildings as of the end of 2018.⁵⁸ However, global sales of heat pumps for water heating grew rapidly compared with the previous decade.⁵⁹ In 2019, heat pump sales for sanitary water heating in China reached 1.5 million units.⁶⁰ Japan also is a large market for water heating applications of heat pumps, with more than 0.5 million sales in 2019 after four consecutive years of strong market growth.⁶¹ In Europe, sales of heat pumps for sanitary hot water totalled around 0.2 million.⁶²

China dominated the global market for air-source heat pumps for space heating, with sales numbering in the tens of millions in 2019.⁶³ In the United States, where the market has grown for a decade, more than 3.1 million air-source heat pumps were sold.⁶⁴ For the European market, 2019 was the sixth year in a row with market growth above 10%, and by year's end heat pumps met nearly 10% of space heating demand in European buildings.⁶⁵ Air was the dominant energy source, used in more than 90% of the 1.5 million heat pumps sold in Europe for residential and commercial applications.⁶⁶

Large heat pumps are well suited to district heating and cooling applications and have been implemented in systems across Europe, including in Denmark, France, Scotland and Serbia.⁶⁷ In Denmark, 13 large heat pumps at 11 combined heat and power plants with a total capacity of 29.7 MW were installed in 2019.⁶⁸ In Serbia, a heat pump for industrial heating and residential cooling was in planning, and large heat pumps form part of the city of Belgrade's long-term district heating and cooling plan, presented in 2019.⁶⁹

Heat Pump Industry

The year 2019 saw a range of investments by large technology companies in specialised heat pump firms, a focus on incremental cost and efficiency improvements, and the integration of heat pumps alongside renewables and energy storage using digital technologies.

The heat pump industry consists of both large manufacturers and many small and medium-sized enterprises involved in the design, manufacture, installation and maintenance of heat pumps. Large manufacturers included Bosch (Germany), Carrier (United States), Daikin (Japan), Ingersoll-Rand (Ireland), Johnson Controls (United States), Mitsubishi (Japan), Panasonic (Japan), Nibe (Sweden) and Stiebel-Eltron (Germany).

Several large technology firms invested in specialised heat pump companies during the year, often across country or regional boundaries. The air conditioning company Daikin (Japan)

i Heat pumps can typically move three to five units of heat for each unit of electricity consumed, and the output of a heat pump can be 100% renewable when it is driven by renewable electricity and makes use of a renewable heat source (such as ambient heat from the air, the ground or bodies of water). The ratio of heat energy moved over electrical energy consumed is known as the coefficient of performance of the heat pump and varies based on the technical characteristics of a given unit as well as the temperatures of the both heat source and the body where the heat is pumped to (known as the heat "sink").

ii One reason for limited and fragmented data on heat pumps may be variation in how systems are classified. In moderate climates, heat pumps generally are counted as air conditioning equipment, with a side benefit of dehumidification or provision of hot water. In cold climates, the heating service is much more important, and heat pumps thus are counted as heating equipment, with cooling and dehumidification considered welcome by-products.

acquired AHT (Austria), which specialises in the use of natural refrigerants in air conditioning and heat pump systems, and Panasonic (Japan) completed the acquisition of the heat pump business of Kauco Oy (Finland) in early 2020.⁷⁰ In Europe, the building services firm Bravida (Sweden) acquired ICS Cooling Systems (United Kingdom), a specialist in industrial heat pumps, and Swegon Group (Sweden), a ventilation and indoor heating and cooling company, acquired Klimax AS, a major heat pump distributor in Norway.⁷¹ Also in 2019, Dalrada Financial Corporation (United States) acquired Likido (Scotland), a manufacturer of high-efficiency heat pumps, as part of a strategy to expand manufacturing and engineering services.⁷²

Heat pumps are a mature technology, consisting of a basic product design that is expected to remain largely unchanged.⁷³ In Europe in particular, the main focus of the heat pump industry has turned to cost optimisation, and in some locations heat pumps have been subject to new standards that forced manufacturers to improve unit efficiency.⁷⁴ Several manufacturers, including Bosch, Carrier, Ingersoll-Rand and Mitsubishi, released new residential and industrial heat pump products in 2019 that offered improved efficiencies, lower costs or greater durability.⁷⁵ In Denmark, research and development (R&D) on air-to-water heat pumps was under way to increase efficiencies 5-10% and to achieve the highest possible rating under the EU energy label system.⁷⁶

Heat pumps are being incorporated alongside renewable energy, storage and digital technologies to deliver flexible energy services in a range of pilot projects. In the United Kingdom, a demonstration project aims to couple 320 ground-source heat pumps with battery storage to supply heating for social housing.⁷⁷ Planning also is under way in the country for a pilot virtual power plant facility that will combine heat pumps (both air- and water-sourced) with solar PV, battery storage and EVs.⁷⁸ In Bedburg (Germany), a government-backed flexible district energy system plans to use heat pumps powered by wind and solar PV plants to meet heat demand.⁷⁹

ELECTRIC VEHICLES

The use of electric vehiclesⁱ allows for renewable electricity to replace fossil fuels in some transport applications, to the extent that the electricity comes from renewable sources. As their market share grows, EVs also have the potential to support the integration of VRE by presenting options for demand- and supply-side response, such as through vehicle-to-grid (V2G)ⁱⁱ technology. EV uptake in individual markets is influenced greatly by the presence of supportive national and local policies.⁸⁰ (→ See *Policy Landscape chapter and Reference Table R10*.) Although passenger rail is the most electrified form of transport, the largest recent advancements in electric transport have been in road vehicles.⁸¹ Limited examples of commercialised electric marine transport exist, and electric aviation remains pre-commercial.⁸² (→ See *Global Overview*.)

Electric Vehicle Markets

EV markets continued to grow quickly in 2019, with the global EV stock reaching 259 million units.⁸³ The vast majority were two- and three-wheelers, while around 7.2 million of the vehicles were electric cars (passenger EVs), just over half a million were electric buses, and nearly 0.4 million were light commercial vehicles.⁸⁴

The stock of electric cars (passenger EVs) increased 40% in 2019, up more than 2 million from 2018.⁸⁵ (→ See *Figure 54*.) However, growth was lower than in 2018, when 2.2 million of the vehicles were sold and the global stock jumped 63% over the previous year.⁸⁶ In 2019, electric cars still comprised only a small share of all passenger vehicles, at just 0.6% of the global stock.⁸⁷ However, the share of electric cars in new car sales reached 2.5%, a record high.⁸⁸

China was home to 47% of the global electric car stock by the end of 2019, followed by Europe (25%) and the United States (20%).⁸⁹ Chinese sales of new electric cars reached just over 1 million units, around 20,000 units less than in 2018.⁹⁰ Europe had the next highest sales, at 560,000 units, followed by the United States at 327,000 units.⁹¹ Overall, global sales of electric cars were down 6% in 2019, just above the 4% decline in sales for passenger cars of all types.⁹² Norway remained the leader in the share of electric cars in overall car sales, at 56%, followed by Iceland (25%), the Netherlands (15%) and Sweden (11%).⁹³



- i Electric vehicles include any transport vehicles that use electric drive and can take an electric charge from an external source, or from hydrogen in the case of fuel cell electric vehicles. See Glossary.
- ii Vehicle-to-grid (V2G) refers to a system that allows EVs to communicate with the power grid and provide demand response services by reducing charging rates or returning electricity to the grid. A V2G system can allow EVs to store or discharge VRE if the prevailing electricity mix within a power system includes solar PV or wind power.

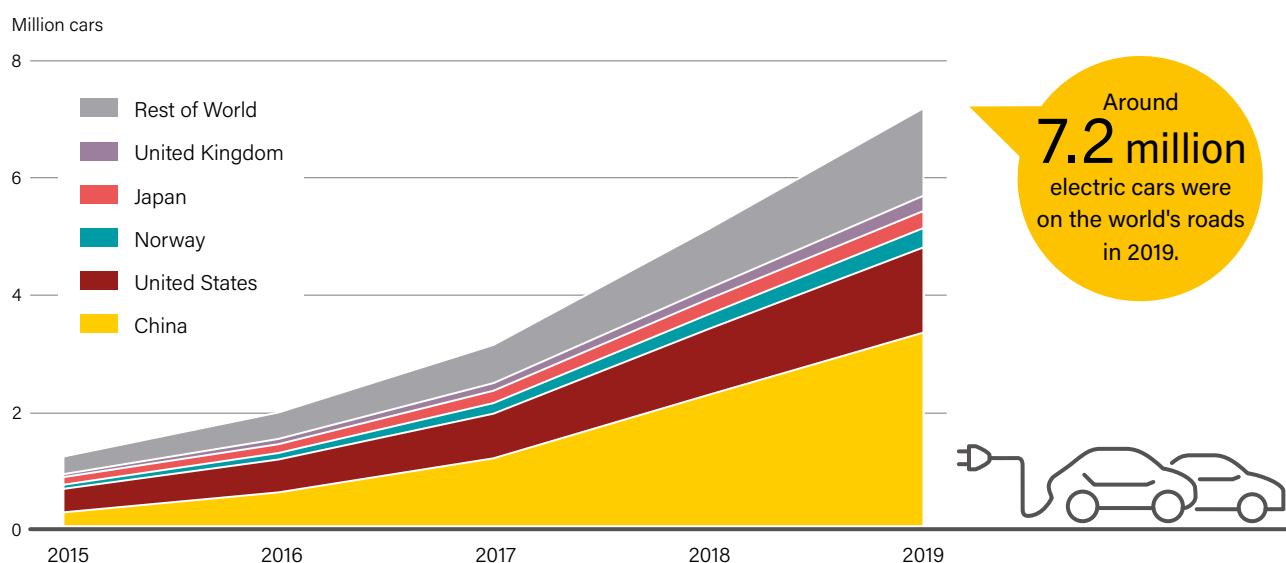
The global stock of electric two- and three-wheelers reached around 251 million in 2019.⁹⁴ Virtually all of these vehicles were in China.⁹⁵

Sales of electric buses declined for the fourth consecutive year.⁹⁶ This drop reflected a 20% decrease in year-on-year sales in China – where some 71,000 new electric buses were registered, or 95% of the global total.⁹⁷ Growth was strong in other regions, but with much lower numbers.⁹⁸ India increased its stock of electric buses to around 800 units, and Europe's stock increased 60% compared with 2018, to around 4,500 units.⁹⁹ In North America,

some 2,200 electric buses were in operation at the end of 2019.¹⁰⁰ (→ See Figure 55.)

Public procurement by local and national governments helped boost EV markets in 2019. In India, the government of the Delhi region approved the purchase of 1,000 electric buses, the largest such commitment outside of China.¹⁰¹ A range of other policies supported EV markets during the year, including e-mobility targets, financial incentives and indirect incentives (such as free parking and preferred access). (→ See *Policy Landscape* chapter.)

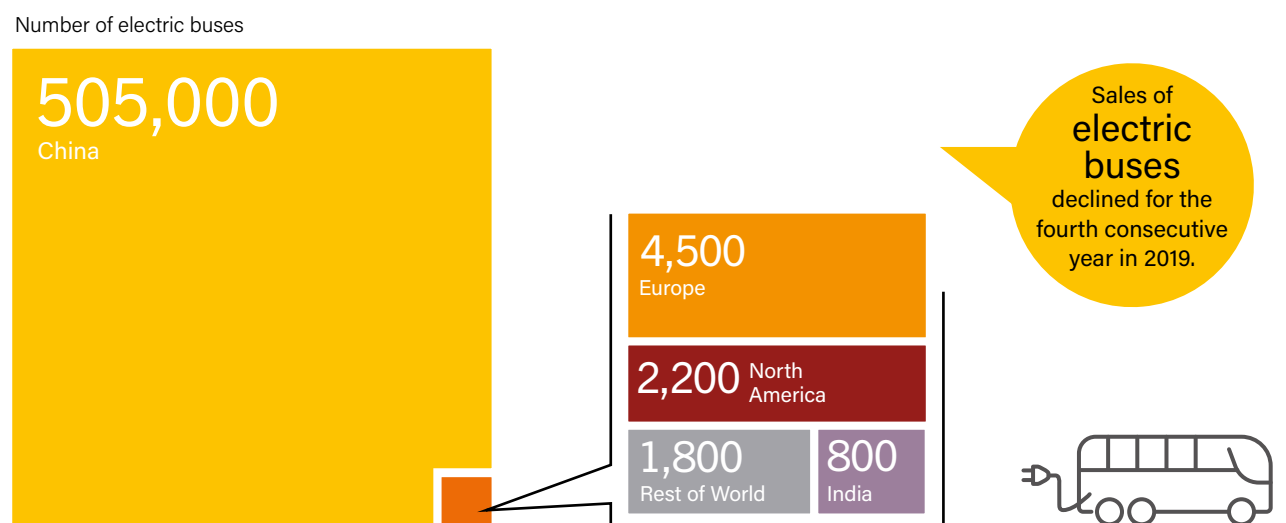
FIGURE 54. Electric Car Global Stock, Top Countries and Rest of World, 2015-2019



Note: Includes battery electric vehicles and plug-in hybrid electric vehicles. Shows countries among the top 5 according to the best available data at the time of publication.

Source: IEA. See endnote 85 for this chapter.

FIGURE 55. Electric Bus Global Stock, China and Selected Regions, 2019



Source: IEA. See endnote 100 for this chapter.

Around 2 million EV charging points were installed in 2019, increasing the global stock 40% to 7.5 million.¹⁰² This includes both private and public, and fast and slow chargers, although nearly 90% of the total is private slow chargers.¹⁰³ The number of private chargers grew just under 40% in 2019, while the number of public chargers increased 60%.¹⁰⁴ China accounted for 80% of the new public fast chargers that entered the global market in 2019 and for just over half of the new public slow chargers.¹⁰⁵

Passenger rail is the only form of transport that is widely electrified, and the share of electrification in the sector increased from 60% in 2000 to around 75% in early 2019.¹⁰⁶ The highest rates of passenger rail electrification are in Europe and Japan.¹⁰⁷ In the Americas, rail remains predominantly diesel-powered, and in most world markets freight rail is much less electrified than passenger rail.¹⁰⁸

Electric rail can only be considered as a partially renewable form of transport depending on the prevailing shares of renewable energy in a given power supply system. Efforts have been made to directly electrify rail transport using VRE. In the United Kingdom, a trial project launched in 2019 connects solar panels to the direct current network of a rail system in south-east England.¹⁰⁹ Similar systems have been implemented at a small scale in several other countries.¹¹⁰

Electric Vehicle Industry

The electric vehicle industry in 2019 was characterised by diverse commitments and investments from both dedicated EV manufacturers and traditional automakers. The industry also was bolstered by investments from non-automotive companies and by large corporate orders for EV fleets.

In 2019, the leading manufacturers of passenger EVs (including BEVs and PHEVs) were (in order of number of units produced) Tesla (United States); BYD, BAIC and SAIC (all China); BMW and Volkswagen (both Germany), Nissan (Japan), Geely (China), Hyundai (Republic of Korea) and Toyota (Japan).¹¹¹ Tesla surpassed BYD as the global EV sales leader after it recorded strong growth in the European and Chinese markets.¹¹²

Many traditional vehicle manufacturers announced plans to expand their EV offerings.¹¹³ Toyota intends to offer electric versions of all of its vehicles by 2025, and Hyundai aims to offer 44 EV models by 2025.¹¹⁴ In Europe, Volvo (Sweden) plans to launch new EVs every year until 2025, and Volkswagen intends to build 22 million EVs over the next 10 years.¹¹⁵ Several other traditional auto manufacturers planned to release new models in 2020 and beyond.¹¹⁶

Hydrogen fuel cell electric vehicles (FCEV) also advanced in 2019, although the upfront and running costs of the vehicles remain higher than for petrol or diesel equivalents.¹¹⁷ Toyota, which launched the world's first commercial FCEV for the general market – the Mirai sedan – in 2014, unveiled a second version in 2019.¹¹⁸ Hyundai planned to launch two new hydrogen FCEVs by 2025 and partnered with the diesel engine and generator manufacturer Cummins to supply hydrogen fuel cell systems to the transport and electricity sectors.¹¹⁹

Non-automotive companies have moved into the EV space, including the solar technology company SolarEdge (Israel), which announced plans to acquire SMRE, an Italian firm specialised in powertrain technology and electronics for EVs.¹²⁰ Numerous Chinese companies, including online retailer Alibaba, and the internet companies Tencent and Baidu, acquired or increased stakes in EV companies.¹²¹

VRE was increasingly available on EV charging networks in 2019. The largest US public fast-charging network, EVgo, was contracting 100% of its electricity from renewable sources during the year.¹²² In the US state of Texas, the utility Austin Energy offered 100% electricity from wind power to EV users via its network of 800 charging points.¹²³ In Europe, BMW partnered with the Dutch grid operator TenneT to pilot an intelligent charging system that allows EVs to maximise their use of VRE.¹²⁴

Numerous vehicle-to-grid initiatives were under way in 2019, enabling EVs to provide flexibility services to electric grids through the controlled export of electricity from their onboard batteries. By year's end, around 65 V2G projects and initiatives were in progress across 15 countries.¹²⁵ Several projects in the Netherlands, the Republic of Korea and the United Kingdom reached the pilot stage, and others had achieved or were nearing commercial operation in Denmark, Japan, the United Kingdom and the United States.¹²⁶

Variable renewable electricity
was increasingly supplied to EV charging networks in 2019.



ENERGY STORAGE

Energy storage can allow for flexible dispatch of renewable electricity and thermal energy at times of demand, and also can enable surplus or otherwise curtailed VRE to be applied to end-uses such as heating and cooling, mobility (as in EVs) and electricity generation. Energy storage includes mechanical, electrical, electro-chemical, thermal and chemical technologies, all of which can play an important role in the system integration of renewables.

Widely commercialised storage technologies relevant to the integration of renewables include pumped storage, various forms of electro-chemical storage such as lithium-ion, lead-acid and flow batteries, and certain thermal energy storage systems (including molten salt storage and hot water or ice storage). Biofuels also are a form of renewable energy storage, but in this report they are addressed as a primary form of renewable energy rather than as an enabling technology. (→ See *Bioenergy section in Market and Industry chapter*.)

Much of the development of energy storage over the past decade has focused on short-durationⁱ applications. Emerging long-term or long-duration technologies, such as renewable hydrogen, flow batteries and novel forms of mechanical storage, are supported by decreasing costs and rising shares of VRE in many power systems.¹²⁷ Mature storage technologies often are less viable for longer-duration storage because of limitations relating to cost, durability, energy density or resource availability (for example, pumped storage) – a characteristic that has potential importance for wider decarbonisation of the energy sector.¹²⁸

Energy Storage Markets

The global market for energy storage of all types reached 183 GW in 2019.¹²⁹ Mechanical storage in the form of **pumped (hydropower) storage** accounted for most of this capacity, at around 158 GWⁱⁱ, with 0.3 GW of new pumped storage capacity added during the year.¹³⁰

Several new pumped storage facilities were under development in 2019 to directly facilitate the integration of renewables through storage and dispatch of VRE – including in Greece, the United Arab Emirates, the United States and Zimbabwe.¹³¹ In Australia, the public utility Hydro Tasmania planned to connect the electrical grid of Victoria with up to 2.5 GW of new pumped storage capacity on Tasmania, increasing grid flexibility on mainland Australia and enabling higher VRE shares in the national electricity market.¹³²

The leading markets for **battery storage** saw mixed results in 2019.¹³³ The United States had a record year for new capacity, adding 523 MW and 1,113 megawatt-hours (MWh), although project delays impacted the market.¹³⁴ Regulatory changes

slowed growth in the Chinese battery market, with 520 MW and 855 MWh of new capacity added in 2019.¹³⁵ (→ See *Figure 56*.)

In Australia, 143 MWh of grid-scale battery capacity was installed, more than double the amount in 2018.¹³⁶ Australia added 233 MWh of new home batteries to reach 1 gigawatt-hour (GWh) of residential battery capacity.¹³⁷ In the Republic of Korea, battery installations fell 70% relative to 2018, mainly because a series of fires at battery installations triggered safety concerns.¹³⁸

The European energy storage market (excluding pumped storage and TES) also contracted in 2019, with 1 GWh of new storage capacity added for a total of 3.7 GWh.¹³⁹ Despite around 5% growth in the behind-the-meter storage market (mostly residential), a decline in front-of-meter installations contributed to the overall market drop.¹⁴⁰

Renewables-plus-storage has emerged as a major driver of battery market growth, and the direct coupling of batteries with VRE generators has become more widespread.¹⁴¹ In the United States, utility-scale projects combining solar PV and storage were completed in Hawaii, Massachusetts, and Texas, and several other projects coupling solar PV or wind with batteries were under construction or planning.¹⁴² VRE-plus-storage projects also were completed or in planning in Australia, China, the United Kingdom, and smaller or developing countries such as Mali, South Sudan and St. Kitts and Nevis.¹⁴³

The United States is a leading market for stand-alone utility-scale batteries, many of which are being built to indirectly enable higher VRE shares or to directly provide power systems with services that increase flexibility and resilience.¹⁴⁴ In the state of New York, a 4.8 MW (16.4 MWh) battery was installed as part of a demand response programme, and facilities under development in Arizona and Texas planned to provide demand response and ancillary services.¹⁴⁵ Elsewhere in the world, a battery in South Australia entered operations to provide both frequency response and arbitrage services, and in Tonga a battery that aims to enable greater deployment of wind and solar power was expected to enter operations in mid-2020.¹⁴⁶

Decentralised, behind-the-meter battery storage – including both stand-alone storage and VRE-plus-storage – showed strong growth in several markets. Germany was the leading European market for residential storage in 2019, with 369 MWh, and the number of US residential solar-plus-storage installations doubled between 2017 and 2019.¹⁴⁷ In the New England region of the United States, 20 MW of storage capacity – to be aggregated from around 5,000 residential systems – was approved for connection to the local grid, representing the first participation of residential solar-plus-storage in the US wholesale market.¹⁴⁸ Residential storage also grew strongly in South Australia, where the government's Home Battery Scheme secured 5,500 installations and orders by early 2020, equivalent to 62 MWh of storage capacity.¹⁴⁹

i The terminology used to categorise energy storage by duration or discharge period varies widely in academia, industry and the media. The GSR considers "short-duration" storage to be energy storage for less than around 10 hours, and "long-duration" refers to periods of around 10 to 100 hours. "Long-term" or "seasonal" storage describes energy storage for periods in excess of 100 hours, typically for weeks, months and years. Pumped storage is a mature and widely commercialised form of long-term storage.

ii Energy storage installations are specified in terms of both rated power (measured in kilowatts (kW), MW or GW) and the energy capacity (kilowatt-hours (kWh), MWh or GWh). Where possible, information on energy storage installations is reported in terms of both the rated power and the energy capacity of the installation. In some cases, data are reported in terms of only power or energy due to a lack of available information. Energy storage data also are occasionally reported in terms of time (i.e., the number of hours at which a facility can operate at its rated power output, based on its energy storage capacity), notably in concentrating solar thermal power storage markets. In these cases, rated power and storage "hours" may be used to calculate energy capacity in kWh, MWh or GWh.

Thermal energy storage – mainly in the form of molten salts – has been commonly deployed alongside concentrating solar thermal power (CSP) to allow for greater generation flexibility. In 2019, 3.4 GWh of new TES was deployed at CSP facilities, increasing the global installed capacity nearly 20% to 21 GWh.¹⁵⁰ (→ See CSP section in Market and Industry chapter.) Other thermal storage media, including water, were in use or being developed for non-CSP applications. At least 45 cities across Africa, Asia, Europe, the Middle East and North America were using centralised water reservoirs to store hot or cold water in district heating and cooling systems.¹⁵¹

Renewable hydrogen is an emerging storage technology with long-duration and long-term applications, although virtually all hydrogen continued to be produced from fossil fuels in 2019. Renewable hydrogen is produced from water through a VRE-driven electrolysisⁱ process, or alternatively from renewable feedstocks through gasificationⁱⁱ. Producing hydrogen using VRE with electrolyzers can enable significant power system flexibility when surplus VRE is utilised.¹⁵² Renewable hydrogen also can unlock demand for VRE by acting as a substitute for non-renewable hydrogen, which is produced using natural gas and is widely used in global industry.¹⁵³

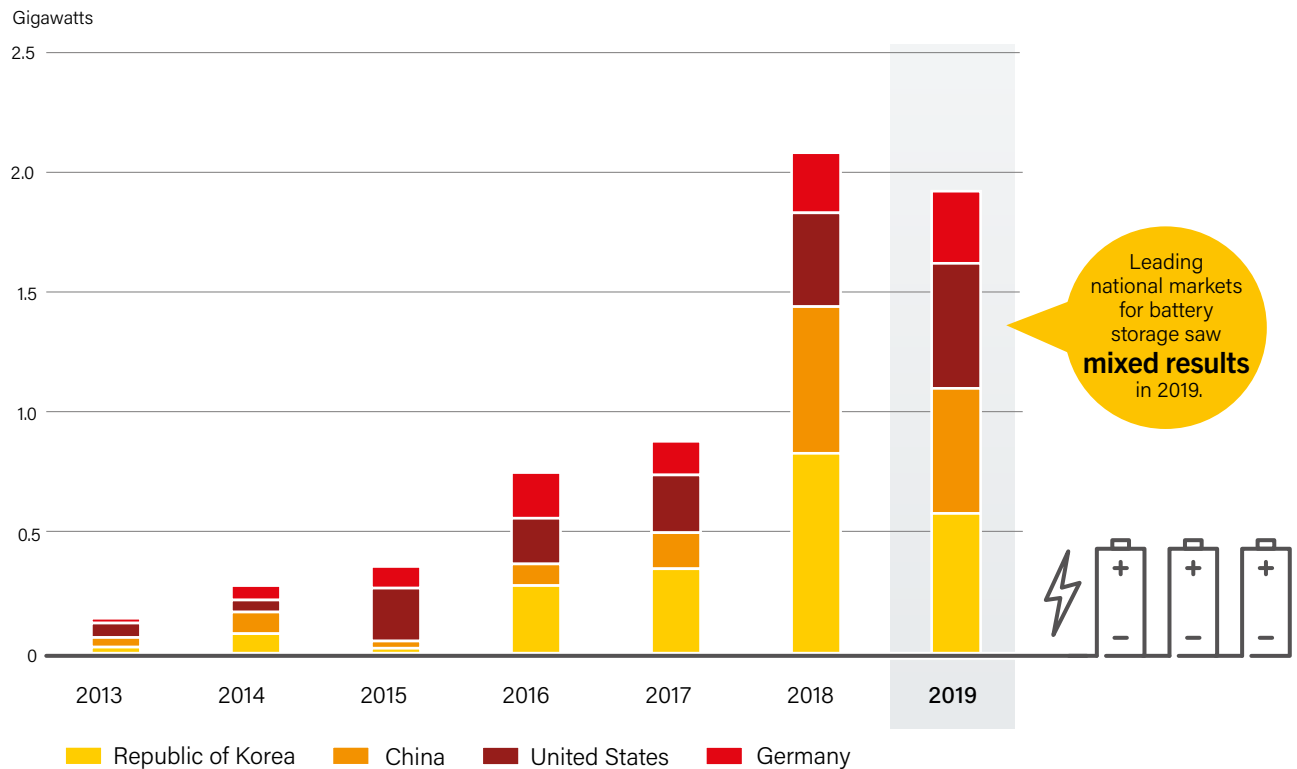
As of early 2020, more than 70 MW of hydrogen electrolyser capacity was in operation globally, with a further 45 MW under

construction.¹⁵⁴ Efforts to scale up hydrogen production and demand received greater public support in 2019, although not always linked to renewable energy. Japan has driven support for the global hydrogen economy by promoting hydrogen-fuelled vehicles and initiatives aimed at greatly reducing hydrogen costs.¹⁵⁵ Australia’s National Hydrogen Strategy targeted the creation of clusters of large-scale demand for hydrogen in ports, cities and rural locations.¹⁵⁶ Australia also planned to export renewable hydrogen to Asian markets, and a large-scale hydrogen production facility driven by 5 GW of wind and solar power capacity was slated to open in 2028.¹⁵⁷ The UK government backed a plan to deploy a GBP 12 billion (USD 16 billion) offshore wind farm in the North Sea with the aim of generating renewable hydrogen.¹⁵⁸

Other long-duration or long-term storage technologies advanced in 2019. For example, a 2 MW (8 MWh) vanadium redox flow battery, originally launched in 2017, became the first battery of this type to be connected to a US wholesale power market (in California).¹⁵⁹ A long-term 1.75 MW (10 MWh) mechanical storage facility developed in Ontario, Canada by Hydrostor (Canada) was built to use (surplus) VRE to store energy in the form of compressed air.¹⁶⁰ The company was developing similar facilities elsewhere.¹⁶¹

- i The electrolysis of renewable hydrogen makes use of an electrical current to split water molecules into hydrogen and oxygen.
- ii The gasification process exposes feedstocks (for example biomass, fossil fuels, or municipal waste) to extremely high temperatures in order to split them into their component elements, including hydrogen, oxygen, and other metallic and nonmetallic byproducts.

FIGURE 56. Battery Storage Annual Additions, Selected Countries, 2013-2019



Note: Capacity shown for selected countries according to available data at the time of publication. Does not reflect global total.

Source: See endnote 135 for this chapter.

Energy Storage Industry

The energy storage industry saw significant cost improvements, increased manufacturing capacity, large investments and ongoing R&D during 2019, with many of these activities focused on short-duration storage applications and battery technologies.

Notable cost improvements occurred for several storage technologies, particularly batteries. The average cost of a unit of lithium-ion battery capacity decreased 85% between 2010 and 2018.¹⁶² Meanwhile, the levelised cost of electricity from lithium-ion batteries fell by half between early 2018 and early 2020.¹⁶³ In certain markets, lithium-ion battery storage coupled with VRE has become competitive with traditional, fossil fuel-based power in providing flexible, “dispatchable” power.¹⁶⁴ Declining lithium-ion costs are driving the increased competitiveness of EVs in relation to conventional fossil fuel-powered equivalents.¹⁶⁵ (→ See *Electric Vehicles* section in this chapter.)

The costs of low-carbon and renewable hydrogen produced via electrolysis fell 45% between 2015 and early 2020, but have remained high relative to non-renewable hydrogen.¹⁶⁶ By one estimate, the cost per kWh of renewable hydrogen produced with solar PV power was roughly two to four times that of petrol in the United States.¹⁶⁷ In Canada, a hydrogen producer began offering partially renewable hydrogen in early 2020 at a cost of USD 2.67 per kilogram (compared with USD 1.50 per kilogram for typical non-renewable hydrogen).¹⁶⁸

The manufacturing capacity of certain types of storage has increased. For lithium-ion batteries, the global manufacturing capacity expanded from 14 GWh in 2010 to 316 GWh in early 2019, with more than 86% of this in China.¹⁶⁹ Large lithium-ion battery factories also were planned in Australia, India, South Africa and the United States.¹⁷⁰ As of mid-2019, the five largest lithium-ion manufacturers by capacity were LG Chem (Republic of Korea), CATL (China), BYD (China), Panasonic (Japan) and Tesla (United States).¹⁷¹

Global capacity for manufacturing renewable hydrogen was expected to grow strongly as of 2019, and in several countries large-scale electrolyzers were either opened, under construction or nearing construction. A 6 MW electrolyser powered by renewable electricity entered operations in Austria.¹⁷² In Germany, a project was announced for what is expected to be the world's largest electrolyser when it opens in 2023 – a 100 MW electrolyser powered by wind and solar energy.¹⁷³ A 1.25 MW electrolyser started construction in Australia, and a 20 MW electrolyser in Canada aimed to start production in 2020.¹⁷⁴

Energy storage, and particularly lithium-ion batteries, attracted significant investment in 2019. Venture capital firms contributed an estimated USD 1.7 billion to battery storage companies, with 80% of the total directed at lithium-ion technologies.¹⁷⁵ Several notable acquisitions occurred in the energy storage sector. For example, US-based private equity firm Energy Capital Partners acquired Convergent, a developer of the largest utility-scale battery projects in North America.¹⁷⁶

Oil and gas companies made strategic investments in energy storage as a way to diversify their services. Shell (Netherlands) acquired 100% of the German battery storage firm Sonnen with the aim of offering cleaner energy solutions to customers, and

BP (United Kingdom) increased its stake in the solar PV and energy storage developer Lightsource.¹⁷⁷ In the areas of mining and battery raw material production, Wesfarmers (Australia) took a controlling stake in lithium mine developer Kidman Resources, which is involved in a lithium hydroxide project in western Australia that aims to supply the EV market.¹⁷⁸

Among public investments in storage, the World Bank announced a partnership with 29 research and industry organisations aimed at advancing energy storage in developing countries.¹⁷⁹ In Tonga, the Asian Development Bank committed USD 44.6 million to a range of renewable-based systems and mini-grids, including battery systems.¹⁸⁰

Significant investments in emerging storage technologies occurred, including in renewable hydrogen, mechanical or gravity-based energy storage, flow batteries, compressed air and cryogenic energy storage.¹⁸¹ Amazon (United States) invested in Plug Power, a US company specialising in hydrogen fuel cells, and Cummins (United States) bought shares in Loop Energy (Canada), a provider of hydrogen fuel cell electric range extenders for commercial trucks.¹⁸² Cummins also acquired the hydrogen and fuel cell technology company Hydrogenics (Canada) in 2019, the same year that Cummins made a commitment to be carbon neutral by 2050.¹⁸³

In Sweden, the electric utility Vattenfall and the oil and fuel company Preem collaborated on designing a 20 GW renewable hydrogen facility that is expected to be Europe's largest water electrolysis facility – one of numerous “green hydrogen” initiatives that Vattenfall is involved in across the transport, power generation and industrial sectors.¹⁸⁴

Among investments in long-term storage, SoftBank (Japan) invested USD 110 million in the mechanical storage company Energy Vault (Switzerland), and a consortium including the oil company Eni (Italy) invested USD 40 million in Form Energy (United States), a long-term chemical storage company.¹⁸⁵ Two long-term storage start-ups also received significant investments: ESS Inc. (United States), focused on iron-flow batteries, and Hydrostor (Canada), which is developing compressed-air storage.¹⁸⁶

Wide-ranging R&D activities related to energy storage included a focus on improving battery efficiency, safety, reliability and cost.¹⁸⁷ The safety of lithium-ion battery storage facilities gained attention after a fire and explosion at a plant in the US state of Arizona and numerous fires in the Republic of Korea; research aimed at reducing these risks through the use of alternative electrolyte materials and other approaches.¹⁸⁸ Batteries also were investigated (alongside solar PV) for military applications, and the US Navy ordered two transportable solar-battery microgrids for test use.¹⁸⁹

R&D in thermal energy storage included the testing of new storage media in Hamburg, Germany, where Siemens Gamesa (Spain) was piloting the use of crushed volcanic rock as the storage medium for VRE converted into heat using electrical resistance heating.¹⁹⁰ Novel applications of water- and ice-based thermal storage also advanced. In the US state of California, a distributed network of ice machines was being developed to produce ice during periods when electricity rates are low and to service air conditioning demand during high-rate periods.¹⁹¹



GOVERNMENT SUPPORT FOR ENERGY EFFICIENCY, JORDAN



The Kingdom of Jordan's Renewable Energy & Energy Efficiency Fund (JREEEF) uses a bottom-up approach to make renewable energy more accessible to citizens. The Fund covers 30% of the costs of household solar PV systems and works with local banks to provide subsidised loans to cover the rest. Across Jordan, some 138 schools and 430 mosques and churches have benefited from JREEEF's support by installing solar water heaters and PV systems, improving insulation and lighting, and reducing their energy bills.

07 ENERGY EFFICIENCY AND RENEWABLES

KEY FACTS

- Global primary energy intensity continued to fall in recent years, enabled in part by increased renewable electricity production.
- Global final energy demand has risen, despite improvements in energy intensity that have facilitated larger renewable energy shares.
- The increase in final energy demand has been driven largely by rapid economic growth and improved energy access in developing and emerging economies and a global shift towards energy-intensive transport.

International efforts to meet energy demand in a safe and reliable manner generally acknowledge the complementary nature of renewable energy deployment and energy efficiency measures.¹ Both renewables and efficiency can contribute significant benefits including lower energy costs on a national, corporate or household level, increased grid reliability, reduced environmental and climate impacts, improved air quality and public health, and increased jobs and economic growth.² The United Nations' Sustainable Development Goal 7ⁱ (SDG 7) recognises that combining renewables and efficiency provides an integrated means towards achieving sustainable energy access for all.³

Energy production and use account for more than two-thirds of global greenhouse gas emissions.⁴ Taken together, renewable energy deployment and energy efficiency measures can potentially achieve most of the carbon reductions required to keep global temperature rise below 1.5 degrees Celsius.⁵ Moreover, renewables and efficiency maximise their emissions mitigation potential when pursued together.⁶

Coalitions of governments, corporations, institutions and non-governmental organisations have boosted global energy efficiency efforts, recognising the potential to greatly reduce greenhouse gas emissions.⁷ As of the end of 2019, 131 parties

ⁱ In 2015, the United Nations General Assembly adopted a set of 17 goals as part of a new global agenda on sustainable development. SDG 7 aims to ensure access to affordable, reliable, sustainable and modern energy for all – including targets to “increase substantially the share of renewable energy in the global energy mix” and to “double the global rate of improvement in energy efficiency” by 2030. See endnote 3 for this chapter.

to the Paris Agreement mentioned renewable energy in their Nationally Determined Contributions (NDCs) to reduce emissions, while 112 parties mentioned energy efficiency, and 94 mentioned both.⁸ Energy efficiency was a main contributor to stabilising global greenhouse gas emissions in 2019, along with renewables.⁹ (→ See Box 1.)

Energy intensity, which represents primary energy supply per unit of economic outputⁱ, plays an important role in evaluating developments in energy efficiency (for example, it is a key indicator for tracking efficiency improvements under SDG 7). Energy intensity is complemented by carbon intensity, which measures the amount of carbon dioxide emitted per

ⁱ See Glossary for expanded definition and for details on why energy intensity is used as a proxy for energy efficiency. Energy intensity is an imperfect indicator for energy efficiency, as it reflects not only changes in relative energy efficiency but also structural changes in economic activity (such as a shift from heavy industry towards services and commerce). (→ See Box 2.)

BOX 1. Energy Efficiency and the Deployment of Renewables: Working Together with Limited Resources

Energy efficiency and renewables generally complement each other in an integrated approach to achieve common global goals. In some cases, however, trade-offs can occur between the two, due mainly to competing costs. Given that financial resources are inherently limited in most economies and for most actors, the relative prices for energy efficiency and renewable energy have the capacity to reduce the incentive to implement one or the other. This is not necessarily a negative phenomenon, as both efficiency and renewables serve largely the same objective.

The costs of generating electricity from renewable energy technologies continued to decline in 2019, with solar photovoltaic (PV), hydropower, onshore wind power, bioenergy and geothermal projects becoming increasingly competitive with fossil energy generation. (→ See Sidebar 5.) In some locations, however, renewable electricity prices for end-consumers remain higher than conventional electricity pricesⁱ.

Meanwhile, plenty of no- or low-cost energy conservation and efficiency measures exist that can be implemented at a wide scale, such as turning off appliances that are not in use or activating “sleep” settings, switching to low-energy lighting and installing insulation films for windows. The public

and private sectors are increasingly recognising how such “low-hanging fruit” can yield major energy cost savings.

Ultimately, the optimal combination of efficiency and renewables is both location- and sector-specific. Additionally, implementing efficiency measures facilitates the deployment of renewable energy either concurrently or subsequently. Integrated strategies for efficiency and renewables thus can be the most effective approach for maximising the potential of both. For example, in the Seychelles an Energy Efficiency and Renewable Energy Programme in place since 2017 aims to encourage residents to buy energy-efficient appliances and renewable energy, and Morocco’s Jiha Tinou programme seeks to stimulate renewables and efficiency initiatives in cities and regions. (→ See Policy Landscape chapter for additional developments in 2019.)

ⁱ Some of this price discrepancy can be attributed to ongoing adjustments to variable electricity supplies in power markets and to the diverse business models of energy utilities and infrastructure operators. Conventional electricity prices are those from fossil fuel and nuclear power plants.

Source: See endnote 9 for this chapter.



unit of final energy consumed^{i,10}. In general, interactions between the deployment of renewable energy technologies and improvements in energy efficiency are complementary, as efficiency reduces the overall primary energy needed, while the use of renewables minimises both the primary energy needed as well as the carbon intensity.¹¹ (→ See Box 2.)

Factors behind these reductions in primary energy demand and carbon emissions include:

■ **Interactions between renewables and primary energy efficiency.** Primary energy demand includes all of the energy contained in all the energy sources required to meet the final energy consumption of end-users, taking into account losses from transforming primary energy (such as oil, coal or natural gas) into secondary energy (such as electricity or oil distillates). Because the use of some sources of renewable power – particularly hydropower, solar PV and wind power technologies – reduces the overall transformation losses in generation, the

uptake of renewables lessens the amount of primary energy needed to meet final energy needs, thus improving primary energy intensity.¹² Increasing the share of electricity generation from renewables also helps to reduce overall carbon intensity.

■ **Interactions between renewables and final energy efficiency.** Energy efficiency measures are necessary for increasing the overall share of renewables in final energy consumption. By lowering final energy consumption, energy efficiency allows the same level of renewable energy uptake to meet a larger share of energy consumption, and also reduces the capital investment required to supply the demand through on-site and/or off-site renewables. This is particularly pertinent in light of rising energy use in developing and emerging economies, and in light of barriers that limit the speed of renewables deployment (such as land scarcity, potential opposition by local communities, etc.).¹³ (→ See *Feature chapter*.)

i Energy intensity and carbon intensity are complementary because, taken together, they indicate the primary energy required per unit of GDP and the carbon dioxide emissions produced through the transformation and use of this energy.

BOX 2. Energy Optimisation: Efficiency, Conservation and Structural Changes

The term energy efficiency is often used as a proxy term for energy savings. Yet improvements in efficiency alone do not necessarily lead to energy savings. Energy reduction or optimisation is simultaneously influenced by:

- energy efficiency improvements through technology and design;
- energy conservation measures, which are related to the behaviours and habits of energy end-users; and
- structural changes, or changes in the composition of sectors or within a sector (for example, a switch to less energy-intensive or more service-oriented industries), which can be achieved through policies, investments and planning processes.

Both energy efficiency improvements and the integration of behavioural measures are necessary within energy optimisation strategies, whereas structural changes generally are kept outside of the scope.

Energy efficiency measures without behavioural awareness can lead to a “rebound effect”, whereby the energy reductions generated by nominal efficiency improvements are either lower than expected or even negative. For example, in response to improved insulation in buildings, residents may opt to maintain warmer homes rather than to reduce their energy consumption – resulting in a direct rebound effect – or they may spend the cost savings on other goods and services that also require energy to provide (an indirect rebound effect).

Often, the benefits of efficiency are not “lost” but rather are redirected; thus, it is important to distinguish two types of impact of the rebound effect:

- The reduction in energy expenditure due to energy efficiency leads to wasteful energy use with no appreciable increase in utility to the consumer. This could include, for example, leaving the lights on in a vacant room because lighting is cheap.
- The reduction in energy expenditure due to energy efficiency leads to the opportunity to increase the consumer’s utility, by using some or all of the energy that is otherwise saved for new or improved energy services. This could include, for example, increasing space heating to a range of comfort from a previously unhealthy state, or efficient lighting allowing for more study time during non-daylight hours.



Source: See endnote 11 for this chapter.

In addition, specific efficiency measures in end-use sectors, such as energy-efficient building codes, can be enablers for both energy efficiency and renewable energy. These efficiency measures often are coupled with measures to supply the remaining energy demand either directly with renewables (for example, bioenergy, solar thermal and geothermal heat) or indirectly with renewables-based electricity.¹⁴ The electrification of end-use sectors, such as heating, cooling and transport, is one pathway to achieving a double benefit: electrified systems can be more energy efficient than their fossil fuel-based counterparts, and electricity demand can be sourced more readily from a wide variety of renewables.¹⁵ (→ See *Systems Integration chapter*.)

Renewables and energy efficiency maximise their **emissions mitigation potential** when pursued together.

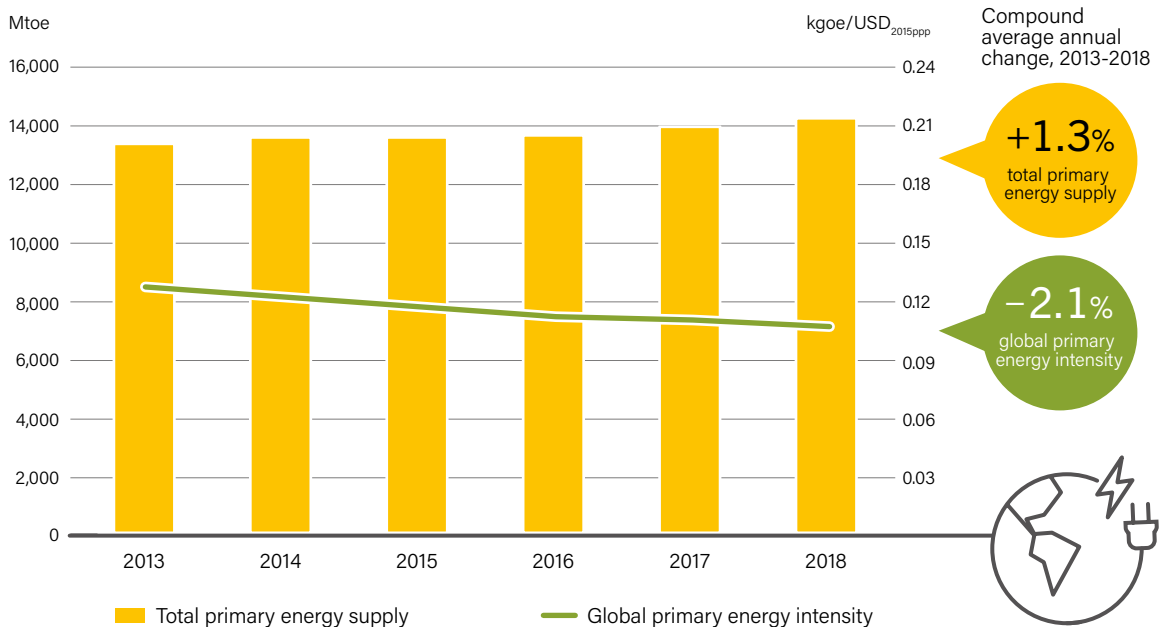
RENEWABLES AND PRIMARY ENERGY EFFICIENCY

The world's total primary energy demand increased 2.3% in 2018, the largest increase since 2010, driven by global economic growth.¹⁶ However, improvements in primary energy intensity helped limit the growth in demand to some extent. Global primary energy intensity decreased more than 10% during the five-year period between 2013 and 2018, at an average annual rate of 2.1%.¹⁷ (→ See *Figure 57*.) On a year-to-year basis, the improvement in energy intensity has slowed more recently, falling from 3.0% in 2015 to 1.2% in 2018.¹⁸

If the total primary energy demand had moved in tandem with global economic growthⁱ – with no reduction in energy intensity – during 2013-2018, and considering that primary energy demand grew 6.5% over this period (average annual growth of 1.3%), total primary energy demand would have risen 19.2% over the five-year span (or 3.6% per year).¹⁹ In the context of a growing global economy, improvements in energy intensity thus are key to curbing global growth in energy demand.

i This does not take into account unknown feedback from higher energy intensity on economic growth. In other words, global economic growth might not have been as large over the observed period if not for the benefit of more efficient use of energy in economic activity.

FIGURE 57. Global Primary Energy Intensity and Total Primary Energy Supply, 2013-2018



Note: Dollars are at constant purchasing power parities. Mtoe = megatonnes of oil equivalent; kgoe = kilograms of oil equivalent.

Source: Enerdata. See endnote 17 for this chapter.

In 2017, the world's total primary energy supply was 584 exajoules (EJ).²⁰ Each year, more than 23% of the primary energy supply is dissipated through various transformation processes (such as conventional electricity generation).²¹ The fossil fuel energy industry itself consumes another 6% of the total primary energy supply through its net demand for energy, including for operating oil refineries and mining and extracting fossil fuels.²² Less than 2% of the total primary energy supply goes to "non-productive" losses, which occur mainly during the transmission and distribution of electricity.²³

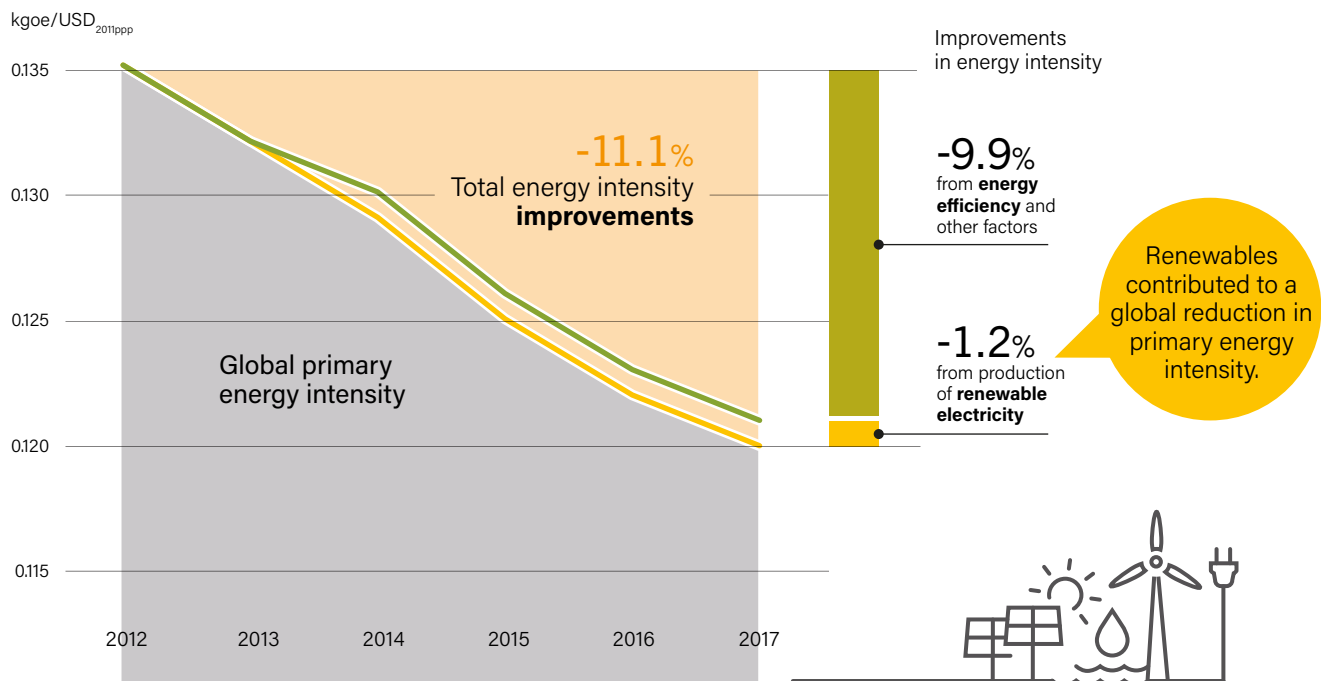
Looking specifically at thermal power plants (combustion only; biomass-, coal-, natural gas- and oil-fired power plants), more than half of the primary energy input is lost during the transformation process.²⁴ Non-thermal renewable energy technologies (such as wind power and solar PV) also have a low conversion efficiency, but in these cases the energy loss is irrelevant, because any potential energy not harnessed by these technologies is never part of the primary energy supply, unlike with fossil fuels that are extracted for electricity generation and for the production of refined fuels.²⁵ As a consequence,

non-thermal renewables have a higher primary energy efficiency. Additionally, the dissipated energy in fossil fuel power plants (unlike "lost" solar and wind energy) manifests itself in increased emissions of greenhouse gases and other pollutants.

Based on these factors, improving primary energy efficiency (and thus reducing greenhouse gas emissions) in the power sector can be achieved in one of two ways: either by improving the efficiency of thermal power plants (through greater thermal conversion efficiency and through direct use of residual heat, or co-generation), or by reducing transformation losses through a shift to non-thermal renewable energy technologies.

Between 2012 and 2017, the increase in renewable electricity production reduced global primary energy intensity an estimated 1.2%.²⁶ Meanwhile, general improvements reduced global primary energy intensity an estimated 9.9%, with energy efficiency playing a role alongside fuel switching and regional shifts in energy demand, among other factors.²⁷ (→ See Figure 58.)

FIGURE 58. Estimated Impact of Increased Renewable Electricity Production on Global Primary Energy Intensity, 2012-2017



Note: The figure estimates the additional primary energy input that would have been required in the absence of the renewable electricity uptake since 2012, all else being equal. The estimation accounts for the difference in transformation losses between conventional and renewable electricity generation but does not account for potential feedback loops on the energy demand itself due to energy prices, structural changes in economic activity or similar effects. The figure is not intended to provide results of a comprehensive energy model. For further explanation of the methodology, see endnote 27 for this chapter.

Source: See endnote 27 for this chapter.

Dollars are at constant purchasing power parities.
kgoe = kilograms of oil equivalent.

RENEWABLES AND FINAL ENERGY CONSUMPTION

Total final energy consumption (TFEC) – that is, what remains of the total primary energy demand following all of the losses that occurred during the processes of transformation, energy sector use, transmission and distribution – amounted to 370 EJ in 2017.²⁸

Like primary energy intensity, global final energy intensity improved during the 2012-2017 period, although by a higher margin of 13%.²⁹ Because of this higher improvement in final energy intensity, which reduces overall energy demand, the same renewable energy sources can supply a larger share of the world’s final energy needs.³⁰

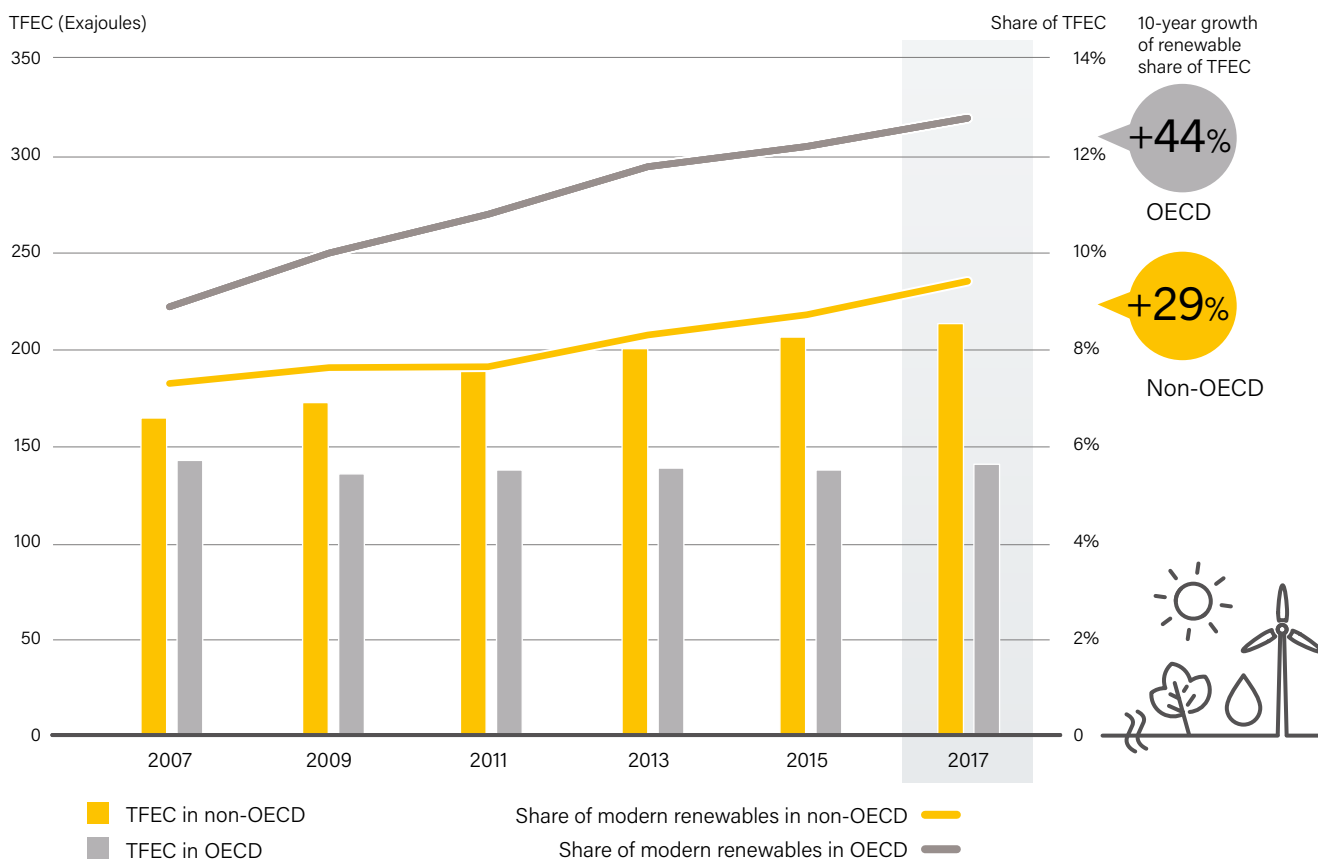
Between 2007 and 2017, global TFEC increased 1.4% annually, while the share of TFEC met by modern renewables grew at an average annual rate of 3.0%.³¹ Differences are evident between the member countries of the Organisation for Economic Co-operation and Development (OECD) and the countries outside of it.³² (→ See Figure 59.)

■ In **OECD countries**, contrary to the global trend, TFEC decreased 1.8% between 2007 and 2017, due in part to a 14% improvement in final energy intensity during this period.³³ This decrease facilitated larger growth in the share of consumption met by renewables: while consumption of renewable energy increased around 42% between 2007 and 2017, the share of modern renewables in TFEC increased 44% during the period.³⁴

■ **Non-OECD countries** experienced a large rise in energy demand (TFEC increased 30%) between 2007 and 2017, driven by rapid economic growth and improved energy access, but limited to an extent by a 20% improvement in final energy intensity.³⁵ This growth tempered the increase in the share of consumption met by renewable energy. While the absolute amount of renewable energy in TFEC grew at a higher rate than in OECD countries (68%) during the period, the share of renewables in TFEC increased to a lesser extent (29%).³⁶

i The member states of the OECD (37 countries, as of end-2019) account for the majority of the world's gross domestic product (GDP) and are among the countries with the highest GDP per capita as well as rank near the top of the Human Development Index. They typically are classified as countries with developed economies. Non-OECD countries are normally classified as countries with developing or emerging economies, some of which have seen rapid rises in GDP per capita in recent decades.

FIGURE 59. Total Final Energy Consumption and Share of Modern Renewables in OECD and non-OECD Countries, 2007-2017



Note: TFEC = total final energy consumption.

Source: Based on IEA. See endnote 32 for this chapter.

BUILDINGS

The buildings sector accounted for around 33% of global TFEC in 2018.³⁷ Residential buildings consumed nearly three-quarters of this energy, and the rest was used in commercial and public buildings.³⁸ In 2017, electricity end-uses (for example, lighting and appliances) accounted for less than 25% of building energy demand, with various fuels (natural gas, biomass, fuel oil, coal, etc.) serving most of the remaining (mostly thermal) demand.³⁹ Although the overall share of renewable energy used to meet building energy demand remained low (13.6%), renewables were the fastest growing energy source in the sector.⁴⁰ (→ See *Global Overview chapter*.)

Despite the development of more-efficient appliances and improvements in building structure and construction, the energy demand of buildings rose 38% globally between 2000 and 2017.⁴¹ In OECD countries, TFEC in the buildings sector *decreased* 2.6% between 2005 and 2017, whereas in non-OECD countries it *increased* 26% during this period.⁴² Various factors explain these differences, shaping the trends in energy consumption.⁴³ As a consequence, issues related to the share of renewables in the sector, and how to increase it, can differ.

In **OECD countries**, the energy intensity of buildings – measured as the final energy use per unit of floor area – fell 1.3% annually between 2000 and 2018, leading to a decrease in final energy consumption.⁴⁴ Although energy use for cooling per OECD household has increased in recent years, this has been offset by a decrease in the average energy intensities of space heating and lighting.⁴⁵ Since 2010, heating and lighting have seen the highest efficiency improvements among household energy uses in OECD countries, with average annual energy intensity improvements per dwelling of 1.4% for heating and 1.7% for lighting.⁴⁶

Electricity is the predominant energy carrier used in OECD countries, accounting for 37% of the energy consumption of residential buildings.⁴⁷ The overall improvement in the energy intensity of buildings in these countries reflects declines in the average electricity use per electrified household in Europe (down 9% since 2010), North America (down 5%) and the Pacific (down 14%).⁴⁸

Interest in energy-efficient buildings is increasing, mainly in developed countries where the implementation and updating of energy codes, certification policies and energy performance requirements for construction and renovation at the national level are influencing energy use in the sector.⁴⁹ Numerous building standards emphasise a high commitment to energy efficiency, ensuring that the energy performance of buildings is as efficient as possible, and often interlinking efficiency with on-site and/or off-site renewable generation (mostly through solar PV) to cover residents' remaining energy use.⁵⁰ However, policy approaches to energy efficiency and renewables in the buildings sector range widely in their level of commitment. (→ See *Policy Landscape chapter*.)

Despite advances in energy efficiency, **global energy demand** in buildings has continued to rise.

The market penetration of energy-efficient buildingsⁱ is difficult to estimate due to varying definitions and a lack of monitoring.⁵¹ However, a clear upward trend can be seen in the United States and Canada, where the number of zero energy housing units either in the design phase, under

construction or completed increased 59% between 2017 and 2018, from 13,960 units to 22,146 units.⁵² This still represents only a tiny share of the reported 1.47 million new construction starts in 2017 in the two countries.⁵³ In the European Union, the ZEBRA2020 project monitors the market uptake of “nearly zero-energy buildings” across 17 Member States and shows the wide variance in deployment across the region.⁵⁴

Countries outside of the OECD have the highest growth in building energy demand, but in many instances mandatory building energy standards and policies either are not in place or cover a small portion of building energy use.⁵⁵ The average annual electricity consumption in non-OECD countries, at around 2,100 kilowatt-hours (kWh) per household, remains below the global average (some 3,500 kWh per household) and is less than one-third that of the OECD countries.⁵⁶ However, average electricity consumption increased in non-OECD countries between 2010 and 2018, mainly in Asia (up 37%) and Africa (15%) but also in Latin America (4%).⁵⁷

The growth in electricity consumption in non-OECD countries can be explained mainly by rising wealth and increased access to energy in these countries. Many poor and lower-middle income residents have gained access to modern energy services for the first time: between 2015 and 2017, an estimated 153 million people gained electricity access worldwide.⁵⁸ (→ See *Distributed Renewables chapter*.) Consumers also are opting for larger homes, increasing the building floor area and appliance ownership per household, which ultimately expands energy use.⁵⁹ This shift, coupled with a lack of access to efficient systems and appliances due primarily to a lack of economic resources, has led to the overall rise in energy demand – despite the introduction of minimum energy performance standards in many countries.⁶⁰

This challenge is particularly apparent in the cooling sector. While many lower- to middle-income people in developing countries are now able to purchase cooling systems, their preference for the most affordable (upfront) solution leads to greater inefficiency and impacts the rise in energy use and associated greenhouse gas emissions.⁶¹ Efforts to implement regulations in the sector include the COOL_ME project to scale up “sustainable cooling” in the Middle East (funded through Germany's International Climate Initiative) and China's Green and High-Efficiency Cooling Action

i Such buildings are characterised by the efficient use of energy (and sometimes of water and other resources, as in “green buildings”); they can include generation from renewables to fulfil their current energy consumption (e.g., “zero energy”, “zero emission” or “energy neutral” buildings), to meet their future energy consumption (e.g., “zero energy ready” buildings) or even to produce more energy than they consume (e.g., “energy positive” buildings). See Glossary for definitions.

Plan, released in 2019.⁶² Ultimately, rising energy demand from increased access is related to improving quality of life, but it poses threats of long-term lock-in to fossil fuel use if the access is provided by renewables coupled with energy efficiency.

Meanwhile, the deployment of renewables and efficiency has played a major role in electrifying rural areas of developing countries, where on average 77% of the population has access to electricity.⁶³ The deployment of off-grid solar systems such as solar lighting and solar home systems has emerged as an important driver of rural energy access.⁶⁴ Between 2011 and 2016, the global number of people connected to off-grid renewables grew by a factor of six, to nearly 133 million, with countries in Africa and Asia accounting for most of the growth.⁶⁵ (→ See *Distributed Renewables chapter*.) In this context, the interaction between efficiency and renewables is evident, as energy-efficient appliances enable a wider spectrum of electricity services to be delivered by small-scale renewable energy systems that offer both reduced capacity and lower costs. (→ See *Box 1 in Distributed Renewables chapter*.)

INDUSTRY

The industrial sector accounts for nearly 35% of global TFEC, excluding non-energy uses of fossil fuels. Despite a 19% improvement in global industrial energy intensity between 2010 and 2017 (a 3% yearly decrease in intensity on average), industrial energy use has gradually increased, at an annual average rate of 0.9% during the period.⁶⁶

As in the residential sector, key contributors to improved energy intensity in industry are:

- **Deployment of more-efficient technologies** and operational improvements, leading to gains in overall efficiency. This is due mainly to more-efficient heavy industrial production in emerging economies such as China and India, with a consequent greater decrease in energy intensity in the region.⁶⁷ More recently, however, the impact of annual efficiency gains in the industry and services sector has fallen, from around 4% savings in final energy demand in 2015 to just under 2% savings in 2018, a return to the trend of previous years (2012-2014).⁶⁸
- **Structural factors**, notably the shift, primarily in developed countries, away from energy-intensive industry and towards less energy-intensive sectors of the economy (particularly services) as well as higher value-addedⁱ economic activities (such as automotive manufacturing, food and beverages, and textiles). However, this effect has slowed globally since 2013 as energy-intensive manufacturing has shown renewed growth.⁶⁹ As of 2017, renewable energy, including renewable electricity, supplied more than 14% of industrial energy demand.⁷⁰ This share grew only slightly between 2007 and 2017, despite increases in the use of renewables in the sector over the period.⁷¹ (→ See *Global Overview chapter*.)

Electrification of industry can potentially play a role in increasing the share of renewables in TFEC. For example, during the 2007-2017 period the share of electricity in industrial TFEC grew from 25% to 27%.⁷²



As in the buildings sector, electrification of industry generally results in gains in final energy efficiency, thereby reducing overall energy demand, and it facilitates the uptake of renewables indirectly to the extent that the electricity comes from renewable sources.⁷³

TRANSPORT

Energy use in the transport sector grew 20% between 2007 and 2017 – at an average annual rate of 1.8% – and accounted for 32% of TFEC in 2017.⁷⁴ Most of the increase in energy use reflects the growing size and number of vehicles on the world's roads (and the accompanying passenger-kilometres travelled) as well as, to a lesser extent, rising air transport.⁷⁵ As of 2016, road transport continued to account for the bulk of energy demand for transport (at 75%), followed by aviation (11%), marine transport (9.6%) and rail (1.8%).⁷⁶ (→ See *Global Overview chapter*.)

In developed countries, passenger road transport data reveal a shift towards the use of light-duty vehicles and continued growth in sales of sport utility vehicles (SUVs).⁷⁷ Between 2010 and 2018, the average passenger-kilometres travelled per person for buses decreased 9%, whereas for light-duty vehicles it increased 15%.⁷⁸ However, major differences exist between countries: bus use has increased in Australia, France and Portugal (up 11%, 25% and 33% respectively) but has decreased in Belgium, the United Kingdom and the United States (down 17%, 20% and 33% respectively).⁷⁹ Considering that the average energy intensity per passenger-kilometre of a bus, at 0.89 megajoules (MJ), is about half that of a light-duty vehicle (1.71 MJ), this has led to increased energy demand from road transport.⁸⁰ Furthermore, fuel economy standards for light-duty vehicles exist in only 37 countries, and just 5 countries have fuel economy policies for trucks. (→ See *Policy Landscape chapter*.)

The shift towards more energy-intensive transport modes is not specific to developed countries and can be observed globally. Coupled with behavioural factors and consumer preferences,

i Higher value-added sectors generate a larger margin between the final price of a good or service and the cost of the energy inputs used to produce it.

Electric vehicles

show a complementarity between energy efficiency and renewable energy.

such as lower vehicle occupancy and a demand for larger cars and SUVs, this can counteract any improved efficiency of motor vehicles.⁸¹

The transport sector has the lowest penetration rate of renewable energy among end-use sectors, with renewables supply-

ing only a small share of final energy (3.3%), mostly in the form of biofuels and the remaining share from renewable electricity.⁸² Overall, both renewable and non-renewable electricity supply only around 1.1% of the TFEC of transport, mostly in road transport (15%) and rail (around 70%).⁸³

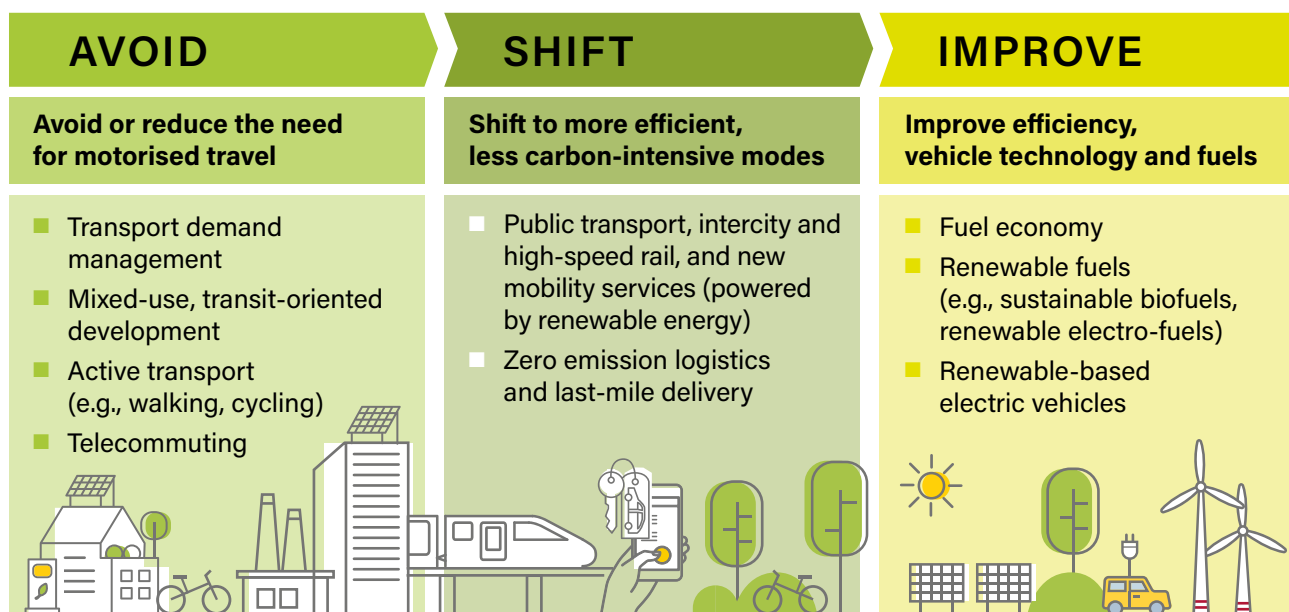
In addition to efforts to incorporate more renewables in the transport sector (through both renewable fuels and electricity from renewable sources), renewable energy can benefit from wider initiatives to decrease energy demand in the sector, as this could help boost the renewable share. Ways to reduce energy demand include avoiding the need for motorised transport, transitioning to more-efficient transport modes such as (renewable based) public transport and rail and efforts to improve vehicle technology and fuels, such as through higher fuel efficiencies and emission standards.⁸⁴ (→ See *Global Overview chapter*.)

These actions, commonly referred to together as Avoid-Shift-Improve, seek to address broader policy maker concerns in the transport sector, such as environmental and health impacts (e.g., congestion, pollution, road safety) and transport security.⁸⁵ (→ See *Figure 60*.)

Electric vehicles (EVs) for passenger and freight use highlight an area where a complementarity between energy efficiency and renewable energy can clearly be seen. EVs have a higher technical efficiency than vehicles with internal combustion engines (higher kilometres travelled per unit of energy) and can be supplied easily with renewable energy, both as distributed generation with renewables rises and as electricity systems gradually integrate higher renewable energy shares.⁸⁶ (→ See *Systems Integration chapter*.) Although policy maker attention to EVs has increased in recent years, policies and targets for EVs rarely include a direct link to renewable electricity; meanwhile, the number of countries with biofuel blend mandates has levelled off in recent years (standing at 70 countries since 2017).⁸⁷

The worldwide EV market has grown dramatically in recent years, with the global stock of passenger EVs surpassing 7 million in 2019.⁸⁸ Nevertheless, the rise in renewable energy use related to EV deployment remains a slow process, due to the need to both shift the vehicle fleet and to install charging stations that are either directly linked to renewable electricity or planned in parallel with shares of renewables in electricity generation.⁸⁹

FIGURE 60. Avoid-Shift-Improve Framework in the Transport Sector



Note: Transport demand management refers to encouraging travelers to avoid trips or shift to more resource-efficient options to limit vehicle traffic. Mixed-use development refers to having more than one use or purpose within a building or development area, ranging from housing on upper floors of a building and office or commercial space on the ground floor, to comprehensive developments with multiple buildings having separate but compatible uses. Transit-oriented development refers to mixed urban development around or near a transit station to reduce the need for motorised trips.

Source: See endnote 85 for this chapter.



CO-OPERATIVE RENEWABLE ENERGY CAMPAIGNS, MAURITIUS



In Mauritius, a coalition of groups formed the People's Cooperative Renewable Energy Society in 2013 and launched a Power Shift Campaign to accelerate the transition to renewables. The campaign challenges the privately owned, non-renewable sector by providing co-operative solar energy alternatives that unemployed farmers can use to power greenhouses and improve local food production. The campaign's actions led to the cancellation of plans for a new coal plant, and have improved government transparency by pushing for the creation of a national commission to review Mauritius' energy policies.

08

FEATURE: PUBLIC SUPPORT FOR RENEWABLES

KEY FACTS

- The extent to which renewables gain public support and are able to attract adequate private or public investment is key to their further uptake.
- Although individuals and some groups have expressed concerns about specific renewable energy projects, opinion polls indicate strong public support for the growth of renewables.
- Governments have sought to improve public participation, strengthen regulatory control and share economic benefits with host communities to further build citizen support for renewable energy projects.

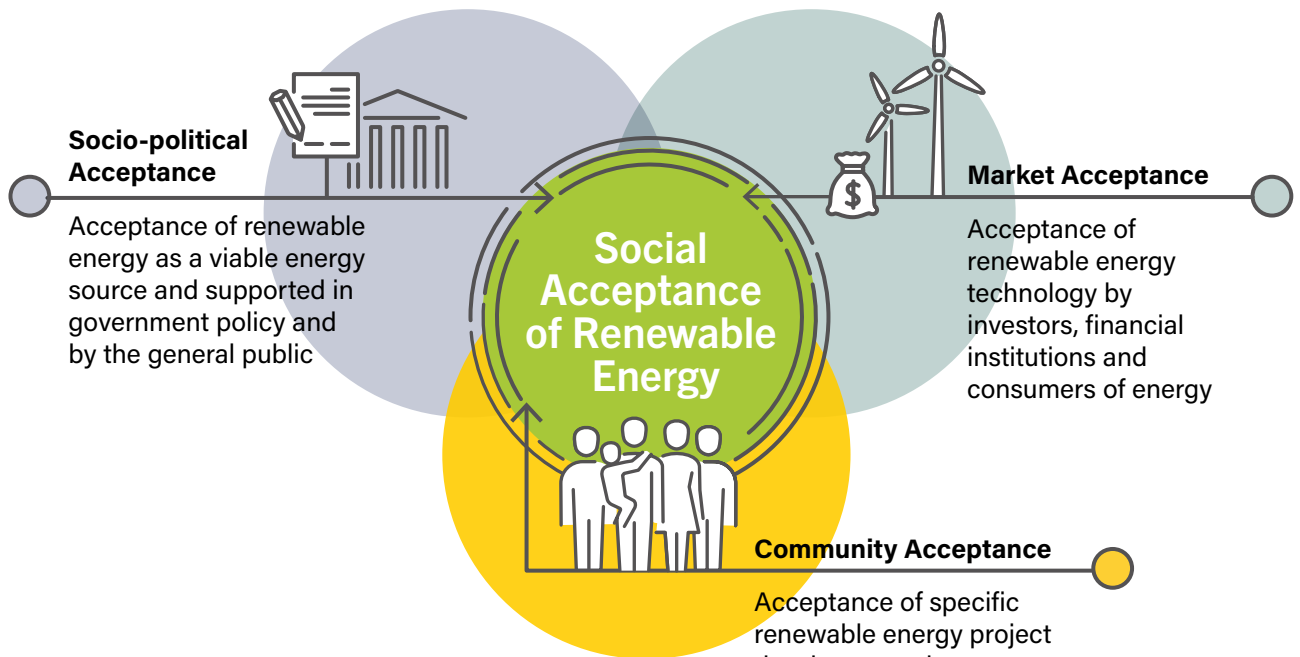
A complex array of technological, economic, environmental and social factors can affect the extent and pace of renewable energy deployment. However, also critical is how these technologies are perceived by society. In 2019, global climate strikes and opinion polls revealed rising public demand for a shift away from fossil fuels; at the same time, opposition from local communities limited the implementation of renewable energy projects in some regions. The extent to which renewables gain public supportⁱ and are able to attract adequate private or public investment is a key factor in increasing their deployment. Consideration of the range of reactions related to the public response to renewables can help build support for these technologies and ultimately encourage broader inclusion and participation.

Although the views of local communities are an important factor in the uptake of renewables, they are only one part of a broader condition of social acceptance of renewables that also includes market and socio-political dimensions.¹ (→ See *Figure 67*.) Each of these three dimensions can influence the overall acceptability of renewable energy, and each has the potential to stimulate a virtuous or detrimental cycle of support or opposition. Rather than looking at public support for renewables solely through the lens of concepts such as “NIMBYism”ⁱⁱ (→ See *Box 1*), a more holistic approach includes community engagement, financial measures, political leadership and market confidence.²

ⁱ For the purposes of this chapter, “public” is defined, in most cases, as all citizens/residents and does not include specific private or state energy interests or non-governmental organisations; the public often is distinguished from those most directly affected by energy projects, which are referred to here as “host communities”.

ⁱⁱ NIMBY (“Not In My Backyard”) and NIMBYism refer to the behaviour of a person or group of people that objects to a development project (such as a renewable energy plant) being built near to where they live.

FIGURE 61. Dimensions of Social Acceptance of Renewable Energy



Source: See endnote 1 for this chapter.

Many of the factors that shape the rate and nature of renewable energy uptake depend on local, regional and national contexts. They also include issues such as the availability of renewable resources (such as solar and wind energy), environmental constraints (such as settlement patterns or protected landscapes), political conditions, planning and environmental governance, and procurement and financial arrangements.³ Likewise, the extent and features of public support vary depending on demographics, socio-economic characteristics and the local/national context, which can be influenced by a complex set of issues.⁴



FACTORS BEHIND PUBLIC SUPPORT FOR RENEWABLES

LANDSCAPE OF REACTIONS TOWARDS RENEWABLE ENERGY

Although individuals may express concerns about specific renewable energy projects, the public generally has shown support for renewables based on the multiple benefits that these technologies provide.⁵ For example, people may recognise that renewable energy brings health improvements (through reduced pollution), greater energy reliability and resilience, increased energy security, climate change mitigation and the alleviation of energy poverty.⁶ In specific locations, residents may appreciate the job creation and other economic opportunities that come from renewables, which are necessary for an inclusive and just energy transition.⁷ (→ See *Sidebar 2*)

In the past few years, opinion polls have consistently indicated strong public support for the expansion of renewables. In a 2019 survey in the European Union (EU-28), 90% of respondents agreed that the region should encourage greater investment in renewable energy, and participants showed widespread support for all renewable technologies.⁸ A poll in Indonesia, Pakistan, the Philippines, South Africa, Turkey and Vietnam identified a strong preference (61-89%) for “clean energy”, with solar power receiving the highest positive responses.⁹ Strong preferences for renewables also are visible in Australia, Canada, France, Switzerland and the United States.¹⁰ Meanwhile, in a 2017 survey of more than 26,000 people across 13 countries in Asia Pacific,

BOX 1. Social Acceptance and NIMBYism

Often, local disputes about proposed development projects, including new renewable energy infrastructure, are associated with the concept of NIMBY, or “Not In My Backyard”. The term is used to imply that individuals opposing a development are acting out of self-interest – in other words, while they may recognise the benefits of the infrastructure (implied by societal support for technologies, climate response, etc.), they do not want projects sited close to their residences because of perceived impacts and costs to themselves.

Many studies, however, assert that the NIMBY label is unhelpful, pejorative and a myth. The concept is criticised for failing to explore the actual motivations of individuals opposing a development, the strong influence of wider institutional arrangements for regulating such developments and the value of competing concepts such as attachment to place. The term NIMBY also is “weaponised”, as it implies that any objection to a proposed project is due to the irrational and selfish attitude of host communities, rather than to issues related to project design or the decision-making process. Thus, use of the term allows developers and regulators to displace responsibility for community acceptance.

In some cases, the use of “NIMBY” can increase conflict over proposed developments, as the host community often deeply resents the implication that a dispute over a project is because of them. This outcome can reduce the conditions for effective dialogue and community engagement, which have been shown to offer more effective responses to such situations.

Source: See endnote 2 for this chapter.



Europe and North America, 82% of respondents – independent of age, education and political ideology – believed that it was important to create a world “fully powered” by renewable energy.¹¹

Despite this support, many individual renewable energy projects – including wind, solar, bioenergy, geothermal and hydropower plants – still face opposition from local host communities. This creates an apparent “**social gap**” between strong overall support for renewables and the disapproval with specific proposed projects expressed at a local level.¹² Although the social gap varies depending on the context, project scale and type of technology being deployed, policy makers are faced with the challenge of developing an appropriate response to this gap. To better understand the nature of public support for (or opposition to) renewable energy projects at the local, national and global levels, the public’s reaction has to be considered within the wider context of public engagement with energy and related issues, including climate action.¹³

Public engagement with renewables reflects a broad continuum – from collective mass movements to individual action – and it can either align or conflict with wider energy objectives. The landscape of social responses to renewables illustrates a wide range of aspirations and motivations, including concerns about technologies, projects or processes; visions for the future; and/or inertia and resistance to change. Reactions can range from apathy to “strongly against” or “strongly in favour”, and can occur at scales from a societal level (for example, global climate action) to a local level (relating to individual projects).

At a **societal level**, global climate strikes and litigation often are aligned with implicit support for renewable energy. During 2019, millions of people participated in international strikes and protests in more than 4,500 locations across 150 countries, demanding political action on climate change.¹⁴ In addition, more than 1,300 climate lawsuits were filed around the world between 1990 and 2019 to oppose the ongoing reliance on fossil fuels, representing civil society efforts to hold companies and governments accountable for supporting activities that exacerbate the climate challenge.¹⁵ Most of these disputes – which arose not just in the United States (where they have been most common) but increasingly in Asia, Europe and Latin America – target national governments, but some also target private companies for their contribution to climate change.¹⁶

At the same time, public reactions at a societal level can hinder the development of renewables, particularly when perceptions of unfairness or a lack of transparency lead people to oppose these technologies. In France and Iran, protests emerged in late 2018 and 2019, respectively, against government energy policies that disproportionately impacted lower-income households and adversely affected living standards.¹⁷ Fuel taxation efforts in France, for example, may have stimulated negative public perception of environmentally driven policies and projects, a response that manifested in the so-called yellow vest protests.¹⁸ In Canada, the implementation of carbon taxes (which generally lead to net economic benefits) also triggered ideological opposition, resulting in the election of provincial governments that rejected renewable energy policies and projects.¹⁹

Industry actions can lead to opposition to renewables as well, for example if companies lack transparency or engage in real or perceived violations of human rights, labour rights, (indigenous) land rights and others.²⁰ The neglect of socially responsible and ethical practices in renewable energy manufacturing and project development could result in broad societal opposition to the industry, diminishing the prospects of renewables in certain regions as well as globally.²¹

Opinion polls have consistently indicated **strong public support** for the expansion of renewables.

At the **local level**, movements for energy sufficiency and conservationⁱ have spread around the world since the early 2000s, as both community energy projects and the number of prosumersⁱⁱ continue to grow. In Australia, Europe, and North America, and increasingly in Asia and Latin America, communities have established “transition towns” aimed at boosting energy self-sufficiency (often through renewables) to counter the effects of climate change and economic instability.²²

Although community energy initiatives have existed since the mid-19th century, it was not until the late 1970s that these efforts became more associated with modern renewables, beginning in Denmark. (→ See *Feature chapter in GSR 2016*.) On the Danish island of Samsø, for example, community financial participation has played a major role in the development of renewable energy sources.²³

At the same time, host communities may be sceptical of, or oppose, certain forms of infrastructure development (transport, commercial and even residential) because of the perceived



impacts on the character of a neighbourhood or landscape.²⁴ Renewable energy projects in particular may trigger concerns because of their proposed locations – for example, wind projects sited on relatively untouched landscapes, or the presence of multiple dispersed renewable energy projects within a host community (as opposed to a single large, thermal (e.g., fossil fuel) power station that is typically out of sight).

The term “NIMBYism” has been used to depict opposition by individuals or grassroots organisations to local renewable energy projects; however, this type of dissent commonly reflects ineffective consent-building and project development processes, rather than any ideological objection by locals.²⁵ Still, such opposition has taken root against many different types of renewable energy projects, including geothermal, wind, solar, hydropower and production of biofuels.²⁶ Over the last decade, there has been a growing recognition that effectively engaging local communities around renewable energy projects is critical for gaining sufficient public support, and necessary for larger objectives of decarbonising the energy supply.

INFLUENCING FACTORS AND THE ROLE OF STAKEHOLDERS

A wide range of complex and inter-related **factors** can influence the public's perception of local or regional renewable energy projects, often based on different perceptions of justice.²⁷ These could be generalised as follows:

- *Concerns about health and environmental impacts.* Potential impacts include the noise or shadow flicker from wind energy projects, emissions from bioenergy or geothermal plants, the disruption of landscapes, land acquisitions and impacts on biodiversity. To respond to concerns about environmental justice, some of these impacts can be ameliorated through effective project design, planning regulations and other environmental safeguards.
- *Perceptions of the distribution of economic costs and benefits.* Some local communities have expressed concerns that renewable energy project developers are securing economic gain at the expense of local amenities, farming or fishing assets, or residential property values. Responses to these concerns have included the creation of community benefit funds, local procurement and employment policies, and encouraging community investment in a project to create a sense of distributive justice.
- *Perceived fairness of the consenting process.* Some communities have argued that decision making for renewable energy projects has not been transparent or that public engagement has not been appropriate. In such cases, more effective community engagement, information giving and openness can help to create a better atmosphere of trust and generate a sense of procedural justice.

i See Energy Efficiency chapter and Glossary.

ii A prosumer, in the context of the energy sector, is an individual or entity that both generates and consumes energy. Many different categories of prosumers exist, including residential, commercial and industrial scale, but the most common is homeowners who install solar PV on their rooftops. See Systems Integration chapter and Glossary.

These factors are managed and perceived differently by the range of key **stakeholders** in the energy system. Among the stakeholders that have crucial roles in the social acceptance of renewable energy are national governments, cities and municipal regulatory bodies, developers, energy trade bodies and host communities.

- *National governments* are responsible for meeting overall energy goals, including renewable energy targets. They are central to fostering socio-political and market acceptance of renewables by being primarily responsible for setting strategic policy directions, aligning energy policy with other objectives, and deploying financial instruments to support renewable energy and enabling technology uptake. National governments also frame the standards and regulatory arrangements around renewable energy projects, which play a critical role in community acceptance. In some countries, state or provincial governments can have a similar supporting role.
- *Municipalities and other regulatory bodies* often are responsible for local consenting permits (such as planning permissions) and planning policy, and for ensuring that the environmental and socio-economic impacts of projects are minimised. In some cases, these bodies have the capacity to develop economic instruments, which some have used to bring energy under local democratic control.²⁸
- *Developers* have the ability to propose high-quality projects at appropriate sites and to act with transparency and integrity towards host communities.
- *Energy trade bodies* have a critical role in ensuring effective standards across the renewable energy sector, issuing guidance and protocol, and sharing best practices.
- *Host communities* can be given the capacity to participate appropriately in consenting and engagement processes. Through such engagement, they can articulate their concerns about projects in their communities and better ensure that their perspectives and needs are taken into account.



LEVERS TO BUILD PUBLIC SUPPORT AND ENCOURAGE ACTION

As governments have become aware of the impacts that community concerns can have on renewable energy development, they have sought to pursue more effective responses. These include improving public participation, strengthening regulatory control (such as through more detailed planning policy) and making efforts to better share the economic benefits with host communities (for example, through benefit funds, local share offers and community-run energy projects).

Around the world, a wide range of initiatives seek to advance citizen support for renewables, including awareness campaigns, policy and regulatory measures, and new approaches to participation, control and ownershipⁱ.

AWARENESS CAMPAIGNS

Campaigns to **raise awareness about renewable energy technologies** are important measures to build citizen support and have been employed widely in recent years, often at the national level. Such campaigns typically aim not just to increase awareness, but also to **encourage changes in energy use** and "climate-friendly" behaviour. For example, a national energy transition awareness project in Mauritius aims to increase the presence of women in the renewable energy sector, and the Netherlands' Save Energy Now! campaign encourages residents to increase energy efficiency at home and to install rooftop solar PV and other domestic renewables.²⁹ Some campaigns target a global audience: for example, the Global Bioenergy Partnership aims to both facilitate the development of bioenergy and raise awareness of the technology worldwide.³⁰

Governments also can raise awareness of the benefits of renewables and energy efficiency by making **declarations on the "climate emergency"** or "climate crisis". Such declarations have become more frequent in recent years and often are combined with efforts to reduce reliance on fossil fuels. In November 2019, the EU declared a climate emergency and emphasised the need to reduce greenhouse gas emissions and phase out fossil fuel subsidies in the region by 2050.³¹ As of April 2020, at least 1,490 jurisdictions in 29 countries worldwide, covering a total population of 822 million, had issued climate emergency declarations.³²

In addition, many non-governmental organisations have initiated campaigns to raise awareness about climate change, stressing the urgent need for a renewable energy transition. Numerous student-led groups and other campaigns have called on corporations, governments and others to divest from fossil fuels.³³ In late 2019, Greenpeace Australia launched REenergise, one of its biggest campaigns yet, to address carbon dioxide emissions in Australia and to urge the country's largest energy-consuming companies to switch to 100% renewable electricity use.³⁴

i This chapter provides examples of only a small selection of initiatives; a more extensive list can be found in the GSR 2020 data pack at www.ren21.net/GSR.

POLICIES IMPACTING PUBLIC ENGAGEMENT WITH RENEWABLES

A range of public bodies have adopted policies and other regulatory measures that enable civic and market actors to engage in the development and procurement of renewable energy. These include efforts designed to encourage energy efficiency, new forms of energy ownership and "green consumerism" to help achieve national, state and local climate and energy targets, based on complex market incentives and measures to encourage grassroots development of renewables.

Feed-in tariff (FIT) schemes have been conducive to renewable energy development not only at a large scale but also at the community and residential levels.³⁵ Such efforts have involved households, small and medium-sized businesses, energy co-operatives and municipalities, with benefits for energy democracy, citizen participation and social acceptance of renewables.³⁶ Since the early 2010s, however, interest has shifted away from FITs and towards competitive tendering schemes such as auctions, as a way to improve cost effectiveness and increase control over renewable capacity levels, although FITs remain in place in 87 countries.³⁷ (→ See *Policy Landscape chapter*.) The introduction of auctions has tended to favour large-scale developers and to disadvantage citizen-driven initiatives seeking to participate in ongoing decarbonisation efforts.³⁸

Both Ireland and Germany have put in place measures to encourage **community ownership** of renewable energy as a means to retain stakeholder diversity, wider public engagement and citizen support.³⁹ Similarly, governments can enable the growth of renewable energy **prosumers** through grid integration, peer-to-peer models and prosumer community groups.⁴⁰ Consumers also can be encouraged to purchase renewable energy as part of more conventional **electricity contracts**: "green power programmes" are now offered in Australia, Canada, Denmark, Finland, France, Germany, the Netherlands, Slovenia, Sweden and the United

States, among others, and "green electricity" certification schemes are offered by many companies, such as Blue Energy (Slovenia), Eesti Energi (Estonia), EKOenergy (Finland), Green-e (United States) and Nanoenergies (Czech Republic).⁴¹

By necessity, a transition towards more renewable energy means phasing out high-carbon industries that rely on fossil fuels, including coal mining and oil and gas extraction. However, this shift may impact regional economies and communities that depend heavily on such industries, resulting in opposition to initiatives and projects – such as renewable energy developments – that displace these sectors. **Ensuring a "just" energy transition** is central to the wider objectives of a sustainable economy.⁴² The EU's Green Deal, for example, includes a Just Transition Fund aimed at guaranteeing a fair allocation of impacts and equitable distribution of benefits of its climate plans; similar efforts have emerged in Spain, Ireland and among US philanthropic institutions.⁴³

In some countries, it has become common for developers to establish some form of **benefits package for local communities**, whether through a fund for local community projects, education bursaries or discounts on electricity bills. The United Kingdom's Coastal Communities Funds give a percentage of state royalties from offshore wind energy to adjacent coastal areas.⁴⁴ These "passive" forms of financial participation are becoming increasingly formalised and institutionalised.⁴⁵ For example, Scotland has a searchable register of community benefits packages associated with wind power projects, with the aim of increasing fairness and transparency, and in 2009 Denmark introduced a compulsory option-to-purchase share scheme that requires developers of wind energy projects to offer a proportion of investment in the project to the local community.⁴⁶



Awareness campaigns, supporting policies, and new forms of participation, control and ownership further **build citizen support** for renewables.

i Green consumerism refers to the willingness of consumers to purchase goods that have been produced in a manner that protects the natural environment, such as from renewable energy.

PUBLIC PARTICIPATION, CONTROL AND OWNERSHIP

The distributed nature of many new renewable energy projects has shifted the scale and geography of energy generation, creating new opportunities for more dispersed patterns of ownership and control of energy production.⁴⁷ This has given rise to the concept of **energy democracy**, which covers different aspects of renewable energy – from “good governance” and public consultation in policy making (such as Citizen Assemblies or civil society movements for decarbonisation, for example the Mauritian Power Shift Plan) to more widespread civil society ownership and control of energy infrastructure.⁴⁸

Greater democratic engagement in energy systems increases social acceptance and can lead to more equitable socio-economic outcomes.⁴⁹ The movement for energy democracy has many disparate and contested goals and instruments.⁵⁰ In developing countries, for example, narratives remain focused on issues such as energy justice or energy sovereignty.⁵¹

The opportunities for community participation in renewable energy have been expressed in many different ways. For example, efforts to ensure stakeholder engagement throughout the life cycle of a renewable energy project are considered best practice as part of environmental impact assessments (EIAs) or environmental and social impact assessments (ESIAs). Examples of **extended participation processes** include the Stakeholder Engagement Plans for the Baikonur Solar Power plant in Kazakhstan and the Sebzor Hydropower Plant Project in Tajikistan.⁵² In many jurisdictions, stakeholder engagement is mandatory: Ireland’s proposed Renewable Electricity Support Scheme includes provisions on how communities should be consulted during project development, and in Victoria, Australia proof of community engagement is required as part of the 2017 renewable energy auction scheme.⁵³

Although the private sector plays a strong role in driving renewable energy projects in many parts of the world, public bodies, particularly municipalities, have assumed more direct involvement in energy projects. In some cases, public ownership is considered an instrument for energy democratisation, because of the accountability that elected officials have towards citizens and their mandate to protect the public interest. Between 2005 and 2019, some 374 processes to re-municipalise energy generation and supply were undertaken across 19 countries.⁵⁴

Re-municipalisationⁱⁱ often is a result of grassroots activity and engagement.⁵⁵ Communities also have become more directly engaged in the ownership of energy. **Community ownership** implies a high level of control and allows local residents to maximise economic benefits. Locally owned energy co-operatives involve various technologies and have burgeoned across diverse geographies, from the El Cuá community hydropower project in Nicaragua to the Aran Islands Energy Co-operative in Ireland.⁵⁶








Some models of ownership have wider definitions of community. In Japan, more than 200 open shareholder models, which are not restricted to a specific geographic area, provide over 70 megawatts of renewable power.⁵⁷ In Costa Rica, four regional co-operatives distribute and transmit electricity to rural areas that were not being serviced by the state or private companies, covering a geographical area representing 9% of the national territory.⁵⁸









i EIAs/ESIAs are usually required under legislation before consent is granted for construction and are sometimes a condition attached to receipt of project finance from financial institutions; however, the quality of engagement and consultation varies widely in practice.

ii Re-municipalisation refers to efforts by citizens or cities to reverse the privatisation of local services such as water provision, waste collection and management services, and energy generation and distribution through local or municipally owned utility companies. See REN21’s *Renewables in Cities 2019 Global Status Report* at www.ren21.net/cities.

■ TABLE R1. Global Renewable Electricity Capacity, Heat Demand and Biofuel Production, 2019

Power Capacity (GW)	Change in 2019	Existing at End-2019
 Bio-power	8.3	139
 Geothermal power	0.7	13.9
 Hydropower	15.6	1,150
 Ocean power	~0	0.5
 Solar PV ^a	115	627
 Concentrating solar thermal power (CSP)	0.6	6.2
 Wind power	60	651

Heat Demand (EJ)	Change in 2019	Consumption in 2019
 Modern bio-heat	0.2	14.1
 Geothermal direct use ^b	<0.1	0.4
 Solar hot water ^c	~0	1.4

Transport Fuel Production (billion litres per year)	Change in 2019	Production in 2019
 Ethanol	3	114
 Biodiesel (FAME)	1.4	47
 Biodiesel (HVO)	0.5	6.5

^a Solar PV data are provided in direct current (DC).

^b Data do not include heat pumps.

^c Data do not include air, PV-thermal or concentrating collectors.

Note: Annual capacity additions are net. Values are rounded to the nearest full number, with the exceptions of numbers <15, which are rounded to the first decimal point, and transport fuels; where totals do not add up, the difference is due to rounding. Rounding is to account for uncertainties and inconsistencies in available data. Capacity amounts of <50 MW (including pilot projects) and heat consumption <0.01 EJ are designated by “~0”. FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil. For more precise data, see Reference Tables R13-R19, Market and Industry chapter and related endnotes.

Source: See endnote 1 for this section.

■ TABLE R2. Renewable Power Capacity, World and Top Regions/Countries^a, 2019

Technology	World Total	BRICS ^b	EU-28	China	United States	India	Germany	Japan	United Kingdom
	GW			GW					
 Bio-power	139	48	44	22.5	16.0	10.8	8.9	4.3	7.9
 Geothermal power	13.9	0.1	0.9	~0	2.5	0	~0	0.6	0
 Hydropower	1,150	530	131	326	80	45	5.6	22	1.9
 Ocean power	0.5	0	0.2	0	0	0	0	0	~0
 Solar PV ^c	627	256	132	205	76	43	49	63	13.4
 Concentrating solar thermal power (CSP)	6.2	1.1	2.3	0.4	1.7	0.2	0	0	0
 Wind power	651	292	192	236	106	38	61	3.9	24
Total renewable power capacity (including hydropower)	2,588	1,127	502	790	282	137	124	94	47
Total renewable power capacity (not including hydropower)	1,438	597	371	464	202	92	119	72	45
Per capita capacity (kilowatts per inhabitant, not including hydropower)	0.2	0.2	0.7	0.3	0.6	0.1	1.4	0.6	0.7

^a Table shows the top six countries by total renewable power capacity not including hydropower; if hydropower were included, countries and rankings would differ (the top six would be China, the United States, Brazil, India, Germany and Canada).

^b The five BRICS countries are Brazil, the Russian Federation, India, China and South Africa.

^c Solar PV data are in direct current (DC). See Solar PV section in Market and Industry chapter and Methodological Notes for more information.

Note: Global total reflects additional countries not shown. Numbers are based on the best data available at the time of production. To account for uncertainties and inconsistencies in available data, numbers are rounded to the nearest 1 GW, with the exception of the following: capacity totals below 20 GW and per capita totals are rounded to the nearest decimal point. Where totals do not add up, the difference is due to rounding. Capacity amounts of <50 MW (including pilot projects) are designated by "~0". For more precise capacity data, see Global Overview and Market and Industry chapters and related endnotes. Numbers should not be compared with prior versions of this table to obtain year-by-year increases, as some adjustments are due to improved or adjusted data rather than to actual capacity changes. Hydropower totals, and therefore the total world renewable capacity (and totals for some countries), reflect an effort to omit pure pumped storage capacity. For more information on hydropower and pumped storage, see Methodological Notes.

Source: See endnote 2 for this section.

■ TABLE R3. Renewable Energy Shares of Primary and Final Energy, Targets as of End-2019 and Status in 2018

Note: Text in **bold** indicates new/ revised in 2019, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Primary Energy		Final Energy	
	Target	Status in 2018 ^a	Target	Status in 2018 ^a
EU-28		13.3%	→ 20% by 2020 → 32% by 2030	18.9%
Afghanistan			→ 10% ^b	8.8%
Albania	→ 18% by 2020	34.4%	→ 38% by 2020	34.9%
Angola	→ 7.5% by 2025			4.4%
Armenia	→ 21% by 2020 → 26% by 2025	12.4%		6.4%
Austria ^c		30.1%	→ 45% by 2020	33.4%
Bangladesh		24.8%	→ 10% by 2020 ^d	0.2%
Belarus		5.5%	→ 32% by 2020	6.8%
Belgium	→ 9.7% by 2020	6.7%	→ 13% by 2020	9.4%
<i>Wallonia</i>			→ 20% by 2020	
Benin		59.6%	→ 25% by 2025 ^d	8.8%
Bosnia and Herzegovina		24.9%	→ 40% by 2020	8.9%
Brazil		40.3%	→ 45% by 2030 → 81% by 2029	43.3%
Brunei Darussalam			→ 10% by 2035	0.1%
Bulgaria ^c		10.7%	→ 16% by 2020 → 27% by 2030	20.5%
Burundi			→ 2.1% by 2020	2.6%
Canada		17.4% (2016)		17.4% (2016)
China ^e	→ 15% by 2020 → 20% by 2030	8.4%		7.8%
Chile			→ 20% by 2024 ^d	21%
Côte d'Ivoire	→ 15% by 2020 → 20% by 2030	3%		7.6%
Croatia		23.3%	→ 20% by 2020 → 36.4% by 2030	28%
Cuba				19.3%
Cyprus		7.3%	→ 13% by 2020	13.9%
Czech Republic ^c		10.5%	→ 13.5% by 2020	15.1%
Denmark		30%	→ 35% by 2020 → 100% by 2050	36.1%
Djibouti	→ 17% by 2035			
Egypt	→ 14% by 2020	3.8%	→ 25% by 2020	4%
Estonia		17.6%	→ 25% by 2020	30%
Fiji			→ 23% by 2030	30.1%
Finland		31.2%	→ 38% by 2020 → 40% by 2025 ^c	41.2%
France		9.6%	→ 23% by 2020 → 33% by 2030	16.6%
Gabon		76.7%	→ 80% by 2020	60.1%
Germany ^c		13.8%	→ 18% by 2020 → 30% by 2030 → 45% by 2030 → 65% by 2030	16.5%
Ghana		42.5%	→ Increase 10% by 2030 (base year 2010)	13.5%

■ TABLE R3. Renewable Energy Shares of Primary and Final Energy, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, and text in italics indicates mandates adopted at the state/provincial level.

Country	Primary Energy		Final Energy	
	Target	Status in 2018 ^a	Target	Status in 2018 ^a
Greece ^c		12.1%	→ 20% by 2020 → 35% by 2030	18%
Grenada	→ 20% by 2020			0.7%
Guatemala		63%		
Guinea			→ 30% by 2030	2.4%
Guinea-Bissau				7.8%
Guyana			→ 20% by 2025	20.8%
Hungary ^c		11.5%	→ 14.65% by 2020	12.5%
Iceland		89.5%	→ 64% by 2020	77%
India			→ 40% by 2030	9.9%
Indonesia	→ 23% by 2025 → 31% by 2050	13%		6.2%
Ireland		7.9%	→ 16% by 2020	11.1%
Israel		2.4%	→ 13% by 2025 → 17% by 2030	3.7%
Italy		17.4%	→ 17% by 2020	17.8%
Jamaica		18.6%	→ 20% by 2030	7.5%
Jordan	→ 10% by 2020	16%	→ 15% by 2025	2.8%
Korea, Republic of	→ 6.1% by 2020 → 11% by 2030	1.7%		2.7%
Kosovo ^f			→ 25% by 2020	24.9%
Lao PDR		80%	→ 30% by 2025 ^d	23.4%
Latvia		39.1%	→ 40% by 2020	40.3%
Lebanon			→ 12% by 2020 → 15% by 2030	1.6%
Liberia	→ 30% by 2030	5%	→ 10% by 2030	73.8%
Libya	→ 10% by 2020			
Lithuania	→ 20% by 2025	19.6%	→ 45% by 2030	24.4%
Luxembourg		5.6%	→ 11% by 2020	9.1%
Macedonia, North		15.7%	→ 28% by 2020	18.1%
Madagascar			→ 54% by 2020 ^d	38.6%
Malawi	→ 7% by 2020			47.3%
Mali	→ 15% by 2020			4.3%
Malta		3.2%	→ 10% by 2020	8%
Mauritania	→ 20% by 2020			1.1%
Moldova	→ 20% by 2020	10.3%	→ 17% by 2020	14.3%
Mongolia	→ 20-25% by 2020	3.2%		1.4%
Montenegro		30.6%	→ 33% by 2020	38.8%
Nepal	→ 10% by 2030 ^d	84.1%		6.4%
Netherlands ^c		4.9%	→ 14% by 2020	7.4%
Niger	→ 10% by 2020 ^d	74.7%		
Norway		49.2%	→ 67.5% by 2020	72.8%
Palau	→ 20% by 2020			
Palestine, State of	→ 20% by 2020		→ 25% by 2020	4.4%
Panama	→ 30% by 2050	21.1%		16.4%
Philippines		30%		

■ TABLE R3. Renewable Energy Shares of Primary and Final Energy, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Primary Energy		Final Energy	
	Target	Status in 2018 ^a	Target	Status in 2018 ^a
Poland	→ 12% by 2020	8.5%	→ 15% by 2020	11.3%
Portugal		26.8%	→ 31% by 2020 → 47% by 2030	30.3%
Qatar			→ 25% by 2030	
Romania		18.7%	→ 24% by 2020	23.9%
Rwanda				8.2%
Samoa	→ 20% by 2030			4.8%
Serbia		13.1%	→ 27% by 2020	20.3%
Slovak Republic		9.7%	→ 14% by 2020	11.9%
Slovenia		16.8%	→ 25% by 2020	21.1%
Spain ^c		14.6%	→ 20% by 2020	17.4%
Sudan	→ 20% by 2020			24.7%
Sweden ^c			→ 49% by 2020	54.6%
Tajikistan		37%	→ 50% by 2020	44.6%
Tanzania	→ 24% by 2020	22.3%		19.8%
Thailand		19.2%	→ 25% by 2021 → 40% by 2035	14.4%
Togo		78.9%	→ 4% ^b	12.7%
Tonga				0.8%
Tunisia		78.9%		1.3%
Ukraine	→ 18% by 2030	3%	→ 11% by 2020 → 25% by 2035	1.9%
United Arab Emirates			→ 44% by 2050	
United Kingdom		8.2%	→ 15% by 2020	11%
Vanuatu			→ 65% by 2020	11%
Vietnam	→ 5% by 2020 → 8% by 2025 → 11% by 2050	0.28%		13.3%

^a Status data are for 2018 unless otherwise noted.

^b No date given.

^c Final energy targets by 2020 for all EU-28 countries are set under EU Directive 2009/28/EC. The governments of Austria, the Czech Republic, Germany, Greece, Hungary, Spain and Sweden have set higher targets, which are shown in this table. The government of the Netherlands has reduced its more ambitious target to the level set in the EU Directive.

^d Targets may exclude large-scale hydropower and/or traditional biomass. Large-scale hydropower generally is defined as more than 10 MW of installed capacity, but the definition may vary by country.

^e The Chinese target is for share of "non-fossil" energy. All targets include nuclear power.

^f Kosovo is not a member of the United Nations.

Note: Traditional biomass has been removed from share of final energy. Actual percentages are rounded to the nearest whole decimal for numbers over 10% except where associated targets are expressed differently. Historical targets have been added as they are identified by REN21. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable energy for the country. Some countries shown have other types of targets (→ See Reference Tables R4-R8). Some targets shown may be non-binding.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R4. Renewable Heating and Cooling, Targets as of End-2019 and Status in 2017

Note: Text in **bold** indicates new/revised in 2019.

Country	Target	Status in 2017 ^a
EU-28	1.3% annual increase in the share of renewable heat through 2030	19.5%
Albania		24.9%
Austria	33% by 2020	32%
Belgium	11.9% by 2020	8.1%
Bhutan	Solar thermal: 3 MW equivalent by 2025	
Bulgaria	24% by 2020	30%
China	Solar thermal: 800 million m ² by 2020	462.9 million m ² (2016)
Croatia	19.6% by 2020	36.6%
Cyprus	23.5% by 2020	24.5%
Czech Republic	14.1% by 2020	19.7%
Denmark	39.8% by 2020 100% by 2050	46.5%
Estonia	38% by 2020	51.6%
Finland	47% by 2020 10% of heating for construction machines and fitted motors from bio-based light fuel oil starting in 2021	54.8%
France	38% by 2030	21.4%
Germany	14% by 2020	13.7%
Greece	20% by 2020 30% by 2030 (60% domestic hot water from solar thermal systems)	26.6%
Hungary	18.9% by 2020	19.6%
India	Solar water heating: 14 GW _{th} (20 million m ²) by 2022	6.7 GW _{th} (2016)
Ireland	15% by 2020	6.8%
Italy	171% by 2020 Bioenergy: 5,670 ktoe by 2020 Geothermal: 300 ktoe by 2020 Solar water and space heating: 1,586 ktoe by 2020	20% 6,320 ktoe 207 ktoe (2016) 231.3 ktoe (2016)
Jordan	Solar water heating: 30% of households by 2020	882 MW _{th} of solar thermal (2015)
Kenya	Solar water heating: 60% of annual demand for buildings that use more than 100 litres of hot water per day (voluntary/no date)	
Kosovo ^b	45.6% by 2020	50.5%
Latvia	53.4% by 2020	54.6%
Lebanon	15% renewables in gross final consumption in power and heating by 2030	
Libya	Solar water heating: 80 MW _{th} by 2015; 250 MW _{th} by 2020	
Lithuania	90% of district heating and cooling by 2030 80% of household-based heating and cooling by 2030	46.5%
Luxembourg	8.5% of gross final heating and cooling use by 2020	8.1%
Macedonia, North	11% by 2020	36.4%
Malawi	Solar water heating: produce 2,000 solar water heaters; increase total installed to 20,000 by 2030	
Malaysia	B10 in industrial sector by 2020 ^c	

■ TABLE R4. Renewable Heating and Cooling, Targets as of End-2019 and Status in 2017 (continued)

Note: Text in **bold** indicates new/revised in 2019.

Country	Target	Status in 2017 ^a
Malta	6.2% by 2020	19.8%
Mexico	Solar water heating: 18.2 million m ² of collectors by 2027	3.4 million m ²
Moldova	27% by 2020	
Montenegro	38.2% by 2020	67.5%
Morocco	Solar water heating: 1.2 GW _{th} (1.7 million m ²) by 2020	316 MW _{th} (2015)
Mozambique	Solar water and space heating: 100,000 rural systems (no date)	1 MW _{th} of solar thermal (2015)
Netherlands	8.7% by 2020	5.9%
Poland	17% by 2020; emission standards for heating appliances in single-family homes banning use of coal and wood in 11 of 16 regions, 2022-2027	14.5%
Portugal	34% by 2020	41%
	38% by 2030	
	69-72% by 2050	
Romania	22% by 2020	26.6%
Serbia	30% by 2020	24.4%
Sierra Leone	Solar water heating: 2% in hotels, guest houses and restaurants by 2020, and 5% by 2030; 1% in the residential sector by 2030	
Slovak Republic	14.6% by 2020	9.8%
Slovenia	30.8% by 2020	33.2%
Spain	17.3% by 2020	17.5%
Sweden	62.1% by 2020	69%
Thailand	Bioenergy: 8,200 ktoe by 2022	6,573 ktoe
	Biogas: 1,000 ktoe by 2022	495 ktoe
	Organic municipal solid waste ^d : 35 ktoe by 2022	88 ktoe
	Solar water heating: 100 ktoe and 300,000 systems in operation by 2022	11.3 ktoe (2016)
Ukraine	12.4% by 2020	
United Kingdom	12% by 2020	7.5%
Uruguay	50% solar thermal water heating in certain types of non-residential buildings/refurbishments after 2014	

^a Status data are for 2017 unless otherwise noted. Status and targets are for overall share of renewable heat unless otherwise noted.

^b Kosovo is not a member of the United Nations.

^c The Malaysia target is mandated for industry in general, not specifically for heating.

^d It is not always possible to determine whether municipal solid waste (MSW) data include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

Note: Targets and status refer to share of renewable heating and cooling in total energy supply unless otherwise noted. Historical targets have been added as they are identified by REN21. A number of countries have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable heat. Because calculation of heating and cooling shares is not standardised across countries, the table presents a variety of targets for the purpose of general comparison.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R5. Renewable Transport, Targets as of End-2019 and Status in 2017

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2017 ^a	Country	Target	Status in 2017 ^a
EU-28	→ 10% of transport final energy demand by 2020 → 14% minimum share of renewable fuels for transport energy by 2030 (7% cap on share from conventional food and feed-based biofuels)	8.3%	Luxembourg	→ 10% by 2020	6.4%
Albania	→ 10% by 2020	13.4%	Macedonia, North	→ 2% by 2020	0.1%
Austria	→ 11.4% by 2020	9.7%	Malta	→ 10.7% by 2020	6.8%
Belgium	→ 10% by 2020	6.6%	Moldova	→ 20% by 2020	
<i>Wallonia</i>	→ 10.14% by 2020		Montenegro	→ 10.2% by 2020	1%
Bulgaria	→ 11% by 2020	7.2%	Netherlands	→ 10% by 2020	5.9%
Croatia	→ 10% by 2020	1.2%	Norway	→ 20% by 2020	19.7%
Cyprus	→ 10% by 2020	2.6%	Poland	→ 20% by 2020	4.2%
Czech Republic	→ 10.8% by 2020	6.6%	Portugal	→ 10% by 2020	7.9%
Denmark	→ 10% by 2020	6.8%		→ 13% by 2025	
	→ 100% by 2050			→ 20% by 2030 ^b	
Estonia	→ 10% by 2020	0.4%	Qatar	→ 10% by 2020	
Finland	→ 40% by 2030	18.8%	Romania	→ 10% by 2020	6.6%
France	→ 15% by 2020	9.1%	Serbia	→ 10% by 2020	1.2%
Germany	→ 10% by 2020	7%	Slovak Republic	→ 10% by 2020	7%
Greece	→ 10.1% by 2020	14%	Slovenia	→ 10.5% by 2020	2.7%
Hungary	→ 10% by 2020	6.8%	Spain	→ 10% by 2020	5.9%
Iceland	→ 10% by 2020	7.2%	Sri Lanka	→ 20% biofuels by 2020	
India	→ 20% by 2030		Sweden	→ Vehicle fleet independent from fossil fuels by 2030	38.6%
Ireland	→ 10% by 2020	7.4%	Thailand	→ 9 million litres per day ethanol consumption by 2022	
Italy	→ 10.1% (2,899 ktoe) by 2020	6.5%		→ 6 million litres per day bio-diesel consumption by 2022	
Latvia	→ 10% by 2020	2.5%		→ 25 million litres per day advanced biofuel production by 2022	
Liberia	→ 5% palm oil blends in transport fuel by 2030		Ukraine	→ 10% by 2020	
Lithuania	→ 10% by 2020 → 15% by 2030	3.6%	United Kingdom	→ 10.3% by 2020	5.1%
			Vietnam	→ 5% of transport petroleum energy demand replaced by 2025	

^a Status data are for 2017 unless otherwise noted.

^b Excluding aviation and shipping

Note: Targets refer to share of renewable transport in total energy supply unless otherwise noted. Historical targets have been added as they are identified by REN21. A number of countries have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable energy for the country.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018

Note: Text in **bold** indicates new/revised in 2019, brackets '[']' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018 ^a
EU-28	→ 57% by 2030	32.1%
Afghanistan ^b	→ 100% by 2050	86.1%
Algeria	→ 27% by 2030 → 22 GW by 2030	2% of installed capacity (2012)
Antigua and Barbuda	→ 10% by 2020 → 15% by 2030	
Argentina	→ 12% by 2019 → 16% by 2021 → 18% by 2023 → 20% by 2025	2%
Armenia	→ 40% by 2025	12%
Aruba	→ 100% by 2020	
Australia	→ 23% by 2020	19%
<i>Tasmania</i>		90% (2017)
<i>Australian Capital Territory</i>	→ 100% by 2025	
<i>Northern Territory</i>	→ 50% by 2030	
<i>Queensland</i>	→ 50% by 2030	
<i>Victoria</i>	→ 25% by 2020 → 40% by 2025 → 50% by 2030	
Austria	→ 70.6% by 2020	77%
Azerbaijan	→ 20% by 2020	
Bahamas, The	→ 15% by 2020 → 30% by 2030	
Bahrain	→ 5% by 2025 → 700 MW by 2030 → 10% by 2035	
Bangladesh ^b	→ 10% by 2020 → 100% by 2050	
Barbados ^b	→ 65% by 2030 → 100% by 2050	
Belgium	→ 21% by 2020	20% (2018)
Belize	→ 85% by 2030	91%
Benin	→ 50% by 2025 (off-grid and rural)	
Bhutan ^b	→ 100% by 2050	
Bolivia	→ 79% by 2030	
Brazil ^c	→ 87% by 2026	83.3%
Brunei Darussalam	→ 10% by 2035	
Bulgaria	→ 16.7% by 2020	17%
Burkina Faso ^b	→ 50% by 2025 → 100% by 2050	
Cambodia	→ 100% by 2025 [100% by 2035] [50% by 2020]	
Cameroon	→ 25% by 2035	
Canada	→ no national target	65.19% ^d
<i>Alberta</i>	→ 30% by 2030	
<i>British Columbia</i>	→ 93% (no date)	
<i>New Brunswick</i>	→ 40% by 2020	

Country	Target	Status in 2018 ^a
<i>Nova Scotia</i>	→ 40% by 2020	
<i>Saskatchewan</i>	→ 50% by 2030	
Cabo Verde	→ 100% by 2025	25%
Chile	→ 70% by 2030	22.8% (2019)
China	→ 35% by 2030	26.7%
<i>Hainan Province</i>	→ 80% by 2030 ^e	23% (2019)
Chinese Taipei	→ 9% by 2020 → 20% by 2025	4.5%
Colombia ^b	→ 70% by 2030 → 100% by 2050	
Comoros ^b	→ 43% by 2030 → 100% by 2050	
Congo, Democratic Republic of the ^b	→ 100% by 2050	
Congo, Republic of	→ 85% by 2025	
Costa Rica	→ 100% by 2030	99.62% (2019)
Côte d'Ivoire	→ 42% by 2020	
Croatia	→ 39% by 2020	71%
Cuba	→ 24% by 2030	4%
Cyprus	→ 16% by 2020	8%
Czech Republic	→ 14.3% by 2020	13.7% (2018)
Denmark ^f	→ 50% by 2020 → 100% by 2050	76%
Djibouti	→ 100% by 2020	
Dominica	→ 100% (no date)	
Dominican Republic ^b	→ 25% by 2025 → 70% by 2030 → 100% by 2050	12%
Egypt	→ 20% by 2022 → 37-42% by 2035	
Eritrea	→ [50% (no date)] → 70% by 2030	
Estonia	→ 17.6% by 2020	14%
Ethiopia ^b	→ 100% by 2050	
Fiji	→ 100% by 2030	
Finland	→ 33% by 2020	44%
France	→ 40% by 2030	20%
Gabon	→ 70% by 2020 → 80% by 2025	
Gambia ^b	→ 35% by 2020 → 100% by 2050	
Germany	→ 40-45% by 2025 → 55-60% by 2030 → 80% by 2050	38%
Ghana ^b	→ 10% by 2020 → 100% by 2050	
Greece	→ 34.3% by 2020 → 63.54% by 2030	32%
Grenada ^b	→ 100% by 2050	
Guatemala ^b	→ 80% by 2030 → 100% by 2050	59%

■ TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[']' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018 ^a	Country	Target	Status in 2018 ^a
Guyana	→ 90% (no date)		Malaysia	→ 9% by 2020 → 20% by 2030	2%
Haiti ^b	→ 70% by 2030 → 100% by 2050		Maldives ^b	→ 100% by 2050	
Honduras ^b	→ 60% by 2022 → 70% by 2030 → 80% by 2038 → 100% by 2050	60% (2017)	Mali ^h	→ 25% by 2033	
Hungary	→ 10.9% by 2020		Malta	→ 3.8% by 2020	16%
Iceland	→ 100% by 2020		Marshall Islands ^b	→ 20% by 2020 → 100% by 2050	
India ^a	→ 10% by 2022	9.2%	Mauritania	→ 60% by 2020	
Indonesia	→ 23% by 2020 → 26% by 2025	12% (2017)	Mauritius	→ 35% by 2025	22% (2019)
Iraq	→ 10% by 2020		Mexico	→ 30% by 2021 → 35% by 2024 → 38% by 2030 → 40% by 2035 → 50% by 2050	11.5% (2013)
Ireland	→ 42.5% by 2020 → 70% by 2030	29%	Micronesia, Federated States of	→ 10% in urban centres and 50% in rural areas by 2020	
Israel	→ 10% by 2020 → 17% by 2030	2%	Moldova	→ 10% by 2020	
Italy	→ 26% by 2020	39%	Mongolia ^b	→ 20% by 2020 → 30% by 2030 → 100% by 2050	
Jamaica	→ 50% by 2030		Montenegro	→ 51.4% by 2020	
Japan	→ 24% by 2030	17.84%	Morocco	→ 42% by 2020 → 52% by 2030 → 11 GW by 2030 → 100% by 2050	
Jordan	→ 20% by 2020 → 1.8 GW by 2020 → 30% by 2030		Namibia	→ 70% by 2030	
Kazakhstan	→ 3% by 2020 → 50% by 2030	2.3%	Nepal ^b	→ 100% by 2050	100%
Kenya ^b	→ 100% by 2050		Netherlands	→ 37% by 2020	15%
Kiribati ^b	→ 3% by 2020 → 100% by 2050		New Zealand	→ 90% by 2025	83.21%
Korea, Republic of	→ 6% by 2019 → 7% by 2020 → 20% by 2030 → 35% by 2040	6% (2017)	<i>Cook Islands</i>	→ 100% by 2020	
Kuwait	→ 15% by 2030 4.5 GW by 2030		<i>Niue</i>	→ 100% by 2020	
Latvia	→ 60% by 2020	50%	<i>Tokelau</i>	→ 100% (no date)	
Lebanon ^b	→ 12% by 2020 → 30% by 2030 → 100% by 2050		Nicaragua	→ 90% by 2027	50%
Lesotho	→ 35% by 2020 (off-grid and rural)		Niger ^b	→ 100% by 2050	
Liberia	→ 30% by 2021		Nigeria ⁱ	→ 10% by 2020	
Libya	→ 7% by 2020 → 10% by 2025 → 22% by 2030		Norway		99% (2016)
Lithuania	→ 45% by 2030 → 100% by 2050	83%	Oman	→ 10% by 2020 → 2.6 GW by 2025	
Luxembourg	→ 11.8% by 2020	58%	Palau ^b	→ 100% by 2050	
Macedonia, North	→ 24.7% by 2020	24.8%	Palestine, State of ^b	→ 10% by 2020 → 100% by 2050	
Madagascar ^b	→ 85% by 2030 → 100% by 2050		Papua New Guinea	→ 100% by 2030	
Malawi ^b	→ 100% by 2050		Paraguay	→ 60% increase 2014-2030	
			Peru	→ 70% by 2030	59.44% (2017)
			Philippines ^b	→ 40% by 2020 → 100% by 2050	24.56% (2017)
			Poland	→ 19.3% by 2020	14%
			Portugal	→ 59.6% by 2020 → 80% by 2030 → 100% by 2050	52.2%

■ TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018 ^a
Qatar	→ 2% by 2020 → 20% by 2030	
Romania	→ 43% by 2020	41%
Russian Federation ^l	→ 20% by 2024 (including large hydro)	18%
<i>Altai Republic</i>	→ 80% by 2020	
Rwanda ^b	→ 100% by 2050	
Samoa	→ 100% by 2030	
São Tomé and Príncipe	→ 47% (no date)	
Saudi Arabia	→ 9.6 GW by 2023 → 30% by 2030	
Senegal ^b	→ 100% by 2050	
Serbia	→ 37% by 2020	28.7%
Seychelles	→ 5% by 2020 → 15% by 2030	
Sierra Leone	→ 33% by 2020 → 36% by 2030	
Singapore	→ 8% (no date)	
Slovak Republic	→ 24% by 2020	23%
Slovenia	→ 39.3% by 2020	32%
Solomon Islands	→ 100% by 2030	
South Africa	→ 9% by 2030	3.11%
South Sudan ^b	→ 100% by 2050	
Spain	→ 39% by 2020 → 70% by 2030 → 100% by 2050	38%
Sri Lanka ^b	→ 20% by 2020 → 100% by 2050	
St. Lucia ^b	→ 35% by 2020 → 100% by 2050	
St. Vincent and the Grenadines	→ 60% by 2020	
Sudan ^b	→ 11% by 2031 → 100% by 2050	
Sweden	→ 100% by 2040	55%
Syria	→ 4.3% by 2030	
Tajikistan	→ 10% (no date)	
Tanzania ^b	→ 100% by 2050	
Thailand ^k	→ 20% by 2036	
Timor-Leste ^b	→ 50% by 2020 → 100% by 2050	
Togo	→ 15% by 2020	
Tonga	→ 50% by 2020	

Country	Target	Status in 2018 ^a
Trinidad and Tobago	→ 5% of peak demand (or 60 MW) by 2020	
Tunisia ^b	→ 30% by 2030 → 4.7 GW by 2030 → 100% by 2050	
Turkey	→ 65% by 2023	64%
Tuvalu	→ 100% by 2020	
Ukraine	→ 11% by 2020 → 20% by 2030 → 25% by 2035	5.68%
United Arab Emirates	→ 44% by 2050	0.59% (2017)
<i>Abu Dhabi</i>	→ 7% by 2020	
<i>Dubai</i>	→ 25% by 2030	
United Kingdom	→ no national target	34%
<i>Scotland</i>	→ 100% by 2020	
<i>Wales</i>	→ 70% by 2030	
United States ^l	→ no national target	18.2% (2019)
<i>Arizona</i>	→ 15% by 2025	
<i>California</i>	→ 33% by 2020 → 60% by 2030	
<i>Colorado</i>	→ 30% by 2020 ^m	
<i>Connecticut</i>	→ 27% by 2020 → 40% by 2030	
<i>Delaware</i>	→ 25% by 2026	
<i>Hawaii</i>	→ 25% by 2020 → 40% by 2030 → 100% by 2045	
<i>Illinois</i>	→ 25% by 2026	
<i>Maine</i>	→ 100% by 2050	
<i>Maryland</i>	→ 25% by 2020 → 50% by 2030	
<i>Massachusetts</i>	→ 40% by 2030 → 100% by 2090	
<i>Michigan</i>	→ 15% by 2021	
<i>Minnesota</i>	→ 31.5% by 2020 Xcel Energy (utility) [25% by 2025 (other utilities)] → 26.5% by 2025 (IOUs) ^l	
<i>Missouri</i>	→ 15% by 2021 ^l	
<i>Nevada</i>	→ 25% by 2025	23% (2015)
<i>New Hampshire</i>	→ 24.8% by 2025	
<i>New Jersey</i>	→ 20.38% by 2020 → 4.1% solar by 2027 → 50% by 2030	

■ TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[']' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018 ^a	Country	Target	Status in 2018 ^a
<i>New Mexico</i> ⁿ	→ 50% by 2030 → 80% by 2040		<i>Vermont</i>	→ Increasing by 4% every three years until reaching 75% by 2032	
<i>New York</i>	→ 70% by 2030		<i>Washington, DC</i>	→ 15% by 2020 → 100% by 2032	
<i>North Carolina</i>	→ 12.5% by 2021		<i>Washington State</i>	→ 100% by 2045	
<i>Ohio</i>	→ 12.5% by 2026		<i>District of Columbia</i>	→ 100% by 2032	
<i>Oregon</i>	→ 50% by 2040 [25% by 2025 (utilities with 3% or more of state's load); 10% by 2025 (utilities with 1.5-3% of state's load); 5% by 2025 (utilities with less than 1.5% of state's load)]		<i>Puerto Rico</i>	→ 20% by 2035 → 100% by 2050	
<i>Pennsylvania</i>	→ 18% by 2021		<i>U.S. Virgin Islands</i>	→ 30% by 2025	
<i>Rhode Island</i>	→ 38.5% by 2035		Uzbekistan	→ 19.7% by 2025	12.6%
			<i>Vanuatu</i>	→ 65% by 2020 → 100% by 2030	
			<i>Vietnam</i> ^b	→ 7% by 2020 → 10% by 2030 → 100% by 2050	
			<i>Yemen</i> ^b	→ 15% by 2025 → 100% by 2050	

^aStatus data are for 2018 unless otherwise noted.

^b100% by 2050 target established by the Climate Vulnerable Forum.

^cBrazil's target excludes all hydropower.

^dCanada's share excludes all hydropower.

^eHainan's share of 80% is from both renewables and nuclear energy.

^fIn March 2012, Denmark set a target of 50% electricity consumption supplied by wind power by 2020.

^gIndia does not classify hydropower installations larger than 25 MW as renewable energy sources, so hydropower >25 MW is excluded from national targets. De facto sub-national targets have been set through existing RPS policies.

^hMali's target excludes large-scale hydropower.

ⁱNigeria's target excludes hydropower plants >30 MW.

^jThe Russian Federation's targets exclude hydropower plants >25 MW.

^kThailand does not classify hydropower installations larger than 6 MW as renewable energy sources, so hydropower >6 MW is excluded from national shares and targets.

^lThe United States does not have a national renewable electricity target. De facto state-level targets have been set through RPS policies.

^mRPS mandate for investor-owned utilities (IOUs), which operate under private control rather than government or co-operative operation.

ⁿRPS mandate for co-operative utilities.

Note: Unless otherwise noted, all targets and corresponding shares represent all renewables, including hydropower. A number of state/provincial and local jurisdictions have additional targets not listed here. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2019. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable electricity for the country. Some countries shown have other types of targets (→ See Tables R3-R8). See Policy Landscape chapter for more information about sub-national targets. Existing shares are indicative and may need adjusting if more accurate national statistics are published. Sources for reported data often do not specify the accounting method used; therefore, shares of electricity are likely to include a mixture of different accounting methods and thus are not directly comparable or consistent across countries. Where shares sourced from EUROSTAT differed from those provided to REN21 by country contributors, the former was given preference.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R7. Renewable Power, Targets for Technology-Specific Share of Electricity Generation as of End-2019

Note: Text in **bold** indicates new/revised in 2019, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Technology	Target
Denmark	Wind power	50% by 2020
Eritrea	Wind power	50% (no date)
Egypt	Wind power	12% by 2020
Germany	Solar power	17% by 2030
Guinea	Solar power	6% by 2025
	Wind power	2% by 2025
Haiti	Bio-power	5.6% by 2030
	Hydropower	24.5% by 2030
	Solar power	7.55% by 2030
	Wind power	9.4% by 2030
India ^a		
<i>Bihar</i>	<i>Solar power</i>	<i>1.75% by 2018-19; 2% by 2019-20; 2.5% by 2020-21; 3% by 2012-22</i>
<i>Himachal Pradesh</i>	<i>Solar power</i>	<i>0.75% by 2018-19; 1% by 2019-20; 2% by 2020-21; 3% by 2021-22</i>
<i>Kerala</i>	<i>Solar power</i>	<i>0.25% by 2021-22</i>
Japan	Bio-power	3.7-4.6% by 2030
	Geothermal power	1% to 1.1% by 2030
	Hydropower	8.8-9.2% by 2030
	Solar PV	7% by 2030
	Wind power	1.7% by 2030
United Kingdom	Wind power (offshore)	33% by 2030

^a India has established state-specific solar power purchase obligations.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation as of End-2019

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target	
Algeria	Electricity	4.5 GW by 2020; 22 GW by 2030	
	Bio-power from waste-to-energy	360 MW by 2020; 1 GW by 2030	
	Geothermal power	5 MW by 2020; 15 MW by 2030	
	Solar PV	3 GW by 2020; 13.5 GW by 2030	
	CSP	2 GW by 2030	
	Wind power	1 GW by 2020; 5 GW by 2030	
Antigua and Barbuda	Electricity	5 MW by 2030	
Armenia	Hydropower (small-scale)	377 MW by 2020; 397 MW by 2025	
	Geothermal power	50 MW by 2020; 100 MW by 2025	
	Solar PV	40 MW by 2020; 80 MW by 2025	
	Wind power	50 MW by 2020; 100 MW by 2025	
Austria	Bio-power from solid biomass and biogas	200 MW added 2010-2020	
	Hydropower	1 GW added 2010-2020	
	Solar PV	1.2 GW added 2010-2020	
	Wind power	2 GW added 2010-2020	
Australia	Electricity	33,000 GWh by 2020	
Azerbaijan	Electricity	1 GW by 2020	
Bahrain	Electricity	255 MW by 2020; 710 MW by 2030	
	Bio-power	5 MW by 2025; 10 MW by 2035	
	Solar power (PV and CSP)	200 MW by 2025; 400 MW by 2035	
	Wind power	50 MW by 2025; 300 MW by 2035	
Bangladesh	Bio-power	7 MW by 2021	
	Biogas power	7 MW by 2021	
	Waste-to-energy	40 MW by 2021	
	Hydropower	4 MW by 2021	
	Solar power	1,676 MW by 2021	
	Wind power	1,370 MW by 2021	
Belarus	Electricity	2.6 billion kWh through 2035	
Belgium		no national target	
	<i>Flanders</i>	<i>Solar PV</i>	<i>Increase production 30% by 2020</i>
	<i>Wallonia</i>	<i>Electricity</i>	<i>8 TWh per year by 2020</i>
Bhutan	Electricity	20 MW by 2025	
	Bio-power from solid biomass	5 MW by 2025	
	Solar PV	5 MW by 2025	
	Wind power	5 MW by 2025	
Bolivia	Electricity	160 MW capacity added 2015-2025	
Bosnia and Herzegovina	Hydropower	120 MW by 2030	
	Solar PV	4 MW by 2030	
	Wind power	175 MW by 2030	
Burundi	Bio-power from solid biomass	4 MW (no date)	
	Hydropower	212 MW (no date)	
	Solar PV	40 MW (no date)	
	Wind power	10 MW (no date)	
Canada		no national target	
	<i>Ontario</i>	<i>Electricity</i>	<i>20 GW by 2025 supplied by a mix of technologies, including:</i>
		<i>Hydropower</i>	<i>9.3 GW by 2025</i>

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Canada (continued)		
Ontario	Solar PV	40 MW by 2025
	Wind power	5 GW by 2025
Prince Edward Island	Wind power	30 MW increase by 2030 (base year 2011)
China	Electricity	680 GW non-fossil generation capacity by 2020
	Bio-power	15 GW by 2020
	Hydropower	340 GW by 2020
	Solar power	110 GW by 2020; 5 GW solar thermal power by 2020
	Wind power	210 GW by 2020 (including 5 GW grid-connected offshore wind)
Chinese Taipei	Electricity	10.9 GW by 2020; 27.4 GW by 2025
	Geothermal power	150 MW by 2020; 200 MW by 2025
	Solar PV	6.5 GW by 2020; 20 GW by 2025
	Wind power (onshore)	814 MW by 2020; 1.2 GW by 2025
	Wind power (offshore)	520 MW by 2020; 3-5.7 GW by 2025
Croatia	Hydropower	1,655 MW by 2020
Cuba	Electricity	2.1 GW biomass, wind, solar and hydropower capacity by 2030
Djibouti	Electricity	1 GW by 2035
	Geothermal power	500 MW by 2035
	Solar power (PV and CSP)	200 MW by 2035
	Wind power	300 MW by 2035
Egypt	Hydropower	2.8 GW by 2020
	Solar PV	17.3 GW by 2035
	CSP	1.1 GW by 2020; 11 GW by 2035
	Wind power	7.2 GW by 2022; 21 GW by 2035
Ethiopia	Bio-power from bagasse	103.5 MW (no date)
	Hydropower	22 GW by 2030
	Wind power	7 GW by 2030
Finland	Bio-power	13.2 GW by 2020
	Hydropower	14.6 GW by 2020
	Wind power	884 MW by 2020
France	Hydropower	0.1 to 2 GW by 2023
	Ocean power	380 MW by 2020
	Solar power	18.2-20.2 GW by 2023; [8 GW by 2020]; 45 GW by 2030
	Wind power (offshore)	1 GW per year; 2.4 GW by 2023; 4.7 to 5.2 GW by 2028
	Wind power (onshore)	21.8 to 26 GW by 2023
Germany	Bio-power	100 MW added per year
	Solar PV	2.5 GW added per year; 98 GW by 2030
	Wind power (onshore)	2.8 GW tendered per year through 2019; 2.9 GW per year after 2019
	Wind power (offshore)	20 GW added by 2030
	Wind power (total)	67 to 71 GW by 2030
Greece	Solar PV	2.2 GW by 2030
Grenada	Geothermal power	15 MW (no date)
	Solar power	10 MW (no date)
	Wind power	2 MW (no date)

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
India	Electricity	175 GW by 2022; 450 GW by 2030
	Bio-power	10 GW by 2022
	Hydropower (small-scale) ^a	5 GW by 2022
	Solar PV	20 million solar lighting systems added 2010-2022
	Solar PV and CSP	100 GW by 2022
	Wind power	60 GW by 2022
<i>Andhra Pradesh</i>	<i>Electricity</i>	<i>18 GW capacity added by 2020-21</i>
<i>Delhi</i>	<i>Solar PV</i>	<i>5,000 MW added 2015-2020</i>
	<i>Solar power</i>	<i>1 GW by 2020; 2 GW by 2025</i>
<i>Rajasthan</i>	<i>Hybrid (solar PV and wind)</i>	3.5 GW by 2024-2025
	<i>Wind</i>	2 GW by 2024-2025
	<i>Solar power^b</i>	25 GW by 2020 30 GW by 2024-2025
<i>Jharkhand</i>	<i>Solar PV</i>	<i>2,650 MW installed by 2019-2020</i>
Indonesia	Geothermal power	12.6 GW by 2025
	Hydropower	2 GW by 2025, including 0.43 GW micro-hydro
	Pumped storage ^c	3 GW by 2025
	Solar power	5 GW by 2020 [156.8 MW solar PV by 2025]
	Wind power	100 MW by 2025
Iraq	Solar PV	2.24 GW by 2020
Iran	Solar power and wind power	5 GW by 2020
Italy	Bio-power	19,780 GWh per year generation from 2.8 GW capacity by 2020
	Geothermal power	6,759 GWh per year generation from 920 MW capacity by 2020
	Hydropower	42,000 GWh per year generation from 17.8 GW capacity by 2020
	Solar PV	50 GW by 2030
	Wind power (onshore)	18,000 GWh per year generation and 12 GW capacity by 2020
	Wind power (offshore)	2,000 GWh per year generation and 680 MW capacity by 2020
Japan	Ocean power (wave and tidal)	1.5 GW by 2030
Jordan	Electricity	1.8 GW by 2020; 3.22 GW by 2025
	Bio-power	50 MW by 2025
	Solar PV	1 GW by 2020; 2.5 GW by 2025
	Wind power	1.2 GW by 2020
Kazakhstan	Bio-power	15.05 MW at three stations by 2020
	Hydropower	539 MW at 41 stations by 2020
	Solar power	713.5 MW at 28 plants by 2020
	Wind power	1,787 MW at 34 stations by 2020
Kenya	Geothermal power	5 GW by 2030
Korea, Republic of	Electricity	13,016 GWh per year; 21,977 GWh per year (4.7%) by 2020; 39,517 GWh per year (7.7%) by 2030 supplied by a mix of technologies, including:
	Bio-power from solid biomass	2,628 GWh per year by 2030
	Bio-power from biogas	161 GWh per year by 2030
	Bio-power from landfill gas	1,340 GWh per year by 2030
	Geothermal power	2,046 GWh per year by 2030
	Hydropower (large-scale)	3,860 GWh per year by 2030
	Hydropower (small-scale)	1,926 GWh per year by 2030
	Ocean power	6,159 GWh per year by 2030
	Solar PV	2,046 GWh per year by 2030
	CSP	1,971 GWh per year by 2030
	Wind power	16,619 GWh per year by 2030
	Wind power (offshore)	2.5 GW by 2019

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Kosovo ^d	Hydropower	140 MW by 2020
Kuwait	Solar PV	3.5 GW by 2030
	CSP	1.1 GW by 2030
	Wind power	3.1 GW by 2030
Lebanon	Wind power	400-500 MW by 2020
Lesotho	Electricity	260 MW by 2030
Libya	Solar PV	300 MW by 2020; 800 MW by 2025, 3.35 GW by 2030
	CSP	150 MW by 2020; 400 MW by 2025; 400 MW by 2030
	Wind power	600 MW by 2020; 1 GW by 2025
Macedonia, North	Bio-power from solid biomass	50 GWh by 2020
	Bio-power from biogas	20 GWh by 2020
	Hydropower (small-scale)	216 GWh by 2020
	Solar PV	14 GWh by 2020
	Wind power	300 GWh by 2020
Malaysia	Electricity	2.1 GW (excluding large-scale hydro), 11.2 TWh per year, or 10% of national supply (no date given); 11% by 2020; 14% by 2030; 36% by 2050
	Solar power	1 GW capacity added by 2020
Mauritania	Electricity	60 MW by 2020
Morocco	Electricity	6GW by 2020; 11 GW by 2030
	Hydropower	2 GW by 2020
	Solar PV and CSP	2 GW by 2020; 4.56 GW by 2030
	Wind power	2 GW by 2020; 4.2 GW by 2030
Mozambique	Bio-digesters for biogas	1,000 systems installed (no date)
	Hydropower, solar PV, wind power	2 GW each (no date)
	Solar PV	82,000 solar home systems installed (no date)
	Wind turbines for water pumping	3,000 stations installed (no date)
	Renewable energy-based productive systems	5,000 systems installed (no date)
Myanmar	Renewable power	27% of installed power capacity by 2030
Nigeria	Bio-power	400 MW by 2025
	Hydropower (small-scale)	2 GW by 2025 ^e
	Solar PV (large-scale, >1 MW)	500 MW by 2025
	CSP	5 MW by 2025
	Wind power	40 MW by 2025
Norway	Electricity	26.4 TWh common electricity certificate market with Sweden by 2020
Palestine, State of	Bio-power	21 MW by 2020
	Solar PV	45 MW by 2020
	CSP	20 MW by 2020
	Wind power	44 MW by 2020
Philippines	Electricity	Triple the 2010 capacity by 2030
	Bio-power	277 MW added 2010-2030
	Geothermal power	1.5 GW added 2010-2030
	Hydropower	5,398 MW added 2010-2030
	Ocean power	75 MW added 2010-2030
	Solar PV	284 MW added 2010-2030
	Wind power	2.3 GW added 2010-2030
Poland	Wind power (offshore)	10 GW by 2040

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Portugal	Electricity	14.7 GW by 2020; 27.9 GW by 2030
	Hydropower	7 GW by 2020; 8.7 GW by 2030
	Wind power	5.4 GW by 2020; 9.3 GW by 2030
	Solar	1.9 GW by 2020; 9 GW by 2030
	Other (biopower, geothermal and wave)	0.5 GW by 2020; 0.6 GW by 2030
Qatar	Electricity	500 MW by 2030
	Bio-power	50 MW by 2030
	Solar power	400 MW by 2030
	Wind power	50 MW by 2030
Russian Federation ^f	Electricity	5.5 GW by 2024
	Hydropower (small-scale)	425.4 MW by 2024
	Solar PV	1.8 GW by 2024
	Wind power	3.4 GW by 2024
<i>Altai Republic</i>	<i>Solar PV</i>	<i>150 MW by 2021</i>
Saudi Arabia	Electricity	27.3 GW by 2023; 58.7 GW by 2030
	Geothermal, bio-power (waste-to-energy) ^g , wind power	13 GW combined by 2040
	Solar PV	20 GW by 2023; 40 GW by 2030
	CSP	300 MW by 2023; 2.7 MW by 2030
	Wind	7 GW by 2023; 16 GW by 2030
Serbia	Wind power	1.4 GW (no date)
Sierra Leone	Electricity	1 GW (no date)
Singapore	Solar PV	350 MW by 2020
Solomon Islands	Geothermal power	20 to 40 MW (no date)
	Hydropower	3.77 MW (no date)
	Solar power	3.2 MW (no date)
South Africa	Electricity	17.8 GW by 2030; 42% of new capacity installed 2010-2030
Spain	Solar	77 GW by 2030
Sudan	Electricity	16 GW by 2031
	Bio-power from solid biomass	54 MW by 2031
	Bio-power from biogas	68 MW by 2031
	Hydropower	54 MW by 2031
	Solar PV	750 MW by 2031
	CSP	50 MW by 2031
	Wind power	680 MW by 2031
Sweden	Electricity	25 TWh more renewable electricity annually by 2020 (base year 2002)
	Electricity	26.4 TWh common electricity certificate market with Norway by 2020
Switzerland	Electricity	12 TWh per year by 2035; 24.2 TWh per year by 2050
	Hydropower	43 TWh per year by 2035
Syria	Bio-power	140 MW by 2020; 260 MW by 2025; 400 MW by 2030
	Solar PV	380 MW by 2020; 1.1 GW by 2025; 1.8 GW by 2030
	CSP	50 MW by 2025; 1.3 GW by 2030
	Wind power	1 GW by 2020; 1.5 GW by 2025; 2 GW by 2030
Tajikistan	Hydropower (small-scale)	100 MW by 2020
Thailand	Bio-power from solid biomass	4.8 GW by 2021
	Bio-power from biogas	600 MW by 2021
	Bio-power from organic MSW ^g	400 MW by 2021
	Geothermal power	1 MW by 2021

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Thailand (continued)	Hydropower	6.1 GW by 2021
	Ocean power (wave and tidal)	2 MW by 2021
	Solar PV	3 GW by 2021; 6 GW by 2036
	Wind power	1.8 GW by 2021
Trinidad and Tobago	Wind power	100 MW (no date)
Tunisia	Electricity	4.7 GW by 2030
	Bio-power from solid biomass	300 MW by 2030
	Solar power	10 GW by 2030
	Wind power	16 GW by 2030
Turkey	Bio-power from solid biomass	1 GW by 2023
	Geothermal power	1 GW by 2023
	Hydropower	34 GW by 2023
	Solar PV	5 GW by 2023
	Wind power	20 GW by 2023
United Kingdom	Wind power (offshore)	39 GW by 2030, one-third of electricity by 2030
United States		no national target
<i>Iowa</i>	<i>Electricity</i>	<i>105 MW generating capacity for IOUs^h</i>
<i>Massachusetts</i>	<i>Wind power (offshore)</i>	<i>1.6 GW by 2027; additional 1.6 GW by 2035</i>
	<i>Wind power (total)</i>	<i>2,000 MW by 2020</i>
	<i>Solar power</i>	<i>1600 MW by 2020</i>
<i>New York</i>	<i>Energy storage</i>	<i>1.5 GW of energy storage by 2025 and 3 GW by 2030</i>
<i>Texas</i>	<i>Electricity</i>	<i>5,880 MW</i>
Uzbekistan	Solar PV	157.7 MW installed by 2019; 382.5 by 2020; 601.9 by 2021; 1.24 GW by 2025
	Wind power	102 MW installed by 2021; 302 MW installed by 2025
Venezuela	Electricity	613 MW new capacity installed 2013-2019, including:
	Wind power	500 MW new capacity installed 2013-2019
Vietnam	Hydropower	21.6 GW by 2020; 24.6 GW by 2025; 27.8 GW by 2030
	Solar power	850 MW by 2020; 4 GW by 2025; 12 GW by 2030
	Wind power	800 MW by 2020; 2 GW by 2025; 6 GW by 2030
Yemen	Electricity	714.25 MW by 2025
	Bio-power	6 MW by 2025
	Geothermal power	200 MW by 2025
	Solar PV	8.25MW by 2025
	CSP	100 MW by 2025
	Wind power	400 MW by 2025

^a India does not classify hydropower installations larger than 25 MW as renewable energy sources. Therefore, national targets and data for India do not include hydropower facilities >25 MW.

^b Utility or grid-scale solar parks are to account for 24 GW, distributed generation for 4 GW, solar rooftops for 1 GW and solar pumps for the remaining 1 GW.

^c Pumped storage plants are not energy sources but a means of energy storage. As such, they involve conversion losses and are powered by renewable or non-renewable electricity. Pumped storage is included here because it can play an important role as balancing power, particularly for variable renewable resources.

^d Kosovo is not a member of the United Nations.

^e Nigeria's target excludes hydropower plants >30 MW.

^f The Russian Federation's targets exclude hydropower plants >25 MW.

^g It is not always possible to determine whether municipal solid waste (MSW) data include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

^h Investor-owned utilities (IOUs) are those operating under private control rather than government or co-operative operation.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R9. Renewable Heating and Cooling Policies, as of End-2019

Note: Text in **bold** indicates new/revised in 2019.

Country	Financial Support Policies						Bans/Mandates	
	Investment subsidy/grants	Rebates	Tax credits	Tax deductions and exemptions	Loans	Feed-in tariff	Targeted fossil fuel bans in buildings/industry	Renewable heat mandates
Argentina			I/C	I/C	I/C			●
Armenia ^c	I/C				R/C			
Australia	R/C							●
Austria	C			I	R		●	
Belgium				C				
Brazil								●
Bulgaria	R/I/P							
Canada	I/C		C	C				
Chile	R			C				
China	I							●
Costa Rica				I				
Croatia						I		
Cyprus	R/C							
Czech Republic	R/C			I				
Denmark				I	I	I	●	
Egypt				I				
Estonia	R							
Finland	I/C							
France	R/I/C/P		R	R/C	R			●
Georgia ^c					R/C			
Germany	R/C/P				I/C			●
Greece	R/I			R/I/C		I		●
Hungary	R/C/P							
India	R/I/C/P	I						● ^a
Ireland	R/I/C/P			C		I/C/P		●
Israel								●
Italy	R	R/C/P	R/I/C					● ^a
Japan	I							
Jordan	R							●
Korea, Republic of	R							●
Latvia				C				
Lebanon					R/I/C			
Lithuania	R			I	R	I		
Luxembourg	R/C/P							
Macedonia, North	R							
Malawi								●
Malta		R						
Mexico	R							
Morocco	I							
Namibia								●

■ TABLE R9. Renewable Heating and Cooling Policies, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019.

Country	Financial Support Policies						Bans/Mandates	
	Investment subsidy/grants	Rebates	Tax credits	Tax deductions and exemptions	Loans	Feed-in tariff	Targeted fossil fuel bans in buildings/industry	Renewable heat mandates
Netherlands			I/C			R/I/C/P		
New Zealand	I							
Norway	C/P	R					●	●
Philippines	I							
Poland	R				R/C/P		●	
Portugal	R/I/C							●
Romania	R/I/C ^b /P							
Slovak Republic	I							
Slovenia	R				R			
South Africa	R/I/C							●
Spain	I/C			I	R/C			●
Sweden				R/C				
Switzerland	R							● ^a
Thailand	I/C							
Tunisia	R/C							
Turkey	I					I		
Ukraine					R			
United Arab Emirates								●
United Kingdom	R/I/C/P					R/C/P	●	
United States	R/I/C/P		R					●
Uruguay	R							●

R Residential
I Industrial
C Commercial
P Public facilities

^a City level

^b Agricultural renewable heat installation subsidies financed by the European Agricultural Fund for Rural Development (EAFRD).

^c Incentives provided by the European Bank for Reconstruction and Development under the Caucasus Energy Efficiency Program II.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019

Note: Text in **bold** indicates new/revised in 2019, brackets '[']' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
EU					0.2% by 2022, 1% by 2025; 3.5% by 2030		13 million zero- or low-emission vehicles by 2025
Angola		10%					
Argentina	10%	12%					
Australia							
<i>New South Wales</i>	2%	7%					
<i>Queensland</i>	1%	3%					
Austria	6.3%	3.4%	5.75%	8.75% by 2020	0.5% of total transport energy from 2020		
Belgium	6% [4%]	8.5% [4%]			0.1% total transport energy by 2020		
Brazil	11% [10%]	27%		15% biodiesel by 2022 and 30% by 2030; 10% biokerosene in aviation fuel by 2030			
Bulgaria	6%	8%			1% of total transport fuel		
Cabo Verde							35% EVs by 2025; 70% by 2030; 100% by 2035
Canada	2%	5%					Ban on sale of new petrol or diesel vehicles by 2040; 10% ZEV sales by 2025, 30% by 2030; 825,000 ZEVs by 2025, 2.7 million by 2030, 14 million by 2040
<i>Alberta</i>	2%	5%					
<i>British Columbia</i>	4%	5%					<i>Ban on most gasoline and diesel cars after 2040</i>
<i>Manitoba</i>	2%	9%					
<i>Ontario</i>	4%	5%		<i>10% ethanol in gasoline by 2020</i>			
<i>Quebec</i>				10% ethanol and 2% biodiesel by 2021; 15% ethanol and 4% biodiesel by 2025			
<i>Saskatchewan</i>	2%	8%					
Chile							40% EVs in vehicle stock by 2050
China ^a		10%					20% of total car sales to be hybrid and electric vehicles by 2025; 2 million annual EV sales by 2020
<i>Hainan Province</i>							ICE ban (sales) by 2030
Chinese Taipei	1%						Ban on sales of ICE vehicles by 2040; zero-emission two-wheelers by 2035

■ TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets ‘[]’ indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Colombia	10%	10% [8%]					10% ZEVs by 2025; 600,000 EVs by 2030
Costa Rica	20%	7%					25% of vehicles, 70% of buses and taxis to be zero emission by 2035; 100% of vehicle sales, 60% of vehicles and 100% of buses to be zero emission by 2050
Croatia	5.75%	0.97%	6.92%		0.1% second-generation biofuels ^b		
Czech Republic	6%	4.1%			0.5% of transport energy in 2020		
Denmark			5.75%		0.9% of transport energy from 2020		Ban on sale of new petrol or diesel vehicles by 2030
Ecuador	5%	10%					
Estonia	3.1%			10% by 2020	At least 0.5% in diesel fuel from 2019		
Ethiopia		10%					
Finland			15%	30% by 2029; 30% in aviation by 2030	0.5% in total transport by 2020; 10% by 2030		250,000 BEVs/PHEVs by 2030
France		7.5%	7.9% biofuels in motor fuel	8.2% in motor fuel by 2020	2.3% of diesel and 3.4% of petrol from advanced biofuels by 2023		Sales of all diesel and petrol cars and vans banned by 2040
Germany					Minimum 0.05% market share from 2020 for companies that supplied more than 20 PJ of fuel in the previous year; increase to 0.5% by 2025.		100,000 public EV charging stations by 2020; 7-10 million BEVs/FCEVs by 2030
Greece			7%				
Guatemala		5%					
Hungary	4.9%	4.9%					
Iceland							No new registrations of diesel and gasoline cars by 2030
India	20%	10%					Ban on sale of new petrol or diesel vehicles by 2030; EVs to be 15% of all sales by 2025 and 30% by 2030
<i>Delhi</i>							20% of all vehicle parking in residential and commercial parking complexes to be EV ready; all leased or hired cars used for government commuting to transition to electric by the end of 2020

■ TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets ‘[]’ indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Indonesia	30% [20%]	3%		30% biodiesel from 2025; 20% ethanol from 2025; 5% biofuel in aviation fuel by 2025. Increase the portion of diesel blended with crude palm oil (CPO) from the current 20% (B20) to 30% (B30) starting January next year and to 50% (B50) by the end of 2020.^e		B20 blending mandate expanded from road transport to rail-roads and power plants	2200 EVs by 2025
Ireland	10%			11% from 2020; 10% in petrol and 12% in diesel by 2030	0.25% of transport energy in 2020		950,000 EVs by 2030
Israel					6.7% cap on conventional biofuels by 2022		100% EV or natural gas vehicle sales by 2030; 177,000 EVs by 2025; 1.4 million by 2030
Italy			7%		0.9% by 2020; 1.85% by 2022		6 million EVs by 2030 (including 1.6 million BEVs)
Jamaica		10%					
Japan							Ban on sales of ICE vehicles by 2050
Korea, Republic of	3%						30% of all new car sales in the country to be electric by 2020; 1,000 hydrogen buses by 2022 (from natural gas)
Lithuania					0.5% by 2020		
Malawi		10%					
Malaysia	10%	10%		20% from 2020			100,000 EVs by 2030
Malta					0.5% by 2020		
Mexico ^c		10% [5.8%]					5% ZEV sales by 2030, 50% by 2040
Mozambique		15%		20% ethanol from 2021			
Nepal							Increase EV share to 20% by 2020 (2010 base year)
Netherlands			16.4% [8.5%]	16.4% from 2020	1% by 2020		100% sales of hydrogen and electric cars by 2030
New Zealand	7%		Max. 3% methanol blend				64,000 EVs by 2021
Norway	4%			20% ethanol by 2020	0.5% in aviation by 2020 and 30% by 2030		Ban on sale of new petrol or diesel vehicles by 2025

■ TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets ‘[]’ indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Pakistan							30% EV sales by 2030
Panama		10%				30% of new vehicle purchases for public fleets to be flex-fuel (no date)	
Paraguay	1%	25%					
Peru	2%	8%					
Philippines	2%	10%					
Poland			7.5%	8.5% by 2020	0.1% by 2020		1 million EVs by 2025
Portugal			9%				
Romania	6.5%	8%		10% by 2020			
Slovak Republic			5.8%		0.5% in 2020-2024; 0.75% in 2025-2030		
Slovenia			7.5%	100% biodiesel for heavy-duty trucks by 2030	0.5% in 2020		Ban on sale of new petrol or diesel vehicles by 2030; 12% of vans and trucks to be electric by 2030
South Africa	5%	2%					
Spain			6%		0.1% from 2020		
<i>Balearic Islands</i>							Ban on sale of new petrol or diesel vehicles by 2035
Sri Lanka							Ban on sale of new petrol or diesel vehicles by 2040
Sudan		5%					
Sweden							Ban on sale of cars with petrol or diesel engines after 2030 ; all buses and government vehicles to be electric by 2030
Thailand	7%	5%		41 billion litres of ethanol and 5.1 billion litres of biodiesel by 2036	25 million litres per day by 2022		1.2 million EVs by 2036
Turkey		2%					
Ukraine		7%					

■ TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets ‘[]’ indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
United Kingdom			7.25%	9.75% from 2020	3.1% by 2032		50% to 70% of new car sales and 40% of van sales to be ultra-low emission by 2030, and 25% of the government fleet to be ultra-low emission by 2022; ban on sale of new petrol, diesel or hybrid cars by 2035 [2040]
<i>Scotland</i>							<i>Ban on sales of all diesel and petrol cars and vans by 2032; USD 1.7 million to promote e-bikes</i>
United States				Energy Independence and Security Act of 2007 mandatory target: 113.5 billion litres by 2020, 125 billion litres by 2021, 136.2 billion litres by 2022. ^d	18.6 billion litres in 2019; 19.3 billion litres by 2020	Renewable Fuel Standard (RFS) 2019 standards: 75.4 billion litres total renewable fuels, including 1.6 billion litres cellulosic biofuel, 9.2 billion litres biomass-based diesel and a cap of 56.7 billion litres for conventional biofuels. ^d	
<i>California</i>							<i>5 million ZEVs on the road by 2030; 250,000 vehicle charging stations by 2025, 200 hydrogen refuelling stations by 2025; all-electric buses by 2040</i>
<i>California, Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont</i>							<i>California Air Resources Board (CARB) programme target of 3.3 million ZEVs (PHEV, BEV, FCEV) by 2025, also adopted by 10 other states</i>
<i>Hawaii, Missouri and Montana</i>		10%					
<i>Louisiana</i>	2%	2%					
<i>Massachusetts</i>	5%						
<i>Minnesota</i>	10%	20% [10%]					
<i>New Mexico</i>	5%						

■ TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets ‘[]’ indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Oregon	5%	10%					
Pennsylvania						<i>E10 one year after 1.3 billion litres produced; B5 one year after 379 million litres produced, B10 one year after 757 million litres produced, and B20 one year after 1.5 billion litres produced^d</i>	
Washington	2%	2%				<i>B5 180 days after in-state feedstock and oil-seed crushing capacity can meet 3% requirement</i>	
Uruguay	5%	5%					
Vietnam		5%					
Zimbabwe		20% [15%]					

^a China's E10 mandate was extended to cover 15 regions.

^b Blending mandate of 0.1% for second-generation biofuels, which may increase in 2019 depending on available supplies.

^c Mexico's E10 maximum blend was subsequently halted in response to several court cases challenging the increase.

^d Original target(s) set in gallons and converted to litres for consistency.

^e Not yet enforced.

Note: ZEV = zero emission vehicle; EV = electric vehicle; ICE = internal combustion engine

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R11. Feed-in Electricity Policies, Cumulative Number of Countries/States/Provinces and 2019 Revisions

Note: Text in **bold** indicates new/revised in 2019, and text with a ~~strike through~~ indicates discontinuation and text in *italics* indicates policies adopted at the state/provincial level.

Year	Cumulative ^a #	Countries/States/Provinces Added That Year
1978	1	United States ^b
1988	2	Portugal
1990	3	Germany
1991	4	Switzerland
1992	5	Italy ^c
1993	7	Denmark; India
1994	10	Luxembourg ; Spain ; Greece
1997	11	Sri Lanka
1998	12	Sweden
1999	14	Norway ; Slovenia
2000	14	[none identified]
2001	17	Armenia; France; Latvia
2002	23	Algeria; Austria; Brazil ; Czech Republic; Indonesia; Lithuania
2003	29	Cyprus; Estonia; Hungary; Slovak Republic; Republic of Korea ; Maharashtra (India)
2004	34	Israel; Nicaragua; Prince Edward Island (Canada); Andhra Pradesh and Madhya Pradesh (India)
2005	41	China ^d ; Ecuador; Ireland; Turkey; Karnataka, Uttar Pradesh and Uttarakhand (India)
2006	46	Argentina; Pakistan; Thailand; Ontario (Canada) ; Kerala (India)
2007	55	Albania; Bulgaria; Croatia; Dominican Republic ; Finland; North Macedonia; Moldova; Mongolia; South Australia (Australia)
2008	70	Iran; Kenya ^e ; Liechtenstein; Philippines; San Marino; Tanzania; Queensland (Australia) ; Chhattisgarh, Gujarat, Haryana, Punjab, Rajasthan, Tamil Nadu and West Bengal (India); California (United States)
2009	81	Japan; Serbia; South Africa ; Ukraine ; Australian Capital Territory, New South Wales and Victoria (Australia); Chinese Taipei ; Hawaii, Oregon and Vermont (United States)
2010	87	Belarus; Bosnia and Herzegovina; Malaysia; Malta; Mauritius ; United Kingdom
2011	95	Ghana; Montenegro ; Netherlands; Syria; Vietnam; Nova Scotia (Canada) ^f ; Rhode Island (United States); Angola ^g
2012	101	Jordan; Nigeria; State of Palestine; Rwanda; Uganda; Malawi ^h
2013	103	Kazakhstan; Pakistan
2014	107	Egypt; Vanuatu; <i>Virgin Islands (United States)</i> ; Mozambique ⁱ
2015	107	[none identified]
2016	108	Czech Republic (reinstated); Chile
2017	111	Zambia; Vietnam; <i>Massachusetts (United States)</i>
2018	113	Senegal; Bermuda (UK)
2019	113	[none identified]
Unknown year	126	Andorra; Honduras; Maldives; Panama; Peru; Poland; Russian Federation; Tajikistan; Bihar, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Odisha (India)
Total Removed	13	
Total Existing	113	

2019 FIT Policy Adjustments

Australia – Queensland	Solar FIT reduced
Bermuda	FIT increased for solar PV power generators
China	New solar FIT policy
Chinese Taipei	FIT reduced for offshore wind projects
Germany	Cap removed on solar FIT programme
Luxembourg	FIT increased for solar PV power generators
Montenegro	FIT surcharge abolished
Ukraine	FIT for new wind and solar power projects commissioned after 2020 to be reduced. FIT for biomass and biogas to remain at current level until 2030.
United Kingdom	FITs for solar energy replaced with new Small Export Guarantee obligating electricity suppliers to offer a tariff (came into force 1 January 2020)

^a“Cumulative number” refers to number of jurisdictions that had enacted feed-in policies as of the given year.

^bThe US PURPA policy (1978) is an early version of the FIT, which has since evolved.

^cThe FIT for solar PV in Italy ended in 2013.

^dThe FIT for CSP in China ended in 2016.

^eKenya planned to replace its FIT system with an energy auction tariff.

^f Nova Scotia's community FIT (COMFIT) was removed in 2015, the same year that the province's Developmental Tidal Feed-in Tariff Program was introduced.

^g Angola's policy was adopted but had not yet been enacted as of end-2019.

^hThe FIT was in use but had not yet been formally approved by the Ministry and Malawi Energy Regulatory Authority.

ⁱ Although the decree was available, injection of power into the grid could not yet happen pending the approval of regulation.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R12. Renewable Power Tenders Held at the National/State/Provincial Levels, 2019

Country	Technology	Description
Australia	Solar PV, energy storage	250 MW solar PV and 20 MW / 40 MWh battery energy storage system announced
Belgium	Wind power (offshore)	At least 1.7 GW after 2020 announced
Brazil	Mix of technologies (including bio-power, hydropower, solar PV, wind power)	401.6 MW awarded
	Technology-neutral among renewable and non-renewable technologies	104 GW wind power awarded 530 MW solar PV awarded 445 MW hydropower 229.62 MW biomass awarded 734.13 MW natural gas awarded
Burkina Faso	Solar PV	30 MW announced
Cabo Verde	Solar PV	5 MW announced
	Wind power	10 MW announced
Cambodia	Solar PV	60 MW awarded
China	Solar PV	22.78 GW of ground-mounted and distributed generation awarded
Colombia	Solar power and wind power	1,374 MW awarded
Denmark	Solar PV	83 MW awarded
	Solar power and wind power (hybrid)	93 MW solar-wind hybrid facilities awarded (including 34.1 MW solar PV capacity)
Ethiopia	Solar PV	250 MW awarded
	Solar PV	750 MW announced
	Solar PV	Design, supply and commissioning of solar mini-grid projects in 25 rural towns and villages announced
France	Wind power (offshore)	600 MW awarded
	Solar PV (ground-mounted)	855 MW awarded
	Solar PV (ground-mounted)	858 MW awarded
Gambia	Solar PV and storage	Utility-scale solar PV park with 150 MW battery storage announced
Ghana	Solar PV	12 MWp announced
Germany	Solar PV	153 MW awarded
	Solar PV	501 MW awarded
	Wind power (onshore)	500 MW awarded
Greece	Solar power and wind power (joint auction)	437.78 MW awarded
	Solar PV	143 MW awarded
	Solar power	105.09 MW awarded
	Wind power	179.5 MW awarded
	Wind power	224 MW awarded
Guinea Bissau	Solar PV	22 MWp ground-mounted solar power plant and 30 kV transmission line announced
India	Solar PV	30 GW announced
	Transmission line supply and reactor package installation	Installation of reactor packages and supply of transmission lines announced
	Solar PV (floating)	70 MW announced
	Wind power (offshore)	Undisclosed capacity announced
Iraq	Solar PV	755 MW offered
Ireland	Technology-neutral among renewable technologies	13,500 GWh announced
	Energy storage	110 MW awarded
Italy	Solar power, wind power	4.8 GW announced (650 MW combined solar and wind, 600 MW rooftop PV)

■ TABLE R12. Renewable Power Tenders Held at the National/State/Provincial Levels, 2019 (continued)

Country	Technology	Description
Japan	Solar power	195.8 MW awarded
Lithuania	Technology-neutral among renewable technologies	300 GWh allocated
Mali	Solar PV + storage	1.3 MW with 1.5 MW/2 MWh storage announced
	Solar PV-diesel hybrid	Four 80 kWp mini-grids announced
Malaysia	Solar power	491 MW large-scale solar projects awarded
Mauritius	Energy storage	14 MW for a pre-existing solar plant announced
Mexico	Geothermal power	Additional drilling at the Los Azufres geothermal field announced
Netherlands	Wind power	760 MW awarded
Nigeria	Solar PV + storage	15 MW ground-mounted solar with 5 MW battery system offered
Poland	Wind power (onshore)	2.5 GW awarded
Portugal	Solar power	1.3 GW awarded
	Energy storage	50-100 MW announced
	Solar PV (floating)	50 MW offered
Russian Federation	Wind power	78 MW awarded
Seychelles	Solar PV (floating)	4 MW awarded
Togo	Solar PV	Tender announced for the development, operation and maintenance of solar PV based mini-grids in 317 localities
Tonga	Solar PV	6 MW awarded
Tunisia	Solar power	500 MW offered
Turkey	Wind power	1 GW awarded
United Arab Emirates	Solar power	900 MW awarded
United Kingdom	Wind power (offshore)	5.47 GW awarded
	Wind power (onshore)	330 MW awarded
Vietnam	Solar PV (floating)	400 MW announced in pilot auctions
Zambia	Hydropower (small-scale)	100 MW announced
	Solar PV	120 MW awarded
	Solar PV	100 MW announced
Zimbabwe	Solar PV, energy storage	19.65 MWp announced

State/Provincial Renewable Energy Auctions Held in 2019

Country	State	Technology	Description
India	Chhattisgarh	Solar power	Supply and installation of 5,000 small solar irrigation pumps and 700 solar trees awarded
	Kerala	Solar power	Construction and supply of three solar-powered boats offered
	Maharashtra	Bio-power	50 MW of power from bagasse-based co-generation announced
	Rajasthan	Solar PV	750 kW of grid-connected solar PV announced for electric vehicle charging stations at selected highways/cities

Note: This table provides an overview of identified renewable energy tenders in 2019 and may not constitute a comprehensive picture of all capacity offered through tenders during the year.

Source: See the REN21 GSR 2020 data pack online at www.ren21.net/GSR.

■ TABLE R13. Biofuels Global Production, Top 15 Countries and EU-28, 2019

Country	Ethanol	Biodiesel (FAME)	Biodiesel (HVO)	Change Relative to 2018
	Billion litres			
United States	59.7	4.0	2.5	-1.7
Brazil	35.3	5.9	0.0	2.9
Indonesia	0.0	7.9	0.0	3.9
China	4.0	0.6	0.0	0.7
Germany	0.8	3.8	0.0	0.0
France	0.9	2.8	0.2	-0.3
Argentina	1.1	2.5	0.0	-0.2
Thailand	1.6	1.7	0.0	0.3
Spain	0.5	2.0	0.0	0.1
Netherlands	0.4	1.0	1.1	0.1
Canada	2.0	0.3	0.0	0.3
India	2.1	0.2	0.0	0.5
Malaysia	0.0	1.6	0.0	0.7
Poland	0.2	1.0	0.0	0.1
Italy	0.0	0.8	0.2	0.2
EU-28	4.7	12.4	2.9	-0.1
World Total	113.7	40.9	6.5	7.8

Note: Production levels are rounded to the nearest 0.1 billion litres. Rounding is to account for uncertainties in available data. Countries are ranked according to total biofuel production in 2019. FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil.

Source: See endnote 13 for this section.

■ TABLE R14. Geothermal Power Global Capacity and Additions, Top 10 Countries, 2019.

Country	Added 2019	Total End-2019
	MW	GW
Top Countries by Additions		
Turkey	232	1.5
Indonesia	182	2.1
Kenya	160	0.8
Costa Rica	55	0.3
Japan	54	0.6
Mexico	27	0.9
United States	15	2.5
Germany	6	0.05
Top Countries by Total Capacity		
United States	15	2.5
Indonesia	182	2.1
Philippines	–	1.9
Turkey	232	1.5
New Zealand	–	1.0
Mexico	27	0.9
Italy	–	0.8
Iceland	–	0.8
Kenya	160	0.8
Japan	54	0.6
World Total	728	13.9

Note: Capacity additions are rounded to the nearest 1 MW, and totals are rounded to the nearest 0.1 GW, with the exception of Germany, which is rounded to the nearest 0.01 GW. Rounding is to account for uncertainties and inconsistencies in available data. Table reflects known new capacity and capacity increases at existing facilities but does not indicate known capacity decommissioning or derating of existing facilities, although those may be reflected (at least partially) in total capacity values. For more information and statistics, see Geothermal section in Market and Industry chapter and related endnotes.

Source: See endnote 14 for this section.

■ TABLE R15. Hydropower Global Capacity and Additions, Top 10 Countries, 2019

Country	Added 2019	Total End-2019
	GW	
Top Countries by Additions		
Brazil	4.9	109
China	3.9	326
Lao PDR	1.9	7.2
Bhutan	0.7	2.3
Tajikistan	0.6	6.4
Russian Federation	0.5	48
Angola	0.3	3.4
Uganda	0.3	1.0
Ethiopia	0.3	4.1
Turkey	0.2	29
Top Countries by Total Capacity		
China	3.9	326
Brazil	4.9	109
Canada	-	81
United States	~0	80
Russian Federation	0.5	48
India	0.2	45
Norway	0.1	31
Turkey	0.2	29
Japan	-	22
France	~0	20
World Total	16	1,150

Note: Capacity additions are rounded to the nearest 0.1 GW, and totals are rounded to the nearest 1 GW except when totals are less than 10 GW. Rounding is to account for uncertainties and inconsistencies in available data. Capacity amounts of less than 50 MW are designated by “~0”. For more information and statistics, see Hydropower section in Market and Industry chapter and related endnotes.

Source: See endnote 15 for this section.

■ TABLE R16. Solar PV Global Capacity and Additions, Top 10 Countries, 2019

	Total End-2018	Added 2019	Total End-2019
	GW		
Top Countries by Additions			
China	175.4	30.1	204.7
United States	62.7	13.3	76
India	32.9	9.9	42.8
Japan	56	7	63
Vietnam	0.1	4.8	4.9
Spain	5.2	4.8	9.9
Germany	45.2	3.8	49
Australia	11	3.7	14.7
Ukraine	1.3	3.5	4.8
Republic of Korea	8.1	3.1	11.2
Top Countries by Total Capacity			
China	175.4	30.1	204
United States	62.7	13.3	76
Japan	56	7	63
Germany	45.2	3.8	49
India	32.9	9.9	42.8
Italy	20.1	0.7	20.8
Australia	11	3.7	14.7
United Kingdom	13.1	0.3	13.4
Republic of Korea	8.1	3.1	11.2
Spain	5.2	4.8	9.9
World Total	512	115	627

Note: Country data are rounded to the nearest 0.1 GW, and world totals are rounded to the nearest 1 GW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding. Data are provided in direct current (DC); data for India, Japan and the United States were converted from official data reported in alternating current (AC) into DC by sources listed for this table. Data are from a variety of sources, some of which differ significantly because of variations in accounting or methodology. For more information, see Solar PV section in Market and Industry chapter and related endnotes.

Source: See endnote 16 for this section.

■ TABLE R17. Concentrating Solar Thermal Power (CSP) Global Capacity and Additions, 2019

Country	Total End-2018	Added 2019	Total End-2019
		MW	
Spain	2,304	–	2,304
United States	1,738	–	1,738
Morocco	516	–	516
South Africa	400	100	500
China	220	200	420
Israel	–	240	240
India	225	–	225
United Arab Emirates	100	–	100
Saudi Arabia	50	–	50
Kuwait	–	50	50
Algeria	20	–	20
Egypt	20	–	20
Iran	17	–	17
France	–	9	9
World Total	5,610	600	6,210

Note: Table includes all countries with operating commercial CSP capacity at end-2019. Pilot and demonstration facilities and facilities with capacities of 5 MW or less are excluded from the table. Additional countries that had small (5 MW or less) pilot or demonstration plants in operation by year’s end include Australia (4.1 MW), Denmark (4 MW), Canada (1.1 MW), France (0.25 MW), Germany (1.5 MW), Italy (6 MW), Oman (7 MW), Thailand (5 MW) and Turkey (5 MW). National data are rounded to the nearest MW, and world totals are rounded to the nearest 5 MW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding. Capacity data reflect net capacity; where it is not possible to verify if reported capacity reflects net or gross capacity, capacity is assumed to be net. For more information, see CSP section in Market and Industry chapter and related endnotes.

Source: See endnote 17 for this section.

■ TABLE R18. Solar Water Heating Collectors and Total Capacity End-2018 and Newly Installed Capacity 2019, Top 20 Countries

Country	Total End-2018			Gross Additions 2019		
	GW _{th}			MW _{th}		
	Glazed	Unglazed	Total	Glazed	Unglazed	Total
China	337.6	–	337.6	22,750	–	22,750
Turkey	17.6	–	17.6	1,320	–	1,320
India	9.5	–	9.5	1,270	–	1,270
Brazil	7.1	4.2	11.3	461	464	925
United States	2.2	15.7	17.9	112	487	600
Australia	2.6	3.9	6.5	122	266	388
Germany	13.5	0.4	13.9	358	–	358
Mexico	2.0	1.0	3.0	203	83	286
Greece	3.3	–	3.3	253	–	253
Israel	3.3	–	3.4	252	–	252
Poland	1.8	–	1.8	184	–	184
Spain	2.9	0.1	3.0	143	2	145
Denmark	1.2	–	1.2	137	–	137
South Africa	0.7	0.9	1.5	70	42	112
Italy	3.3	–	3.3	106	–	106
Austria	3.3	0.2	3.6	63	–	64
Cyprus	0.6	1.5	2.1	49	–	49
Tunisia	0.7	–	0.7	44	–	44
Palestine, State of	1.3	–	1.3	32	–	32
Switzerland	1.1	0.1	1.2	28	3	32
Total Top 20 Countries	415.4	28.1	443.5	27,957	1,348	29,305
World Total	452	30	482	29,840	1,455	31,295

Note: Countries are ranked according to newly installed glazed collector capacity in 2019. Data are for glazed and unglazed water collectors excluding air collectors, which added at least 1.1 GW_{th} to the year-end world total for 2018, and excluding concentrating collectors, which achieved 364 MW_{th} at the end of 2018. End-2018 data for individual countries and Total 20 Top Countries are rounded to the nearest 0.1 GW_{th}; end-2018 World Total data are rounded to the nearest GW_{th}; additions for individual countries and Total 20 Top Countries are rounded to the nearest 1 MW_{th}. Where totals do not add up, the difference is due to rounding. By accepted convention, 1 million square metres = 0.7 GW_{th}. The year 2018 is the most recent one for which firm global data on total capacity in operation were available. However, 479 GW_{th} of solar thermal capacity (water and non-concentrating collectors only) was estimated to be in operation worldwide by end-2019. For details and source information on 2019 additions, see Solar Thermal section in Market and Industry chapter and related endnotes.

Source: See endnote 18 for this section.

■ TABLE R19. Wind Power Global Capacity and Additions, Top 10 Countries, 2019

Country	Total End-2018	Added 2019	Total End-2019
	GW		
Top Countries by Additions			
China ^a	184.2/209.5	25.7/26.8	210/236.3
United States	96.5	9.1	105.6
United Kingdom	21.1	2.4	23.5
India	35.1	2.4	37.5
Spain	23.5	2.3	25.8
Germany	59.3	2.1	61.4
Sweden	7.4	1.6	9.0
France	15.3	1.3	16.6
Mexico	4.9	1.3	6.2
Argentina	0.7	0.9	1.6
Top Countries by Total Capacity			
China ^a	184.2/209.5	25.7/26.8	210/236.3
United States	96.5	9.1	105.6
Germany	59.3	2.1	61.4
India	35.1	2.4	37.5
Spain	23.5	2.3	25.8
United Kingdom	21.1	2.4	23.5
France	15.3	1.3	16.6
Brazil	14.7	0.7	15.5
Canada	12.8	0.6	13.4
Italy	10.1	0.5	10.5
World Total	591	60	651

^a For China, data to the left of the "/" are the amounts officially classified as connected to the grid and operational (receiving FIT premium) by year's end; data to the right are total installed capacity, most, if not all, of which was connected to substations by year's end. The world totals include the higher numbers for China. See Wind Power section in Market and Industry chapter and related endnotes for more details.

Note: Country data are rounded to the nearest 0.1 GW; world data are rounded to the nearest GW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding or to repowering/removal of existing projects. Several countries repowered or decommissioned existing capacity during the year, which is reflected in the table to the extent possible. Data are from a variety of sources, some of which differ significantly because of variations in accounting or methodology. For more information, see Wind Power section in Market and Industry chapter and related endnotes.

Source: See endnote 19 for this section.

■ TABLE R20. Electricity Access by Region and Country, Status in 2018 and Targets

World/Region/Country	Population with Electricity Access in 2018	Population Without Electricity Access in 2018	Target
	Share of population with access	Millions	Share of population with electricity access
World^a	89%	861	
All Developing Countries	86%	861	
Africa	54%	601	
North Africa	>99%	<1	
Sub-Saharan Africa	45%	600	
Developing Asia	94%	226	
Central and South America	97%	16	
Middle East	93%	18	
Africa			
Angola	45%	17	→ 100% by 2030
Benin	35%	8	→ 95% by 2025 (urban) → 65% by 2025 (rural)
Botswana	59%	<1	→ 100% by 2030
Burkina Faso	20%	16	→ 100 by 2025
Burundi	11%	10	→ 25% by 2025
Cameroon	70%	7	
Central African Republic	<5%	5	→ 50% by 2030
Chad	9%	14	
Congo, Democratic Republic of the	9%	77	→ 60% by 2025
Congo, Republic of	69%	2	
Côte d'Ivoire	63%	9	→ 100% by 2025
Djibouti	42%	<1	→ 100% by 2035
Egypt	>95%	<1	
Equatorial Guinea	83%	<1	
Eritrea	49%	3	
Eswatini	87%	<1	→ 75% by 2018 → 85% by 2020 → 100% by 2025
Ethiopia	45%	59	→ 100% by 2030
Gabon	92%	<1	
Gambia	47%	1	→ 100% by 2030
Ghana	84%	5	→ 100% by 2020
Guinea	17%	10	→ 100% by 2030
Guinea-Bissau	10%	2	→ 80% by 2030
Kenya	75%	13	→ 100% by 2022
Lesotho	36%	<1	→ 40% by 2020
Liberia	11%	4	→ 100% by 2030
Madagascar	25%	20	
Malawi	15%	16	→ 30% by 2020
Mali	40%	12	→ 87% by 2030
Mauritania	30%	3	
Morocco	>95%	<1	
Mozambique	29%	22	→ 100% by 2025

■ TABLE R20. Electricity Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Electricity Access in 2018	Population Without Electricity Access in 2018	Target
	Share of population with access	Millions	Share of population with electricity access
Africa (continued)			
Namibia	56%	1.1	
Niger	12%	19	→ 65% by 2030
Nigeria	60%	78	→ 75% by 2020 → 90% by 2030
Rwanda	49%	6	→ 100% by 2030
Senegal	69%	5	→ 100% by 2025
Sierra Leone	25%	6	→ 100% by 2025
Somalia	18%	13	
South Africa	95%	3	→ 100% by 2019
South Sudan	<5%	12	
Sudan	47%	22	
Tanzania	37%	37	→ 75% by 2030
Togo	43%	5	→ 82% by 2030
Uganda	23%	34	→ 98% by 2030
Zambia	37%	11	→ 66% by 2030
Zimbabwe	34%	11	→ 66% by 2030 → 90% by 2030 (urban) → 51% by 2030 (rural)
Developing Asia			
Bangladesh	85%	25	→ 100% by 2021
Brunei Darussalam	>95%	<1	
Cambodia	72%	5	→ 70% by 2030 (rural)
India	95%	74	→ 100% by 2019
Indonesia	98%	5	
Korea, Democratic People's Republic	27%	19	→ 90% by 2017
Lao PDR	95%	<1	
Mongolia	91%	<1	
Myanmar	43%	31	→ 87% by 2030
Nepal	94%	2	
Pakistan	77%	46	
Philippines	>95%	5	
Vietnam	>95%	<1	
Central and South America			
Argentina	>95%	<1	
Bolivia	92%	<1	→ 100% by 2025 (rural)
Brazil	>95%	<1	
Colombia	>95%	2	→ 97.45% by 2017
Costa Rica	>95%	<1	
Cuba	>95%	<1	
Dominican Republic	>95%	<1	
Ecuador	>95%	<1	→ 98.9% by 2022 (urban) → 96.3% by 2022 (rural)
El Salvador	>95%	<1	

■ TABLE R20. Electricity Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Electricity Access in 2018	Population Without Electricity Access in 2018	Target
	Share of population with access	Millions	Share of population with electricity access
Central and South America (continued)			
Guatemala	93%	1	
Haiti	39%	7	→ 50% by 2020
Honduras	79%	2	
Jamaica	>95%	<1	
Nicaragua	>95%	<1	
Panama	93%	<1	
Paraguay	>95%	<1	
Peru	>95%	1	
Trinidad and Tobago	>95%	<1	
Uruguay	>95%	<1	
Venezuela	>95%	<1	
Middle East			
Bahrain	>95%	<1	
Iran	>95%	<1	
Iraq	>95%	<1	
Jordan	>95%	<1	
Kuwait	>95%	<1	
Lebanon	>95%	<1	
Oman	>95%	<1	
Saudi Arabia	>95%	<1	
Syria	>95%	1	
Qatar	>95%	<1	
United Arab Emirates	>95%	<1	
Yemen	47%	15	
Oceania			
Federated States of Micronesia ^b	80%	<1	→ 90% by 2020 (rural)

Disclaimer: The tracking of data related to energy access and DREA systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

^a Includes countries in the OECD and economies in transition.

^b For the Federated States of Micronesia, rural electrification rate is defined by electrification of all islands outside of the four that host the state capital (which is considered urban).

Source: See endnote 20 for this section.

■ TABLE R21. Clean Cooking Access by Region and Country, Status in 2018 and Targets

World/Region/Country	Population with Access to Clean Cooking in 2018	Population Without Access to Clean Cooking in 2018	Target
	Share of population	Millions	Share of population with access to clean cooking
World^a	65%	2,651	
All Developing Countries	56%	2,651	
Africa	29%	910	
Sub-Saharan Africa	17%	905	
North Africa	98%	1.1	
Developing Asia	57%	1,674	
Central and South America	89%	57	
Middle East	96%	10	
Africa			
Algeria	92%	4	
Angola	50%	15	→ 100% by 2030
Benin	5%	11	
Botswana	66%	<1	
Burkina Faso	14%	17	→ 100% by 2030 (urban) → 65% by 2030 (rural)
Burundi	<5%	11	
Cabo Verde	83%	<1	→ 100% by 2020
Cameroon	25%	19	
Central African Republic	<5%	5	
Chad	7%	14	
Comoros	12%	<1	
Congo, Democratic Republic of the	<5%	81	
Congo, Republic of	26%	4	
Côte d'Ivoire	30%	18	
Djibouti	13%	<1	
Egypt	>95%	<1	
Equatorial Guinea	37%	<1	
Eritrea	18%	4	
Eswatini	52%	<1	→ 100% by 2030
Ethiopia	7%	100	→ 100% by 2025
Gabon	80%	<1	
Gambia	11%	2	→ 100% by 2030
Ghana	25%	22	→ 100% by 2030
Guinea	<5%	13	→ 50% by 2025
Guinea-Bissau	5%	2	→ 75% by 2030
Kenya	15%	43	→ 100% by 2022
Lesotho	37%	1	
Liberia	<5%	5	→ 100% by 2030
Libya	>95%	<1	
Madagascar	<5%	26	
Malawi	<5%	18	
Mali	<5%	19	→ 100% by 2030
Mauritania	48%	2	

■ TABLE R21. Clean Cooking Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Access to Clean Cooking in 2018	Population Without Access to Clean Cooking in 2018	Target
	Share of population	Millions	Share of population with access to clean cooking
Africa			
Mauritius	93%	<1	
Morocco	>95%	<1	
Mozambique	6%	29	
Namibia	43%	2	
Niger	<5%	21	→ 100% by 2030 (urban) → 60% by 2030 (rural)
Nigeria	9%	178	
Rwanda	<5%	12	→ 100% by 2030
São Tomé and Príncipe	16%	<1	
Senegal	30%	12	
Seychelles	91%	<1	
Sierra Leone	<5%	8	
Somalia	6%	14	
South Africa	87%	8	
South Sudan	<5%	12	
Sudan	46%	23	
Tanzania	6%	56	→ 75% by 2030
Togo	8%	7	→ 80% by 2030
Tunisia	>95%	<1	
Uganda	6%	42	→ 99% by 2030
Zambia	17%	15	
Zimbabwe	31%	12	
Developing Asia			
Bangladesh	19%	135	
Brunei Darussalam	>95%	<1	
Cambodia	20%	13	
China	72%	399	
India	49%	688	
Indonesia	68%	85	
Korea, Democratic People's Republic	12%	23	
Lao PDR	6%	7	
Malaysia	>95%	<1	
Mongolia	46%	2	
Myanmar	21%	43	
Nepal	30%	21	
Pakistan	46%	108	
Philippines	44%	59	
Singapore	>95%	<1	
Sri Lanka	28%	16	
Thailand	76%	17	
Vietnam	73%	26	

■ TABLE R21. Clean Cooking Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Access to Clean Cooking in 2018	Population Without Access to Clean Cooking in 2018	Target
	Share of population	Millions	Share of population with access to clean cooking
Central and South America			
Argentina	>95%	<1	
Bolivia	82%	2	
Brazil	>95%	9	
Chile ^b	92%	1.5	
Colombia	93%	4	
Costa Rica	94%	<1	
Cuba	80%	2	
Dominican Republic	91%	<1	
Ecuador	>95%	<1	
El Salvador	88%	<1	
Guatemala	46%	9	
Haiti	6%	10	
Honduras	55%	4	
Jamaica	92%	<1	
Mexico ^a	85%	19	
Nicaragua	55%	3	
Panama	90%	<1	
Paraguay	69%	2	
Peru	78%	7	
Trinidad and Tobago	>95%	<1	
Uruguay	>95%	<1	
Venezuela	>95%	<1	
Middle East			
Bahrain	>95%	<1	
Iran	>95%	<1	
Iraq	>95%	<1	
Jordan	>95%	<1	
Kuwait	>95%	<1	
Lebanon	>95%	<1	
Oman	>95%	<1	
Saudi Arabia	>95%	<1	
Qatar	>95%	<1	
United Arab Emirates	>95%	<1	
Yemen	66%	10	



Disclaimer: The tracking of data related to energy access and DREA systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

^a Includes countries in the OECD and economies in transition.

^b Based on 2016 data

Source: See endnote 21 for this section.

■ TABLE R22. Global Trends in Renewable Energy Investment, 2009–2019

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Billion USD										
New Investment by Stage											
Technology Research and Start-up											
Government R&D	5.4	4.9	4.8	4.7	5.2	4.5	4.4	5.1	5.1	5.5	5.7
Corporate R&D	3.3	3.8	4.3	4.1	4.0	4.3	4.1	4.3	6.9	7.8	7.7
Venture capital	1.6	2.6	2.6	2.4	0.8	1.0	1.4	0.8	0.8	0.2	1.2
Scale-up											
Public markets	11.7	10.6	9.9	3.8	9.8	14.9	12.0	6.2	5.6	6.0	6.6
Private equity expansion capital	3.0	5.3	2.4	1.6	1.3	1.7	1.8	1.7	0.7	2.2	1.8
Projects											
Asset finance	111.8	152.2	189.6	170.1	171.5	228.4	267.7	247.5	272.6	242.0	230.1
(re-invested equity)	-3.7	-1.8	-2.1	-2.9	-1.2	-3.5	-6.7	-4.1	-2.9	-5.8	-3.4
Small-scale distributed capacity	34.7	60.9	75.1	69.9	40.2	36.7	32.6	32.5	42.5	38.2	52.1
Total New Investment	167.8	238.5	286.6	253.7	231.7	288.1	317.3	293.9	331.4	296.0	301.7
Merger & Acquisition Transactions											
	61.5	57.3	75.0	65.7	67.0	88.8	108.1	133.9	146.2	151.5	100.7
Total Transactions	229.3	295.8	361.6	319.3	298.7	376.9	425.4	427.8	477.7	447.5	402.4
New Investment by Technology											
 Wind power	72.5	97.8	83.3	78.3	83.3	111.1	119.7	123.5	133.4	132.7	142.7
 Solar power	63.6	102.0	160.1	144.0	120.4	147.8	176.6	145.9	180.8	143.5	141.0
 Biomass and waste-to-energy	13.4	17.3	20.9	15.4	14.6	13.1	10.4	15.2	7.4	11.5	11.2
 Biofuels	9.4	10.1	10.5	7.7	5.1	5.5	3.6	2.1	3.3	3.3	3.0
 Hydropower <50 MW	6.0	8.2	7.7	6.3	5.7	7.4	4.2	4.3	4.0	2.3	2.5
 Geothermal	2.5	2.8	3.8	1.7	2.4	2.9	2.5	2.7	2.4	2.5	1.2
 Ocean power	0.3	0.3	0.3	0.3	0.2	0.4	0.2	0.2	0.2	0.2	0.2
Total New Investment	167.8	238.5	286.6	253.7	231.7	288.1	317.3	293.9	331.4	296.0	301.7

Note: Excludes large hydropower projects of more than 50 MW.

Source: See endnote 22 for this section.

ENERGY UNITS AND CONVERSION FACTORS

METRIC PREFIXES

kilo	(k)	=	10 ³
mega	(M)	=	10 ⁶
giga	(G)	=	10 ⁹
tera	(T)	=	10 ¹²
peta	(P)	=	10 ¹⁵
exa	(E)	=	10 ¹⁸

VOLUME

1 m ³	=	1,000 litres (l)
1 US gallon	=	3.785412 l
1 Imperial gallon	=	4.546090 l

Example: 1 TJ = 1,000 GJ = 1,000,000 MJ = 1,000,000,000 kJ = 1,000,000,000,000 J

ENERGY UNIT CONVERSION

Multiply by:	GJ	Toe	MBtu	MWh
GJ	1	0.024	0.948	0.278
Toe	41.868	1	39.683	11.630
MBtu	1.055	0.025	1	0.293
MWh	3.600	0.086	3.412	1

Toe = tonnes (metric) of oil equivalent

1 Mtoe = 41.9 PJ

Example: 1 MWh x 3.600 = 3.6 GJ

BIOFUELS CONVERSION

Ethanol: 21.4 MJ/l

Biodiesel (FAME): 32.7 MJ/l

Biodiesel (HVO): 34.4 MJ/l

Petrol: 36 MJ/l

Diesel: 41 MJ/l

SOLAR THERMAL HEAT SYSTEMS

1 million m² = 0.7 GW_{th}

Used where solar thermal heat data have been converted from square metres (m²) into gigawatts thermal (GW_{th}), by accepted convention.

Note on Biofuels:

- 1) These values can vary with fuel and temperature.
- 2) Around 1.7 litres of ethanol is energy equivalent to 1 litre of petrol, and around 1.2 litres of biodiesel (FAME) is energy equivalent to 1 litre of diesel.
- 3) Energy values from [http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Tonnes_of_oil_equivalent_\(toe\)](http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Tonnes_of_oil_equivalent_(toe)) except HVO, which is from *Neste Renewable Diesel Handbook*, p. 15, https://www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf.

DATA COLLECTION AND VALIDATION

REN21 has developed a unique renewable energy reporting culture, allowing it to become recognised as a neutral data and knowledge broker that provides credible and widely accepted information. **Transparency is at the heart** of the REN21 data and reporting culture, and the following text explains some of the GSR's key processes for data collection and validation.

DATA COLLECTION

Production of REN21's GSR is a continuous process occurring on an annual basis. The data collection process begins following the launch of the previous year's report with an Expression of Interest form to mobilise REN21's GSR contributors. During this time, the GSR team also prepares the questionnaires that will be filled in by contributors. The questionnaires are updated each year with emerging and relevant topics as identified by the REN21 Secretariat.

REN21 collects data in seven main ways:

- 1. Country questionnaire.** In the country questionnaire, contributors from around the world submit data on renewable energy in their respective countries or countries of interest. This covers information about market trends, policy developments and local perspectives. Each data point is provided with a source and verified independently by the GSR team. Data collection with the country questionnaire typically begins in October.
- 2. DREA questionnaire.** The Distributed Renewables for Energy Access (DREA) questionnaire collects data related to energy access from contributors around the world and focuses on developing and emerging countries. This covers information about the status of electrification and clean cooking in a certain country or region, as well as policies and programmes for energy access and markets for distributed renewables.
- 3. Technology questionnaire.** The technology questionnaire functions similarly to the country questionnaire, but the input focuses specifically on annual developments for certain renewable energy technologies. As in the country questionnaire, all submitted data are validated with reliable, primary sources.
- 4. Peer review.** To further collect data and project examples and to ensure that significant developments have not been overlooked, GSR contributors and reviewers participate in an open peer review process that takes place twice during each report cycle. The first round typically occurs in January and includes Round 1 chapters such as Policy Landscape, while the second round is held typically in March/April and includes Round 2 chapters such as Global Overview and Market and Industry Trends. Peer review is open to all interested experts.
- 5. Expert interviews.** REN21's global community consists of a wide range of professionals who provide their expert input on renewable energy trends in the target year through interviews and personal communication with the REN21 GSR team and chapter authors. The vast majority of the information is backed up by primary sources.
- 6. Desk research.** To fill in remaining gaps in the GSR and to pursue new topics, the REN21 GSR team and chapter authors conduct extensive desk research. Topics of research vary widely between GSR years and depend on emerging topics, important trends and annual availability of formal or informal data in the target sector.
- 7. Data sharing agreements.** REN21 holds several data sharing agreements with some of the largest and most reliable data providers/aggregators in the energy sector. These formal data are used exclusively in some cases or, in others, form the foundation of calculations and estimations presented in the GSR.

DATA VALIDATION

REN21 ensures the accuracy and reliability of its reports by conducting data validation and fact-checking as a continuous process. Beginning during the first submission of the country questionnaires, data are continually verified up through the design period and until the final report is published. **All data provided by contributors, whether written or verbal, are validated by primary sources, which are published alongside the full report.**

METHODOLOGICAL NOTES

This 2020 report is the 15th edition of the *Renewables Global Status Report (GSR)*, which has been produced annually since 2005 (with the exception of 2008). Readers are directed to the previous GSR editions for historical details.

Most 2019 dataⁱ for national and global capacity, output, growth and investment provided in this report are preliminary. Where necessary, information and data that are conflicting, partial or older are reconciled by using reasoned expert judgment. Endnotes provide additional details, including references, supporting information and assumptions where relevant.

Each edition draws from thousands of published and unpublished references, including: official government sources; reports from international organisations and industry associations; input from the GSR community via hundreds of questionnaires submitted by country, regional and technology contributors as well as feedback from several rounds of formal and informal reviews; additional personal communications with scores of international experts; and a variety of electronic newsletters, news media and other sources.

Much of the data found in the GSR is built from the ground up by the authors with the aid of these resources. This often involves extrapolation of older data, based on recent changes in key countries within a sector or based on recent growth rates and global trends. Other data, often very specific and narrow in scope, come more-or-less prepared from third parties. The GSR attempts to synthesise these data points into a collective whole for the focus year.

The GSR endeavours to provide the best data available in each successive edition; as such, data should not be compared with previous versions of this report to ascertain year-by-year changes.

NOTE ON ESTABLISHING RENEWABLE ENERGY SHARES OF TOTAL FINAL ENERGY CONSUMPTION (TFEC)

Assumptions Related to Renewable Electricity Shares of TFEC

When estimating electricity consumption from renewable sources, the GSR must make certain assumptions about how much of the estimated gross output from renewable electricity generating resources actually reaches energy consumers, as part of total final energy consumption.

The International Energy Agency's (IEA) *World Energy Statistics and Balances* reports electricity output by individual technology. However, it does not report electricity consumption by technology – only total consumption of electricity.

The difference between gross output and final consumption is determined by:

- The energy industry's own-use, including electricity used for internal operations at power plants. This includes the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants, and other uses such as electricity use in coal mining and fossil fuel refining.

- Transmission and distribution losses that occur as electricity finds its way to consumers.

Industry's own-use. The common method is to assume that the proportion of consumption by technology is equal to the proportion of output by technology. This is problematic because logic dictates that industry's own-use cannot be proportionally the same for every generating technology. Further, industry's own-use must be somewhat lower for some renewable generating technologies (particularly non-thermal renewables such as hydropower, solar PV and wind power) than is the case for fossil fuel and nuclear power technologies. Such thermal power plants consume significant amounts of electricity to meet their own internal energy requirements (see above).

Therefore, the GSR has opted to apply differentiated "industry own-use" by generating technology. This differentiation is based on explicit technology-specific own-use (such as pumping at hydropower facilities) as well as on the apportioning of various categories of own-use by technology as deemed appropriate. For example, industry own-use of electricity at coal mines and oil refineries is attributed to fossil fuel generation.

Differentiated own-uses by technology, combined with global average losses, are as follows: solar PV, ocean energy and wind power (8.2%); hydropower (10.1%); concentrating solar thermal power (CSP) (14.2%); and bio-power (15.2%). For comparison, the undifferentiated (universal) combined losses and industry own-use would be 16.7% of gross generation. Estimated technology-specific industry own-use of electricity from renewable sources is based on data for 2016 from IEA, *World Energy Statistics and Balances, 2019 edition* (Paris: 2019).

Transmission and distribution losses. Such losses may differ (on average) by generating technology. For example, hydropower plants often are located far from load centres, incurring higher than average transmission losses, whereas some solar PV generation may occur near to (or at) the point of consumption, incurring little (or zero) transmission losses. However, specific information by technology on a global scale is not available.

Therefore, the GSR has opted to apply a global average for transmission and distribution losses. Global average electricity losses are based on data for 2017 from IEA, *World Energy Statistics and Balances, 2019 edition* (Paris: 2019).

NOTES ON RENEWABLE ENERGY IN TOTAL FINAL ENERGY CONSUMPTION, BY ENERGY USE

GSR 2020 presents an illustration of the share of renewable energy in total final energy consumption (TFEC) by sector in 2017. (→ See *Figure 3 in Global Overview chapter*.) The share of TFEC consumed in each sector is provided as follows: thermal (51%), transport (32%) and electricity (17%). There are three important points about this figure and about how the GSR treats end-use TFEC in general:

ⁱ For information on renewable energy data and related challenges, see Sidebar 4 in GSR 2015 and Sidebar 1 in GSR 2014.

1. Definition of Heating and Cooling and Thermal Applications

In the GSR, the term “heating and cooling” refers to applications of thermal energy including space and water heating, space cooling, refrigeration, drying and industrial process heat, as well as any use of energy other than electricity that is used for motive power in any application other than transport. In other words, thermal demand refers to all end-uses of energy that cannot be classified as electricity demand or transport.

2. Sectoral Shares of TFEC

In Figure 3, each sectoral share of TFEC portrays the energy demand for all end-uses within the sector. The shares of TFEC allocated to thermal and to transport also account for the electricity consumed in these sectors – that is, electricity for space heating and space cooling, industrial process heat, etc., and electricity for transport. These amounts have been reallocated from final demand in the electricity sector. Therefore, the share of TFEC allocated to the electricity sector comprises all final end-uses of electricity that are not used for heating, cooling or transport. This is a methodological change from GSR 2018 that is intended to strengthen the accuracy of the representation. In total, the final energy consumption of all electrical energy accounted for 20.8% of TFEC in 2017.

3. Shares of Non-renewable Electricity

Figure 3 illustrates the share of non-renewable electricity in thermal and in transport to emphasise that electricity demand is being allocated to each sector. The share of non-renewable electricity is not critical to the figure content, so the percentage value of non-renewable electricity in each sector is not explicitly shown, but it is included in this note. In 2017, all electricity for heating and cooling met 7.2% of final energy demand in the sector (1.9% renewable and 5.3% non-renewable electricity). All electricity for transport met 1.1% of final energy demand in the sector (0.3% renewable and 0.8% non-renewable electricity).

NOTES ON RENEWABLE ENERGY CAPACITIES AND ENERGY OUTPUT

A number of issues arise when counting renewable energy capacities and energy output. Some of these are discussed below:

1. Capacity versus Energy Data

The GSR aims to give accurate estimates of capacity additions and totals, as well as of electricity, heat and transport fuel production in the focus year. These measures are subject to some uncertainty, which varies by technology. The Market and Industry chapter includes estimates for energy produced where possible, but it focuses mainly on power or heat capacity data. This is because capacity data generally can be estimated with a greater degree of confidence than generation data. Official heat and electricity generation data often are not available for the target year within the production time frame of the GSR.

2. Constructed Capacity versus Connected Capacity and Operational Capacity

Over a number of years in the past decade, the solar PV and wind power markets saw increasing amounts of capacity that was connected to the grid but not yet deemed officially operational, or constructed capacity that was not connected to the grid by year’s end. Therefore, since the 2012 edition the GSR has aimed to count only capacity additions that were grid-connected or that otherwise went into service (e.g., capacity intended for off-grid use) during the previous calendar (focus) year. However, it appears that this phenomenon is no longer an issue, with the exception of wind power installations in China, where it has been particularly evident over the period 2009-2019. For details on the situation in China and on the reasoning for capacity data used in this GSR, see endnote 24 in the Wind Power section of the Market and Industry chapter.

3. Retirements and Replacements

Data on capacity retirements and replacements (re-powering) are incomplete for many technologies, although data on several technologies do attempt to account for these directly. It is not uncommon for reported new capacity installations to exceed the implied net increase in cumulative capacity; in some instances, this is explained by revisions to data on installed capacity, while in others it is due to capacity retirements and replacements. Where data are available, they are provided in the text or relevant endnotes.

4. Bioenergy Data

Given existing complexities and constraints (→ see *Figure 6 in GSR 2015 and Sidebar 2 in GSR 2012*), the GSR strives to provide the best and latest data available regarding biomass energy developments. The reporting of biomass-fired combined heat and power (CHP) systems varies among countries; this adds to the challenges experienced when assessing total heat and electricity capacities and total bioenergy outputs.

Wherever possible, the bio-power data presented include capacity and generation from both electricity-only and CHP systems using solid biomass, landfill gas, biogas and liquid biofuels. Electricity generation and capacity numbers are based on national data for the focus year in the major producing countries and on forecast data for remaining countries for the focus year from the IEA.

The methodology is similar for biofuels production data, with data for most countries (not major producers) from the IEA; however, data for hydrotreated vegetable oil (HVO) are estimated based on production statistics for the (relatively few) major producers. Bio-heat data are based on an extrapolation of the latest data available from the IEA based on recent growth trends. (→ See *Bioenergy section in Market and Industry chapter*.)

5. Hydropower Data and Treatment of Pumped Storage

Starting with the 2012 edition, the GSR has made an effort to report hydropower generating capacity without including pure pumped storage capacity (the capacity used solely for shifting water between reservoirs for storage purposes). The distinction is made because pumped storage is not an energy source but rather a means of energy storage. It involves conversion losses and can be fed by all forms of electricity, renewable and non-renewable.

Some conventional hydropower facilities do have pumping capability that is not separate from, or additional to, their normal generating capability. These facilities are referred to as “mixed” plants and are included, to the extent possible, with conventional hydropower data. It is the aim of the GSR to distinguish and separate only the pure (or incremental) pumped storage component.

Where the GSR presents data for renewable power capacity not including hydropower, the distinction is made because hydropower remains the largest single component by far of renewable power capacity, and thus can mask developments in other renewable energy technologies if included. Investments and jobs data separate out large-scale hydropower where original sources use different methodologies for tracking or estimating values. Footnotes and endnotes provide additional details.

6. Solar PV Capacity Dataⁱ

The capacity of a solar PV panel is rated according to direct current (DC) output, which in most cases must be converted by inverters to alternating current (AC) to be compatible with end-use electricity supply. No single equation is possible for calculating solar PV data in AC because conversion depends on many factors, including the inverters used, shading, dust build-up, line losses and temperature effects on conversion efficiency. The difference between DC and AC power can range from as little as 5% (conversion losses or inverter set at the DC level) to as much as 40% (due to grid regulations limiting output or to the evolution of utility-scale systems), and most utility-scale plants built in 2019 have ratios in the range of 1.1 to 1.6ⁱⁱ.

The GSR attempts to report all solar PV capacity data on the basis of DC output (where data are known to be provided in AC, this is specified) for consistency across countries. Some countries (for example, Canada, Chile, India, Japan, Malaysia, Spain, Sweden and the United States) report official capacity data on the basis of output in AC; these capacity data were converted to DC output by data providers (see relevant endnotes) for the sake of consistency. Global renewable power capacity totals in this report include solar PV data in DC; as with all statistics in this report, they should be considered as indicative of global capacity and trends rather than as exact statistics.

7. Concentrating Solar Thermal Power (CSP) Data

Global CSP data are based on commercial facilities only. Demonstration and pilot facilities as well as facilities of 5 MW or less are excluded from capacity data, with the exception of certain plants in China that are described as “demonstration” plants by government but are nonetheless large- (utility-) scale, grid-connected plants that are operating or will operate commercially. Discrepancies between REN21 data and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals. The GSR aims to report net CSP capacities for specific CSP plants that are included. In certain cases, it may not be possible to verify if the reported capacity of a given CSP plant is net or gross capacity. In these cases net capacity is assumed.

8. Solar Thermal Heat Data

Starting with GSR 2014, the GSR includes all solar thermal collectors that use water as the heat transfer medium (or heat carrier) in global capacity data and the ranking of top countries. Previous GSRs focused primarily on glazed water collectors (both flat plate and evacuated tube); the GSR now also includes unglazed water collectors, which are used predominantly for swimming pool heating. Since the GSR 2018, data for concentrating collectors are available. These include new installations overall as well as in key markets and total in operation by year's end. The market for solar air collectors (solar thermal collectors that use air as the heat carrier) and hybrid or PV-thermal technologies (elements that produce both electricity and heat) is small and the data rather uncertain. All three collector types – air, concentrating and hybrid collectors – are included where specified.

Estimates for 2019 additions in China were based on produced collector area and included export volumes in the national statistics for 2019 and earlier years. The export volumes for previous years were not known at the time of publication, and to the extent possible GSR 2021 will reflect corrected statistics.

OTHER NOTES

Editorial content of this report closed by 29 May 2020 for technology data, and by 15 May 2020 or earlier for other content.

Growth rates in the GSR are calculated as compound annual growth rates (CAGR) rather than as an average of annual growth rates.

All exchange rates in this report are as of 31 December 2019 and are calculated using the OANDA currency converter (<http://www.oanda.com/currency/converter>).

Corporate domicile, where noted, is determined by the location of headquarters.

ⁱ Based largely on information drawn from the following: IEA Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global PV Markets 2020* (Paris: April 2020), p. 11, https://iea-pvps.org/wp-content/uploads/2020/04/IEA_PVPS_Snapshot_2020.pdf; IEA PVPS, *Trends in Photovoltaic Applications 2019* (Paris: 2019), p. 9, https://iea-pvps.org/trends_reports/2019-edition/; G. Masson, Becquerel Institute and IEA PVPS, personal communication with REN21, May 2017; D. Renné, International Solar Energy Society, personal communication with REN21, March 2017; M. Schmela, SolarPower Europe, personal communication with REN21, 11 May 2019; Becquerel Institute, personal communication with REN21, April 2020.

ⁱⁱ See IEA PVPS, *Trends in Photovoltaic Applications 2019*, p. 9, and IEA PVPS, *Snapshot of Global PV Markets 2020*, p. 11.

GLOSSARY

Absorption chillers. Chillers that use heat energy from any source (solar, biomass, waste heat, etc.) to drive air conditioning or refrigeration systems. The heat source replaces the electric power consumption of a mechanical compressor. Absorption chillers differ from conventional (vapour compression) cooling systems in two ways: 1) the absorption process is thermochemical in nature rather than mechanical, and 2) the substance that is circulated as a refrigerant is water rather than chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), also called Freon. The chillers generally are supplied with district heat, waste heat or heat from co-generation, and they can operate with heat from geothermal, solar or biomass resources.

Adsorption chillers. Chillers that use heat energy from any source to drive air conditioning or refrigeration systems. They differ from absorption chillers in that the adsorption process is based on the interaction between gases and solids. A solid material in the chiller's adsorption chamber releases refrigerant vapour when heated; subsequently, the vapour is cooled and liquefied, providing a cooling effect at the evaporator by absorbing external heat and turning back into a vapour, which is then re-adsorbed into the solid.

Auction. See Tendering.

Bagasse. The fibrous matter that remains after extraction of sugar from sugar cane.

Behind-the-meter system. Any power generation capacity, storage or demand management on the customer side of the interface with the distribution grid (i.e., the meter). (Also see Front-of-meter system.)

Biodiesel. A fuel produced from oilseed crops such as soy, rapeseed (canola) and palm oil, and from other oil sources such as waste cooking oil and animal fats. Biodiesel is used in diesel engines installed in cars, trucks, buses and other vehicles, as well as in stationary heat and power applications. Most biodiesel is made by chemically treating vegetable oils and fats (such as palm, soy and canola oils, and some animal fats) to produce fatty acid methyl esters (FAME). (Also see Hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA).)

Bioeconomy (or bio-based economy). Economic activity related to the invention, development, production and use of biomass resources for the production of food, fuel, energy, chemicals and materials.

Bioenergy. Energy derived from any form of biomass (solid, liquid or gaseous) for heat, power and transport. (Also see Biofuel.)

Biofuel. A liquid or gaseous fuel derived from biomass, primarily ethanol, biodiesel and biogas. Biofuels can be combusted in vehicle engines as transport fuels and in stationary engines for heat and electricity generation. They also can be used for domestic heating and cooking (for example, as ethanol gels). Conventional biofuels are principally ethanol produced by fermentation of sugar or starch crops (such as wheat and corn), and FAME biodiesel produced from oil crops such as palm oil and canola and from waste oils and fats. Advanced biofuels are made from feedstocks derived from the lignocellulosic fractions of

biomass sources or from algae. They are made using biochemical and thermochemical conversion processes, some of which are still under development.

Biogas/Biomethane. Biogas is a gaseous mixture consisting mainly of methane and carbon dioxide produced by the anaerobic digestion of organic matter (broken down by microorganisms in the absence of oxygen). Organic material and/or waste is converted into biogas in a digester. Suitable feedstocks include agricultural residues, animal wastes, food industry wastes, sewage sludge, purpose-grown green crops and the organic components of municipal solid wastes. Raw biogas can be combusted to produce heat and/or power. It also can be refined to produce biomethane.

Biomass. Any material of biological origin, excluding fossil fuels or peat, that contains a chemical store of energy (originally received from the sun) and that is available for conversion to a wide range of convenient energy carriers.

Biomass, traditional (use of). Solid biomass (including fuel wood, charcoal, agricultural and forest residues, and animal dung), that is used in rural areas of developing countries with traditional technologies such as open fires and ovens for cooking and residential heating. Often the traditional use of biomass leads to high pollution levels, forest degradation and deforestation.

Biomass energy, modern. Energy derived from combustion of solid, liquid and gaseous biomass fuels in high-efficiency conversion systems, which range from small domestic appliances to large-scale industrial conversion plants. Modern applications include heat and electricity generation, combined heat and power (CHP) and transport.

Biomass gasification. In a biomass gasification process, biomass is heated with a constrained amount of air or oxygen, leading to the partial combustion of the fuels and production of a mix of combustion gases that, depending on the conditions, can include carbon monoxide and dioxide, methane, hydrogen and more complex materials such as tars. The resulting gas can either be used for power generation (e.g., in an engine or turbine) or else further purified and treated to form a "synthesis gas". This can then be used to produce fuels including methane, alcohols, and higher hydrocarbon fuels, including bio-gasoline or jet fuel. While gasification for power or heat production is relatively common, there are few examples of operating plants producing gas of high enough quality for subsequent synthesis to more complex fuels.

Biomass pellets. Solid biomass fuel produced by compressing pulverised dry biomass, such as waste wood and agricultural residues. Pellets typically are cylindrical in shape with a diameter of around 10 millimetres and a length of 30-50 millimetres. Pellets are easy to handle, store and transport and are used as fuel for heating and cooking applications, as well as for electricity generation and CHP. (Also see Torrefied wood.)

Biomethane. Biogas can be turned into biomethane by removing impurities including carbon dioxide, siloxanes and hydrogen sulphides, followed by compression. Biomethane can be injected directly into natural gas networks and used as a substitute for natural gas in internal combustion engines without risk of corrosion. Biomethane is often known as renewable natural gas (RNG), especially in North America.

Blockchain. A decentralised ledger in which digital transactions (such as the generation and sale of a unit of solar electricity) are anonymously recorded and verified. Each transaction is securely collected and linked, via cryptography, into a time-stamped “block”. This block is then stored on distributed computers as a “chain”. Blockchain may be used in energy markets, including for micro-trading among solar photovoltaic (PV) prosumers.

Building energy codes and standards. Rules specifying the minimum energy standards for buildings. These can include standards for renewable energy and energy efficiency that are applicable to new and/or renovated and refurbished buildings.

Capacity. The rated power of a heat or electricity generating plant, which refers to the potential instantaneous heat or electricity output, or the aggregate potential output of a collection of such units (such as a wind farm or set of solar panels). Installed capacity describes equipment that has been constructed, although it may or may not be operational (e.g., delivering electricity to the grid, providing useful heat or producing biofuels).

Capacity factor. The ratio of the actual output of a unit of electricity or heat generation over a period of time (typically one year) to the theoretical output that would be produced if the unit were operating without interruption at its rated capacity during the same period of time.

Capital subsidy. A subsidy that covers a share of the upfront capital cost of an asset (such as a solar water heater). These include, for example, consumer grants, rebates or one-time payments by a utility, government agency or government-owned bank.

Carbon neutrality. The achievement of a state in which every tonne of carbon dioxide emitted to the atmosphere is compensated by an equivalent tonne removed (e.g., sequestered). Emissions can be compensated for by carbon offsets.

Combined heat and power (CHP) (also called co-generation). CHP facilities produce both heat and power from the combustion of fossil and/or biomass fuels, as well as from geothermal and solar thermal resources. The term also is applied to plants that recover “waste heat” from thermal power generation processes.

Community energy. An approach to renewable energy development that involves a community initiating, developing, operating, owning, investing and/or benefiting from a project. Communities vary in size and shape (e.g., schools, neighbourhoods, partnering city governments, etc.); similarly, projects vary in technology, size, structure, governance, funding and motivation.

Competitive bidding. See Tendering.

Concentrating photovoltaics (CPV). Technology that uses mirrors or lenses to focus and concentrate sunlight onto a relatively small area of photovoltaic cells that generate electricity (see Solar photovoltaics). Low-, medium- and high-concentration CPV systems (depending on the design of reflectors or lenses used) operate most efficiently in concentrated, direct sunlight.

Concentrating solar collector technologies. Technologies that use mirrors to focus sunlight on a receiver (see Concentrating solar thermal power). These are usually smaller-sized modules that are used for the production of heat and steam below 400 °C for industrial applications, laundries and commercial cooking.

Concentrating solar thermal power (CSP) (also called solar thermal electricity, STE). Technology that uses mirrors to focus sunlight into an intense solar beam that heats a working fluid in a solar receiver, which then drives a turbine or heat engine/generator to produce electricity. The mirrors can be arranged in a variety of ways, but they all deliver the solar beam to the receiver. There are four types of commercial CSP systems: parabolic troughs, linear Fresnel, power towers and dish/engines. The first two technologies are line-focus systems, capable of concentrating the sun’s energy to produce temperatures of 400 °C, while the latter two are point-focus systems that can produce temperatures of 800 °C or higher.

Conversion efficiency. The ratio between the useful energy output from an energy conversion device and the energy input into it. For example, the conversion efficiency of a PV module is the ratio between the electricity generated and the total solar energy received by the PV module. If 100 kWh of solar radiation is received and 10 kWh of electricity is generated, the conversion efficiency is 10%.

Crowdfunding. The practice of funding a project or venture by raising money – often relatively small individual amounts – from a relatively large number of people (“crowd”), generally using the Internet and social media. The money raised through crowdfunding does not necessarily buy the lender a share in the venture, and there is no guarantee that money will be repaid if the venture is successful. However, some types of crowdfunding reward backers with an equity stake, structured payments and/or other products.

Curtailement. A reduction in the output of a generator, typically on an involuntary basis, from what it could produce otherwise given the resources available. Curtailement of electricity generation has long been a normal occurrence in the electric power industry and can occur for a variety of reasons, including a lack of transmission access or transmission congestion.

Degression. A mechanism built into policy design establishing automatic rate revisions, which can occur after specific thresholds are crossed (e.g., after a certain amount of capacity is contracted, or a certain amount of time passes).

Demand-side management. The application of economic incentives and technology in the pursuit of cost-effective energy efficiency measures and load-shifting on the customer side, to achieve least-cost overall energy system optimisation.

Demand response. Use of market signals such as time-of-use pricing, incentive payments or penalties to influence end-user electricity consumption behaviours. Usually used to balance electrical supply and demand within a power system.

Digitalisation. The application of digital technologies across the economy, including energy.

Digitisation. The conversion of something (e.g., data or an image) from analogue to digital.

Distributed generation. Generation of electricity from dispersed, generally small-scale systems that are close to the point of consumption.

Distributed renewable energy. Energy systems are considered to be distributed if 1) the systems are connected to the distribution

network rather than the transmission network, which implies that they are relatively small and dispersed (such as small-scale solar PV on rooftops) rather than relatively large and centralised; or 2) generation and distribution occur independently from a centralised network. Specifically for the purpose of the chapter on Distributed Renewables for Energy Access, “distributed renewable energy” meets both conditions. It includes energy services for electrification, cooking, heating and cooling that are generated and distributed independent of any centralised system, in urban and rural areas of the developing world.

Distribution grid. The portion of the electrical network that takes power off the high-voltage transmission network via sub-stations (at varying stepped-down voltages) and distributes electricity to customers.

Drop-in biofuel. A liquid biofuel that is functionally equivalent to a liquid fossil fuel and is fully compatible with existing fossil fuel infrastructure.

Electric vehicle (EV). Includes any road-, rail-, sea- and air-based transport vehicle that uses electric drive and can take an electric charge from an external source, or from hydrogen in the case of a fuel cell electric vehicle (FCEV). Electric road vehicles encompass battery electric vehicles (BEVs), plug-in hybrids (PHEVs) and FCEVs, all of which can include passenger vehicles (i.e., electric cars), commercial vehicles including buses and trucks, and two- and three-wheeled vehicles.

Energy. The ability to do work, which comes in a number of forms including thermal, radiant, kinetic, chemical, potential and electrical. Primary energy is the energy embodied in (energy potential of) natural resources, such as coal, natural gas and renewable sources. Final energy is the energy delivered for end-use (such as electricity at an electrical outlet). Conversion losses occur whenever primary energy needs to be transformed for final energy use, such as combustion of fossil fuels for electricity generation.

Energy audit. Analysis of energy flows in a building, process or system, conducted with the goal of reducing energy inputs into the system without negatively affecting outputs.

Energy conservation. Any change in behaviour of an energy-consuming entity for the specific purpose of affecting an energy demand reduction. Energy conservation is distinct from energy efficiency in that it is predicated on the assumption that an otherwise preferred behaviour of greater energy intensity is abandoned. (See Energy efficiency and Energy intensity.)

Energy efficiency. The measure that accounts for delivering more services for the same energy input, or the same amount of services for less energy input. Conceptually, this is the reduction of losses from the conversion of primary source fuels through final energy use, as well as other active or passive measures to reduce energy demand without diminishing the quality of energy services delivered. Energy efficiency is technology-specific and distinct from energy conservation, which pertains to behavioural change. Both energy efficiency and energy conservation can contribute to energy demand reduction.

Energy intensity. Primary energy consumption per unit of economic output. Energy intensity is a broader concept than

energy efficiency in that it is also determined by non-efficiency variables, such as the composition of economic activity. Energy intensity typically is used as a proxy for energy efficiency in macro-level analyses due to the lack of an internationally agreed-upon high-level indicator for measuring energy efficiency.

Energy service company (ESCO). A company that provides a range of energy solutions including selling the energy services from a (renewable) energy system on a long-term basis while retaining ownership of the system, collecting regular payments from customers and providing necessary maintenance service. An ESCO can be an electric utility, co-operative, non-governmental organisation or private company, and typically installs energy systems on or near customer sites. An ESCO also can advise on improving the energy efficiency of systems (such as a building or an industry) as well as on methods for energy conservation and energy management.

Energy subsidy. A government measure that artificially reduces the price that consumers pay for energy or that reduces energy production cost.

Energy sufficiency. Entails a change or shift in actions and behaviours (at the individual and collective levels) in the way energy is used. Results in access to energy for everyone while limiting the impacts of energy use on the environment. For example, avoiding the use of cars and spending less time on electrical devices.

Ethanol (fuel). A liquid fuel made from biomass (typically corn, sugar cane or small cereals/grains) that can replace petrol in modest percentages for use in ordinary spark-ignition engines (stationary or in vehicles), or that can be used at higher blend levels (usually up to 85% ethanol, or 100% in Brazil) in slightly modified engines, such as those provided in “flex-fuel” vehicles. Ethanol also is used in the chemical and beverage industries.

Fatty acid methyl esters (FAME). See Biodiesel.

Feed-in policy (feed-in tariff or feed-in premium). A policy that typically guarantees renewable generators specified payments per unit (e.g., USD per kWh) over a fixed period. Feed-in tariff (FIT) policies also may establish regulations by which generators can interconnect and sell power to the grid. Numerous options exist for defining the level of incentive, such as whether the payment is structured as a guaranteed minimum price (e.g., a FIT), or whether the payment floats on top of the wholesale electricity price (e.g., a feed-in premium).

Final energy. The part of primary energy, after deduction of losses from conversion, transmission and distribution, that reaches the consumer and is available to provide heating, hot water, lighting and other services. Final energy forms include, among others, electricity, district heating, mechanical energy, liquid hydrocarbons such as kerosene or fuel oil, and various gaseous fuels such as natural gas, biogas and hydrogen.

(Total) Final energy consumption (TFEC). Energy that is supplied to the consumer for all final energy services such as transport, cooling and lighting, building or industrial heating or mechanical work. Differs from total final consumption (TFC), which includes all energy use in end-use sectors (TFEC) as well as for non-energy applications, mainly various industrial uses, such as feedstocks for petrochemical manufacturing.

Fiscal incentive. An incentive that provides individuals, households or companies with a reduction in their contribution to the public treasury via income or other taxes.

Flywheel energy storage. Energy storage that works by applying available energy to accelerate a high-mass rotor (flywheel) to a very high speed and thereby storing energy in the system as rotational energy.

Front-of-meter system. Any power generation or storage device on the distribution or transmission side of the network. (Also see Behind-the-meter system.)

Generation. The process of converting energy into electricity and/or useful heat from a primary energy source such as wind, solar radiation, natural gas, biomass, etc.

Geothermal energy. Heat energy emitted from within the earth's crust, usually in the form of hot water and steam. It can be used to generate electricity in a thermal power plant or to provide heat directly at various temperatures.

Green bond. A bond issued by a bank or company, the proceeds of which will go entirely into renewable energy and other environmentally friendly projects. The issuer will normally label it as a green bond. There is no internationally recognised standard for what constitutes a green bond.

Green building. A building that (in its construction or operation) reduces or eliminates negative impacts and can create positive impacts on the climate and natural environment. Countries and regions have a variety of characteristics that may change their strategies for green buildings, such as building stock, climate, cultural traditions, or wide-ranging environmental, economic and social priorities – all of which shape their approach to green building.

Green energy purchasing. Voluntary purchase of renewable energy – usually electricity, but also heat and transport fuels – by residential, commercial, government or industrial consumers, either directly from an energy trader or utility company, from a third-party renewable energy generator or indirectly via trading of renewable energy certificates (such as renewable energy credits, green tags and guarantees of origin). It can create additional demand for renewable capacity and/or generation, often going beyond that resulting from government support policies or obligations.

Heat pump. A device that transfers heat from a heat source to a heat sink using a refrigeration cycle that is driven by external electric or thermal energy. It can use the ground (geothermal/ground-source), the surrounding air (aerothermal/air-source) or a body of water (hydrothermal/water-source) as a heat source in heating mode, and as a heat sink in cooling mode. A heat pump's final energy output can be several multiples of the energy input, depending on its inherent efficiency and operating condition. The output of a heat pump is at least partially renewable on a final energy basis. However, the renewable component can be much lower on a primary energy basis, depending on the composition and derivation of the input energy; in the case of electricity, this includes the efficiency of the power generation process. The output of a heat pump can be fully renewable energy if the input energy is also fully renewable.

Hydropower. Electricity derived from the potential energy of water captured when moving from higher to lower elevations.

Categories of hydropower projects include run-of-river, reservoir-based capacity and low-head in-stream technology (the least developed). Hydropower covers a continuum in project scale from large (usually defined as more than 10 MW of installed capacity, but the definition varies by country) to small, mini, micro and pico.

Hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA). Biofuels produced by using hydrogen to remove oxygen from waste cooking oils, fats and vegetable oils. The result is a hydrocarbon that can be refined to produce fuels with specifications that are closer to those of diesel and jet fuel than is biodiesel produced from triglycerides such as fatty acid methyl esters (FAME).

Inverter (and micro-inverter), solar. Inverters convert the direct current (DC) generated by solar PV modules into alternating current (AC), which can be fed into the electric grid or used by a local, off-grid network. Conventional string and central solar inverters are connected to multiple modules to create an array that effectively is a single large panel. By contrast, micro-inverters convert generation from individual solar PV modules; the output of several micro-inverters is combined and often fed into the electric grid. A primary advantage of micro-inverters is that they isolate and tune the output of individual panels, reducing the effects that shading or failure of any one (or more) module(s) has on the output of an entire array. They eliminate some design issues inherent to larger systems, and allow for new modules to be added as needed.

Investment. Purchase of an item of value with an expectation of favourable future returns. In this report, new investment in renewable energy refers to investment in: technology research and development, commercialisation, construction of manufacturing facilities and project development (including the construction of wind farms and the purchase and installation of solar PV systems). Total investment refers to new investment plus merger and acquisition (M&A) activity (the refinancing and sale of companies and projects).

Investment tax credit. A fiscal incentive that allows investments in renewable energy to be fully or partially credited against the tax obligations or income of a project developer, industry, building owner, etc.

Joule. A joule (J) is a unit of work or energy equal to the work done by a force equal to one newton acting over a distance of one metre. One joule is equal to one watt-second (the power of one watt exerted over the period of one second). The potential chemical energy stored in one barrel of oil and released when combusted is approximately 6 gigajoules (GJ); a tonne of oven-dry wood contains around 20 GJ of energy.

Levelised cost of energy/electricity (LCOE). The cost per unit of energy from an energy generating asset that is based on the present value of its total construction and lifetime operating costs, divided by total energy output expected from that asset over its lifetime.

Long-term strategic plan. A strategy to achieve energy savings over a specified period of time (i.e., several years), including specific goals and actions to improve energy efficiency, typically spanning all major sectors.

Mandate/Obligation. A measure that requires designated parties (consumers, suppliers, generators) to meet a minimum – and often gradually increasing – standard for renewable energy (or energy efficiency), such as a percentage of total supply, a stated amount of capacity, or the required use of a specified renewable technology. Costs generally are borne by consumers. Mandates can include renewable portfolio standards (RPS); building codes or obligations that require the installation of renewable heat or power technologies (often in combination with energy efficiency investments); renewable heat purchase requirements; and requirements for blending specified shares of biofuels (biodiesel or ethanol) into transport fuel.

Market concession model. A model in which a private company or non-governmental organisation is selected through a competitive process and given the exclusive obligation to provide energy services to customers in its service territory, upon customer request. The concession approach allows concessionaires to select the most appropriate and cost-effective technology for a given situation.

Merit order. A way of ranking available sources of energy (particularly electricity generation) in ascending order based on short-run marginal costs of production, such that those with the lowest marginal costs are the first ones brought online to meet demand, and those with the highest are brought on last. The merit-order effect is a shift of market prices along the merit-order or supply curve due to market entry of power stations with lower variable costs (marginal costs). This displaces power stations with the highest production costs from the market (assuming demand is unchanged) and admits lower-priced electricity into the market.

Mini-grid / Micro-grid For distributed renewable energy systems for energy access, a mini-grid/micro-grid typically refers to an independent grid network operating on a scale of less than 10 MW (with most at very small scale) that distributes electricity to a limited number of customers. Mini-/micro-grids also can refer to much larger networks (e.g., for corporate or university campuses) that can operate independently of, or in conjunction with, the main power grid. However, there is no universal definition differentiating mini- and micro-grids.

Molten salt. An energy storage medium used predominantly to retain the thermal energy collected by a solar tower or solar trough of a concentrating solar power plant, so that this energy can be used at a later time to generate electricity.

Monitoring. Energy use is monitored to establish a basis for energy management and to provide information on deviations from established patterns.

Municipal solid waste. Waste materials generated by households and similar waste produced by commercial, industrial or institutional entities. The wastes are a mixture of renewable plant and fossil-based materials, with the proportions varying depending on local circumstances. A default value that assumes that at least 50% of the material is “renewable” is often applied.

Net metering / Net billing. A regulated arrangement in which utility customers with on-site electricity generators can receive credits for excess generation, which can be applied to offset consumption in other billing periods. Under net metering,

customers typically receive credit at the level of the retail electricity price. Under net billing, customers typically receive credit for excess power at a rate that is lower than the retail electricity price. Different jurisdictions may apply these terms in different ways, however.

Net zero carbon building / Net zero energy building / Nearly zero energy building. Various definitions have emerged of buildings that achieve high levels of energy efficiency and meet remaining energy demand with either on-site or off-site renewable energy. For example, the World Green Building Council's Net Zero Carbon Buildings Commitment considers use of renewable energy as one of five key components that characterise a net zero building. Definitions of net zero carbon, net zero energy and nearly zero energy buildings can vary in scope and geographic relevance.

Ocean power. Refers to technologies used to generate electricity by harnessing from the ocean the energy potential of ocean waves, tidal range (rise and fall), tidal streams, ocean (permanent) currents, temperature gradients (ocean thermal energy conversion) and salinity gradients. The definition of ocean power used in this report does not include offshore wind power or marine biomass energy.

Off-take agreement. An agreement between a producer of energy and a buyer of energy to purchase/sell portions of the producer's future production. An off-take agreement normally is negotiated prior to the construction of a renewable energy project or installation of renewable energy equipment in order to secure a market for the future output (e.g., electricity, heat). Examples of this type of agreement include power purchase agreements and feed-in tariffs.

Off-taker. The purchaser of the energy from a renewable energy project or installation (e.g., a utility company) following an off-take agreement. (See Off-take agreement.)

Pay-as-you-go (PAYGo). A business model that gives customers (mainly in areas without access to the electricity grid) the possibility to purchase small-scale energy-producing products, such as solar home systems, by paying in small instalments over time.

Peaker generation plant. Power plants that run predominantly during peak demand periods for electricity. Such plants exhibit the optimum balance – for peaking duty – of relatively high variable cost (fuel and maintenance cost per unit of generation) relative to fixed cost per unit of energy produced (low capital cost per unit of generating capacity).

Pico solar devices / pico solar systems. Small solar systems such as solar lanterns that are designed to provide only a limited amount of electricity service, usually lighting and in some cases mobile phone charging. Such systems are deployed mainly in areas that have no or poor access to electricity. The systems usually have a power output of 1-10 watts and a voltage of up to 12 volts.

Plug-in hybrid electric vehicle. This differs from a simple hybrid vehicle, as the latter uses electric energy produced only by braking or through the vehicle's internal combustion engine. Therefore, only a plug-in hybrid electric vehicle allows for the

use of electricity from renewable sources. Although not an avenue for increased penetration of renewable electricity, hybrid vehicles contribute to reduced fuel demand and remain far more numerous than EVs.

Power. The rate at which energy is converted into work, expressed in watts (joules/second).

Power purchase agreement (PPA). A contract between two parties, one that generates electricity (the seller) and one that is looking to purchase electricity (the buyer).

Power-to-gas (P2G). The conversion of electricity, either from renewable or conventional sources, to a gaseous fuel (for example, hydrogen or methane).

Primary energy. The theoretically available energy content of a naturally occurring energy source (such as coal, oil, natural gas, uranium ore, geothermal and biomass energy, etc.) before it undergoes conversion to useful final energy delivered to the end-user. Conversion of primary energy into other forms of useful final energy (such as electricity and fuels) entails losses. Some primary energy is consumed at the end-user level as final energy without any prior conversion.

Primary energy consumption. The direct use of energy at the source, or supplying users with unprocessed fuel.

Product and sectoral standards. Rules specifying the minimum standards for certain products (e.g., appliances) or sectors (industry, transport, etc.) for increasing energy efficiency.

Production tax credit. A tax incentive that provides the investor or owner of a qualifying property or facility with a tax credit based on the amount of renewable energy (electricity, heat or biofuel) generated by that facility.

Productive use of energy. Often used in the context of distributed renewables for energy access to refer to activities that use energy to generate income, increase productivity, enhance diversity and create economic value. Productive uses of energy may include local activities such as agriculture, livestock and fishing; light mechanical works such as welding, carpentry and water pumping; small retail and commercial activities such as tailoring, printing, catering and entertainment; and small and medium-scale production such as agro-processing (grinding, milling and husking), refrigeration and cold storage, drying, preserving and smoking.

Property Assessed Clean Energy (PACE) financing. Provides access to low-interest loans for renewable energy that can be repaid through increases on property taxes.

Prosumer. An individual, household or small business that not only consumes energy but also produces it. Prosumers may play an active role in energy storage and demand-side management.

Public financing. A type of financial support mechanism whereby governments provide assistance, often in the form of grants or loans, to support the development or deployment of renewable energy technologies.

Pumped storage. Plants that pump water from a lower reservoir to a higher storage basin using surplus electricity, and that reverse the flow to generate electricity when needed. They are not energy sources but means of energy storage and can have overall system efficiencies of around 80-90%.

Regulatory policy. A rule to guide or control the conduct of those to whom it applies. In the renewable energy context, examples include mandates or quotas such as renewable portfolio standards, feed-in tariffs and technology/fuel-specific obligations.

Renewable energy certificate (REC). A certificate awarded to certify the generation of one unit of renewable energy (typically 1 MWh of electricity but also less commonly of heat). In systems based on RECs, certificates can be accumulated to meet renewable energy obligations and also provide a tool for trading among consumers and/or producers. They also are a means of enabling purchases of voluntary green energy.

Renewable hydrogen. Hydrogen produced from renewable energy, most commonly through the use of renewable electricity to split water into hydrogen and oxygen in an electrolyser. The vast majority of hydrogen is still produced from fossil fuels, and the majority of policies and programmes focused on hydrogen do not include a focus on renewables-based production.

Renewable natural gas (RNG). Gas that is produced through the anaerobic digestion of organic matter and processed to remove the carbon dioxide and other gases, leaving methane that meets a high specification and that can be interchangeable with conventional natural gas. See Biomethane.

Renewable portfolio standard (RPS). An obligation placed by a government on a utility company, group of companies or consumers to provide or use a predetermined minimum targeted renewable share of installed capacity, or of electricity or heat generated or sold. A penalty may or may not exist for non-compliance. These policies also are known as "renewable electricity standards", "renewable obligations" and "mandated market shares", depending on the jurisdiction.

Reverse auction. See Tendering.

Sector integration (also called sector coupling). The integration of energy supply and demand across electricity, thermal and transport applications, which may occur via co-production, combined use, conversion and substitution.

Smart energy system. An energy system that aims to optimise the overall efficiency and balance of a range of interconnected energy technologies and processes, both electrical and non-electrical (including heat, gas and fuels). This is achieved through dynamic demand- and supply-side management; enhanced monitoring of electrical, thermal and fuel-based system assets; control and optimisation of consumer equipment, appliances and services; better integration of distributed energy (on both the macro and micro scales); and cost minimisation for both suppliers and consumers.

Smart grid. Electrical grid that uses information and communications technology to co-ordinate the needs and capabilities of the generators, grid operators, end-users and electricity market stakeholders in a system, with the aim of operating all parts as efficiently as possible, minimising costs and environmental impacts and maximising system reliability, resilience and stability.

Smart grid technology. Advanced information and control technology that is required for improved systems integration and resource optimisation on the grid.

Smart inverter. An inverter with robust software that is capable of rapid, bidirectional communications, which utilities can control remotely to help with issues such as voltage and frequency fluctuations in order to stabilise the grid during disruptive events.

Solar collector. A device used for converting solar energy to thermal energy (heat), typically used for domestic water heating but also used for space heating, for industrial process heat or to drive thermal cooling machines. Evacuated tube and flat plate collectors that operate with water or a water/glycol mixture as the heat-transfer medium are the most common solar thermal collectors used worldwide. These are referred to as glazed water collectors because irradiation from the sun first hits a glazing (for thermal insulation) before the energy is converted to heat and transported away by the heat transfer medium. Unglazed water collectors, often referred to as swimming pool absorbers, are simple collectors made of plastics and used for lower-temperature applications. Unglazed and glazed air collectors use air rather than water as the heat-transfer medium to heat indoor spaces or to pre-heat drying air or combustion air for agriculture and industry purposes.

Solar cooker. A cooking device for household and institutional applications that converts sunlight to heat energy that is retained for cooking. There are several types of solar cookers, including box cookers, panel cookers, parabolic cookers, evacuated tube cookers and trough cookers.

Solar home system. A stand-alone system composed of a relatively low-power photovoltaic module, a battery and sometimes a charge controller that can provide modest amounts of electricity for home lighting, communications and appliances, usually in rural or remote regions that are not connected to the electricity grid. The term solar home system kit is also used to define systems that usually are branded and have components that are easy for users to install and use.

Solar photovoltaics (PV). A technology used for converting light directly into electricity. Solar PV cells are constructed from semiconducting materials that use sunlight to separate electrons from atoms to create an electric current. Modules are formed by interconnecting individual cells. Building-integrated PV (BIPV) generates electricity and replaces conventional materials in parts of a building envelope, such as the roof or facade.

Solar photovoltaic-thermal (PV-T). A solar PV-thermal hybrid system that includes solar thermal collectors mounted beneath PV modules to convert solar radiation into electrical and thermal energy. The solar thermal collector removes waste heat from the PV module, enabling it to operate more efficiently.

Solar-plus-storage. A hybrid technology of solar PV with battery storage. Other types of renewable energy-plus-storage plants also exist.

Solar water heater (SWH). An entire system consisting of a solar collector, storage tank, water pipes and other components. There are two types of solar water heaters: pumped solar water heaters use mechanical pumps to circulate a heat transfer fluid through the collector loop (active systems), whereas thermosiphon solar water heaters make use of buoyancy forces caused by natural convection (passive systems).

Storage battery. A type of battery that can be given a new charge by passing an electric current through it. A lithium-ion battery uses a liquid lithium-based material for one of its electrodes. A lead-acid battery uses plates made of pure lead or lead oxide for the electrodes and sulphuric acid for the electrolyte, and remains common for off-grid installations. A flow battery uses two chemical components dissolved in liquids contained within the system and most commonly separated by a membrane. Flow batteries can be recharged almost instantly by replacing the electrolyte liquid, while simultaneously recovering the spent material for re-energisation.

Sustainable aviation fuel. According to the International Civil Aviation Organization, such fuels are produced from three families of bio-feedstock: the family of oils and fats (or triglycerides), the family of sugars and the family of lignocellulosic feedstock.

Target. An official commitment, plan or goal set by a government (at the local, state, national or regional level) to achieve a certain amount of renewable energy or energy efficiency by a future date. Targets may be backed by specific compliance mechanisms or policy support measures. Some targets are legislated, while others are set by regulatory agencies, ministries or public officials.

Tender (also called auction / reverse auction or tender). A procurement mechanism by which renewable energy supply or capacity is competitively solicited from sellers, who offer bids at the lowest price that they would be willing to accept. Bids may be evaluated on both price and non-price factors.

Thermal energy storage. Technology that allows the transfer and storage of thermal energy. (See Molten salt.)

Torrefied wood. Solid fuel, often in the form of pellets, produced by heating wood to 200-300 °C in restricted air conditions. It has useful characteristics for a solid fuel including relatively high energy density, good grindability into pulverised fuel and water repellency.

Transmission grid. The portion of the electrical supply distribution network that carries bulk electricity from power plants to sub-stations, where voltage is stepped down for further distribution. High-voltage transmission lines can carry electricity between regional grids in order to balance supply and demand.

Variable renewable energy (VRE). A renewable energy source that fluctuates within a relatively short time frame, such as wind and solar energy, which vary within daily, hourly and even sub-hourly time frames. By contrast, resources and technologies that are variable on an annual or seasonal basis due to environmental changes, such as hydropower (due to changes in rainfall) and thermal power plants (due to changes in temperature of ambient air and cooling water), do not fall into this category.

Vehicle fuel standard. A rule specifying the minimum fuel economy of automobiles.

Vehicle-to-grid (V2G). A system in which electric vehicles – whether battery electric or plug-in hybrid – communicate with the grid in order to sell response services by returning electricity from the vehicles to the electric grid or by altering the rate of charging.

Virtual net metering. Virtual (or group) net metering allows electricity utility consumers to share the output of a renewable power project. By receiving “energy credits” based on project output and their ownership share of the project, consumers are able to offset costs on their electricity utility bill.

Virtual power plant (VPP). A network of decentralised, independently owned and operated power generating units combined with flexible demand units and possibly also with storage facilities. A central control station monitors operation, forecasts demand and supply, and dispatches the networked units as if they were a single power plant. The aim is to smoothly integrate a high number of renewable energy units into existing energy systems; VPPs also enable the trading or selling of power into wholesale markets.

Virtual power purchase agreement (PPA). A contract under which the developer sells its electricity in the spot market. The developer and the corporate off-taker then settle the difference between the variable market price and the strike price, and the off-taker receives the electricity certificates that are generated. This is in contrast to more traditional PPAs, under which the developer sells electricity to the off-taker directly.

Voltage and frequency control. The process of maintaining grid voltage and frequency stable within a narrow band through management of system resources.

Watt. A unit of power that measures the rate of energy conversion or transfer. A kilowatt is equal to 1 thousand watts; a megawatt to 1 million watts; and so on. A megawatt-electrical (MW_e) is used to refer to electric power, whereas a megawatt-thermal (MW_{th}) refers to thermal/heat energy produced. Power is the rate at which energy is consumed or generated. A kilowatt-hour is the amount of energy equivalent to steady power of 1 kW operating for one hour.



LIST OF ABBREVIATIONS

AC	Alternating current	kgoe	Kilogram of oil equivalent
ACER	Agency for the Cooperation of Energy Regulators	ktoe	Kilotonne of oil equivalent
AfDB	African Development Bank	kW/kWh	Kilowatt/kilowatt-hour
AUD	Australian dollar	kW _{th}	kilowatt-thermal
BEV	Battery electric vehicle	LBG	Liquefied biogas
Bloomberg NEF	Bloomberg New Energy Finance	LCOE	Levelised cost of energy (or electricity)
BRICS	Brazil, Russian Federation, India, China and South Africa	LNG	Liquefied natural gas
BRL	Brazilian real	LPG	Liquefied petroleum gas
CAD	Canadian dollar	M&A	Mergers and acquisitions
CCA	Community choice aggregation	m ²	Square metre
CHP	Combined heat and power	m ³	Cubic metre
CNG	Compressed natural gas	MAD	Moroccan dirham
CNY	Chinese yuan	MENA	Middle East and North Africa
CO ₂	Carbon dioxide	MJ	Megajoule
COP	Conference of the Parties	MSW	Municipal solid waste
CSP	Concentrating solar thermal power	Mtoe	Megatonne of oil equivalent
DC	Direct current	MW/MWh	Megawatt/megawatt-hour
DFI	Development finance institution	MW _{th}	Megawatt-thermal
DHC	District heating and cooling	MXN	Mexican peso
DRE	Distributed renewable energy	NDC	Nationally Determined Contribution
DREA	Distributed renewables for energy access	NIMBY	Not In My Back Yard
EC	European Commission	NOK	Norwegian krone
EGS	Enhanced (or engineered) geothermal systems	O&M	Operations and maintenance
EDFI	Association of bilateral European Development Finance Institutions	OECD	Organisation for Economic Co-operation and Development
EIA	Environmental impact assessment	OTEC	Ocean thermal energy conversion
EJ	Exajoule	P2G	Power-to-gas
EMEC	European Marine Energy Centre	PAYGo	Pay-as-you-go
EPA	Environmental Protection Agency	PERC	Passivated Emitter Rear Cell
ESCO	Energy service company	PHEV	Plug-in hybrid electric vehicle
ESIA	Environmental and social impact assessment	PJ	Petajoule
EU	European Union (specifically the EU-28)	PLN	Polish zloty
EUR	Euro	PPA	Power purchase agreement
EV	Electric vehicle	PPP	Purchasing power parity
FAME	Fatty acid methyl esters	PTC	Production Tax Credit
FCEV	Fuel cell electric vehicle	PV	Photovoltaic
FIT	Feed-in tariff	QAR	Qatari rial
FS	Frankfurt School	R&D	Research and development
FTA	Free trade agreement	REC	Renewable electricity certificate
G5	Group of Five	RED	EU Renewable Energy Directive
G20	Group of Twenty	RFS	US Renewable Fuel Standard
GBP	British pound	RNG	Renewable natural gas
GDP	Gross domestic product	RPS	Renewable portfolio standard
GO	Guarantee of origin	SDG	Sustainable Development Goal
GSR	Global Status Report	SEK	Swedish krona
GW/GWh	Gigawatt/gigawatt-hour	SHIP	Solar heat for industrial processes
GW _{th}	Gigawatt-thermal	SUV	Sport utility vehicle
GWEC	Global Wind Energy Council	TES	Thermal energy storage
HEFA	Hydrotreated esters and fatty acids	TFC	Total final consumption
HJT	Heterojunction cell technology	TFEC	Total final energy consumption
HVAC	Heating, ventilation, and air-conditioning	THB	Thai baht
HVO	Hydrotreated vegetable oil	Toe	Tonne of oil equivalent
ICAO	International Civil Aviation Organization	TW/TWh	Terawatt/terawatt-hour
ICE	Internal combustion engine	UN	United Nations
IDCOL	Infrastructure Development Company Limited	UNEP	United Nations Environment Programme
IEC	International Electrotechnical Commission	UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency	UNHCR	United Nations High Commissioner for Refugees
IEA PVPS	IEA Photovoltaic Power Systems Programme	USD	United States dollar
IEA SHC	IEA Solar Heating and Cooling Programme	V2G	Vehicle-to-grid
IFC	International Finance Corporation	VAT	Value-added tax
IHA	International Hydropower Association	VC/PE	Venture capital and private equity
INR	Indian rupee	VNM	Virtual net metering
IPP	Independent power producer	VRE	Variable renewable electricity
ISCC	Integrated solar combined-cycle	W/Wh	Watt/watt-hour
IRENA	International Renewable Energy Agency	WTO	World Trade Organization
ITC	Investment Tax Credit	ZEV	Zero emission vehicle

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France



GLOBAL OVERVIEW

1 This chapter strives to capture the cross-cutting and sectoral trends in renewable energy – within the larger energy and climate context – during the year 2019, and in some cases, early 2020. Where older data are used, these were the latest data available to REN21 at the time of publication. **Sidebar 1** based on the following sources: Saudi Arabia and the Russian Federation increased oil production following suspension of agreed cuts among the Organization of the Petroleum Exporting Countries (OPEC) and partner countries, leading to an oversupply, from US Energy Information Administration (EIA), "Oil market volatility is at an all-time high", *Today in Energy*, 27 March 2020, <https://www.eia.gov/todayinenergy/detail.php?id=43275>, and from C. Krauss, "Oil companies on tumbling prices: 'disastrous, devastating'", *New York Times*, 31 March 2020, <https://www.nytimes.com/2020/03/31/business/energy-environment/crude-oil-companies-coronavirus.html>; reductions in electricity demand from International Energy Agency (IEA), "Electricity", in *Global Energy Review 2020* (Paris: April 2020), <https://www.iea.org/reports/global-energy-review-2020/electricity>; growth in demand for renewables from IEA, "Renewables", in *Global Energy Review 2020*, op. cit. this note, <https://www.iea.org/reports/global-energy-review-2020/renewables>; carbon intensity from IEA, "Electricity", op. cit. this note, and from D. Jones, "Analysis: Coronavirus has cut CO₂ from Europe's electricity system by 39%", *Carbon Brief*, 29 April 2020, <https://www.carbonbrief.org/analysis-coronavirus-has-cut-co2-from-europes-electricity-system-by-39-per-cent>; air quality from American Geophysical Union, "COVID-19 lockdowns significantly impacting global air quality", 11 May 2020, <https://phys.org/news/2020-05-covid-lockdowns-significantly-impacting-global.html>; record CO₂ concentration from R. Betts et al., "Analysis: What impact will the coronavirus pandemic have on atmospheric CO₂?" *Carbon Brief*, 7 May 2020, <https://www.carbonbrief.org/analysis-what-impact-will-the-coronavirus-pandemic-have-on-atmospheric-co2>, and from United Nations Environment Programme (UNEP), "Record global carbon dioxide concentrations despite COVID-19 crisis", 11 May 2020, <https://www.unenvironment.org/news-and-stories/story/record-global-carbon-dioxide-concentrations-despite-covid-19-crisis>; long-term impacts from World Economic Forum, *The A-Z of the Energy Transition: Knowns and Unknowns* (Geneva: 2020), http://www3.weforum.org/docs/WEF_Energy_transition_known_and_unknown_2020.pdf, and from D. G. Victor, "Forecasting energy futures amid the coronavirus outbreak", *Brookings*, 3 April 2020, <https://www.brookings.edu/blog/order-from-chaos/2020/04/03/forecasting-energy-futures-amid-the-coronavirus-outbreak>; accommodations in electricity networks from S. Jewkes and C. Steitz, "Grid operators turn control centers into campsites to keep coronavirus at bay", *Reuters*, 26 March 2020, <https://www.reuters.com/article/us-health-coronavirus-power-grids/grid-operators-turn-control-centers-into-campsites-to-keep-coronavirus-at-bay-idUSKBN21D0P1>. Historic highs from the following sources: Smart Energy International, "Renewables set to win during China's COVID-19 lockdown", 27 March 2020, <http://www.smart-energy.com/renewable-energy/renewables-set-to-win-during-chinas-covid-19-lockdown>; Wärtsilä Corporation, "European responses to Covid-19 accelerate the electricity system transition by a decade, according to Wärtsilä analysis", 17 April 2020, <https://news.cision.com/wartsila-corporation/tr/european-responses-to-covid-19-accelerate-the-electricity-system-transition-by-a-decade--according-t-c3090780>; S. Diehn, "Living Planet: German renewables break new record", *DW*, 7 May 2020, <https://www.dw.com/en/living-planet-german-renewables-break-new-record/av-53359568>; C. Farand, "Coronavirus lockdown speeds India's shift from coal to solar power", *Climate Home News*, 7 May 2020, <https://www.climatechangenews.com/2020/05/07/coronavirus-lockdown-speeds-indias-shift-coal-solar-power>; Smart Energy International, "UK first: Renewables overtook coal in Q1 2020, partly thanks to COVID-19", 7 April 2020, <https://www.smart-energy.com/renewable-energy/uk-first-renewables-overtook-coal-in-q1-2020-partly-thanks-to-covid-19>; S. Feaster, "IEEFA update: Renewables surpass coal in U.S. power generation throughout the month of April 2020", *Institute for Energy Economics and Financial Analysis*, 4 May 2020, <https://ieefa.org/ieefa-update-renewables-surpass-coal-in-u-s-power-generation-throughout-the-month-of-april-2020>. Fall of coal-fired generation in EU and UK from Wärtsilä Corporation, op. cit. this note. Curtailments from J. St. John, "California renewables curtailments surge as coronavirus cuts energy demand", *GTM*, 2 April 2020, <https://www.greentechmedia.com/amp/article/>

california-renewable-curtailments-spike-as-coronavirus-reduces-demand, from A. Moyo, "Uncertainties shroud renewable energy deals in short-term", *ITWeb*, 4 May 2020, <https://www.itweb.co.za/content/JN1gP7OYm8jqJL6m>, and from Jewkes and Steitz, op. cit. this note. Labour and supply chain challenges from the following: B. Eckhouse, "U.S. solar workforce could be halved by virus, group says", *Bloomberg*, 23 March 2020, <https://www.bloomberg.com/news/articles/2020-03-23/u-s-solar-workforce-could-be-cut-in-half-by-virus-group-says>; BloombergNEF, "Covid-19 wreaks havoc on the wind industry", 1 April 2020, <https://about.bnef.com/blog/covid-19-wreaks-havoc-on-the-wind-industry>; D. Marhewka, L. Blunson and D. Haverbeke, "Coronavirus: An ill wind for corporate PPAs?" *pv magazine*, 7 April 2020, <https://www.pv-magazine.com/2020/04/07/coronavirus-an-ill-wind-for-corporate-ppas>; WindEurope, "COVID-19 wind information hub", <https://windeurope.org/newsroom/covid19>, viewed 11 May 2020; supply from China from Global Wind Energy Council (GWEC), "Wind industry & COVID-19 update", 8 April 2020, <https://gwec.net/wp-content/uploads/2020/04/20200408-Wind-Industry-COVID19-Update-Impact-in-China.pdf>. Turbine manufacturers from A. Frangoul, "Coronavirus continues to impact the wind energy sector as Germany's Nordex withdraws guidance", *CNBC*, 6 May 2020, <https://www.cnbc.com/2020/05/06/coronavirus-continues-to-impact-wind-energy-nordex-withdraws-guidance.html>; offshore wind from BloombergNEF, "Covid-19 wreaks havoc on the wind industry", op. cit. this note; government extensions from idem; B. Geman, "Treasury Department plans breathing room for renewable energy industry", *Axios*, 8 May 2020, <https://www.axios.com/treasury-department-renewable-energy-relief-b9c13602-2847-4d00-a5ec-9eb46e72ed39.html>; ETEnergyWorld, "COVID-19: MNRE grants 30-day extension for renewable energy projects beyond lockdown", 21 April 2020, <https://energy.economictimes.indiatimes.com/news/renewable/covid-19-mnre-grants-30-day-extension-for-renewable-energy-projects-beyond-lockdown/75274193>. Examples of invaluable DREA systems from the following: hospitals from Sustainable Energy for All (SEforALL), "COVID-19 response: Powering health facilities", <https://www.seforall.org/energy-and-health/covid-19-response-powering-health-facilities>, viewed 27 May 2020, and from "Fighting COVID-19: A solar-powered hospital in rural Jharkhand takes on the pandemic", *Sun Connect News*, 25 May 2020, <https://www.sun-connect-news.org/articles/off-grid-living/details/fighting-covid-19-a-solar-powered-hospital-in-rural-jharkhand-takes-on-the-pandemic>; digital service centres from SELCO Foundation, "Solar powered digital service centres supporting communities during COVID19. Stories of resilience", 30 April 2020, <https://www.covid-19.selcofoundation.org/stories-of-resilience-solar-powered-digital-service-centres-supporting-communities-during-covid19>; facilities producing personal protective equipment (PPE) from SELCO Foundation, "Solar powered tailoring centre for PPE in remote Meghalaya. Stories of resilience", 25 April 2020, <https://www.covid-19.selcofoundation.org/stories-of-resilience-solar-powered-tailoring-centre-for-ppe-in-remote-meghalaya>, and from SELCO Foundation, "Solar-powered mask production centre by the Urmul Desert Crafts. Stories of resilience", 8 May 2020, <https://www.covid-19.selcofoundation.org/stories-of-resilience-solar-powered-ppe-production-centre-by-the-urmul-desert-crafts>. Threats to DREA future and possible responses from Alliance for Rural Electrification (ARE), "Call to action: Roadmap for the DRE sector to survive and flourish in the wake of the COVID-19 crisis", <http://www.ruralelec.org/publications/call-action-roadmap-dre-sector-survive-and-flourish-wake-covid-19-crisis>, viewed 27 May 2020, and from K. Peters, "COVID-19: How GOGLA is helping the off-grid solar industry deal with the crisis", *GOGLA*, 17 April 2020, <https://www.gogla.org/about-us/blogs/covid-19-how-gogla-is-helping-the-off-grid-solar-industry-deal-with-the-crisis>. PPAs from D. Marhewka, L. Blunson and D. Haverbeke, "Coronavirus: An ill wind for corporate PPAs?" *pv magazine*, 7 April 2020, <https://www.pv-magazine.com/2020/04/07/coronavirus-an-ill-wind-for-corporate-ppas>, and from J. Tundermann, "Understanding the Impact of COVID-19 on the Renewable Energy Industry", *Level Ten Energy*, 13 April 2020, <https://leveltenenergy.com/blog/clean-energy-experts/covid-renewable-energy-industry>; economic recession from A. Rappeport and J. Smialek, "I.M.F. predicts worst downturn since the Great Depression", *New York Times*, 29 April 2020, and from B. White, "Fears mount of a coronavirus-induced depression", *Politico*, 23 March 2020, <https://www.politico.com/news/2020/03/23/great-depression-coronavirus-induced-calamity-145304>; pressure on budgets from H. Bahar,

- "The coronavirus pandemic could derail renewable energy's progress. Governments can help", IEA, 4 April 2020, <https://www.iea.org/commentaries/the-coronavirus-pandemic-could-derail-renewable-energy-s-progress-governments-can-help>; credit crunch from G. Gopinath, "The great lockdown: Worst economic downturn since the Great Depression", IMF, 14 April 2020, <https://blogs.imf.org/2020/04/14/the-great-lockdown-worst-economic-downturn-since-the-great-depression/>; lender reluctance from Tundermann, op. cit. this note; low oil and gas prices from E. Crooks, "Renewable energy shows its strength in the coronavirus crisis", Wood Mackenzie, 1 May 2020, <https://www.woodmac.com/news/opinion/renewable-energy-shows-its-strength-in-the-coronavirus-crisis/>; capacity to cope from BloombergNEF, "Covid-19 wreaks havoc on the wind industry", op. cit. this note; Bahar, op. cit. this note; recovery packages from C. Hepburn et al., "Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?" *Oxford Review of Economic Policy*, 8 May 2020, <https://academic.oup.com/oxrep/advance-article/doi/10.1093/oxrep/graa015/5832003>; energy security from US National Renewable Energy Laboratory (NREL), *Renewable Energy to Support Energy Security* (Golden, CO: October 2019), pp. 1-3, <https://www.nrel.gov/docs/fy20osti/74617.pdf>; benefits of renewables from Renewable Energy Policy Network for the 21st Century (REN21), *Renewables in Cities: 2019 Global Status Report* (Paris: 2019), https://www.ren21.net/wp-content/uploads/2019/05/REC-2019-GSR_Full_Report_web.pdf. Calls for a green recovery from, for example, the following: Bahar, op. cit. this note; IMF Department of Fiscal Affairs, *Greening the Recovery* (Washington, DC: 2020), pp. 1-3, <https://www.imf.org/~media/Files/Publications/covid19-special-notes/en-special-series-on-covid-19-greening-the-recovery.ashx>; A. Guterres, "Parallel threats of COVID-19, climate change, require 'brave, visionary and collaborative leadership': UN chief", UN News, 28 April 2020, <https://news.un.org/en/story/2020/04/1062752>; Institutional Investors Group on Climate Change (IIGCC), "Global statement on a sustainable economic recovery from the Covid-19 pandemic", 4 May 2020, <https://www.iigcc.org/resource/global-statement-on-a-sustainable-recovery-from-the-covid-19-pandemic/>; IEA, "Ministerial roundtable on Economic Recovery through Investments in Clean Energy", 24 April 2020, <https://www.iea.org/events/ministerial-roundtable-on-economic-recovery-through-investments-in-clean-energy/>; F. Simon, "Energy firms rally behind green stimulus call", EURACTIV, 6 May 2020, <https://www.euractiv.com/section/energy-environment/news/energy-firms-rally-behind-green-stimulus-call>.
- 2 Carbon Tracker Initiative, *How to Waste Over Half a Trillion Dollars: The Economic Implications of Deflationary Renewable Energy for Coal Power Investments* (London: 2020), <https://carbontracker.org/reports/how-to-waste-over-half-a-trillion-dollars/>; BloombergNEF, "Scale-up of solar and wind puts existing coal, gas at risk", 28 April 2020, <https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/>; SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023* (Brussels: 2019), pp. 9, 13, <https://www.solarpowereurope.org/global-market-outlook-2019-2023/>; J. Yan et al., "City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China", *Nature Energy*, 12 August 2019, <https://www.nature.com/articles/s41560-019-0441-z>; K. Samanta, "India's renewable energy cost lowest in Asia Pacific: WoodMac", *Reuters*, 29 July 2019, <https://www.reuters.com/article/us-india-renewables-woodmac/indias-renewable-energy-cost-lowest-in-asia-pacific-woodmac-idUSKCN1UO0L8>.
 - 3 Carbon Tracker Initiative, op. cit. note 2; BloombergNEF, op. cit. note 2; SolarPower Europe, op. cit. note 2, pp. 9, 13; Samanta, op. cit. note 2.
 - 4 Note that costs vary and are dependent on size, location and technology, from US EIA, *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020* (Washington, DC: February 2020), https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf; US Department of Energy (DOE), *2018 Wind Technologies Market Report* (Washington, DC: 2019), p. 61, https://emp.lbl.gov/sites/default/files/wtmr_final_for_posting_8-9-19.pdf; BloombergNEF, op. cit. note 2; SolarPower Europe, op. cit. note 2, pp. 9, 13; GWEC, *Global Wind Report 2019* (Brussels: 2020), p. 8, <https://gwec.net/global-wind-report-2019/>; International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2019* (Abu Dhabi: 2020), <https://www.irena.org/costs>.
 - 5 Estimate of 32 countries in 2019 from data for more than 75 countries based on the world's top countries for cumulative capacity of hydropower, wind, solar PV, bio-power, concentrating solar thermal power (CSP), geothermal and ocean power; see Market and Industry chapter and related endnotes for more details. **Hydropower** data from IHA, *Hydropower Status Report 2020* (London: May 2020), https://www.hydropower.org/sites/default/files/publications-docs/2020_hydropower_status_report_-_28_may_2020.pdf and personal communication with REN21, 25 May 2020; from China National Energy Agency, "National Energy Administration released statistics on national power industry in 2018", 18 January 2019, http://www.nea.gov.cn/2019-01/18/c_137754977.htm, and from Federal Ministry for Economic Affairs and Energy (BMWi), Working Group on Renewable Energy Statistics (AGEE-Stat), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland – Stand: Februar 2020* (Dessau-Roßlau: 2020), https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html. **Wind power** data from GWEC, op. cit. note 4, p. 36, and from endnote 22 in Wind Power section of Market and Industry chapter. **Solar PV** data collected in direct current and mainly from IEA Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global Photovoltaic Markets 2020*, p. 6, <https://iea-pvps.org/snapshot-reports/snapshot-2020>, and from endnote 25 in Solar PV section of Market and Industry chapter. **Bio-power** from IEA, *Renewables 2019* (Paris: 2019), <https://www.iea.org/reports/renewables-2019>, and from US Federal Energy Regulatory Commission, "Office of Energy Projects Energy Infrastructure Update for December 2019" (Washington, DC: 2019), <https://www.ferc.gov/legal/staff-reports/2018/dec-energy-infrastructure.pdf>; BMWi, "Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, 1990-2019", Table 4, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html, updated March 2020; UK Department for Business, Energy and Industrial Strategy (BEIS), "Energy Trends: Renewables", Table 6.1, <https://www.gov.uk/government/statistics/energy-trends-section-6-renewables>, updated 26 March 2020; Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements) for 2018 and 2019", <https://mnre.gov.in/physical-progress-achievements>, viewed 23 February 2020; data for other countries based on forecast 2019 capacity figures from IEA, op. cit. this note, datafiles. **Geothermal** from the following sources: IEA, op. cit. this note; *US EIA, Electric Power Monthly with Data for December 2019* (Washington, DC: February 2020), Table 6.2.B, https://www.eia.gov/electricity/monthly/current_month/epm.pdf; BMWi, op. cit. this note; Turkey from endnote 1 in Geothermal section of Market and Industry chapter. **CSP** capacity was limited to 14 countries; for data and references, see CSP section of Market and Industry chapter and Reference Table R17. **Ocean power** capacity was negligible worldwide and had no effect on capacity rankings or whether or not a certain country exceeded 10 GW of capacity. Where national data were unavailable from previously referenced sources, gaps were filled from IRENA, "Renewable Electricity Capacity and Generation Statistics", <http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=54>, viewed on multiple occasions in April and May 2020; figure of 19 countries in 2009 from IRENA, idem.
 - 6 **Sidebar 2** from the following sources: *Power for All, Powering Jobs Census 2019: The Energy Access Workforce* (July 2019), <https://www.powerforall.org/resources/reports/powering-jobs-census-2019-energy-access-workforce/>; IRENA, *Renewable Energy and Jobs – Annual Review 2019* (Abu Dhabi: 2019), <https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019>; IRENA, *Renewable Energy: A Gender Perspective* (Abu Dhabi: 2019), <https://www.irena.org/publications/2019/Jan/Renewable-Energy-A-Gender-Perspective>. **Figure 11** from Power for All, op. cit. this note.
 - 7 BloombergNEF, "Corporate clean energy buying leapt 44% in 2019, sets new record", 28 January 2020, <https://about.bnef.com/blog/corporate-clean-energy-buying-leapt-44-in-2019-sets-new-record>.
 - 8 Ibid.
 - 9 Ibid.; S. Pichai, "Our biggest renewable energy purchase ever", Google, 19 September 2019, <https://www.blog.google/outreach-initiatives/sustainability/our-biggest-renewable-energy-purchase-ever>.
 - 10 S. Hanley, "Google signs up for renewable energy to run Taiwan data center", *CleanTechnica*, 23 January 2019, <https://cleantechnica.com/2019/01/23/google-signs-up-for-renewable-energy-to-run-taiwan-data-center/>; E. Bellini, "First corporate

- PPA for large scale solar signed in France", pv magazine, 22 May 2019, <https://www.pv-magazine.com/2019/05/22/first-corporate-ppa-for-large-scale-solar-signed-in-france>.
- 11 RE100, "235 RE100 companies have made a commitment to go '100% renewable'. Read about the actions they are taking and why", <http://there100.org/companies>, viewed 26 March 2020.
- 12 IEA, "Global CO2 emissions in 2019", 11 February 2020, <https://www.iea.org/articles/global-co2-emissions-in-2019>.
- 13 The decline in power sector emissions was attributed in part to fuel switching from coal to natural gas as well as to higher nuclear power output, from Ibid.
- 14 D. Carrington, "School climate strikes: 1.4 million people took part, say campaigners", *The Guardian* (UK), 19 March 2019, <https://www.theguardian.com/environment/2019/mar/19/school-climate-strikes-more-than-1-million-took-part-say-campaigners-greta-thunberg>; J. Calma, "2019 is the year of the 'climate strike'", *The Verge*, 8 November 2019, <https://www.theverge.com/2019/11/8/20955589/climate-strike-word-of-the-year-collins-dictionary>; H. Ott, "Millions hit the streets for global climate change strike", CBS News, 20 September 2019, [cbsnews.com/live-news/global-climate-change-strike-protests-today-2019-09-20-live-updates](https://www.cbsnews.com/live-news/global-climate-change-strike-protests-today-2019-09-20-live-updates).
- 15 Climate Emergency Declaration, "Climate emergency declarations in 1,490 jurisdictions and local governments cover 820 million citizens", 13 May 2020, <https://climateemergencydeclaration.org/climate-emergency-declarations-cover-15-million-citizens>.
- 16 E3G, "Polling finds citizens in six belt and road countries want clean energy, not coal", press release (London and Brussels: 24 April 2019), <https://www.e3g.org/news/media-room/polling-citizens-six-belt-and-road-countries-want-clean-energy-not-coal>; European Commission (EC), *Europeans' Attitudes on EU Energy Policy* (Brussels: September 2019), <https://ec.europa.eu/comfrontoffice/publicopinion/index.cfm/survey/getsurveydetail/instruments/special/surveyky/2238>; Greenpeace, "Poll: Australians want renewable energy", 6 August 2018, <https://www.greenpeace.org.au/research/polling-australians-want-renewable-energy>; Lowy Institute, "Climate change and energy", 2019, <https://www.lowyinstitute.org/themes/climate-change-and-energy>; A. Boutillier, "Canadians back shift to renewable energy: Poll", *The Star*, 22 January 2018, <https://www.thestar.com/news/canada/2018/01/22/canadians-back-shift-to-renewable-energy-poll.html>; ADEME, "#Barometre: Les Francais et L'environnement", press release (Paris: 11 February 2020), <https://presse.ademe.fr/2020/02/barometre-les-francais-et-lenvironnement.html>; J. Cousse, M. Kubli and R. Wüstenhagen, *10th Consumer Barometer of Renewable Energy* (St. Gallen, Switzerland: University of St. Gallen, April 2020), https://kuba.iwoe.unisg.ch/wp-content/uploads/Technical-report_Consumer-Barometer_2020.pdf; C. Roselund, "2/3 of U.S. voters say 100% renewable electricity by 2030 is important", pv magazine, 19 April 2019, <https://pv-magazine-usa.com/2019/04/19/2-3-of-u-s-voters-say-100-renewable-electricity-by-2030-is-important>; T. Cama, "Greens' poll shows support for renewable energy transition in swing states", *The Hill*, 19 March 2018, <https://thehill.com/policy/energy-environment/379097-greens-poll-shows-support-for-renewable-energy-transition-in-swing>; Ørsted, "The largest-ever survey of attitudes towards green energy", <https://orsted.com/en/Barometer>, viewed 27 March 2020.
- 17 Y. Cadan, A. Mokgopo and C. Vondrich, *\$11 Trillion and Counting*, 350.org and Divest Invest, 2019, https://631nj1ki9k11gbkx39b3qzpwengine.netdna-ssl.com/divestment/wp-content/uploads/sites/52/2019/09/FF_11Trillion-WEB.pdf. During the year, the European Investment Bank announced that it would end financing for fossil fuel energy projects from the end of 2021, from R. Willis, "EU bank launches ambitious climate strategy and energy lending policy", press release (Brussels: European Investment Bank, 14 November 2019), <https://www.eib.org/en/press/all/2019-313-eu-bank-launches-ambitious-new-climate-strategy-and-energy-lending-policy>. Norway's sovereign wealth fund, worth USD 1.1 trillion, announced that it would divest from companies dedicated solely to oil and gas exploration and production (although it would maintain stakes in refiners and other downstream firms), from T. Olsvik, "Norway sovereign wealth fund to divest oil explorers, keep refiners", *Reuters*, 1 October 2019, <https://www.reuters.com/article/us-norway-swf-oil/norway-sovereign-wealth-fund-to-divest-oil-explorers-keep-refiners-idUSKBN1WG4R9>. US bank Goldman Sachs announced that it would no longer finance oil and gas drilling in the Arctic or invest in new thermal coal mines anywhere worldwide, from S. Kirchaessner, "Goldman Sachs to stop financing new drilling for oil in the Arctic", *The Guardian* (UK), 15 December 2019, <https://www.theguardian.com/business/2019/dec/16/goldman-sachs-to-stop-financing-new-drilling-for-oil-in-the-arctic>.
- 18 Cadan, Mokgopo and Vondrich, op. cit. note 17.
- 19 Financing the Future, *Final Summit Report* (Cape Town, South Africa: December 2019), <https://financingthefuture.global/final-summit-report>.
- 20 C. Keating, "Sahel summit backs 'Desert to Power' plan to bring solar to 60 million", PV-Tech, 17 September 2019, <https://www.pv-tech.org/news/sahel-summit-backs-desert-to-power-plan-to-bring-pv-power-to-60-million>.
- 21 E. Kosolapova, "77 countries, 100+ cities commit to net zero carbon emissions by 2050 at Climate Summit", International Institute for Sustainable Development (IISD) SDG Knowledge Hub, 24 September 2019, <https://sdg.iisd.org/news/77-countries-100-cities-commit-to-net-zero-carbon-emissions-by-2050-at-climate-summit>; IISD, "European Commission launches green deal to reset economic growth for carbon neutrality", 19 December 2019, <https://sdg.iisd.org/news/european-commission-launches-green-deal-to-reset-economic-growth-for-carbon-neutrality>; "EU carbon neutrality: Leaders agree 2050 target without Poland", *BBC News*, 13 December 2019, <https://www.bbc.com/news/world-europe-50778001>. A key principle to decarbonising the EU energy system is to prioritise energy efficiency and develop a power sector based on renewable energy, from EC, *Clean Energy: The European Green Deal* (Brussels: December 2019), https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6723. For 14 countries: Energy and Climate Intelligence Unit, "Net Zero Tracker", viewed 23 April 2020, <https://eciu.net/netzerotracker>.
- 22 World Resources Institute (WRI), "Zero Carbon Buildings for All initiative launched at UN Climate Action Summit", 23 September 2019, <https://wri.org/news/zero-carbon-buildings-all-initiative-launched-un-climate-action-summit>.
- 23 Global Maritime Forum, "Getting to Zero Coalition", <https://www.globalmaritimeforum.org/getting-to-zero-coalition>, viewed April 2020. The coalition supports so-called clean fuels, which include fuels based on biomass and hydrogen produced from renewable electricity, but also natural gas combined with carbon capture and storage.
- 24 Carbon pricing remains key to spurring the uptake of renewables, especially in the heating and transport sectors; see World Bank, "Year in review: 2019 in 14 charts", 20 December 2019, <https://www.worldbank.org/en/news/feature/2019/12/20/year-in-review-2019-in-charts>.
- 25 REN21 research based on data from IRENA, "Renewable Energy in the NDCs", <https://www.irena.org/Statistics/View-Data-by-Topic/Climate-Change/Renewable-Energy-in-the-NDCs>, viewed 12 April 2020, and from United Nations Framework Convention on Climate Change (UNFCCC), "NDC Registry", <https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx>, viewed 12 April 2020.
- 26 C40 Cities, "Mayors announce support for Global Green New Deal; recognize global climate emergency", press release (Los Angeles: 9 October 2019), https://www.c40.org/press_releases/global-gnd; C. Crowe, "Mayors announce Global Green New Deal at C40 Summit", *Smart Cities Dive*, 10 October 2019, <https://www.smartcitiesdive.com/news/mayors-announce-global-green-new-deal-at-c40-summit/564732>.
- 27 REN21, op. cit. note 1, p. 50.
- 28 Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance (FS-UNEP) and BloombergNEF, *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020), <https://www.fs-uneep-centre.org>.
- 29 Global new investment in renewable power and fuels does not include hydropower projects larger than 50 megawatts, from Ibid.
- 30 Ibid.
- 31 Ibid.; S. Prateek, "China announces 2019 feed-in-tariff levels for solar projects", *Mercom India*, 2 May 2019, <https://mercomindia.com/china-feed-in-tariff-levels-solar>.
- 32 M. Willuhn, "Shell and Total join fossil fuel companies bidding for a piece of Europe's PV renaissance", pv magazine, 28 February 2019, <https://www.pv-magazine.com/2019/02/28/shell-and-total-join-fossil-fuel-companies-bidding-for-a-piece-of-europes-pv-renaissance>; "Equinor to invest nearly \$550 million in floating wind power off Norway", *Reuters*, 11 October 2019, <https://www.reuters.com/article/us-equinor-windfarm/equinor-to-invest-nearly-550-million-in-floating-wind-power-off-norway-idUSKBN1WQ0DZ>.

- 33 J. Ambrose, "Oil and gas companies undermining climate goals, says report", *The Guardian* (UK), 6 September 2019, <https://www.theguardian.com/environment/2019/sep/06/oil-and-gas-companies-undermining-climate-goals-says-report>; J. Ambrose and J. Jolly, "Royal Dutch Shell may fail to reach green energy targets", *The Guardian* (UK), 3 January 2020, <https://www.theguardian.com/business/2020/jan/03/royal-dutch-shell-may-fail-to-reach-green-energy-targets>; J. Murray, "How the six major oil companies have invested in renewable energy projects", *NS Energy*, 16 January 2020, <https://www.nsenerybusiness.com/features/oil-companies-renewable-energy>.
- 34 Oil and gas majors have spent USD 1 billion on lobbying since 2016, from InfluenceMap, *Big Oil's Real Agenda on Climate Change* (London: 2019), <https://influencemap.org/report/How-Big-Oil-Continues-to-Oppose-the-Paris-Agreement-38212275958aa21196dae3b76220bddc>; S. Laville, "Top oil firms spending millions lobbying to block climate change policies, says report", *The Guardian* (UK), 22 March 2019, <https://www.theguardian.com/business/2019/mar/22/top-oil-firms-spending-millions-lobbying-to-block-climate-change-policies-says-report>.
- 35 IEA et al., *Tracking SDG 7: The Energy Progress Report 2020* (Washington, DC: 2020), https://trackingsdg7.esmap.org/data/files/download-documents/tracking_sdg_7_2020-full_report_-_web_0.pdf.
- 36 IEA, *World Energy Outlook 2019 Access to Electricity Database*, <https://iea.blob.core.windows.net/assets/ecaa2844-dce8-4710-80fb-4085a58f292f/WEO2019-Electricity-database.xlsx>; A. Contejean, IEA, Paris, personal communication with REN21, 20 May 2020.
- 37 Energy Sector Management Assistance Program (ESMAP), *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. Executive Summary* (Washington, DC: World Bank, 2019), p. 5, <https://openknowledge.worldbank.org/handle/10986/31926>; SEforALL, *Integrated Electrification Pathways for Universal Access to Electricity: A Primer* (Vienna: 2019), <https://www.seforall.org/publications/integrated-electrification-pathways-for-universal-access-to-electricity>.
- 38 The definition of clean from the Multi-Tier Framework encompasses as indicators only the health and environmental impacts of cooking, regardless of the type of stoves/fuels being used (for example, liquefied petroleum gas (LPG) is counted alongside modern renewable fuels). See Distributed Renewables chapter. IEA, "Sustainable Development Goal 7: Access to clean cooking", <https://www.iea.org/sdg/cooking>, viewed 23 March 2020.
- 39 IEA, op. cit. note 38.
- 40 Estimated shares based on the following sources: total final energy consumption in 2018 (estimated at 378.0 exajoules, EJ) is based on 370.1 EJ for 2017, from IEA, *World Energy Statistics and Balances, 2019 edition* (Paris: 2019), <https://webstore.iea.org/world-energy-statistics-and-balances-2019>, and escalated by the 2.2% increase in estimated global total final consumption (including non-energy use) from 2017 to 2018, derived from IEA, *World Energy Outlook 2019* (Paris: 2019). Estimate of traditional biomass from idem. Modern bioenergy for heat and geothermal heat based on 2017 values from IEA, *World Energy Statistics and Balances*, op. cit. this note, and escalated to 2018 based on combined annual average growth rates from 2012 to 2017. Biofuels used in transport in 2018 from IEA, op. cit. note 5. Solar thermal heating and cooling from M. Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communication with REN21, March-April 2020, and from W. Weiss and M. Spörk-Dür, *Solar Heat Worldwide. Global Market and Development Trends in 2019, Detailed Market Figures 2018* (Paris: IEA Solar Heating and Cooling Programme, 2020), <http://www.iea-shc.org/solar-heat-worldwide>. Nuclear power final consumption based on generation of 2,701.4 TWh, from BP, *Statistical Review of World Energy 2019* (London: 2019), <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf>, and global average electricity losses and estimated industry own-use of nuclear power in 2018 based on IEA, *World Energy Statistics and Balances*, op. cit. this note. Electricity consumption from renewable sources based on estimates of 2017 generation from IEA, *Renewables 2019 Databook*, online database, viewed March-April 2020, and global average electricity losses and estimated technology-specific industry own-use of electricity from renewable sources in 2018, based on IEA, *World Energy Statistics and Balances*, op. cit. this note. Estimates of industry own-use of electricity are differentiated by technology based on explicit technology-specific own-use (such as pumping at hydropower facilities) as well as apportioning of various categories of own-use by technology as deemed appropriate. For example, industry own-use of electricity at coal mines and oil refineries are attributed to fossil fuel generation. Industry own-use includes the difference between gross and net generation at thermal power plants (the difference lies in the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants), and other uses such as electricity use in coal mining and fossil fuel refining. Differentiated own-use by technology, combined with global average losses, are as follows: solar PV, ocean energy and wind power (8.2%); hydropower (10.1%); CSP and geothermal (14.2%); and biopower (15.2%).
- 41 **Figure 1** based on Ibid., all references.
- 42 Ibid.
- 43 Ibid.
- 44 Ibid.
- 45 Ibid.
- 46 **Figure 2** based on Ibid.
- 47 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 48 Based on Ibid.
- 49 Ibid.
- 50 **Figure 3** based on Ibid.
- 51 Bundesministerium Nachhaltigkeit und Tourismus (BMNT), "#mission2030 'Mobilitätsoffensive'", 3 January 2019, https://www.klimaaktiv.at/mobilitaet/elektromobilitaet/foerderaktion_emob2019.html.
- 52 REN21, op. cit. note 1, pp. 51-52.
- 53 Fossil fuel subsidies based on estimates for 2018 from IEA and Organisation for Economic Co-operation and Development (OECD), *Update on Recent Progress in Reform of Inefficient Fossil-fuel Subsidies That Encourage Wasteful Consumption*, contribution to 2nd Energy Transitions Working Group Meeting, Toyama, Japan, 18-19 April 2019, p. 3, <https://www.oecd.org/g20/summits/osaka/G20-Update-Report-2019-reform-of-inefficient-fossil-fuel-subsidies.pdf>.
- 54 Ibid. Renewable subsidies amounted to USD 140 billion in 2016, according to IMF estimates, from D. Coady et al., *Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates* (Washington, DC: IMF, 2019), p. 8, <https://www.imf.org/en/Publications/WP/Issues/2019/05/02/Global-Fossil-Fuel-Subsidies-Remain-Large-An-Update-Based-on-Country-Level-Estimates-46509>.
- 55 As countries implement fossil fuel subsidy reform, reallocation of savings could aid in the energy transition as well as lead to other economic, social and environmental benefits, from R. Bridle et al., *Fossil Fuel to Clean Energy Subsidy Swaps: How to Pay for an Energy Revolution* (Winnipeg, Manitoba: IISD, 2019), <https://www.iisd.org/library/fossil-fuel-clean-energy-subsidy-swap>.
- 56 Coady et al., op. cit. note 54.
- 57 Carbon Brief, "Global coal power", <https://www.carbonbrief.org/mapped-worlds-coal-power-plants>, viewed 26 March 2020. An estimated 46 GW of a new coal capacity came into service in 2019, while 28 GW of coal capacity was retired; for natural gas, 50 GW was added and 20 GW was retired; and for nuclear, some 5 GW came online but 10 GW was retired, all from FS-UNEP and BloombergNEF, op. cit. note 28.
- 58 End Coal, "Global Coal Public Finance Tracker", <https://endcoal.org/finance-tracker>, viewed 26 March 2020; IEA, *Chinese Companies Energy Activities in Emerging Asia* (Paris: April 2019), <https://www.iea.org/reports/chinese-companies-energy-activities-in-emerging-asia>.
- 59 Rainforest Action Network, *Banking on Climate Change Fossil Fuel Financial Report* (San Francisco: March 2020), https://www.ran.org/wp-content/uploads/2020/03/Banking_on_Climate_Change__2020_vF.pdf.
- 60 T. Murray, "European Investment Bank will stop funding fossil fuel projects by end of 2021", *Reuters*, 15 November 2019, <https://www.euronews.com/2019/11/14/phasing-out-fossil-fuel-europe-to-discuss-ending-investments-in-coal-oil-and-gas>.
- 61 D. Keating, "Failure in Madrid as COP25 climate summit ends in disarray", *Forbes*, 15 December 2019, <https://www.forbes.com/sites/davekeating/2019/12/15/failure-in-madrid-as-cop25-climate-summit-ends-in-disarray/#9c42e7b3d1fe>;

- A. Chandrasekhar, "The UN climate talks ended in deadlock. Is this really the best the world can manage?" *The Guardian* (UK), 21 December 2019, <https://www.theguardian.com/commentisfree/2019/dec/21/un-climate-talks-deadlock-cop25>.
- 62 UNFCCC, "COP26 postponed", press release (Bonn: 1 April 2020), <https://unfccc.int/news/cop26-postponed>.
- 63 Sectoral energy share based on IEA, *World Energy Statistics and Balances*, op. cit. note 40. Emissions include both direct and indirect emissions, such as power generation for electricity, and exclude the estimated portion of overall industry devoted to manufacturing building construction materials such as steel, cement and glass, from Global Alliance for Buildings and Construction (GlobalABC), IEA and UNEP, *2019 Global Status Report for Buildings and Construction* (Paris: 2019), p. 12, <https://globalabc.org/sites/default/files/2020-03/GSR2019.pdf>.
- 64 Ibid.
- 65 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40. **Figure 4** based on idem and on sources in endnote 40.
- 66 GlobalABC, IEA and UNEP, op. cit. note 63, p. 12. Other studies have shown that aggressive energy efficiency policies are crucial if buildings are to make any significant contribution to climate protection and to make renewable heating technologies competitive in the future, from Agora Energiewende, *Building Sector Efficiency: A Crucial Component of the Energy Transition* (Berlin: 2020), <https://www.agora-energiewende.de/en/publications/building-sector-efficiency-a-crucial-component-of-the-energy-transition>.
- 67 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 68 GlobalABC, IEA and UNEP, op. cit. note 63.
- 69 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 70 GlobalABC, IEA and UNEP, op. cit. note 63, p. 12.
- 71 **Figure 5** estimated shares in 2018 based on historical data from IEA, *World Energy Balances and Statistics*, op. cit. note 40. Figure of 2.81 EJ of renewable electricity for heat in buildings in 2018 from IEA, op. cit. note 5, and for previous years based on compound annual growth rate of 5.3%, from idem. Total heat demand in buildings includes electricity for heating and cooling, derived from estimated renewable electricity for heat and calculated share of renewable energy in electricity production for target year. See also endnote 40.
- 72 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 73 Based on Ibid.
- 74 Based on Ibid.
- 75 Based on Ibid.
- 76 Based on Ibid.
- 77 Based on Ibid.
- 78 Based on Ibid.
- 79 The top European countries in 2017 and their respective shares of renewable district heat in final heat demand were Iceland (89.2%), Denmark (38.6%), Lithuania (38.5%), Sweden (36.6%), Finland (15.4%) and Norway (3.7%); in Norway, renewable electricity represented 60% of the heat market, all from Euroheat & Power, *Country by Country 2019* (Brussels: 2019), https://www.euroheat.org/cbc_publications/cbc-2019.
- 80 Ibid.
- 81 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40., and on IEA, op. cit. note 5, p. 139.
- 82 See, for example, Agora Energiewende, op. cit. note 66, and J. Rosenow and R. Lowes, *Heating Without the Hot Air: Principles for Smart Heat Electrification* (Brussels: 2020), <https://www.raponline.org/wp-content/uploads/2020/03/rap-rosenow-lowes-principles-heat-decarbonisation-march-2020.pdf>.
- 83 Several of these initiatives and projects have been part of the Rocky Mountain Institute's (RMI) "Accelerating the Electrification of Buildings at e-Lab Accelerator 2019" and covered projects in the US states of California, Massachusetts, Minnesota and Rhode Island. See R. Cole, "Accelerating the Electrification of Buildings at e-Lab Accelerator 2019", RMI, 1 May 2019, <https://rmi.org/accelerating-the-electrification-of-buildings-at-elab-accelerator-2019>. See also the following: WRI, *Shifting Currents: Opportunities for Low-Carbon Electric Cities in the Global South* (Washington, DC: 2019), https://wriorg.s3.amazonaws.com/s3fs-public/shifting-currents_0.pdf; WRI, *Accelerating Building Decarbonization* (Washington, DC: 2019), <https://www.wri.org/publication/accelerating-building-decarbonization>; Agora Energiewende, op. cit. note 66.
- 84 Even in European countries with extensive gas grids, such as the United Kingdom and Germany, electrification with renewables is still seen as a core strategy for decarbonisation as opposed to renewable hydrogen, from Rosenow and Lowes, op. cit. note 82; California from Building Decarbonization Coalition, *Strategies and Approaches for Building Decarbonization* (Petaluma, CA: 2019), http://www.buildingdecarb.org/uploads/3/0/7/3/30734489/bdc_report_3_approaches_for_building_decarb.pdf, and from Building Decarbonization Coalition, *Rate Design for Beneficial Electrification* (Petaluma, CA: 2019), http://www.buildingdecarb.org/uploads/3/0/7/3/30734489/bdc_report_2_rate_design.pdf.
- 85 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 86 Based on Ibid.
- 87 IEA, op. cit. note 5, p. 139.
- 88 IEA et al., op. cit. note 35.
- 89 Ibid. Coal use for cooking is mostly in rural areas and decreased from 11% in 2000 to 2% in 2018. Kerosene use for cooking was mostly in urban areas and decreased from 9% in 2000 to 2% in 2018.
- 90 Ibid.
- 91 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 92 Based on Ibid. For discussion on rooftop solar PV, see Solar PV section in Market and Industry chapter.
- 93 Bundesverband Solarwirtschaft e.V., "Nearly 100,000 new PV prosumers in Germany", 30 March 2020, <https://www.solarwirtschaft.de/en/2020/03/30/nearly-100-000-new-pv-prosumers-in-germany>; Clean Energy Council, *Clean Energy Australia Report 2020* (Sydney: 2020), p. 64, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf>.
- 94 Figure of 420 million people benefiting from basic access based on an estimated 18 million solar PV lighting products and 66 million solar home systems in use, taking into account life cycles and considering five people impacted by a product, from International Finance Corporation (IFC), *Off-grid Solar Market Trends Report 2020. Report Summary* (Washington, DC: 2020), p. 6, <https://www.lightingglobal.org/resource/2020marketrendsreport>.
- 95 ESMAP, op. cit. note 37, p. 5.
- 96 R. Lowes, University of Exeter, personal communication with REN21, 6 May 2020.
- 97 The four national governments were Austria, Norway, Poland and the United Kingdom. Commitments and policies varied from bans on some types of fuels, to the type of building concerned (new or existing). See Heating and Cooling section in Policy Landscape chapter.
- 98 See for example: WRI, *Accelerating Building Decarbonization*, op. cit. note 83; WRI, *Zero Carbon Buildings for All: A UNSG "Summitable" Outcome – Executive Summary* (Washington, DC: 2019), <https://wrirosscities.org/sites/default/files/Zero%20Carbon%20Buildings%20for%20All%20--%20UNSG%20Summitable%20Outcome%20for%20Buildings%20%28Final%29.pdf>; World Green Building Council (WGBC), *From Thousands to Billions: Coordinated Action Towards 100% Net Zero Carbon Buildings by 2050* (London: 2017), https://www.worldgbc.org/sites/default/files/From%20Thousands%20To%20Billions%20WorldGBC%20report_FINAL%20issue%20310517.compressed.pdf. In 2018, Architecture 2030 released the ZERO Code, a national and international building energy standard that integrates energy efficiency standards with on-site and/or off-site renewable energy, from Architecture 2030, "ZERO Code: The future has arrived", April 2018, <https://architecture2030.org/zero-code>. Soon after, the China Academy of Building Research released its zero-net-carbon code standard "Nearly Zero Energy + On-site/Offsite Renewables". The ZERO Code Renewable Energy Appendix is planned to be included in the 2021 International Energy Conservation Code that will be released later in 2020, from Architecture 2030, op. cit. this note, and from E. Mazria, Architecture 2030, personal communication with REN21, 17 April 2020.
- 99 WGBC, "The Net Zero Carbon Buildings Commitment", <https://worldgbc.org/thecommitment>, viewed 26 April 2020.
- 100 EC, "nzeb", https://ec.europa.eu/energy/content/nzeb-24_en, viewed 2 May 2020; Rosenow and Lowes, op. cit. note 82.

- 101 GlobalABC, IEA and UNEP, op. cit. note 63. For information on NDCs related to renewables for heating and cooling, see Policy Landscape chapter.
- 102 Ibid.
- 103 Ibid.
- 104 Ibid. For discussion on renovation rates, see Buildings Performance Institute of Europe, *A Guide to Developing Strategies for Building Energy Renovation* (Brussels: 2013), http://www.bpie.eu/documents/BPIE/Developing_Building_Renovation_Strategies.pdf.
- 105 EC, *The European Green Deal* (Brussels: 11 December 2019), p. 9, https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf.
- 106 Sectoral energy share based on IEA, *World Energy Statistics and Balances*, op. cit. note 40. Emissions include the estimated portion of overall industry devoted manufacturing building construction materials such as steel, cement and glass, from GlobalABC, IEA and UNEP, op. cit. note 63, p. 12. See also endnote 40.
- 107 IEA, op. cit. note 5, p. 145.
- 108 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 109 Sectoral heat share based on Ibid. For energy use in industry, see, for example, S. Friedmann, Z. Fan and K. Tang, *Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today* (New York: Columbia University Center on Global Energy Policy, 2019), https://energypolicy.columbia.edu/sites/default/files/file-uploads/LowCarbonHeat-CGEP_Report_100219-2_0.pdf, and S. Moss, "Solar energy isn't just for electricity", *Scientific American*, 19 April 2019, <https://blogs.scientificamerican.com/observations/solar-energy-isnt-just-for-electricity>.
- 110 IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 111 **Figure 6** based on sources in endnote 40.
- 112 IEA, op. cit. note 5, p. 147. See also Bioenergy section in Market and Industry chapter.
- 113 IEA, op. cit. note 5, p. 146. See also Bioenergy section in Market and Industry chapter.
- 114 Friedmann, Fan and Tang, op. cit. note 109; C. Brunner, AEE INTEC, "Solar heat for industrial production processes – latest research and large scale installations", presentation at International Conference on Solar Heating and Cooling, Beijing, 13-15 October 2014, <http://task49.iea-shc.org/Data/Sites/1/publications/SHC-2014--Brunner--Solar-Heat-for-Industrial-Processes.pdf>.
- 115 Industries in iron and steel manufacturing, chemical and petrochemicals, and non-metallic minerals (for example, glass, ceramics and cement) collectively account for around 62% of industrial energy use. These three industries see shares of renewable energy between 4.5 and 6.5%, with the majority supplied by renewable electricity (for electrical end-uses and heat). Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 116 Based on Ibid.
- 117 Based on Ibid.
- 118 B. Epp, "Industrial sector sees record-breaking capacity additions in 2019", *Solarthermalworld.org*, 26 April 2020, <https://www.solarthermalworld.org/news/industrial-sector-sees-record-breaking-capacity-additions-2019>.
- 119 E. Taibi, D. Gielen and M. Bazilian, *Renewable Energy in Industrial Applications: An Assessment of the 2050 Potential* (Vienna: UNIDO, 2010), https://www.solarthermalworld.org/sites/gstec/files/unido_renewables_industrial_applications.pdf; IRENA, *Renewable Energy Options for the Industry Sector: Global and Regional Potential Until 2030* (Abu Dhabi: 2015), https://irena.org/-/media/Files/IRENA/Agency/Articles/2016/Nov/IRENA_RE_Potential_for_Industry_BP_2015.pdf; Friedmann, Fan and Tang, op. cit. note 109; 200-400 from I. di Padua, Solar Heat Europe, personal communication with REN21, 8 April 2020.
- 120 Paint Square, "Solar energy company makes high-temp claims", 16 December 2019, <https://www.paintsquare.com/news/?fuseaction=view&id=21917>; D. Oberhaus, "A solar 'breakthrough' won't solve cement's carbon problem", *Wired*, 22 November 2019, <https://www.wired.com/story/a-solar-breakthrough-wont-solve-cements-carbon-problem/>; D. Perilli, "Solar-powered cement production", *Global Cement*, 20 November 2019, <https://www.globalcement.com/news/item/10119-solar-powered-cement-production>.
- 121 Finland announced an industry-specific target during the year, and the EU announced financial incentives. See Policy Landscape chapter.
- 122 B. Radowitz, "More aggressive EU industrial strategy to back renewables and hydrogen", *Recharge*, 11 March 2020, <https://www.rechargenews.com/transition/more-aggressive-eu-industrial-strategy-to-back-renewables-and-hydrogen/2-1-771220>; M. Hall, "European industrial strategy makes no mention of solar", *pv magazine*, 11 March 2020, <https://www.pv-magazine.com/2020/03/11/european-industrial-strategy-makes-no-mention-of-solar/>; EC, "Commission communication: A new industrial strategy for Europe", 10 March 2020, https://ec.europa.eu/info/files/commission-communication-new-industrial-strategy-europe_en.
- 123 Australian Renewable Energy Agency (ARENA), "Renewable Energy for Process Heat Opportunity Study", 14 February 2020, <https://arena.gov.au/projects/renewable-energy-for-process-heat-opportunity-study>; ARENA, "Renewable Energy for Process Heat Opportunity Study Phase 2", 12 February 2020, <https://arena.gov.au/projects/renewable-energy-for-process-heat-opportunity-study-phase-2>.
- 124 J. Rissman et al., "Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070", *Applied Energy*, 12 March 2020, <https://energyinnovation.org/wp-content/uploads/2020/04/Technologies-and-policies-to-decarbonize-global-industry-review-and-assessment-of-mitigation-drivers-through-2070.pdf>.
- 125 Nucor Steel Sedalia, LLC, personal communication with REN21, 26 May 2020; J. Douglas, "First US steel plants powered by wind, solar energy are coming for industry with big carbon footprint", *CNBC*, 7 December 2019, <https://www.cnbc.com/2019/12/07/first-us-steel-plants-powered-by-wind-solar-energy-are-coming.html>; M. Mazengarb, "Gupta secures China EPC contract for \$350 million Cultana solar farm", *RenewEconomy*, 4 June 2019, <https://reneweconomy.com.au/gupta-secures-china-epc-contract-for-350-million-cultana-solar-farm-46380/>; M. Bloch, "EPC partner for Whyalla's Cultana solar farm announced", *Solar Quotes*, 4 June 2019, <https://www.solarquotes.com.au/blog/cultana-solar-farm-mb1081>.
- 126 SSAB Americas, "SSAB Americas to produce first fossil-free steel in North America", press release (Montpelier, IA: 17 December 2019), https://www.prweb.com/releases/ssab_americas_to_produce_first_fossil_free_steel_in_north_america/prweb16793665.htm.
- 127 Vattenfall, "Vattenfall and Cements take the next step towards a climate neutral cement", press release (Stockholm: 30 January 2019), <https://group.vattenfall.com/press-and-media/news--press-releases/pressreleases/2019/vattenfall-and-cements-take-the-next-step-towards-a-climate-neutral-cement>; G. Ondrey, "A push for 'green' crackers", *Chemical Engineering Online*, 1 April 2020, <https://www.chemengonline.com/push-green-crackers>.
- 128 J. Deign, "Mining companies cozy up to renewables, not just for cost", *GTM*, 26 February 2020, <https://www.greentechmedia.com/articles/read/mining-companies-renewables-cost>; TH Energy, "Renewable energy and mining", <https://www.th-energy.net/english/platform-renewable-energy-and-mining>, viewed 25 March 2020; GTM Creative Strategies, "Decarbonization takes center stage in mining as renewables-plus-storage become cost-competitive", *GTM*, 30 December 2019, <https://www.greentechmedia.com/articles/read/decarbonization-takes-center-stage-in-mining>; executive survey from EY, "Will electrification spark the next wave of mining innovation?" 2019, https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/mining-metals/mining-metals-pdfs/ey-electrification-in-mining-survey.pdf; A. Burger, "Newmont Goldcorp's all-electric Borden mine marks landmark in major miners' clean energy transition", *Solar Magazine*, 27 November 2019, <https://solarmagazine.com/newmont-goldcorp-all-electric-borden-mine-landmark-major-miners-clean-energy-transition>.
- 129 RMI, "Renewable Resources at Mines Tracker", <https://rmi.org/our-work/industry-and-transportation/material-value-chains/renewable-resources-at-mines-tracker>, viewed 25 March 2020.
- 130 Ibid.
- 131 "BHP to take US\$780M hit on renewable move", *Mining Journal*, 21 October 2019, <https://www.mining-journal.com/copper-news/news/1373960/bhp-to-take-ususd780m-hit-on-renewable-move/>; A. Fawthrop, "BHP to transition Chile copper mines to renewable energy supply", *NS Energy*, 22 October 2019, <https://www.nsenergybusiness.com/news/company-news/bhp-renewable-energy-chile-copper>.
- 132 A. Ferrocchio, "Minera Alumbrera comienza a utilizar energía eólica", *Info Alumbrera*, 14 February 2020, <http://www.infoalumbrera.com.ar/eolica> (using Google Translate).

- 133 L. Collins, "World's largest green-hydrogen plant begins operation in Austria", Recharge, 18 November 2019, <https://www.rechargenews.com/transition/worlds-largest-green-hydrogen-plant-begins-operation-in-austria/2-1-708381>; Ørsted, "Ørsted and partners secure funding for renewable hydrogen project", press release (Fredericia, Denmark: 20 December 2019), <https://orsted.com/en/media/newsroom/news/2019/12/945369984118407>; D. Thomas, "Hydrogen production from offshore wind power", presentation for MHI Vestas Thought Leaders Forum, WindEurope Exhibition, Bilbao, Spain, 2 April 2019, <https://windeurope.org/confex2019/wp-content/uploads/files/networking/tlf/day-1/13.30-14.00-Denis-Thomas-Hydrogenics.pdf>; C. Richard, "Offshore wind-to-hydrogen plant plans revealed", Windpower Monthly, 27 January 2020, <https://www.windpowermonthly.com/article/1672014/offshore-wind-to-hydrogen-plant-plans-revealed>.
- 134 Vattenfall, "HYBRIT: SEK 200 million invested in pilot plant for storage of fossil-free hydrogen in Luleå", press release (Stockholm: 3 October 2019), <https://group.vattenfall.com/press-and-media/news--press-releases/pressreleases/2019/hybrit-sek-200-million-invested-in-pilot-plant-for-storage-of-fossil-free-hydrogen-in-lulea>; construction of the original pilot plant began in 2018 and is planned to finish in 2021, from HYBRIT, "Three HYBRIT pilot projects – towards fossil free iron and steel", <http://www.hybritdevelopment.com/articles/three-hybrit-pilot-projects>, viewed 15 May 2020.
- 135 E. Ayanoglu, "Energy efficiency in data centers", *IEEE ComSoc*, 13 November 2019, <https://www.comsoc.org/publications/tcn/2019-nov/energy-efficiency-data-centers>; CISCO, "Cisco Annual Internet Report", <https://www.cisco.com/c/en/us/solutions/executive-perspectives/annual-internet-report/index.html>, updated 9 March 2020.
- 136 Ayanoglu, op. cit. note 135; CISCO, op. cit. note 135.
- 137 Ayanoglu, op. cit. note 135; A. Opiah, "Google data centres seven times more energy efficient due to 100% renewable energy push", Data-Economy, 18 June 2019, <https://data-economy.com/google-data-centres-seven-times-more-energy-efficient-due-to-100-renewable-energy-push>; L. Tung, "Microsoft's green plan: Our data centers will run on 60% renewable energy by 2020", ZDNet, 16 April 2019, <https://www.zdnet.com/article/microsofts-green-plan-our-data-centers-will-run-on-60-renewable-energy-by-2020>; N. Jones, "How to stop data centres from gobbling up the world's electricity", *Nature*, 13 September 2018, <https://www.nature.com/articles/d41586-018-06610-y>; E. Cevenini, "Setting realistic goals for powering data centers with renewable energy", *Data Center Knowledge*, 4 December 2019, <https://www.datacenterknowledge.com/industry-perspectives/setting-realistic-goals-powering-data-centers-renewable-energy>.
- 138 IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 139 **Figure 7** based on Ibid. and on sources in endnote 40.
- 140 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 141 See, for example: L. Cozzi and A. Petropoulos, "Growing preference for SUVs challenges emissions reductions in passenger car markets", IEA, 15 October 2019, <https://www.iea.org/commentaries/growing-preference-for-suvs-challenges-emissions-reductions-in-passenger-car-market>; IEA, "Energy Efficiency Indicators database (2019 edition) – extended version" (Paris: 2019), <http://data.iea.org/payment/products/120-energy-efficiency-indicators-2017-edition.aspx>; IEA, *World Energy Statistics and Balances*, op. cit. note 40; IEA, *Energy Efficiency 2018: Analysis and Outlook to 2040* (Paris: 2018), <https://www.iea.org/efficiency2018>.
- 142 Whereas total CO₂ emissions in the EU decreased 20% between 1990 and 2016, emissions from the transport sector increased 27%, from International Transport Forum (ITF), "Is low-carbon road freight possible?" 6 December 2018, <https://www.itf-oecd.org/low-carbon-road-freight>. Similarly, US transport sector emissions surpassed those of the power sector in 2016, from J. Runyon, "6 key trends in sustainable and renewable energy", *Renewable Energy World*, 15 February 2019, <https://www.renewableenergyworld.com/articles/2019/02/6-key-trends-in-sustainable-and-renewable-energy.html>.
- 143 IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 144 REN21, op. cit. note 1.
- 145 Sustainable Mobility for All, "Transforming the future of mobility", presentation, 2019, https://www.unecce.org/fileadmin/DAM/trans/events/2019/ITC/presentations_81st/4_d__i__SuM4All.pdf; SLOCAT Partnership on Sustainable, Low Carbon Transport, *Transport and Climate Change 2018 Global Status Report* (Shanghai: 2018), p. 3, <https://slocat.net/tcc-gsr>; Transformative Urban Mobility Initiative, *Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I)*, March 2019, p. 2, https://www.transformative-mobility.org/assets/publications/ASI_TUMI_SUTP_iNUA_No-9_April-2019.pdf. Despite the necessary role that renewable energy would play in decarbonising the transport sector, many adaptations of the ASI framework have failed to include renewables or to mention the source of energy under the improve section, focusing only on energy efficiency. IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition* (Abu Dhabi and Paris: 2018), p. 23, <https://www.irena.org/publications/2018/Apr/Renewable-energy-policies-in-a-time-of-transition>; SLOCAT, op. cit. note 145, p. 3.
- 146 Plug-in hybrids differ from simple hybrid vehicles, as the latter use electric energy produced only by braking or through the vehicle's internal combustion engine. Therefore, only plug-in hybrid EVs allow for the use of electricity from renewable sources. Although not an avenue for increased penetration of renewable electricity, hybrid vehicles contribute to reduced fuel demand and remain far more numerous than EVs. Electro-fuels, also known as e-fuels, are synthetic fuels that do not chemically differ from conventional fuels such as diesel or petrol, generated in procedures known as power-to-liquids (PtL) and power-to-gas (PtG). Renewable electro-fuels are generated exclusively from electricity from renewable sources. See Verband der Automobilindustrie, "Synthetic fuels – power for the future", <https://www.vda.de/en/topics/environment-and-climate/e-fuels/synthetic-fuels.html>, viewed 1 May 2019, and N. Aldag, "Role for e-fuels in EU transport?" Sunfire, 12 January 2018, <https://www.transportenvironment.org/sites/te/files/Industry%20perspectives%20on%20the%20future%20development%20of%20electrofuels%2C%20Nils%20Aldag.pdf>.
- 147 See IRENA, IEA and REN21, op. cit. note 145, Figure 3.4, p. 41.
- 148 C. Huizenga, personal communication with REN21, 13 April 2020. In addition, more demonstration and prototype models were released for electric heavy-duty trucks, ships and planes. In aviation, some prototype electric drones and small planes have been developed, as well as hybrid electric and hydrogen-powered planes, while some companies have announced air taxi demonstrations beginning in 2020. See, for example, the following: Airbus, "Electric flight: Bringing zero-emission technology to aviation", <https://www.airbus.com/innovation/future-technology/electric-flight.html>, viewed 16 March 2020; Airbus, "E-Fan X", <https://www.airbus.com/innovation/future-technology/electric-flight/e-fan-x.html>, viewed 16 March 2020; C. Alcock, "ZeroAvia aims to halve operating costs with hydrogen power", AIN online, 16 August 2019, <https://www.ainonline.com/aviation-news/air-transport/2019-08-16/zeroavia-aims-halve-operating-costs-hydrogen-power>; A. J. Hawkins, "This company wants to fill the skies with hydrogen-powered planes by 2022", *The Verge*, 14 August 2019, <https://www.theverge.com/2019/8/14/20804257/zeroavia-hydrogen-airplane-electric-flight>; M. Ros, "7 electric aircraft you could be flying in soon", CNN, 21 November 2017, <https://edition.cnn.com/travel/article/electric-aircraft/index.html>; "Airbus & Audi reveal electric air taxi CityAirbus", *electrive.com*, 12 March 2019, <https://www.electrive.com/2019/03/12/airbus-electric-air-taxi-cityairbus-revealed-before- maiden-flight>; Green Car Congress, "Uber and Hyundai announce aerial ridesharing partnership, release new full-scale electric air taxi model at CES", 7 January 2020, <https://www.greencarcongress.com/2020/01/20200107-hyundaiauber.html>. The Finnish shipping business Viking Line has fitted one of its ships with a rotor sail that enables it to use wind power during trips between Finland and Sweden, from A. Frangoul, "Norwegian cruise ships to be powered using dead fish", CNBC, 20 November 2018, <https://www.cnbc.com/2018/11/20/norwegian-cruise-ships-to-be-powered-using-dead-fish.html>. In 2018, Eco Marine Power developed one demonstration ship in Greece and a commercial sale in Singapore, with an integrated management and automation programme that controls an array of "EnergySails" on its deck to rotate depending on the direction of the sun and wind, with the solar energy collected from the solar PV panels and stored in batteries, from R. Nuwer, "Solar power could reinvent the shipping industry – if we let it", *Nova*, 18 April 2018, <https://www.pbs.org/wgbh/nova/article/solar-power-could-reinvent-the-shipping-industry-if-we-let-it>. See also Magnus, "How global shipping could be powered

- by the wind", <http://magnuss.com/index.html>, viewed March 2020, and International Windship Association, <http://wind-ship.org/en/grid-homepage>, viewed March 2020. Trucks from the following sources: T. Tomes and L. Williams, *Ditching Diesel: A Cost-Benefit Analysis of Electric Refuse Collection Vehicles* (Bristol: Eunomia, 2020), <https://www.eunomia.co.uk/reports-tools/ditching-diesel-analysis-electric-refuse-collection-vehicles>; East Waste, "First electric-powered waste collection truck for SA", 2 September 2019, <https://www.eastwaste.com.au/first-electric-powered-waste-collection-truck-for-sa/>; F. Lambert, "Daimler unveils electric eCascadia semi truck to compete with Tesla Semi, launches electric truck group", *electrek*, 7 June 2018, <https://electrek.co/2018/06/07/daimler-electric-semi-truck-ecascadia-tesla-semi/>; J. Ayre, "Electric semi trucks & heavy-duty trucks – available models & planned models (in-depth list)", *CleanTechnica*, 16 December 2017, <https://cleantechnica.com/2017/12/16/electric-semi-trucks-heavy-duty-trucks-available-models-planned-models>.
- 149 IRENA, IEA and REN21, op. cit. note 145; "Japan is betting future cars will use hydrogen fuel cells", *Financial Times*, 24 October 2017, <https://www.ft.com/content/98080634-a1d6-11e7-8d56-98a09be71849>; more than 95% of hydrogen production is from fossil fuels, from IRENA, *Hydrogen from Renewable Power* (Abu Dhabi: 2018), p. 13, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf.
- 150 Sustainable Mobility for All, *Global Roadmap of Action: Toward Sustainable Mobility* (2019). <http://pubdocs.worldbank.org/en/350451571411004650/Global-Roadmap-of-Action-Toward-Sustainable-Mobility.pdf>; IRENA, *NDCs in 2020: Advancing Renewables in the Power Sector and Beyond* (Abu Dhabi: 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_NDCs_in_2020.pdf; IEA, *Tracking Transport* (Paris: 2019), <https://www.iea.org/reports/tracking-transport-2019>; *Transport & Environment, Draft National Energy and Climate Plans Transport Ranking* (Brussels: 2019), https://www.transportenvironment.org/sites/te/files/publications/2019_06_Draft_NECPT_transport_analysis_final.pdf.
- 151 ITF, op. cit. note 142.
- 152 Based on REN21 research on NDCs, from REN21 Policy Database.
- 153 US EIA, "Transportation sector passenger transport and energy consumption by region and mode", in *International Energy Outlook 2017* (Washington, DC: 2017), <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=50-IEO2017®ion=0-0&cases=Reference&start=2010&end=2020&f=A&linechart=Reference-d082317.2-50-IEO2017&sourcekey=0>.
- 154 IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 155 IEA, *Global EV Outlook 2020* (Paris: 2020), <https://www.iea.org/reports/global-ev-outlook-2020>. In addition, there were an estimated 800 million electric two-wheelers, at least 51 million three-wheelers, 3 million electric four-wheelers and more than 200 million electric bicycles on the world's roads. Electric two- and three-wheelers from idem; electric four-wheelers and bicycles from M. Cardama, N. Medimorec and K. Peet, SLOCAT, personal communication with REN21, 8 March 2019.
- 156 S. C. Betancourt, "First electric highway was inaugurated in Argentina and Latin America", *Auto PortalWatch*, 11 June 2019, <https://www.onlinemarketplaces.com/articles/26286-First-electric-highway-was-inaugurated-in-Arentina-and-Latin-America>.
- 157 The majority of these charging stations were installed in 10 Chinese cities, from L. Yuanyuan, "China installed more than 1000 EV charging stations per day in 2019", *Renewable Energy World*, 13 January 2020, <https://www.renewableenergyworld.com/2020/01/13/china-installed-more-than-1000-ev-charging-stations-per-day-in-2019>.
- 158 For example, in the EU where the renewable share of electricity is higher than in other most regions, EV emissions over the entire vehicle life cycle were estimated to be 17-30% lower than those of petrol or diesel vehicles, from European Environment Agency, "EEA report confirms: Electric cars are better for climate and air quality", 22 November 2018, <https://www.eea.europa.eu/highlights/eea-report-confirms-electric-cars>.
- 159 The estimation of EVs being more efficient than conventional vehicles can be attributed in part to the fact that the energy losses of converting primary energy to electricity (as well as transport and distribution losses) are often underestimated, from IEA, op. cit. note 155.
- 160 By the end of 2018, Austria was the only country with a policy explicitly stimulating the use of renewable electricity in EVs by combining financial and fiscal incentives for electric mobility with the use of renewable electricity. A quota system applies for renewable energy sources used in transport, but investment grants for vehicle conversion or e-mobility also are available within the scope of the "klimaaktiv mobil" programme; see RES Legal, "Austria: Overall summary", <http://www.res-legal.eu/search-by-country/austria>, viewed 2 May 2019; BMNT, op. cit. note 51; BMNT, "klimaaktiv mobil – the National Action Programme for Mobility Management", <https://www.klimaaktiv.at/english/mobility/Mobility.html>, updated 6 May 2019. Previously, policies linking renewables and EVs were in place in Germany and Luxembourg, but they were no longer in place as of 2018 and 2017, respectively.
- 161 BMNT, op. cit. note 51; REN21, op. cit. note 1.
- 162 REN21, op. cit. note 1.
- 163 SLOCAT, *E-Mobility Trends and Targets* (Shanghai: January 2020), https://slocat.net/wp-content/uploads/2020/02/SLOCAT_2020_e-mobility-overview.pdf. These targets primarily incentivise increased EV uptake, but they also have the potential to stimulate interest in biogas vehicles that result in fewer emissions, as well as interest in increased biofuel use in hybrid vehicles, as a major part of a transition towards complete electrification where bans on internal combustion engine vehicles are envisioned. For example, hybrid vehicles are still allowed to enter the city centre of Madrid (Spain), which has put in place bans on petrol and diesel cars registered before 2000 and 2006, respectively, from J. Porter, "Madrid's ban on polluting vehicles cuts traffic by nearly 32 percent in some areas", *The Verge*, 3 December 2018, <https://www.theverge.com/2018/12/3/18123561/vehicle-emissions-pollution-ban-madrid-spain-traffic-decrease>. Increased interest in biogas, for example in the UK, from K. Dickinson, "Waitrose to run HGV fleet on biomethane", *Resource*, 30 July 2018, <https://resource.co/article/waitrose-run-hgv-fleet-biomethane-12768>; A. Sherrard, "Biomethane reaches 91% share in expansive Swedish vehicle gas market", *Bioenergy International*, 22 February 2019, <https://bioenergyinternational.com/markets-finance/biomethane-reaches-91-share-in-expansive-swedish-vehicle-gas-market>; biofuels in hybrid vehicles from R. Ocone, "Does the 2040 ban on new petrol and diesel cars mean the death of biofuels?" *The Conversation*, 30 July 2017, <https://theconversation.com/does-the-2040-ban-on-new-petrol-and-diesel-cars-mean-the-death-of-biofuels-81765>.
- 164 J. Strömberg, Scania, personal communication with REN21, 11 March 2019; "Madrid bans old diesels from city center", *DW*, <https://www.dw.com/en/madrid-bans-old-diesels-from-city-center/av-46908195>, viewed 24 May 2019.
- 165 See Box 2 in Policy Landscape chapter.
- 166 **Box 2** from the following sources: REN21, op. cit. note 1, p. 92; A. Ajao, "Electric scooters and micro-mobility: Here's everything you need to know", *Forbes*, 1 February 2019, <https://www.forbes.com/sites/adeyemijao/2019/02/01/everything-you-want-to-know-about-scooters-and-micro-mobility>; Volkswagen's WeShare platform in Berlin (Germany) has offered EVs powered by 100% renewables since late 2018, from WeShare, "WeShare electrifies Berlin", <https://www.we-share.io/en/#electric-fleet>, viewed 15 October 2019; in the United States, multiple car sharing companies have partnered with EVgo, the largest public EV charging company, which has powered its entire network of EV charging stations with 100% renewables since mid-2019, from EVgo, "Why EVgo?" <https://www.evgo.com>, viewed 15 October 2019, and from C. Teale, "EVgo commits to powering chargers with 100% renewable energy", *Utility Dive*, 8 May 2019, <https://www.utilitydive.com/news/evgo-commits-to-powering-chargers-with100-renewable-energy/554340>; 100% renewable electricity from, for example, A. Lewin, "Electric scooters: Not so 'green' after all", *Sifted*, 11 December 2019, <https://sifted.eu/articles/electric-scooters-green-comparison>; credits or direct purchases from, for example, S. Holder, "Lime wants its battery-charging gig workers to use green energy", *CityLab*, 26 September 2019, <https://www.citylab.com/environment/2019/09/lime-electric-scooter-clean-energy-battery-climate-change/598759>, and from A. Hawkins, "Lime's electric bikes and scooters are going completely 'carbon free'", *The Verge*, 9 October 2018, <https://www.theverge.com/2018/10/9/17955308/lime-bike-scooter-carbon-free-neutral-sustainable>. Some studies, however, have shown higher carbon emissions for the full life cycle of such scooters than many other modes of transport, regardless

- of the source of energy used, from "The environmental impact of today's transport types", [travellandmobility.tech](https://travellandmobility.tech/infographics/carbon-emissions-by-transport-type), 27 November 2019, <https://travellandmobility.tech/infographics/carbon-emissions-by-transport-type>, and from J. Hollingsworth, B. Copeland and J. Johnson, "Are e-scooters polluters? The environmental impacts of shared dockless electric scooters", *IOP Science*, 2 August 2019, <https://iopscience.iop.org/article/10.1088/1748-9326/ab2da8>.
- Ride hailing services from, for example, Lyft, "Lyft commits to full carbon neutrality and 100% renewable energy", 11 September 2018, <https://www.lyft.com/blog/posts/lyft-commits-to-full-carbon-neutrality-and-100-renewable-energy>, and Uber, "The clean air plan", <https://www.uber.com/gb/en/u/drive-journey-to-electric>, viewed March 2020. In 2018, Uber launched a similar subsidy programme in seven cities in the United States and Canada, building off of its existing pilots in two other US cities, from A. Gromis, "Electrifying our network", Uber Newsroom, 19 June 2018, <https://www.uber.com/newsroom/electrifying-our-network>.
- Some cities are considering requiring ride hailing service drivers to operate EVs, although without necessarily a link to renewable electricity, from B. Berman, "Los Angeles considers making Uber and Lyft go all-electric", *electrek*, 27 December 2019, <https://electrek.co/2019/12/27/los-angeles-considers-making-uber-and-lyft-go-all-electric>. Efforts to increase use of EVs included, for example, Nissan offering EVs to Uber drivers at a discounted rate, and Uber's collaboration with EVgo and Powerdot to expand charging infrastructure internationally. Partnership on EV discounts from "Uber strikes deal with Nissan in electric vehicle push", *Financial Times*, 23 January 2020, <https://www.ft.com/content/5926b8d6-3d22-11ea-b232-000f4477fbca>; partnership on expanding charging infrastructure from K. Wiggers, "Uber commits to reporting its rides' environmental impact", *Venture Beat*, 26 September 2019, <https://venturebeat.com/2019/09/26/uber-commits-to-reporting-its-rides-environmental-impact/>; in early 2020, Uber and Hyundai announced a partnership to create an aerial ridesharing network comprised of electric air taxis, from "Uber and Hyundai announce aerial ridesharing partnership, release new full-scale electric air taxi model at CES", *Green Car Congress*, 7 January 2020, <https://www.greencarcongress.com/2020/01/20200107-hyundaiuber.html>; Smart Energy International, "Uber launches Jump electric bicycle service in Brussels", 2 May 2019, <https://www.smart-energy.com/renewable-energy/uber-launches-jump-electric-bicycle-service-in-brussels>; Smart Energy International, "Octopus Energy partners for carbon-neutral inner-city transport", 26 April 2019, <https://www.smart-energy.com/industry-sectors/electric-vehicles/octopus-energy-lime-e-bike-london>; Mercury, "The awesome foursome", <https://www.mercury.co.nz/why-mercury/renewable-energy>, viewed March 2020; Drive, <https://evdrive.co.nz>, viewed March 2020.
- 167 Challenges include a lack of charging infrastructure, a lack of battery-swapping stations in many areas, a lack of standardisation of charging infrastructure, and the potential environmental and social impacts of sourcing raw materials for battery production. See, for example, the following: Chargepoint, "An employer's guide to EV charging in the workplace", <https://incisive.cvtr.io/lp/chargepoint-bg1?wp=2291&locale=1&msgid=577553-f0bac4483b40ec99>, viewed 15 April 2019; Alternative Fuels Observatory, "Fuel map", <https://www.eafo.eu/fuel-map>, viewed 14 March 2019; Runyon, op. cit. note 142; J. Ward and A. Upadhyay, "India's rickshaw revolution leaves China in the dust", *Bloomberg*, 25 October 2018, <https://www.bloomberg.com/news/features/2018-10-25/india-s-rickshaws-outnumber-china-s-electric-vehicles>. Standardisation of charging infrastructure from S. Bajaj, "New EV charging station guidelines announced", *Mercom India*, 18 December 2018, <https://mercomindia.com/ev-charging-station-guidelines-announced>; potential environmental and social impacts from SLOCAT, op. cit. note 145, p. 92; V2G from, for example, J. Spector, "EMotorWerks is using its network of 10,000 EV chargers to bid into wholesale markets", *GTM*, 25 September 2018, <https://www.greentechmedia.com/articles/read/emotorwerks-wholesale-markets-ev-charger-network>.
- 168 Fleet Europe, "Vehicle-to-grid pilot schemes gather pace", 5 August 2019, <https://www.fleeteurope.com/en/new-energies/europe/analysis/vehicle-grid-pilot-schemes-gather-pace/>; E. Wenzel, "Vehicle-to-grid technology is revving up", *GreenBiz*, 12 November 2019, <https://www.greenbiz.com/article/vehicle-grid-technology-revving>; Ros, op. cit. note 148; S. Hanley, "Volkswagen bets on vehicle-to-grid technology, UL approves first V2G certification", *CleanTechnica*, 13 March 2020, <https://cleantechnica.com/2020/03/13/volkswagen-bets-on-vehicle-to-grid-technology-ul-approves-first-v2g-certification>.
- 169 ITF, "How to make urban mobility clean and green", 4 December 2018, <https://www.itf-oecd.org/urban-mobility-clean-green>. To incentivise increased public transport use, some cities have made public transport free. In 2018, Luxembourg became the first country to pledge to make all of its public transport free for users by 2020, although these initiatives are often mainly to decrease congestion and local pollution, from D. Boffey, "Luxembourg to become first country to make all public transport free", *The Guardian* (UK), 5 December 2018, <http://www.theguardian.com/world/2018/dec/05/luxembourg-to-become-first-country-to-make-all-public-transport-free>.
- 170 CNESA, "2019 sees new solar-storage-charging stations launched across China", 29 November 2019, <http://en.cnesa.org/latest-news/2019/11/29/et8hrtqdeblp7knrz3rj16bg4ohjt>. Many other charging stations that use solar EV and energy storage have been developed in China since 2017.
- 171 Nippon, "Train service in Tokyo powered fully by renewable energy", 25 March 2019, <https://www.nippon.com/en/news/yjj2019032500565/train-service-in-tokyo-powered-fully-by-renewable-energy.html>.
- 172 M. Zasiadko, "Melbourne tram network becomes more solar-powered", *RailTech.com*, 13 August 2019, <https://www.railtech.com/policy/2019/08/13/melbourne-tram-network-becomes-more-solar-powered>.
- 173 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 174 IEA, *The Future of Rail* (Paris: 2019), <https://www.iea.org/futureofrail>.
- 175 Based on IEA, *World Energy Statistics and Balances*, op. cit. note 40.
- 176 For example, the Dutch railway company NS achieved its 100% renewable electricity target in 2017, from "18 new biodiesel fuelled trains coming to the Netherlands", *Biofuels International*, 13 July 2017, https://biofuels-news.com/display_news/12601/18_new_biodiesel_fuelled_trains_coming_to_the_netherlands; "Dutch electric trains become 100% powered by wind energy", *Agence France-Presse*, 10 January 2017, <https://www.theguardian.com/world/2017/jan/10/dutch-trains-100-percent-wind-powered-ns>; the Swiss railway company SBB CFF FFS sources 75% of its power from hydropower, from International Union of Railways (UIC), *Railway Statistics: Synopsis* (Paris: 2017), <https://uic.org/IMG/pdf/uic-statistics-synopsis-2017.pdf>, cited in IEA, op. cit. note 174.
- 177 ITF, "Towards road freight decarbonisation", 5 December 2018, <https://www.itf-oecd.org/towards-road-freight-decarbonisation>.
- 178 "Why automakers are driving for uniform fuel efficiency standards", University of Pennsylvania – Knowledge @ Wharton, 14 June 2019, <https://knowledge.wharton.upenn.edu/article/end-california-emissions-standards>.
- 179 ITF, op. cit. note 142.
- 180 ITF, op. cit. note 177. Still, auto manufacturers increased their focus on EVs during the year, with some offering an increasing number of models and others dramatically scaling up investment. M. Matousek, "Electric vehicles are a tiny piece of the global car market, but Volkswagen is making a huge bet on them. It doesn't have a choice", *Business Insider France*, 8 November 2019, <https://www.businessinsider.fr/us/vw-making-huge-bet-on-electric-vehicles-in-next-decade-2019-11>; N. Winton, "VW will be the 1st mass market electric car profit maker: Report", *Forbes*, 9 March 2020, <https://www.forbes.com/sites/neilwinton/2020/03/09/vw-will-be-the-1st-mass-market-electric-car-profit-maker-report>; D. Etherington, "Volvo will only make electric and hybrid cars starting in 2019", *The Crunch*, 5 July 2017, <https://techcrunch.com/2017/07/05/volvo-will-only-make-electric-and-hybrid-cars-starting-in-2019>; more models on offer from M. Coren, "2019 was the year electric cars grew up", *Quartz*, 6 December 2019, <https://qz.com/1762465/2019-was-the-year-electric-cars-grew-up>; P. Eisenstein, "Detroit's Big Three automakers are looking to a battery-powered future, but each is forging its own path", *CNBC*, 8 December 2019, <https://www.cnn.com/2019/12/08/us-automakers-look-to-a-battery-powered-future-but-forge-their-own-paths.html>; A. Hawkins, "Volvo unveils its first fully electric car – and a bold pledge to go carbon-neutral", *The Verge*, 16 October 2019, <https://www.theverge.com/2019/10/16/20915841/volvo-xc40-recharge-electric-suv-specs-miles-range-reveal>.
- 181 Gasum and Valio, "Valio adds Volvo FH LNG as Finland's first biogas-fueled milk collection truck", *NGV Global News*, 18 February 2019, <https://www.ngvglobal.com/blog/valio-adds-volvo-fh-lng-as-finlands-first-biogas-fueled-milk-collection->

- truck-0218; Gasum, "Volvo trucks using liquefied biogas trialled by Swedish electronics company", NGV Global News, 8 April 2019, <https://www.ngvglobal.com/blog/volvo-trucks-using-liquefied-biogas-trialled-by-swedish-electronics-company-0408>.
- 182 IEA, *World Energy Statistics and Balances*, op. cit. note 40; O. Merk, "Climate change: What about shipping?" Medium, 5 February 2018, <https://medium.com/@OECD/climate-change-what-about-shipping-471a1344fdd>.
- 183 N. Chestney, "IMO agrees on stricter efficiency targets for some ships", *Reuters*, 17 May 2019, <https://www.reuters.com/article/us-imo-shipping-efficiency/imo-agrees-on-stricter-efficiency-targets-for-some-ships-idUSKCN1SN2BV>; International Shipping News, "New fuel, emission standards for shipping from January", Hellenic Shipping, 30 December 2019, <https://www.hellenicshippingnews.com/new-fuel-emission-standards-for-shipping-from-january>; Euronews, "Shipping industry plans speed limit reductions to cut emissions", 13 May 2019, <https://www.euronews.com/2019/05/13/shipping-industry-plans-speed-limit-reductions-to-cut-emissions>. Previously, in 2018, the International Maritime Organisation (IMO) had adopted energy efficiency standards for international shipping, targeting a 40% reduction in total carbon intensity by 2030 and a 50% reduction in overall greenhouse gas emissions for the sector by 2050, relative to 2008 levels, from IMO, "UN body adopts climate change strategy for shipping", 13 April 2018, <http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGInitialstrategy.aspx>.
- 184 P. Le Feuvre, "Are aviation biofuels ready for take off?" IEA, 18 March 2019, <https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off>.
- 185 "Preem signs agreement for renewable maritime fuel", *Renewable Energy Magazine*, 25 March 2020, <https://www.renewableenergymagazine.com/biogas/preem-signs-agreement-for-renewable-maritime-fuel-20200325>; "Hurtigruten buys fish-based fuel for its future fleet", *The Maritime Executive*, 24 May 2019, <https://www.maritime-executive.com/article/hurtigruten-buys-fish-based-fuel-for-its-future-fleet>.
- 186 Green Car Congress, "Wärtsilä launches first combustion trials with ammonia", 26 March 2020, <https://www.greencarcongress.com/2020/03/20200326-wartsila.html>.
- 187 The programme was established in 2017 led by the Port of Rotterdam (Netherlands) along with Antwerp (Belgium), Barcelona (Spain), Hamburg (Germany), Long Beach and Los Angeles (United States) and Vancouver (Canada). New additions from 2019 include Amsterdam (Netherlands), Le Havre (France), Gothenburg (Sweden), and New York and New Jersey (United States). "Climate action congress plans underway", *Greenport*, 6 September 2019, <https://www.greenport.com/news101/Projects-and-Initiatives/climate-action-congress-plans-underway>; E. Lopez, "From Los Angeles to Hamburg, 7 ports team up to fight climate change", *Supply Chain Dive*, 15 September 2018, <https://www.supplychaindive.com/news/World-Ports-Climate-Action-Program-launch/532431>.
- 188 Port Houston, "Port Commission approves move on renewable energy", press release (Houston, TX: 23 October 2019), https://porthouston.com/wp-content/uploads/Port_Commission_October_Press_Release_revised_Roger_en-002.pdf; B. Houston, Port Houston, personal communication with REN21, 21 January 2020.
- 189 International Shipping News, "New agreement between Swedegas and FordonsGas – liquefied biogas brings further climate benefits to Gothenburg shipping", Hellenic Shipping, 4 June 2019, <https://www.hellenicshippingnews.com/new-agreement-between-swedegas-and-fordonsgas-liquefied-biogas-brings-further-climate-benefits-to-gothenburg-shipping>.
- 190 IEA, op. cit. note 155.
- 191 IEA, *World Energy Statistics and Balances*, op. cit. note 40; Le Feuvre, op. cit. note 184.
- 192 D. Habtemariam, "Global air traffic growth outpaced capacity growth in 2018", *Business Travel News*, 7 February 2019, <https://www.businesstravelnews.com/Global/Air-Traffic-Growth-Outpaced-Capacity-Growth-in-2018>; International Airport Review, "IATA announces 50 per cent decrease in carbon emissions per passenger", 16 December 2019, <https://www.internationalairportreview.com/news/109066/iata-50-per-cent-decrease-carbon-emissions-per-passenger>; H. Tabuchi, "'Worse than anyone expected': Air travel emissions vastly outpace predictions", *New York Times*, 20 September 2019, <https://www.nytimes.com/2019/09/19/climate/air-travel-emissions.html>.
- 193 A. Hawkins, "France will apply an 'ecotax' to nearly all air travel", *The Verge*, 10 July 2019, <https://www.theverge.com/2019/7/10/20688851/france-tax-air-travel-climate-change-ecotax>; Air Transport World, "France calls for European aviation tax," 7 June 2019, <https://atwonline.com/air-transport/safety-ops-regulation/france-calls-european-aviation-tax>; J. Cordero Sapién, "Germany to cut VAT on long distance rail journeys," *Railway News*, 17 October 2019, <https://railway-news.com/germany-vat-long-distance-rail-journeys>.
- 194 International Civil Aviation Organization (ICAO), "Climate change: State action plans and assistance", https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx, viewed 16 March 2020; ICAO, "Environment", <https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx>, viewed 16 March 2020. In early 2020, the ICAO also agreed on the types of carbon offset units eligible under its target for carbon-neutral growth from 2020, although only using average emissions from 2019 as the baseline. Air Transport Action Group, "Aviation industry welcomes progress on CORSIA, despite global emergency", 16 March 2020, <https://www.atag.org/component/news/?view=pressrelease&id=119>. Eighty-two countries will take part in the first (voluntary) phase of the scheme with a target of covering about 80% of the growth in international aviation emissions by the end of 2020. The European Commission has stated that CORSIA is not ambitious enough, from D. Keating, "EU countries urged to reject UN scheme that could thwart action on aviation emissions", *EURACTIV*, 23 September 2019, <https://www.euractiv.com/section/climate-environment/news/eu-countries-urged-to-reject-un-scheme-that-could-thwart-action-on-aviation-emissions>.
- 195 ICAO, "Environment", op. cit. note 194.
- 196 Ongoing deliveries in: Bergen and Oslo (Norway); Stockholm Arlanda, Stockholm Bromma, Halmstad City, Växjö Smaland and Kalmar Öland (Sweden); and Los Angeles (United States). Batch delivery in: the United States, San Francisco and Van Nuys (California), Jackson Hole (Wyoming), Chicago O'Hare (Illinois); in Canada, Toronto-Pearson (Ontario) and Montreal Trudeau (Québec); Brisbane (Australia); Luleå, Umeå, Åre Östersund, Karlstad, Visby, Göteborg Landvetter and Malmö (Sweden). ICAO, "Environment", op. cit. note 194.
- 197 B. Cogley, "World's first commercial electric plane takes off near Vancouver", *Dezeen*, 17 December 2019, <https://www.dezeen.com/2019/12/17/worlds-first-commercial-electric-plane-canada-seaplane/>. Some airports and private companies have already been envisioning fully electric airliners to carry more than 120 passengers in recent years. For example, Wright Electric and EasyJet have partnered to build an electric airliner in the 120-186 seat range, from Ros, op. cit. note 148. A group of European manufacturers announced plans to trial a hybrid electric plane in 2021, from Airbus, op. cit. note 148. In 2018, Norway became the first country (and as of early 2020, still the only country) to see its airports announce a target for electric air travel, with a goal of having all short-haul domestic flights run on electricity by 2040, from "Norway aims for all short-haul flights 100% electric by 2040", *Tech Xplore*, 17 January 2018, <https://techxplore.com/news/2018-01-norway-aims-short-haul-flights-electric.html>. ZeroAvia has conducted test flights as of early 2019 with a target of supplying its technology to manufacturers and operators by 2022, citing its use of renewables-based hydrogen as not only improving power train efficiency and avoiding the volatility of jet fuel pricing, but also more cost effective than conventional turbine aircraft due to its supply through fixed prices on long-term contracts, from Alcock, op. cit. note 148. See also sources in endnote 148.
- 198 Total capacity based on sources in endnote 5, on data provided throughout this report and on data from past GSRs. See Market and Industry chapter, Reference Table R1, and related endnotes for sources and details. **Figure 8** based on idem. For more on renewable power capacity in 2019, see Reference Table R1, technology sections in Market and Industry chapter, and related endnotes.
- 199 Ibid., all references.
- 200 Solar PV from IEA PVPS, op. cit. note 5, p. 6. Capacity provided is in direct current (DC). See Solar PV section in Market and Industry chapter for details.
- 201 Based on capacity additions reported in endnote 5 and throughout this report.
- 202 Ibid.
- 203 Share of added renewable power capacity to non-renewable power capacity was 75%. Renewable power capacity from Ibid.;

- non-renewable power capacity provided by A. Whiteman, IRENA, personal communication with REN21, 8 May 2020. **Figure 9** based on sources in this note.
- 204 See sources in endnote 5.
- 205 Ibid.
- 206 Notable growth for multiple renewable energy technologies from the following: Australia (solar PV and wind power) from Clean Energy Council, op. cit. note 93; Argentina (solar PV and wind power) from Cammesa, *Informe Renovables Marzo 2020* (Buenos Aires: 2020), <https://portalweb.cammesa.com/Documentos%20compartidos/Noticias/Mater/Informe%20Renovables%20MAR%202020.pdf>; Israel (CSP and solar PV) from New Energy Update, op. cit. note 5, and from IEA PVPS, op. cit. note 5; Mexico (solar PV and wind power) from IEA PVPS, op. cit. note 5, and from GWEC, op. cit. note 5; Turkey (hydropower and geothermal power, with moderate additions in both solar PV and wind power) from IHA op. cit. note 5, and from Turkish Electricity Transmission Company (TEİAŞ), <http://www.teias.gov.tr>, viewed May 2020; Vietnam (solar PV and wind power) from IEA PVPS, op. cit. note 5, and from GWEC, op. cit. note 5.
- 207 See sources in endnote 5.
- 208 Estimate of 17 countries in 2019 from sources in endnote 5; 5 countries in 2009 from IRENA, op. cit. note 5.
- 209 Ranking for top countries for non-hydropower capacity based on Ibid. and on various sources throughout Market and Industry chapter.
- 210 Share of generation based on the following: total global electricity generation in 2019 estimated at 27,011 TWh, based on 26,615 TWh in 2018 from BP, op. cit. note 40, and on estimated 1.49% growth in global electricity generation in 2019. Growth rate in 2019 is based on the weighted average change in actual total generation for the following countries/regions (which together accounted for more than two-thirds of global generation in 2018): United States (-1.3% net generation), EU-28 (-1.2%), Russian Federation (+1.2%), India (+0.0%), China (+4.7%), Canada (-0.2%) and Brazil (+2.0%). Generation data for 2018 and 2019 by country or region from the following: US EIA, op. cit. note 5, Table 1.1; EC, Eurostat database, <http://ec.europa.eu/eurostat>; Ministry of Energy of the Russian Federation, "Statistics", <https://minenergo.gov.ru/en/activity/statistic>, viewed April 2020. Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly generation report", <http://www.cea.nic.in/monthlyarchive.html>, viewed April 2020; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2019 national economic and social development", press release (Beijing: 28 February 2020), http://www.stats.gov.cn/english/PressRelease/202002/t20200228_1728917.html (using Google Translate); Statistics Canada, "Electric Power Generation, monthly generation by type of electricity", <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501>, updated 11 May 2020; National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed April 2020. **Hydropower** generation in 2019 of 4,306 TWh from IHA, op. cit. note 5. **CSP** estimated at 15.93 TWh, from IEA, op. cit. note 5, datafiles. **Solar PV** worldwide production potential of 715.15 TWh, from G. Masson and A. Detollenaere, Becquerel Institute and IEA PVPS, personal communication with REN21, 12 April 2020. Estimates for electricity generation from Masson and IEA PVPS are theoretical calculations based on average yield and installed solar PV capacity as of 31 December 2019. **Wind power** estimated wind generation of 1,600 TWh, based on wind power capacity at end-2019 from the following sources: Europe (excluding Turkey) from WindEurope, *Wind in Europe in 2019* (Brussels: 2020), p. 7, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf>; United States from American Wind Energy Association, *U.S. Wind Industry Quarterly Market Report, Fourth Quarter 2019* (Washington: January 2020), p. 3, https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/4q2019_marketreport. Remaining countries and regions from GWEC, "Global Wind Statistics 2019: Status as End of 2019" (Brussels: March 2020); generation estimated with selected weighted average capacity factors by region, and for both onshore and offshore wind power, from the following sources: Asia and China offshore for 2018 (latest data available) from F. Zhao, GWEC, personal communication with REN21, 14 May 2019; Brazil from ONS, *Boletim Mensal de Geração Eólica Março 2020* (Brasília: 2020), p. 20, http://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/Boletim_Geracao_Eolica_202003.pdf; China estimated at 0.24 using national average productivity of 2082 full-load hours for wind turbines from China Energy Portal, "2019 wind power installations and production by province", 28 February 2020, <https://chinaenergyportal.org/en/2019-wind-power-installations-and-production-by-province>; Europe from WindEurope op. cit. this note, p. 18; United States for 2018 (latest available) from US DOE, op. cit. note 4, p. ix, remaining countries and regions from Whiteman, op. cit. note 203. **Geothermal power** generation of 93.6 TWh, from IEA, op. cit. note 5; **ocean energy** generation of 1.1 TWh, from idem; **bio-power** generation of 591 TWh, based on national data from the following sources: US EIA, *Electric Power Monthly* (Washington, DC: March 2020), Table 1.1a, <https://www.eia.gov/electricity/data.php>, corrected for difference between net and gross electricity generation; BMWi, "Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, 1990-2019", op. cit. note 5, Table 3; UK BEIS, op. cit. note 5; other countries based on forecast 2017 capacity figures from IEA, op. cit. note 5, datafiles. New Energy Network, "The installed capacity of biomass power generation in 2019 increased by 26.6% year-on-year", 12 March 2020, <https://newenergy.in-en.com/html/newenergy-2375278.shtml> (using Google Translate).
- 211 **Figure 10** based on Ibid., all references. The remaining share is from geothermal power (1%), CSP (<1%) and ocean power (~0%).
- 212 Estimate for 2009 from Eurostat, "SHARES summary results 2018", <https://ec.europa.eu/eurostat/web/energy/data/shares>, viewed 20 May 2020; 2019 estimate from Agora Energiewende and EMBER, *The European Power Sector in 2019* (London: 2020), <https://ember-climate.org/project/power-2019>.
- 213 Denmark from Danish Energy Agency, "Månedlig elstatistik. Oversigtstabeller", in Monthly Electricity Supply, <https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics>, viewed 15 April 2020; Germany from BMWi, op. cit. note 5; United Kingdom from UK BEIS, op. cit. note 5, Table 6.1. Other notable increases included Belgium (8.5% to 22.8%), Ireland (16% to 34%), Italy (24.5% to 40.0%) and Portugal (38.2% to 54.2%), all estimated from EMBER, Global Electricity Review database, <https://ember-climate.org/project/data-global-electricity-review>, viewed 15 April 2020.
- 214 US EIA, *Annual Energy Review*, "Table 8.2b: Electricity net generation: Electric power sector", <https://www.eia.gov/totalenergy/data/annual>, viewed 17 April 2020.
- 215 Renewable share of generation in 2019 from China Electricity Council, *Statistics of China Power Industry 2019* (Beijing: 2020), <http://english.cec.org.cn/No.110.1941.htm>; 2009 from US EIA, International Data Browser, <https://www.eia.gov/international/data/world/electricity/electricity-generation>, viewed 20 May 2020.
- 216 Australia 2009 share from National Electricity Market, Open NEM Database, <https://opennem.org.au/energy/nem>, viewed 1 May 2020, and 2019 share from Clean Energy Council, op. cit. note 93; Ethiopia and Kenya from EMBER, op. cit. note 213; Uruguay from Uruguayan Ministry of Industry, Energy and Mining (MIEM), "Balance Preliminar 2019", <https://ben.miem.gub.uy/preliminar.html>, viewed 4 May 2020. Many Central and South American countries increased the share of renewables in electricity generation principally through production of hydropower, including Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Nicaragua and Panama.
- 217 FS-UNEP and BloombergNEF, op. cit. note 28.
- 218 IEA, *Status of Power System Transformation 2019: System Flexibility* (Paris: 2019), p. 9, https://webstore.iea.org/download/direct/2782?fileName=Status_of_Power_System_Transformation_2019.pdf. See also Systems Integration section in Policy Landscape chapter.
- 219 REN21 Policy Database. See also Power section in Policy Landscape chapter and Reference Table R12. Capacity increase from FS-UNEP and BloombergNEF, op. cit. note 28.
- 220 REN21 Policy Database. See also Power section in Policy Landscape chapter and Reference Table R11.
- 221 China from F. Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 13 April 2020, and see also endnote 30 in Solar PV section of Market and Industry chapter; Spain from SolarPower Europe, "Spain removes controversial sun tax", 9 October 2018, <https://www.solarpowereurope.org/spain-removes-controversial-sun-tax>.

- 222 WindEurope, "Giles Dickson: Germany must deliver on permitting promises", 12 March 2020, <https://windeurope.org/newsroom/press-releases/giles-dickson-germany-must-deliver-on-permitting-promises>.
- 223 For example, 77% of Brazil's remaining hydropower potential lies on protected lands, from T. Barral Ferreira, Energy Research Office (EPE), personal communication with REN21, 21 February 2020; in the Philippines, geothermal potential is constrained by a government act on protected lands, from J. L. Mayuga, "Lack of incentives crimps investments in geothermal", Business Mirror, 2 March 2020, <https://businessmirror.com.ph/2020/03/02/lack-of-incentives-crimps-investments-in-geothermal>.
- 224 See Policy Landscape chapter and Reference Table R12.
- 225 J. R. Martin, "Brazilian PV outcompetes all in auction debut alongside non-renewables", PV-Tech, 21 October 2019, <https://www.pv-tech.org/news/brazilian-pv-outcompetes-all-in-auction-debut-alongside-non-renewables>.
- 226 See Market and Industry chapter for more information. For examples, see the following: M. Willuhn, "Portuguese auction attracts world record bid of €14.8/MWh for solar", pv magazine, 31 July 2019, <https://www.pv-magazine.com/2019/07/31/portuguese-auction-attracts-world-record-bid-of-e14-8-mwh-for-solar/>; F. Elbahrawi and F. Alzahrani, "Dubai utility gets record low bid to build solar-power plant", *Bloomberg*, 13 October 2019, <https://www.bloomberg.com/news/articles/2019-10-13/dubai-utility-gets-record-low-bid-to-build-solar-power-plant>; M. Willuhn, "Brazil A-4 auction signs 211 MW of solar for record-low price of \$0.0175 kWh", pv magazine, 1 July 2019, <https://www.pv-magazine.com/2019/07/01/brazil-a-4-auction-signs-211-mw-of-solar-for-record-low-price-of-0-0175-kwh/>; L. Collins, "Solar hits new record low with €14.80/MWh winning bid in Portugal", Recharge, 31 July 2019, <https://www.rechargenews.com/transition/solar-hits-new-record-low-with-14-80-mwh-winning-bid-in-portugal/2-1-647124>; E. Bellini, "Qatar's 800 MW tender draws world record solar power price of \$0.01567/kWh", pv magazine, 24 January 2020, <https://pv-magazine-usa.com/2020/01/24/qatars-800-mw-tender-draws-world-record-solar-power-price-of-0-01567-kwh/>; BMWi, op. cit. note 5.
- 227 IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), pp. 13-16, <https://www.irena.org/publications/2019/Dec/Renewable-energy-auctions-Status-and-trends-beyond-price>.
- 228 Ibid., pp. 13-16.
- 229 For examples, see Wind Power and Solar PV sections in Market and Industry chapter, specifically endnotes 186-195 in Wind Power section and endnote 213 in Solar PV section.
- 230 J. Deign, "Key to those record-low solar bids? Rosy merchant income assumptions", GTM, 9 August 2019, <https://www.greentechmedia.com/articles/read/merchant-income-is-key-in-latest-record-solar-bids>.
- 231 In Germany, the rise of auctions and a lack of defined processes for community participation led to no community-led wind power projects being implemented in 2019, from World Wind Energy Association, *Community Wind Under the Auctions Model: A Critical Appraisal* (Bonn: 2019), <https://wwindea.org/blog/2019/09/02/german-government-clearly-misses-all-three-self-imposed-goals-associated-with-auctions>; Windtech International, "A dangerous trend is challenging the success of wind power around the globe: Concentration and monopolisation", 4 February 2020, <https://www.windtech-international.com/view-from-inside/a-dangerous-trend-is-challenging-the-success-of-wind-power-around-the-globe-concentration-and-monopolisation>; IRENA, op. cit. note 227, p. 66.
- 232 A. Rathi and K. Singh, "One of India's largest coal-mining states says it will not build new coal power plants", Quartz India, 16 September 2019, <https://qz.com/india/1709483/after-gujarat-indias-chhattisgarh-wont-build-coal-power-plants>; N. Kabear, "Tata Power decides to pull the plug on coal-based power: Report", Mercom India, 25 April 2019, <https://mercomindia.com/tata-power-decides-to-pull-the-plug-on-coal/>; "Power firm Iberdrola to become coal free in 2020", *Reuters*, 2 December 2019, <https://af.reuters.com/article/energyOilNews/idAFL8N28C317>; United States from Powermag, "Decarbonization: Utilities leading the way", 2 December 2019, <https://www.powermag.com/decarbonization-utilities-leading-the-way/>; J. Pyper, "Tracking progress on 100% clean energy targets", GTM, 12 November 2019, <https://www.greentechmedia.com/articles/read/tracking-progress-on-100-clean-energy-targets>; J. Grice, "Eversource Energy to go 'carbon-neutral' by 2030", Connecticut Post, 11 December 2019, <https://www.ctpost.com/business/article/Eversource-to-go-carbon-neutral-by-2030-14899277.php>; municipal utilities from REN21, op. cit. note 1.
- 233 Kabear, op. cit. note 232.
- 234 Powermag, op. cit. note 232.
- 235 **Asia** from V. Shaw, "China's nuclear operator to develop 1 GW solar field", pv magazine, 15 November 2019, <https://www.pv-magazine.com/2019/11/15/chinas-nuclear-operator-to-develop-1-gw-solar-field>, from N. Prasad, "Coal India invites expression of interest for a 100 MW solar project in Chhattisgarh", Mercom India, 11 November 2019, <https://mercomindia.com/coal-india-invites-expression-interest-solar-project-chhattisgarh>, and from A. Parikh, "Indian Oil floats tender for 1,050 kW of solar projects at Guwahati refinery", Mercom India, 31 July 2019, <https://mercomindia.com/indian-oil-tender-solar-guwahati-refinery>; **Europe** from J. Parnell, "Global renewables giant born as RWE approved for 17GW pipeline deal", GTM, 17 September 2019, <https://www.greentechmedia.com/articles/read/rwe-gets-approval-on-17-gw-renewables-deal>, and from R. Bousso and S. Twidale, "Shell aims to beat power utilities at their own game", *Reuters*, 19 June 2019, <https://www.reuters.com/article/us-shell-power-analysis-idUSKCN1TKIN7>; **Middle East** from M. Habboush, "Builder of Saudi Aramco oil rigs plans to expand into wind power", *Bloomberg*, 26 June 2019, <https://www.bloomberg.com/news/articles/2019-06-26/builder-of-saudi-aramco-oil-rigs-plans-to-expand-into-wind-power>; **United States** from J. Runyon, "New companies are helping maintain, analyze, finance and build the wind industry", Renewable Energy World, 5 September 2018, <https://www.renewableenergyworld.com/2018/05/09/new-companies-are-helping-maintain-analyze-finance-and-build-the-wind-industry>, and from A. Hsu, "How Big Oil of the past helped launch the solar industry of today", NPR, 30 September 2019, <https://www.npr.org/2019/09/30/763844598/how-big-oil-of-the-past-helped-launch-the-solar-industry-of-today>.
- 236 **Denmark** share of net generation based on preliminary net generation data of 16,150 GWh from wind power, 963 GWh from solar PV and total net production of 28,457 GWh, from Danish Energy Agency, op. cit. note 213; **Uruguay** share of total generation based on data from MIEM, "Generación de electricidad por fuente (GWh), 2019", provided by MIEM, personal communication with REN21, 2 April 2020; **Ireland** from EirGrid, "Annual fuel mix", <http://www.eirgridgroup.com/site-files/library/EirGrid/Fuel20Mix.jpg>, viewed 15 April 2020; **Germany** based on data from BMWi, op. cit. note 5; **Portugal** share of net generation based on net generation data of 13,423 GWh from wind power, 1,052 GWh from solar PV and total net production of 48,771 GWh, from REN, "Dados Técnicos 19", p. 8, [https://www.ren.pt/files/2020-03/2020-03-18181207_f7664ca7-3a1a-4b25-9f46-2056eef44c33\\$72f445d4-8e31-416a-bd01-d7b980134d0f\\$ebbb69f10-6bdf-42e0-bcc4-a449cdf60ca\\$\\$storage_image\\$\\$pt\\$1.pdf](https://www.ren.pt/files/2020-03/2020-03-18181207_f7664ca7-3a1a-4b25-9f46-2056eef44c33$72f445d4-8e31-416a-bd01-d7b980134d0f$ebbb69f10-6bdf-42e0-bcc4-a449cdf60ca$$storage_image$$pt$1.pdf); **Spain** share of consumption/production based on provisional data from Red Eléctrica de España, *The Spanish Electricity System - Preliminary Report 2019* (Madrid: January 2020), with estimated data as of 10 January 2020, p. 16, https://www.ree.es/sites/default/files/11_PUBLICATIONES/Documentos/InformesSistemaElectrico/2020/avance_ISE_2019_EN.pdf; **Greece** from the following sources: for interconnected systems, data from Greek Operator of Electricity Market, "DAS Monthly Reports", <http://www.lagie.gr/en/market/market-analysis/das-monthly-reports/>; for non-interconnected islands, data from Hellenic Energy Exchange S.A. (EnEx), <http://www.enxgroup.gr/en/market/market-analysis/das-yearly-report> and from www.enxgroup.gr/en/market/marketanalysis/das-monthly-reports, viewed April 2020 (in Greek and provided by I. Tsipouridis, R.E.D. Pro Consultants, Athens, personal communication with REN21, 17 April 2020); **United Kingdom** share of generation (9.9% onshore wind, 9.9% offshore wind, 3.9% solar PV) from UK BEIS, op. cit. note 5, Table 6.1; **Honduras** from T. Vindel, Secretary of State in the Energy Office of Honduras, provided by G. Bravo, Fundación Bariloche, personal communication with REN21, 27 April 2020; **Nicaragua** share of net generation from Nicaraguan Institute of Energy, Regulatory Entity, "Generación neta sistema eléctrico nacional año 2019", https://www.ine.gov.ni/DGE/estadisticas/2019/generacion_neta_dic19_actmar20.pdf, viewed 17 April 2020.
- 237 Ibid., all references.

- 238 IEA, op. cit. note 218.
- 239 For examples, see Systems Integration chapter.
- 240 W. Gorman et al., "Motivations and options for deploying hybrid generator-plus-battery projects within the bulk power system", *The Electricity Journal*, June 2020, <https://www.sciencedirect.com/science/article/pii/S1040619020300312?via%3Dihub>. Pairing technologies not only side-by-side but at the same interconnection reduces costs of equipment, siting, grid connection, financing as well as operations and maintenance compared to separate projects while also increasing capacity factor.
- 241 G. Parkinson, "South Australia's biggest wind solar hybrid project gets financial green light", *RenewEconomy*, 15 January 2020, <https://reneweconomy.com.au/south-australias-biggest-wind-solar-hybrid-project-gets-financial-green-light-58154>. Also in Australia, the Kennedy Energy Park hybrid project with planned 15 MW of solar PV, 43 MW of wind power and 2 MW of energy storage faced additional delays throughout the year and missed the 2019 deadline for commissioning, from M. Mazengarb, "CSIRO spin-off, Windlab, looks to Africa after 'year of frustration' in Australia", *RenewEconomy*, 6 March 2020, <https://reneweconomy.com.au/csiro-spin-off-windlab-looks-to-africa-after-year-of-frustration-in-australia-90467>. Clarion Energy Editors, "Vattenfall combines wind, solar, batteries in Netherlands energy park", *Renewable Energy World*, 8 December 2019, <https://www.renewableenergyworld.com/2019/08/12/vattenfall-combines-wind-solar-batteries-in-netherlands-energy-park>; E. Bellini, "Aquavoltaics in the Philippines", *pv magazine*, 13 August 2019, <https://www.pv-magazine.com/2019/08/13/aquavoltaics-in-the-philippines>; J. Spector, "'Cheaper than a peaker': NextEra inks massive wind+solar+storage deal in Oklahoma", *GTM*, 25 July 2019, <https://www.greentechmedia.com/articles/read/nextera-inks-even-bigger-windsolarstorage-deal-with-oklahoma-cooperative>; M. Hughlett, "Minnesota wind-solar hybrid project could be new frontier for renewable energy", *Star Tribune*, 23 September 2019, <http://www.startribune.com/minnesota-wind-solar-hybrid-project-could-be-new-frontier-for-renewable-energy/560906672>; A. Colthorpe, "'First of a kind' for the US: Utility to co-locate 30MW battery with 300MW wind, 50MW solar", *Energy Storage News*, 14 February 2019, <https://www.energy-storage.news/news/first-of-a-kind-for-the-us-utility-to-co-locate-30mw-battery-with-300mw-win>; Government of India, "Renewable energy sector makes rapid strides in 2019", press release (New Delhi: 9 January 2020), <https://pib.gov.in/newsite/PrintRelease.aspx?relid=197343>.
- 242 A. Larson, "Solar & hydro hybridization: Ciel & Terre's floating PV plant on Sobradinho Hydroelectric Dam", *Powermag*, 15 October 2019, <https://www.powermag.com/press-releases/solar-hydro-hybridization-ciel-terres-floating-pv-plant-on-sobradinho-hydroelectric-dam>; GCL System, "Floating solar: Philippines switches on its first hybrid floating photovoltaic hydro power project", *pv magazine*, 16 July 2019, <https://www.pv-magazine-australia.com/press-releases/floating-solar-philippines-switches-on-its-first-hybrid-floating-photovoltaic-hydro-power-project>; E. Bellini, "First hybrid hydro-PV project announced in Russia", *pv magazine*, 6 February 2019, <https://www.pv-magazine.com/2019/02/06/first-hybrid-hydro-pv-project-announced-in-russia>; M. Creg Afful, "Burundi: AfDB's Sustainable Energy Fund for Africa approves \$1M support for solar-hydro hybrid project " *Energy News Africa*, 20 December 2019, <https://energynewsafrika.com/index.php/2019/12/20/burundi-afdb-sustainable-energy-fund-for-africa-approves-1m-support-for-solar-hydro-hybrid-project>.
- 243 reve, "Israel inaugurates Negev concentrated solar power plant", 29 August 2019, <https://www.evwind.es/2019/08/29/israel-inaugurates-negev-concentrated-solar-power-plant/70565>; reve, "6 concentrated solar power projects with 350 MW capacity will be newly built in China this year", 11 September 2019, <https://www.evwind.es/2019/09/11/6-concentrated-solar-power-solar-projects-with-350-mw-capacity-will-be-newly-built-in-china-this-year/70772>; reve, "Cerro Dominador concentrated solar power developer plans larger plants in Chile", 17 October 2019, <https://www.evwind.es/2019/10/17/cerro-dominador-concentrated-solar-power-developer-plans-larger-plants-in-chile/71372>; Masdar, "Bid success for Noor Midelt Phase 1 hybrid solar power plant in Morocco", 23 May 2019, <https://news.masdar.ae/en/news/2019/05/23/10/46/noor-midelt-phase-1-hybrid-solar-power-plant>; "Dubai CSP technology inventions accelerate industry cost reductions", *New Energy Update*, 17 April 2019, <http://newenergyupdate.com/csp-today/dubai-csp-technology-inventions-accelerate-industry-cost-reductions>.

POLICY LANDSCAPE

- 1 International Renewable Energy Agency (IRENA), International Energy Agency (IEA) and Renewable Energy Policy Network for the 21st Century (REN21), *Renewable Energy Policies in a Time of Transition* (Abu Dhabi and Paris: 2018), p. 5, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_IEA_REN21_Policies_2018.pdf.
- 2 This chapter is intended to be only indicative of the overall landscape of policy activity and is not a definitive reference. Generally, listed policies are those that have been enacted by legislative bodies. Some of the listed policies may not yet be implemented, or are awaiting detailed implementing regulations. It is difficult to capture every policy change, so some policies may be unintentionally omitted or incorrectly listed. This report does not cover policies and activities related to technology transfer, capacity building, carbon finance and Clean Development Mechanism projects, nor does it attempt to provide a comprehensive list of broader framework and strategic policies – all of which are still important to renewable energy progress. For the most part, this report also does not cover policies that are still under discussion or formulation, except to highlight overall trends. Information on policies comes from a wide variety of sources, including the IEA and IRENA Global Renewable Energy Policies and Measures Database, the US Database of State Incentives for Renewables & Efficiency (DSIRE), press reports, submissions from REN21 regional- and country-specific contributors and a wide range of unpublished data. **Table 3** and **Figures 12 through 19** are based on numerous sources cited throughout this chapter.
- 3 Based on information and sources used throughout this chapter.
- 4 **Sidebar 3** from the following sources: protectionist measures from S. Evenett and J. Fritz, *Going it Alone? Trade Policy After Three Years of Populism* (London: Centre for Economic Policy Research, 2019), <https://www.globaltradealert.org/reports/48>, and from World Trade Organization, "Global trade growth loses momentum as trade tensions persist", press release (Geneva: 2 April 2019), https://www.wto.org/english/news_e/pres19_e/pr837_e.htm; local content requirements from C. M. Dent, "Clean energy trade governance: Reconciling trade liberalism and climate interventionism?" *New Political Economy*, vol. 23, no. 6 (2018), pp. 728–47, <https://www.tandfonline.com/doi/abs/10.1080/13563467.2018.1384456>; free trade agreements from TRade & ENvironment Database (TREND), <http://www.chaire-epi.ulaval.ca/en/trend>, viewed 18 April 2020.
- 5 Government of Scotland, *Protecting Scotland's Future: The Government's Programme for Scotland 2019-2020* (Edinburgh, Scotland: 2019), <https://www.gov.scot/publications/protecting-scotlands-future-governments-programme-scotland-2019-20/pages/5>.
- 6 Netherlands Enterprise Agency, "Stimulation of Sustainable Energy Production – SDE+", <https://english.rvo.nl/subsidies-programmes/sde>, viewed 3 November 2019.
- 7 IEA, "Policies", <https://www.iea.org/topics/renewables/policies>, viewed 21 October 2019.
- 8 S. Djunicic, "Spain targets 120 GW of renewable energy capacity in 2030", *Renewables Now*, 25 February 2019, <https://renewablesnow.com/news/spain-targets-120-gw-of-renewable-energy-capacity-in-2030-644221>.
- 9 **Figure 15** from World Bank, Carbon Pricing Dashboard, <https://carbonpricingdashboard.worldbank.org>, viewed 23 April 2020, and from Energy and Climate Intelligence Unit, Net Zero Tracker, <https://eciu.net/netzerotracker>, viewed 23 April 2020.
- 10 United Nations Framework Convention on Climate Change (UNFCCC), "Costa Rica commits to fully decarbonize by 2050", 4 March 2019, <https://unfccc.int/news/costa-rica-commits-to-fully-decarbonize-by-2050>; S. Rodriguez, "Costa Rica launches 'unprecedented' push for zero emissions by 2050", *Reuters*, 25 February 2019, <https://www.reuters.com/article/us-costa-rica-climatechange-transportati/costa-rica-launches-unprecedented-push-for-zero-emissions-by-2050-idUSKCN1QE253>.
- 11 K. Oroschakoff and J. Posaner, "Germany announces multi-billion euro climate plan", *Politico*, 21 September 2019, <https://www.politico.eu/article/german-government-announces-multi-billion-euro-plan-climate-change>.
- 12 "New York climate plan sets 30-year goal for 100% renewable energy", *Los Angeles Times*, 20 July 2019, <https://www.latimes.com/world-nation/story/2019-07-20/new-york-climate-plan>.
- 13 E. Kirschbaum, "Germany to close all 84 of its coal-fired power plants, will rely primarily on renewable energy", *Los Angeles Times*, 26 January 2019, <https://www.latimes.com/world/europe/la-fg-germany-coal-power-20190126-story.html>; T. Azzopardi, "Chile to phase out coal-fired power generation by 2040", *Bloomberg Environment*, 4 June 2019, <https://news.bloombergenvironment.com/environment-and-energy/chile-to-phase-out-coal-fired-power-generation-by-2040>.
- 14 E. Merchant, "New Mexico's 100% clean energy law praised for worker retraining, but community concerns remain", *GTM*, 29 March 2019, <https://www.greentechmedia.com/articles/read/new-mexico-100-clean-energy-law-community-concerns>; R. Bowers, "Four states updated their renewable portfolio standards in the first half of 2019", *Today in Energy*, US Energy Information Administration (EIA), 24 June 2019, <https://www.eia.gov/todayinenergy/detail.php?id=39953>; J. Ellsmoor, "After pollution crisis, Puerto Rico to eliminate all coal power next year", *Forbes*, <https://www.forbes.com/sites/jamesellsmoor/2019/04/10/after-pollution-crisis-puerto-rico-to-eliminate-all-coal-power-next-year>.
- 15 REN21 research based on the following: IRENA, "Renewable energy in the NDCs", <https://www.irena.org/Statistics/View-Data-by-Topic/Climate-Change/Renewable-Energy-in-the-NDCs>, viewed 14 April 2020; UNFCCC, "NDC Registry", <https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx>.
- 16 International Institute for Sustainable Development (IISD), "European Commission launches green deal to reset economic growth for carbon neutrality", 19 December 2019, <https://sdg.iisd.org/news/european-commission-launches-green-deal-to-reset-economic-growth-for-carbon-neutrality>; "EU carbon neutrality: Leaders agree 2050 target without Poland", *BBC News*, 13 December 2019, <https://www.bbc.com/news/world-europe-50778001>.
- 17 In previous years, Denmark and Norway committed to net zero by 2050, and Sweden's legislation calls for net zero by 2045. R. Russell, "Net-zero by 2050: What does it mean?" *DW*, 31 May 2019, <https://www.dw.com/en/net-zero-by-2050-what-does-it-mean/a-48958487>; UK Department for Business, Energy & Industrial Strategy and The Rt Hon Chris Skidmore MP, "UK becomes first major economy to pass net zero emissions law", 27 June 2019, <https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law>; B. Felix, "France sets 2050 carbon-neutral target with new law", *Reuters*, 27 June 2019, <https://www.reuters.com/article/us-france-energy/france-sets-2050-carbon-neutral-target-with-new-law-idUSKCN1TS30B>; Government of Ireland, Department of Communications, Climate Action and Environment, *Climate Action Plan 2019 to Tackle Climate Breakdown* (Dublin: July 2019), <https://www.dccae.gov.ie/en-ie/climate-action/publications/Pages/Climate-Action-Plan.aspx>; European Commission (EC), *Assessment of the Draft National Energy and Climate Plan of Spain* (Brussels: June 2019), p. 2, https://ec.europa.eu/energy/sites/ener/files/documents/es_swd_en.pdf.
- 18 M. Mazengarb, "New Zealand passes historic zero carbon bill with near unanimous bipartisan support", *RenewEconomy*, 8 November 2019, <https://reneweconomy.com.au/new-zealand-passes-historic-zero-carbon-bill-with-near-unanimous-bipartisan-support-33500>.
- 19 C. Stam, "New Danish government puts climate change centre stage", *Euractiv*, 26 June 2019, <https://www.euractiv.com/section/climate-environment/news/new-danish-government-puts-climate-change-centre-stage>.
- 20 L. Mead, "Japan's long-term strategy pledges emission reductions through 'virtuous cycle of environment and growth'", *IISD*, 9 July 2019, <http://sdg.iisd.org/news/japans-long-term-strategy-pledges-emission-reductions-through-virtuous-cycle-of-environment-and-growth>.
- 21 N. Sauer, "Russia formally joins Paris climate agreement", *Climate Home News*, 23 September 2019, <https://www.climatechangenews.com/2019/09/23/russia-formally-joins-paris-climate-agreement>; A. Grigoryan, "Russia: Government introduces bill to regulate greenhouse gas emissions and absorption", *US Library of Congress*, 7 May 2019, <https://www.loc.gov/law/foreign-news/article/russia-government-introduces-bill-to-regulate-greenhouse-gas-emissions-and-absorptions>; N. Doff, "Russia scraps plans to set climate-change goals for businesses", *Bloomberg*, 7 November 2019, <https://www.bloomberg.com/news/articles/2019-11-07/russia-scraps-plans-to-set-climate-change-goals-for-businesses>.

- 22 C40 Cities, "Mayors announce support for Global Green New Deal; recognize global climate emergency", press release (Los Angeles: 9 October 2019), https://www.c40.org/press_releases/global-gnd; C. Crowe, "Mayors announce Global Green New Deal at C40 Summit", Smart Cities Dive, 10 October 2019, <https://www.smartcitiesdive.com/news/mayors-announce-global-green-new-deal-at-c40-summit/564732>.
- 23 REN21, *Renewables in Cities: 2019 Global Status Report* (Paris: 2019), p. 50, https://www.ren21.net/wp-content/uploads/2019/05/REC-2019-GSR_Full_Report_web.pdf.
- 24 B. Plumer and N. Popovich, "These countries have prices on carbon. Are they working?" *New York Times*, 2 April 2019, <https://www.nytimes.com/interactive/2019/04/02/climate/pricing-carbon-emissions.html>.
- 25 "COP25, the UN climate talks in Madrid, ends in a sad splutter", *The Economist*, 15 December 2019, <https://www.economist.com/science-and-technology/2019/12/15/cop25-the-un-climate-talks-in-madrid-ends-in-a-sad-splutter>.
- 26 Government of South Africa, "Act No. 15 of 2019: Carbon Tax Act" (Cape Town, South Africa: 23 May 2019), https://www.gov.za/sites/default/files/gcis_document/201905/4248323-5act15of2019carbontaxact.pdf; National Environment Agency, "Carbon tax", <https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/climate-change/carbon-tax>, updated 28 January 2019; Climate Action Tracker, "Switzerland country summary", <https://climateactiontracker.org/countries/switzerland>, updated 19 September 2019.
- 27 PWC, "Tax Insights: Federal carbon pricing backstop program – still wondering if you have an obligation?" 24 May 2019, <https://www.pwc.com/ca/en/services/tax/publications/tax-insights/federal-carbon-pricing-backstop-program.html>.
- 28 Ibid.
- 29 J. McDaniel, "Pennsylvania joins Regional Greenhouse Gas Initiative, taking landmark – and controversial – climate step", *Philadelphia Inquirer*, 3 October 2019, <https://www.inquirer.com/news/rggi-pennsylvania-regional-greenhouse-gas-initiative-wolf-climate-change-20191003.html>.
- 30 World Bank, "Carbon Pricing Dashboard", <https://carbonpricingdashboard.worldbank.org>, viewed 22 October 2019.
- 31 IEA, *World Energy Balances and Statistics* (Paris: 2019), <https://www.iea.org/subscribe-to-data-services/world-energy-balances-and-statistics>; IEA, *Renewable Heat Policies* (Paris: 2018), p. 4, https://www.iea.org/publications/insights/insightpublications/Renewable_Heat_Policies.pdf.
- 32 REN21 Policy Database
- 33 IRENA, IEA and REN21, op. cit. note 1, p. 26.
- 34 M. Dzirutwe, "Zimbabwe bans new electric water heaters to save energy", *Reuters*, 13 November 2019, <https://www.reuters.com/article/us-zimbabwe-power/zimbabwe-bans-new-electric-water-heaters-to-save-energy-idUSKBN1XN1J0>.
- 35 **Figure 16** from REN21 Policy Database.
- 36 Target from Ministère de la Transition écologique et solidaire, *Stratégie française pour l'énergie et le climat, Programmation pluriannuelle de l'énergie, 2019-2023, 2024-2028: Projet pour consultation* (Paris: undated), pp. 97-98, https://www.ecologique-solidaire.gouv.fr/sites/default/files/ppe_pour_consultation_du_public.pdf; funding and conditional support from G. De Clerq, "France makes biogas support conditional on cutting costs", *Reuters*, 26 January 2019, <https://www.reuters.com/article/us-france-energy-gas/france-makes-biogas-support-conditional-on-cutting-costs-idUSKCN1PK0E6>.
- 37 Énergir, "Renewable natural gas – adoption of new regulation to support the sector's development", press release (Montreal, Canada: 27 March 2019), <https://www.newswire.ca/news-releases/renewable-natural-gas-adoption-of-new-regulation-to-support-the-sector-s-development-835158545.html>.
- 38 "Oregon adopts renewable natural gas portfolio standards", *National Law Review*, 23 September 2019, <https://www.natlawreview.com/article/oregon-adopts-renewable-natural-gas-portfolio-standards>.
- 39 California Energy Commission, "CEC approves first local energy efficiency standards that go beyond 2019 statewide requirements", 11 December 2019, <https://www.energy.ca.gov/news/2019-12/cec-approves-first-local-energy-efficiency-standards-go-beyond-2019-statewide>.
- 40 IEA, *2019 Global Status Report for Buildings and Construction* (Paris: 2019), p. 20, <https://webstore.iea.org/2019-global-status-report-for-buildings-and-construction>.
- 41 M. Jordan, IEA, Paris, personal communication with REN21, 25 May 2020.
- 42 Energy Step Code, "Implementation updates", https://energystepcode.ca/implementation_updates, viewed 2 February 2020
- 43 Ministère de la Transition écologique et solidaire, "Coup de pouce économies d'énergie 2019-2020", 3 February 2020, <https://www.ecologique-solidaire.gouv.fr/coup-pouce-economies-denergie-2019-2020>.
- 44 APVA (Lietuvos Respublikos aplinkos ministerijos), "Paskelbtas kvietimas senu ir neefektyviu sildymo katilu keitimui (Call for replacement of old and inefficient boilers has been announced)", 2 January 2020, <https://www.apva.lt/paskelbtas-kvietimas-senu-ir-neefektyviu-sildymo-katilu-keitimui-2>.
- 45 B. Epp, "High scrappage bonus for oil boilers", *Solarthermalworld.org*, 3 March 2020, <https://www.solarthermalworld.org/news/high-scrappage-bonus-oil-boilers>.
- 46 Energy Efficiency Alberta, "Clean Energy Improvement Program: Made-in-Alberta PACE program", <https://efficiencyalberta.ca/financing/clean-energy-improvement-program>, viewed 13 December 2019.
- 47 The funding also was for the installation of rooftop solar PV in the city, from U. Juárez, "Instalarán 4.5 millones de m2 de techos solares en la CDMX", *Energia a debate*, 30 July 2019, <https://www.energiaadebate.com/energia-limpia/instalaran-4-5-millones-de-m2-de-techos-solares-en-la-cdmx>.
- 48 Carbonn Center, "Itabashi City", https://carbonn.org/city_profiles/Itabashi_City, viewed 16 December 2019.
- 49 New York City Council, "Climate Mobilization Act", <https://council.nyc.gov/data/green>, viewed 14 April 2020; D. Wetzal, "Are building owners ready for the Climate Mobilization Act?" *Commercial Observer*, 7 October 2019, <https://commercialobserver.com/2019/10/are-building-owners-ready-for-the-climate-mobilization-act/>; A. Hoffmann, "What building owners need to know about New York's Climate Mobilization Act", *Architect*, 20 November 2019, <https://architect.com/firms/release/18781826/what-building-owners-need-to-know-about-new-york-s-climate-mobilization-act/150171299>.
- 50 Eurac Research, "REWARDheat", <http://www.eurac.edu/en/research/technologies/renewableenergy/projects/Pages/REWARDHEAT.aspx>, viewed 3 November 2019; EC, "Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks", <https://cordis.europa.eu/project/rcn/224317/factsheet/en>, updated 28 October 2019; EURAC Research, "Low temperature district heating: New plants for eight European cities", *American Association for the Advancement of Science*, 22 October 2019, https://www.eurekalert.org/pub_releases/2019-10/er-ltd102219.php.
- 51 Agence de l'Environnement et de la Maîtrise de l'Énergie, "Le Fonds Chaleur 2019: Une mesure majeure en faveur du développement des Énergies Renouvelables", ADEME, 2019, pp. 1-4, https://www.ademe.fr/sites/default/files/assets/documents/2019_instructions_generales_fc.pdf.
- 52 DBDH, "Poland to promote renewable district heating", 22 January 2019, <https://dbdh.dk/2019/01/22/poland-to-promote-renewable-district-heating>.
- 53 Vattenfall, "Vattenfall invests for fossil free district heating in Amsterdam", press release (Stockholm: 21 March 2019), <https://group.vattenfall.com/press-and-media/news--press-releases/pressreleases/2019/vattenfall-invests-for-fossil-free-district-heating-in-amsterdam>.
- 54 klimaaktiv, "Neues Ölkesseleinbauverbotsgesetz im Nationalrat beschlossen", 10 August 2019, <https://www.klimaaktiv.at/erneuerbare/erneuerbarewaerme/Ölkesseleinbauverbotsgesetz.html>; Regjeringen, "Innfører forbud mot bruk av mineralolje til oppvarming av bygninger fra 2020", 15 June 2017, <https://www.regjeringen.no/no/aktuelt/oljefyr/id2556868>; C. Giordano, "New homes will no longer be heated by gas from 2025, government says", *The Independent* (UK), 13 March 2019, <https://www.independent.co.uk/news/uk/politics/gas-ban-new-homes-fossil-fuels-government-phillip-hammond-spring-statement-a8821941.html>.
- 55 J. Rosenow and R. Cowart, "Polish coal boiler phase-out: An inspiration for clean heat", *FORESIGHT Climate & Energy*, 10 February 2020, <https://foresightdk.com/polish-coal-boiler-phase-out-an-inspiration-for-clean-heat>.

- 56 "Vienna to ban oil and gas heaters for 80 per cent of new homes", *Business Standard*, 31 July 2019, https://www.business-standard.com/article/pti-stories/vienna-to-ban-oil-and-gas-heaters-for-80-per-cent-of-new-homes-119073101613_1.html.
- 57 S. Cagle, "Berkeley became first US city to ban natural gas. Here's what that may mean for the future", *The Guardian* (UK), 24 July 2019, <https://www.theguardian.com/environment/2019/jul/23/berkeley-natural-gas-ban-environment>. Other cities in California with natural gas bans include Alameda, Morgan Hill, Mountain View and San Luis Obispo, from M. Gough, "Forward-looking cities lead the way to a gas-free future", *Sierra Club*, 11 February 2020, <https://www.sierraclub.org/articles/2020/03/californias-cities-lead-way-gas-free-future>.
- 58 CTV Montreal, "Montreal to phase out oil heating in next decade", 6 May 2019, <https://montreal.ctvnews.ca/montreal-to-phase-out-oil-heating-in-next-decade-1.4410186>.
- 59 A. Derrick, "Mayor Durkan celebrates City Council's passage of her plan to convert thousands of oil-heated Seattle homes to cleaner, lower carbon electric and help fight climate change", press release (Seattle, WA: Office of the Mayor, City of Seattle, 23 September 2019), <https://durkan.seattle.gov/2019/09/mayor-durkan-celebrates-city-councils-passage-of-her-plan-to-convert-thousands-of-oil-heated-seattle-homes-to-cleaner-lower-carbon-electric-and-help-fight-climate-change>.
- 60 C40 Cities, "Net Zero Carbon Buildings Declaration", <https://www.c40.org/other/net-zero-carbon-buildings-declaration>, viewed 2 February 2020.
- 61 S. European cities target net-zero carbon buildings by 2050", *EURACTIV*, 24 May 2019, <https://www.euractiv.com/section/energy-environment/news/european-cities-target-net-zero-carbon-buildings-by-2050>.
- 62 B. Epp, "A new solar cooling standard for Australia", *Solarthermalworld.org*, 15 July 2019, <https://www.solarthermalworld.org/news/new-solar-cooling-standard-australia>.
- 63 **Box 1** based on the following sources: IRENA, "Sector coupling", <https://www.irena.org/energytransition/Power-Sector-Transformation/Sector-Coupling>, viewed 19 November 2019; IRENA, *Hydrogen from Renewable Power: Technology Outlook for the Energy Transition* (Abu Dhabi: September 2018), <https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power>; L. Cox, "Labor promises to 'supercharge' hydrogen industry as green groups say 'no role for coal'", *The Guardian* (UK), 22 January 2019, <https://www.theguardian.com/australia-news/2019/jan/22/labor-promises-to-supercharge-hydrogen-industry-as-green-groups-say-no-role-for-coal>; Australian Institute of Energy, "ATCO'S clean energy innovation hub", 19 August 2019, <http://www.aie.org.au/events/event/aie-perth-atco-s-clean-energy-innovation-hub>; "Australia launches new hydrogen fund", *H2View*, 25 November 2019, <https://www.h2-view.com/story/australia-launches-new-hydrogen-fund>; M. Mazengarb, "WA opens \$10m hydrogen fund to boost renewable gas production and exports", *RenewEconomy*, 18 September 2019, <https://reneweconomy.com.au/wa-opens-10m-hydrogen-fund-to-boost-renewable-gas-production-and-exports-63479>; "Twenty-five European governments support new Hydrogen Initiative", *Greenovate! Europe*, 18 September 2019, <https://www.greenovate-europe.eu/news/twenty-five-european-governments-support-new-hydrogen-initiative>; D. Harley and J. Brumpton, "Australia: Coal, iron ore, LNG... hydrogen?", *DLA Piper*, 20 August 2019, <https://www.dlapiper.com/en/uk/insights/publications/2019/08/energy-infrastructure-and-projects-global-insight-issue-2/coal-iron-ore-lng-hydrogen>; K. Buckland, "Why Asia's biggest economies are backing hydrogen fuel cell cars", *Japan Times*, 24 September 2019, <https://www.japantimes.com.jp/news/2019/09/24/business/asias-biggest-economies-backing-hydrogen-fuel-cell-cars>; Y. Obayashi, "Japan draws support for global hydrogen proposals, including refueling stations", *Reuters*, 25 September 2019, <https://www.reuters.com/article/us-japan-hydrogen/japan-draws-support-for-global-hydrogen-proposals-including-refueling-stations-idUSKBN1WA19R>; T. Stangarone, "South Korea's hydrogen economy ambitions", *The Diplomat*, 31 January 2019, <https://thediplomat.com/2019/01/south-koreas-hydrogen-economy-ambitions>; J. Deign, "10 countries moving toward a green hydrogen economy", *GTM*, 14 October 2019, <https://www.greentechmedia.com/articles/read/10-countries-moving-towards-a-green-hydrogen-economy>.
- 64 Business Finland, "Finland sets new law to increase biofuel use in road traffic", 19 February 2019, <https://www.businessfinland.fi/en/whats-new/news/2019/finland-sets-new-law-to-increase-biofuel-use-in-road-traffic>.
- 65 IEA, "Industry", <https://www.iea.org/tcep/industry>, viewed 3 November 2019.
- 66 EC, *A New Industrial Strategy for Europe* (Brussels: 10 March 2020), https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf.
- 67 "Minister Bruton announces Support Scheme for Renewable Heat", *Bioenergy International*, 4 June 2019, <https://bioenergyinternational.com/policy/minister-bruton-announces-support-for-renewable-heat>.
- 68 IEA, *World Energy Balances and Statistics*, op. cit. note 31; IRENA, IEA and REN21, op. cit. note 1, p. 39; IRENA, "Running on renewables: Transforming transportation through renewable technologies", 14 January 2018, <https://irena.org/newsroom/articles/2018/Jan/Running-on-renewables-transforming-transportation-through-renewable-technologies>; IEA, "Renewables", <https://www.iea.org/topics/renewables>, viewed 30 October 2019.
- 69 SLOCAT Partnership on Sustainable, Low Carbon Transport (SLOCAT), *Transport and Climate Change 2018 Global Status Report* (Shanghai: 2018), p. 1, <https://slocat.net/tcc-gsr>.
- 70 IRENA, IEA and REN21, op. cit. note 1, p. 44.
- 71 IEA, "Renewables 2019: Transport", <https://www.iea.org/renewables2019/transport>, viewed 19 November 2019.
- 72 IRENA, IEA and REN21, op. cit. note 1, p. 45; IEA, "Does security of supply drive key biofuel markets in Asia?" 21 October 2019, <https://www.iea.org/articles/does-security-of-supply-drive-key-biofuel-markets-in-asia>.
- 73 IRENA, IEA and REN21, op. cit. note 1, p. 45.
- 74 REN21, op. cit. note 23, p. 70.
- 75 US ethanol industry meeting, United Nations Environment Programme (UNEP), Paris, France, 13 November 2019.
- 76 The seven revised mandates were in Brazil, Finland, France, Ireland, Indonesia, Malaysia and Quebec (Canada), from REN21 Policy Database.
- 77 C. Bernadette, "Indonesia launches B30 biodiesel to cut costs, boost palm oil", *Reuters*, 23 December 2019, <https://www.reuters.com/article/us-indonesia-biodiesel/indonesia-launches-b30-biodiesel-to-cut-costs-boost-palm-oil-idUSKBN1YR0D2>.
- 78 V. Petrova, "France raises biofuel blending mandate for 2019, 2020", *Renewables Now*, 10 January 2019, <https://renewablesnow.com/news/france-raises-biofuel-blending-mandate-for-2019-2020-639060>.
- 79 E. Voegelé, "Finland to require 30% biofuel, 10% advanced biofuel by 2030", *Biomass Magazine*, 7 February 2019, <http://biomassmagazine.com/articles/15930/finland-to-require-30-biofuel-10-advanced-biofuel-by-2030>; Business Finland, op. cit. note 64.
- 80 "Brazil increases minimum biodiesel fuel blend to 11%", *Biofuels International*, 7 August 2019, <https://biofuels-news.com/news/brazil-increases-minimum-biodiesel-fuel-blend-to-11>.
- 81 S. Kelly, "Trump EPA finalizes 2020 biofuel rule, corn lobby objects", *Reuters*, 19 December 2019, <https://www.reuters.com/article/us-usa-biofuels/trump-epa-finalizes-2020-biofuel-rule-corn-lobby-objects-idUSKBN1YN20M>.
- 82 EC Joint Research Centre, *Sustainable Advanced Biofuels: Technology Market Report* (Brussels: 2019), https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118309/jrc118309_1.pdf.
- 83 Ibid.
- 84 "Government proposes increased use of renewable fuels in Québec, Canada", *Biofuels International*, 4 October 2019, <https://biofuels-news.com/news/government-proposes-increased-use-of-renewable-fuels-in-quebec-canada>.
- 85 Y. Praiswan, "B10 and B20 price subsidies kick in on Tuesday", *Bangkok Post*, 1 October 2019, <https://www.bangkokpost.com/business/1762204/b10-and-b20-price-subsidies-kick-in-on-tuesday>.

- 86 S. Kelly, "Biodiesel tax credit renewal attached to U.S. spending package", *Reuters*, 17 December 2019, <https://www.reuters.com/article/us-usa-biodiesel-subsidy/biodiesel-tax-credit-renewal-attached-to-u-s-spending-package-idUSKBN1YL1T9>; "Spending bill includes long-sought biodiesel tax credit renewal", *Des Moines Register*, 17 December 2019, <https://www.desmoinesregister.com/story/news/2019/12/17/spending-bill-includes-long-sought-biodiesel-tax-credit-renewal/2677476001>.
- 87 L. Alves, "Brazil announces incentives and seeks new investments in ethanol fuel", *Rio Times*, 19 June 2019, <https://riotimesonline.com/brazil-news/brazil/brazil-announces-incentives-and-seeks-new-investments-in-ethanol-fuel>; H.T. Kennedy, "Latest resolution signed into RenovaBio to further boost Brazil's ethanol sector", *Biofuels Digest*, 7 July 2019, <https://www.biofuelsdigest.com/bdigest/2019/07/07/latest-resolution-signed-into-renovabio-to-further-boost-brazils-ethanol-sector>
- 88 IEA, *Renewables 2019* (Paris: 2019), <https://www.iea.org/reports/renewables-2019>.
- 89 City of Toronto, "Turning waste into renewable natural gas", <https://www.toronto.ca/services-payments/recycling-organics-garbage/solid-waste-facilities/renewable-natural-gas>, viewed 19 November 2019.
- 90 B. Osgood, "City's bus fleet to transition to renewable diesel", *Santa Barbara Independent*, 3 December 2019, <https://www.independent.com/2019/12/03/citys-bus-fleet-to-transition-to-renewable-diesel>.
- 91 R. Kotrba, "Minn. grant funding available for biofuel blending infrastructure", *Biodiesel Magazine*, 29 April 2019, <http://biodieselmagazine.com/articles/2516581/minn-grant-funding-available-for-biofuel-blending-infrastructure>.
- 92 S. Nadel, "How might electrification affect electric and gas systems? Recent studies shed both light and heat", American Council for an Energy-Efficient Economy (ACEEE), 18 September 2018, <https://aceee.org/blog/2018/09/how-might-electrification-affect>.
- 93 In Austria, a quota system applies for renewable energy sources used in transport, but investment grants for vehicle conversion or e-mobility also are available within the scope of the country's "klimatektiv mobil" programme; see Bundesministerium Nachhaltigkeit und Tourismus, "#mission2030 'Mobilitätsoffensive'", <https://www.klimatektiv.at/mobilitaet/elektromobilitaet/foerderung/emob2019.html>, viewed 28 February 2020. Policies linking renewables and EVs previously were in place in Germany and Luxembourg but were no longer in place as of 2018 and 2017, respectively.
- 94 REN21, op. cit. note 23, p. 54.
- 95 SLOCAT, *E-Mobility Trends and Targets*, https://slocat.net/wp-content/uploads/2020/02/SLOCAT_2020_e-mobility-overview.pdf, updated January 2020. National purchases for EVs include purchase subsidies and tax reduction, from IEA, *Global EV Outlook 2020* (Paris: 2020), <https://www.iea.org/reports/global-ev-outlook-2020>
- 96 Government of Canada, "Zero-emissions vehicles", 14 August 2019, <https://www.tc.gc.ca/en/services/road/innovative-technologies/zero-emission-vehicles.html>.
- 97 S. Prateek, "National Electric Mobility Plan 2020 targets deployment of up to 7 million EVs across India", Mercom India, 9 July 2019, <https://mercomindia.com/national-electric-mobility-plan>; IEA, *Global EV Outlook 2019* (Paris: May 2019), p. 75, https://webstore.iea.org/download/direct/2807?fileName=Global_EV_Outlook_2019.pdf.
- 98 M. Uddin, "Pakistan's National Electric Vehicle Policy: Charging towards the future", International Council on Clean Transportation (ICCT), 10 January 2020, <https://theicct.org/blog/staff/pakistan%E2%80%99s-national-electric-vehicle-policy-charging-towards-future>.
- 99 UNFCCC, op. cit. note 10; Rodriguez, op. cit. note 10.
- 100 R. Shah, "Government finally wakes up: Sets a realistic goal of 30% electric vehicles by 2030 from existing 100% target", *Financial Express*, 8 March 2019, <https://www.financialexpress.com/auto/car-news/government-finally-wakes-up-sets-a-realistic-goal-of-30-electric-vehicles-by-2030-from-existing-100-target/1091075>.
- 101 Virginia Governor Ralph S. Northam, "Governor Northam announces \$20 million electric school bus initiative", press release (New York: 24 September 2019), <https://www.governor.virginia.gov/newsroom/all-releases/2019/september/headline-847559-en.html>; C. Crowe, "New York transit authority to invest \$1.1B for 500 electric buses", *Utility Dive*, 17 December 2019, <https://www.utilitydive.com/news/new-york-mta-to-invest-11b-for-zero-emission-bus-fleet/569248>.
- 102 UNEP, "Electric buses put Chile on the path to a healthier tomorrow", 27 May 2019, <https://www.unenvironment.org/news-and-stories/story/electric-buses-put-chile-path-healthier-tomorrow>.
- 103 M. Lorduy, "Ley 1964 de 2019: movilidad sostenible", *Asuntos Legales*, 7 September 2019, <https://www.asuntoslegales.com.co/consultorio/ley-1964-de-2019-movilidad-sostenible-2905412>.
- 104 Transport Decarbonization Alliance, "Resolution No. 13 / 2019", 1 February 2019, <http://tda-mobility.org/wp-content/uploads/2019/04/Cabo-Verde-Electric-Mobility-Policy-Chapter.pdf>.
- 105 S. Bajaj, "Uttar Pradesh approves EV charging tariffs for various segments of consumers", Mercom India, 15 March 2019, <https://mercomindia.com/uttar-pradesh-approves-ev-charging-tariffs>.
- 106 New York State Energy Research and Development Authority (NYSERDA), "New statewide initiatives to spur widespread adoption of electric vehicles and increase charging infrastructure", 19 November 2019, <https://www.nyserdera.ny.gov/About/Newsroom/2018-Announcements/2018-11-19-New-Statewide-Initiatives-to-Spur-Widespread-Adoption-of-Electric-Vehicles-and-Increase-Charging-Infrastructure>; C. Campbell, "Maryland Public Service Commission authorizes utilities to install 5,000 electric vehicle charging stations statewide", *Baltimore Sun*, 14 January 2019, <https://www.baltimoresun.com/news-environment/bs-md-electric-vehicle-charging-stations-20190114-story.html>.
- 107 V. Juma, "Assemblers to produce low-emission vehicles", *Business Daily Africa*, 25 November 2019, <https://www.businessdailyafrica.com/corporate/companies/Assemblers-to-produce-low-emission-vehicles/4003102-5362296-64bqlq/index.html>.
- 108 Government of Minnesota, "Governor Tim Walz announces clean car standards in Minnesota", 25 September 2019, <https://mn.gov/governor/news/?id=1055-403887>.
- 109 European Parliament, "MEPs approve new CO₂ emissions limits for trucks", press release (Brussels: 18 April 2019), <https://www.europarl.europa.eu/news/en/press-room/20190412IPR39009/meeps-approve-new-co2-emissions-limits-for-trucks>; European Council, "Heavy-duty vehicles: Council presidency agrees with Parliament on Europe's first-ever CO₂ emission reduction targets for trucks", 19 February 2019, <https://www.consilium.europa.eu/en/press-releases/2019/02/19/heavy-duty-vehicles-eu-presidency-agrees-with-parliament-on-europe-s-first-ever-co2-emission-reduction-targets>.
- 110 Z. Yang and A. Bandivadekar, *2017 Global Update: Light-duty Vehicle Greenhouse Gas and Fuel Economy Standards* (Washington, DC: ICCT, 2017), https://theicct.org/sites/default/files/publications/2017-Global-LDV-Standards-Update_ICCT-Report_23062017_vF.pdf; 40 countries reported in GSR 2019 from IEA, "Fuel economy of cars and vans (light-duty vehicles): Tracking clean energy progress", <https://www.iea.org/tcep/transport/fueleconomy>, viewed 25 April 2019; Z. Yang, ICCT, personal communication with REN21, 6 April 2020.
- 111 International Transport Forum, "Is low-carbon road freight possible?" <https://www.itf-oecd.org/low-carbon-road-freight>, viewed 5 May 2019; A. Bandivadekar, "ICCT: Clock ticking for fuel economy in India", *Global Fuel Economy Initiative*, 23 January 2019, <https://www.globalfueleconomy.org/blog/2019/january/icct-clock-ticking-for-fuel-economy-in-india>.
- 112 G. Topham, "London prepares for launch of ultra-low emissions zone", *The Guardian* (UK), 6 April 2019, <https://www.theguardian.com/uk-news/2019/apr/06/london-prepares-for-launch-of-ultra-low-emissions-zone>. In response, some London firms have retrofitted their vehicles to run on biogas in order to avoid the additional ULEZ charge, from K. Coyne, "Waste food firm runs biogas vehicles to meet new emissions rule", *mrw*, 8 April 2019, <https://www.mrw.co.uk/latest/waste-food-firm-runs-biogas-vehicles-to-meet-new-emissions-rule/10041819.article>.
- 113 "Ireland to ban new petrol and diesel vehicles from 2030", *BBC*, 17 June 2019, <https://www.bbc.com/news/world-europe-48668791>; S. Hanley, "Sweden will ban sale of gasoline & diesel cars after 2030. Germany lags behind", *CleanTechnica*, 23 January 2019, <https://cleantechnica.com/2019/01/23/sweden-will-ban-sale-of-gasoline-diesel-cars-after-2030-germany-lags-behind>; Transport Canada, "Zero-emission

- vehicles", <https://www.tc.gc.ca/en/services/road/innovative-technologies/zero-emission-vehicles.html>, viewed 14 May 2020; Colombia from "National Government presented sustainable and electric mobility strategy", BC News, 28 August 2019, <http://www.bcnoticias.com.co/gobierno-nacional-presento-estrategia-de-movilidad-electrica-y-sostenible> (using Google Translate).
- 114 G. De Clercq, "France to uphold ban on sale of fossil fuel cars by 2040", *Reuters*, 11 June 2019, <https://www.reuters.com/article/us-france-autos/france-to-uphold-ban-on-sale-of-fossil-fuel-cars-by-2040-idUSKCN1TC1CU>.
- 115 Y. Sun and B. Goh, "China considers testing no-go zones for gasoline vehicles: Ministry", *Reuters*, 21 August 2019, <https://www.reuters.com/article/us-china-autos-gasoline/china-considers-testing-no-go-zones-for-gasoline-vehicles-ministry-idUSKCN1VC07R>.
- 116 "Petrol and diesel car sales ban brought forward to 2035", *BBC*, 4 February 2019, <https://www.bbc.com/news/science-environment-51366123>.
- 117 SLOCAT and IEA, op. cit. note 95; REN21 policy database. See GSR 2020 data pack at www.ren21.net/GSR.
- 118 For example, in Athens (Greece), Brussels (Belgium), London (UK), Lisbon (Portugal), Madrid (Spain), Mexico City (Mexico), Paris (France) and Rome (Italy), from *Ibid.*; F. O'Sullivan, "Madrid takes its car ban to the next level", *CityLab*, 24 May 2018, <https://www.citylab.com/transportation/2018/05/madrid-spain-car-ban-city-center/561155/>; T. Leggett, "Polluted Paris steps up war on diesel", *BBC*, 30 May 2018, <https://www.bbc.com/news/business-43925712>; K. Lofgren, "Rome is banning all oil-burning cars by 2024", 3 January 2018, *Inhabitat*, <https://inhabitat.com/rome-is-banning-all-oil-burning-cars-by-2024/>; A. Bendix, "15 major cities around the world that are starting to ban cars", *Business Insider*, 12 January 2019, <https://www.businessinsider.fr/us/cities-going-car-free-ban-2018-12/>; SLOCAT, op. cit. note 69; T. Wenger, "7 cities that are banning cars from their city centers", *Matador Network*, 3 April 2019, <https://matadornetwork.com/read/cities-banning-cars-city-centers/>; L. Garfield, "13 cities that are starting to ban cars", *Business Insider*, 8 June 2018, <https://www.businessinsider.es/cities-going-car-free-ban-2017-8?r=US&IR=T>; M. Barber, "15 cities tackling pollution by curbing cars", *Curbed*, 14 August 2018, <https://www.curbed.com/2017/4/10/15207926/car-ban-cities-pollution-traffic-paris-london-mexico-city/>; P. Plötz, J. Axsen and S. A. Funke, "Designing car bans for sustainable transportation", *Nature Sustainability*, vol. 2 (2019), pp. 534-36, <https://www.nature.com/articles/s41893-019-0328-9>; A. Pinto, "Delhi won't be the first city to ban private cars", *Condé Nast Traveller*, 31 October 2018, <https://www.cntraveller.in/story/delhi-wont-first-city-ban-private-cars>.
- 119 IEA, op. cit. note 97, p. 75.
- 120 Government of Canada, "Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative", <https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/electric-vehicle-alternative-fuels-infrastructure-deployment-initiative/18352>, updated 17 May 2019.
- 121 IEA, op. cit. note 97, p. 73.
- 122 New York State, "Governor Cuomo announces \$31.6 million in funding available to dramatically expand electric vehicle usage", 8 February 2019, <https://www.nyserda.ny.gov/About/Newsroom/2019-Announcements/2019-02-08-Governor-Cuomo-Announces-Millions-in-Funding-Available-to-Dramatically-expand-Electric-Vehicle-Usage>.
- 123 REN21, op. cit. note 23.
- 124 NYSEDA, op. cit. note 106; Campbell, op. cit. note 106.
- 125 **Box 2** based on the following sources: EVgo, "EVgo goes 100% renewable to power the nation's largest public EV fast charging network", press release (Los Angeles: 7 May 2019), <https://www.evgo.com/about/news/evgo-goes-100-renewable-to-power-the-nations-largest-public-ev-fast-charging-network/>; EnelX, "Smart Charge Hawaii program to make EV charging stations available to residents and businesses", press release (Honolulu and San Carlos, CA: 19 September 2019), <https://www.enelx.com/n-a/en/news-media/all-press/smart-charge-hawaii-ev-charging-stations/>; R. Whitlock, "Fastned wins second EV fast charging tender in the North East of England", *Renewable Energy Magazine*, 15 March 2019, https://www.renewableenergymagazine.com/electric_hybrid_vehicles/fastned-wins-second-ev-fast-charging-tender-20190315/; D. McCue, "Delta Invests \$2 million to study biofuel production from forest floor debris", *Renewable Energy Magazine*, 18 September 2019, <https://www.renewableenergymagazine.com/biofuels/delta-invests-2-million-to-study-biofuel-20190918/>; C. Buyck, "Sweden makes a sustainability leap", *AINonline*, 13 June 2019, <https://www.ainonline.com/aviation-news/air-transport/2019-06-13/sweden-makes-sustainability-leap/>; airports with regular distribution of blended alternative fuel included ongoing deliveries in: Bergen and Oslo (Norway); Stockholm Arlanda, Stockholm Bromma, Halmstad City, Vaxjo Smaland and Kalmar Öland (Sweden); and Los Angeles (United States). Batch delivery occurred at the following locations: in the United States, San Francisco and Van Nuys (California), Jackson Hole (Wyoming), Chicago O'Hare (Illinois); in Canada, Toronto-Pearson (Ontario) and Montreal Trudeau (Québec); Brisbane (Australia); and in Sweden, Luleå, Umeå, Åre Östersund, Karlstad, Visby, Göteborg Landvetter and Malmö. See International Civil Aviation Organization (ICAO), "Environment", <https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx>, viewed 16 March 2020. "APT Pranoto Airport to receive 1,800-panel solar rooftop upgrade", *International Airport Review*, 29 November 2019, <https://www.internationalairportreview.com/news/107935/apt-pranoto-airport-to-receive-1800-panel-solar-rooftop-upgrade/>; C. Weydig, "Airports embrace renewable energy to cut air travel emissions", *Axios*, 9 October 2019, <https://www.axios.com/airports-renewable-solar-electric-energy-cut-air-travel-emissions-d4cb8700-3daf-4ef8-a592-bf2d06e62f49.html>; D. McCue, "First inland vessel fueled by 100% sustainable biofuel", *Renewable Energy Magazine*, 20 March 2019, <https://www.renewableenergymagazine.com/biofuels/first-inland-vessel-fueled-by-100-sustainable-20190320/>; M. Hand, "MSC commits to regular biofuels usage to reduce emissions", *Seatrade Maritime News*, 9 December 2019, <https://www.seatrade-maritime.com/bunkering/msc-commits-regular-biofuels-usage-reduce-emissions/>; "Tokyu Setagaya Line in Tokyo becomes first in Japan to be fully powered by renewable energy", *Japan Times*, 25 March 2019, <https://www.asiawatch.net/2019/03/26/tokyu-setagaya-line-in-tokyo-becomes-first-in-japan-to-be-fully-powered-by-renewable-energy/>; H. Coffey, "World's first solar-powered railway line opens in UK", *The Independent* (UK), 23 August 2019, <https://www.independent.co.uk/travel/news-and-advice/solar-power-trains-railway-aldershot-uk-world-first-a9076136.html>.
- 126 Based on IEA, *World Energy Balances and Statistics*, op. cit. note 31; IEA, *World Energy Outlook 2019* (Paris: 2019), <https://www.iea.org/reports/world-energy-outlook-2019>.
- 127 IRENA, IEA and REN21, op. cit. note 1, p. 52.
- 128 Based on IEA, *World Energy Balances and Statistics*, op. cit. note 31; IEA, op. cit. note 126.
- 129 Countries with biofuel targets in aviation include Brazil (10% by 2030), Finland (30% by 2030), Indonesia (5% by 2025) and Norway (0.5% by 2020 and 30% by 2030), from S. Widiyanto, ICAO, "Indonesian aviation biofuels and renewable energy initiatives", presentation at ICAO Seminar on Alternative Fuels 2017, 8-9 February 2017, https://www.icao.int/Meetings/altfuels17/Documents/4%20-Indonesia%20Initiative_Ministries.pdf; J. Moss, "What to expect from Brazil's RenovaBio programme", *informaconnect*, 5 September 2018, <https://informaconnect.com/what-to-expect-from-brazils-renovabio-programme/>; Aviation Benefits Beyond Borders, "Finland to join Nordic forefront in reducing emissions in aviation", 3 June 2019, <https://aviationbenefits.org/newswire/2019/06/finland-to-join-nordic-forefront-in-reducing-emissions-in-aviation/>; E. Voegelé, "Norway to implement biofuel mandate for aviation fuel in 2020", *Biodiesel Magazine*, 11 October 2018, <http://www.biodieselmagazine.com/articles/2516476/norway-to-implement-biofuel-mandate-for-aviation-fuel-in-2020>.
- 130 Aviation Benefits Beyond Borders, op. cit. note 129. In Sweden, a 2019 report commissioned by the government proposed a 1% aviation fuel blending mandate from 2021, increasing to 27% in 2030, although this has not been implemented, from "Sweden proposes aviation greenhouse gas emission reduction target", *Green Car Congress*, 5 March 2019, <https://www.greencarcongress.com/2019/03/20190305-sweden.html>.
- 131 "Sturgeon demands agreement on 'legal' independence referendum", *BBC*, 3 September 2019, <https://www.bbc.com/news/uk-scotland-scotland-politics-49556793>.

- 132 US Department of Energy, "Department of Energy announces \$55 million in funding for electric aviation programs", 17 December 2019, <https://www.energy.gov/articles/department-energy-announces-55-million-funding-electric-aviation-programs>.
- 133 A. J. Hawkins, "France will apply an 'ecotax' to nearly all air travel", *The Verge*, 10 July 2019, <https://www.theverge.com/2019/7/10/20688851/france-tax-air-travel-climate-change-ecotax>; "France calls for European aviation tax," *Air Transport World*, 7 June 2019, <https://atwonline.com/air-transport/safety-ops-regulation/france-calls-european-aviation-tax>.
- 134 J. Cordero Sapién, "Germany to cut VAT on long distance rail journeys," *Railway News*, 17 October 2019, <https://railway-news.com/germany-vat-long-distance-rail-journeys>.
- 135 Government of Norway, Ministry of Climate and Environment, *The Government's Action Plan for Green Shipping* (Oslo: 2019), p. 7, <https://www.regjeringen.no/contentassets/00f527e95d0c4dfd88db637f96ffe8b8/the-governments-action-plan-for-green-shipping.pdf>.
- 136 Government of the UK, Department for Transport, and Nusrat Ghani MP, "Clean maritime plan", 11 July 2019, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/773178/maritime-2050.pdf.
- 137 The programme was established in 2017 led by the Port of Rotterdam (Netherlands) along with Antwerp (Belgium), Barcelona (Spain), Hamburg (Germany), Long Beach and Los Angeles (United States) and Vancouver (Canada). New additions from 2019 include Amsterdam (Netherlands), Le Havre (France), Gothenburg (Sweden), and New York and New Jersey (United States). Greenport, "Climate action congress plans underway", 6 September 2019, <https://www.greenport.com/news101/Projects-and-Initiatives/climate-action-congress-plans-underway>.
- 138 Port Houston, "Port Commission approves move on renewable energy", press release (Houston, TX: 23 October 2019), https://porthouston.com/wp-content/uploads/Port_Commission_October_Press_Release_revised_Roger_en-002.pdf; B. Hensel, Port Houston, personal communication with REN21, 21 January 2020.
- 139 "Sturgeon demands agreement on 'legal' independence referendum", op. cit. note 131; "With renewable energy, rail ministry to transform Indian Railways into 'Green Railways'", *Economic Times*, 3 December 2018, <https://economictimes.indiatimes.com/small-biz/productline/power-generation/with-renewable-energy-rail-ministry-to-transform-indian-railways-into-green-railways/articleshow/72360511.cms>.
- 140 H. Gloystein, "Large-scale solar power set for double-digit growth: Goldman Sachs", *Reuters*, 14 March 2019, <https://www.reuters.com/article/us-solar-power-goldman-sachs/large-scale-solar-power-set-for-double-digit-growth-goldman-sachs-idUSKCN1QV0GI>. For drivers for the shift to small-scale renewables, see, for example: United Nations Department of Economic and Social Affairs, "Policy Brief 24: Energy Sector Transformation: Decentralized Renewable Energy for Universal Access" (New York: 2018), <https://sustainabledevelopment.un.org/content/documents/17589PB24.pdf>; V. Chandrashekar, "As subsidies wane, market forces drive the growth of renewables", *Yale Environment* 360, 12 June 2018, <https://e360.yale.edu/features/as-subsidies-wane-market-forces-drive-the-growth-of-renewables>; J. P. Casey, "Inside India's small-scale renewable revolution", *Power Technology*, 19 October 2019, <https://www.power-technology.com/features/india-renewable-solar-wind-energy>.
- 141 REN21 Policy Database.
- 142 **Box 3** based on the following sources: RE100, "Companies", <http://there100.org/companies>, viewed December 2020; IRENA, *Corporate Sourcing of Renewables: Market and Industry Trends* (Abu Dhabi: 2018), pp. 16-45, https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_Corporate_sourcing_2018.pdf; US National Renewable Energy Laboratory (NREL), *Policies for Enabling Corporate Sourcing of Renewable Energy Internationally: A 21st Century Power Partnership Report* (Golden, CO: May 2017), pp. 7-13, <https://www.nrel.gov/docs/fy17osti/68149.pdf>; S&P Global, *RRA Regulatory Focus: Corporate Renewables in the United States* (New York: March 2019), p. 6, https://www.spglobal.com/marketintelligence/en/documents/01corporaterenewables_adamwilson_spgmi_5.6.19_final.pdf; Bird & Bird LLP, *Corporate PPAs: An International Perspective* (London: September 2019), p. 5, <https://www.twobirds.com/~media/articles/international-corporate-ppas-brochure.pdf?la=en>; E. Bellini, "Portugal drafts new rules to boost rooftop solar", *pv magazine*, 25 October 2019, <https://www.pv-magazine.com/2019/10/25/portugal-drafts-new-rules-to-boost-rooftop-solar>; Laws and Regulations Database of the Republic of China, "Renewable Energy Development Act", <https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0130032>, updated 1 May 2019; Northland Power, "Corporate renewable PPAs", presentation at the Green Financing Forum, Chinese Taipei, 26 April 2019, <https://gwec.net/wp-content/uploads/2019/05/GFT-Sean-McDermott-NPI.pdf>.
- 143 Government of Pakistan, "Alternative and Renewable Energy Policy 2019" (Karachi: 2019), pp. 2-3, http://www.aedb.org/images/Draft_ARE_Policy_2019_-_Version_2_July_21_2019.pdf; World Wind Energy Association, "PRES2019 declaration: Pakistan achieving 30% plus 30% renewable energy by 2030", 1 October 2019, <https://wwindea.org/blog/2019/10/01/pres2019-declaration-pakistan-achieving-30-plus-30-renewable-energy-by-2030>; Government of the Republic of Mauritius, Mauritius Ministry of Energy and Public Utilities, *Renewable Energy Roadmap 2030 for the Electricity Sector* (Port Louis, Mauritius: 5 August 2019), p. 15, http://publicutilities.govmu.org/English/Documents/Doc_2019/Ministry%20of%20Energy%20-%20RE%20ROADMAP%202030%20-%20%20FINAL%20PROOF.pdf.
- 144 Republic of Angola, "New Renewables Strategy", <http://www.angolaenergia2025.com/en/conteudo/new-renewables-strategy>, viewed 1 February 2020; Euroconvention Global, "Euroconvention Global is pleased to announce: RENPOWER ANGOLA – the 2nd Renewable Energy & Power and Infrastructure Investors Conference", press release (Luanda, Angola: 18 July 2019) <https://euroconventionglobal.com/event/renpower-angola-2019>.
- 145 Government of Ghana, *Ghana Renewable Energy Master Plan* (Accra: February 2019), pp. iv-v, <http://www.energy.gov.gh/files/Renewable-Energy-Masterplan-February-2019.pdf>.
- 146 D. Bushell-Embling, "Cities moving to 100% renewable energy", *Gov Tech Review*, 31 October 2019, <https://www.govtechreview.com.au/content/gov-tech/article/cities-moving-to-100-renewable-energy-898336900>.
- 147 Sierra Club, "Los Angeles commits to 100 percent clean energy to power all electricity, buildings, and transportation", press release (Los Angeles: 30 April 2019), <https://www.sierraclub.org/press-releases/2019/11/los-angeles-commits-100-percent-clean-energy-power-all-electricity-buildings>; Sierra Club, "Philadelphia commits to 100% clean, renewable energy", press release (Philadelphia: 2 October 2019), <https://www.sierraclub.org/press-releases/2019/10/philadelphia-commits-100-clean-renewable-energy>.
- 148 Laws and Regulations Database of the Republic of China, "Renewable Energy Development Act", <https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0130032>, amended 1 May 2019; S. Lin, "Legislative Yuan passes energy act amendments", *Taipei Times*, 13 April 2019, <http://www.taipeitimes.com/News/taiwan/archives/2019/04/13/2003713323>.
- 149 V. Volcovici, "Latin America pledges 70% renewable energy, surpassing EU: Colombia minister", *Reuters*, 25 September 2019, <https://www.reuters.com/article/us-climate-change-un-colombia/latin-america-pledges-70-renewable-energy-surpassing-eu-colombia-minister-idUSKBN1WA26Y>.
- 150 Institute for Energy Economics and Financial Analysis, "France, Greece, Bulgaria raise their 2030 national renewable energy targets", 25 September 2019, <https://ieefa.org/france-greece-bulgaria-raise-their-2030-national-renewable-energy-targets/>.
- 151 "South Korea steps up shift to cleaner energy, sets long-term renewable power targets", *Reuters*, 18 April 2019, <https://www.reuters.com/article/us-southkorea-energy/south-korea-steps-up-shift-to-cleaner-energy-sets-long-term-renewable-power-targets-idUSKCN1RV06P>.
- 152 REN21 Policy Database.
- 153 Ibid.
- 154 F. Haugwitz, "Towards a subsidy-free era for China's solar PV market", *Apricum*, 19 November 2019, <https://www.apricum-group.com/towards-a-subsidy-free-era-for-chinas-solar-pv-market>; S. Prateek, "China announces 2019 feed-in-tariff levels for solar projects", *Mercom India*, 2 May 2019, <https://mercomindia.com/china-feed-in-tariff-levels-solar>.

- 155 J. Parnell, "China to support nearly 23GW of solar with new feed-in tariff", PV-Tech, 12 July 2019, <https://www.pv-tech.org/news/china-to-support-nearly-23gw-of-solar-with-new-feed-in-tariff>.
- 156 J. Hill, "China installs 5.2 gigawatts of solar as government unveils 2019 feed-in tariffs", CleanTechnica, 1 May 2019, <https://cleantechnica.com/2019/05/01/china-installs-5-2-gigawatts-solar-as-government-unveils-2019-feed-in-tariffs>.
- 157 J. R. Martin, "Spain fights litigation over retroactive FIT cuts with more subsidies", PV-Tech, 25 November 2019, <https://www.pv-tech.org/news/spain-fights-litigation-over-retroactive-fit-cuts-with-more-subsidies>.
- 158 "What does the end of feed in tariffs in the UK mean for small-scale renewables?" Power Technology, 20 July 2018, <https://www.power-technology.com/features/end-feed-tariffs-uk-mean-small-scale-renewables>; E. Bellini, "Vietnam introduces auction scheme for large-scale PV", pv magazine, 5 December 2019, <https://www.pv-magazine.com/2019/12/05/vietnam-introduces-auction-scheme-for-large-scale-pv>.
- 159 B. Publicover, "Vietnam finally unveils new FITs for large-scale, rooftop, floating PV", pv magazine, 7 April 2020, <https://www.pv-magazine.com/2020/04/07/vietnam-finally-unveils-new-fits-for-large-scale-rooftop-floating-pv>.
- 160 Merchant, op. cit. note 14.
- 161 Bowers, op. cit. note 14; G. Bade, "Puerto Rico governor signs 100% renewable energy mandate", Utility Dive, 12 April 2019, <https://www.utilitydive.com/news/puerto-rico-governor-signs-100-renewable-energy-mandate/552614/>.
- 162 M. Perez, "As demand for 'green' power soars, utilities turn to Guarantees of Origin", Standard and Poors Global, 7 August 2019, <https://www.spglobal.com/en/research-insights/articles/as-demand-for-green-power-soars-utilities-turn-to-guarantees-of-origin>.
- 163 Bird & Bird LLP, op. cit. note 142, p. 5.
- 164 IEA, *20 Renewable Energy Policy Recommendations* (Paris: 2018), p. 18, <https://www.iea.org/reports/20-renewable-energy-policy-recommendations>.
- 165 REN21 Policy Database.
- 166 Ibid.
- 167 Ibid.
- 168 N. Kabeer, "Nigeria's University of Benin issues 15 MW solar tender with 5 MW battery energy storage", Mercom India, 18 January 2019, <https://mercomindia.com/nigeria-university-of-benin-solar-tender-5mw>.
- 169 C. Keating, "Cambodia's 60MW solar auction draws record-low bid", PV-Tech, 6 September 2019, <https://www.pv-tech.org/news/cambodia-solar-auction-draws-record-low-bid>; Pratheeksha, "13 GW of solar projects tendered in June as procurement activity surges post elections", Mercom India, 5 July 2019, <https://mercomindia.com/solar-projects-tendered-june>.
- 170 J. Bowlus, "By adding solar, Portugal pushes all-in on renewables", Energy Reporters, 7 October 2019, <https://www.energy-reporters.com/opinion/by-adding-solar-portugal-pushes-all-in-on-renewables>.
- 171 WindEurope, *Wind Energy in Europe in 2019: Trends and Statistics* (Brussels: 2020), pp. 8, 21, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf>; EurObserv'ER, *Wind Energy Barometer* (Paris: March 2020), p. 9, <https://www.eurobserv-er.org/wind-energy-barometer-2020>.
- 172 "Mexico announces tender for geothermal drilling and new information repository for geothermal projects", New Energy Events, 3 June 2019, <http://newenergyevents.com/mexico-announces-call-for-offers-and-new-information-repository-for-geothermal>.
- 173 I. Shumkov, "Germany's last onshore wind tender for 2019 oversubscribed", Renewables Now, 20 December 2019, <https://renewablesnow.com/news/germanys-last-onshore-wind-tender-for-2019-oversubscribed-681039>; J. Hill, "Germany awards 476 megawatts in latest undersubscribed onshore wind auction", CleanTechnica, 20 February 2019, <https://cleantechnica.com/2019/02/20/germany-awards-476-megawatts-in-latest-undersubscribed-onshore-wind-auction>; five of six onshore auctions undersubscribed, from WindEurope, *Wind Energy in Europe in 2018: Trends and Statistics* (Brussels: 2019), p. 21, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf>.
- 174 E. Bellini and J. Zarco, "Mexico cancels fourth energy auction", pv magazine, 1 February 2019, <https://www.pv-magazine.com/2019/02/01/mexico-cancels-fourth-energy-auction>.
- 175 IEA, "Ukraine Law on renewable energy auctions (Law No. 2712-VIII)", <https://www.iea.org/policies/6529-ukraine-law-on-renewable-energy-auctions-law-no-2712-viii>, viewed 14 May 2020.
- 176 "Poland plays catch-up with launch of major renewable energy auction", Reuters, 5 December 2019, <https://www.reuters.com/article/poland-energy-wind-idUSL8N2862W5>; F. Mangi, "Pakistan plans clean energy wave to make up 20% of its capacity", Bloomberg, 22 July 2019, <https://www.bloomberg.com/news/articles/2019-07-23/pakistan-plans-clean-energy-wave-to-make-up-20-of-its-capacity>.
- 177 "The draft amendments to the renewable energy law of Mongolia are submitted to Parliament", DB>S, 28 May 2019, <https://dblaw.mn/the-draft-amendments-to-the-renewable-energy-law-of-mongolia-are-submitted-to-the-parliament>.
- 178 N. Muchira, "Kenya to phase out costly power deals under new investment model", The East African, 19 June 2019, <https://www.theeastafrican.co.ke/business/Kenya-to-phase-out-costly-power-deals/2560-5163068-116vkipz/index.html>.
- 179 S. Djunicic, "Colombia sets new rules for 2nd renewables auction", Renewables Now, 11 July 2019, <https://renewablesnow.com/news/colombia-sets-new-rules-for-2nd-renewables-auction-661295>.
- 180 E. Bellini, "EU approves Italy's auction scheme for renewables", pv magazine, 22 July 2019, <https://www.pv-magazine.com/2019/06/14/eu-approves-italys-auction-scheme-for-renewables-incentives>.
- 181 Financial incentives for renewable energy and renewable technologies include: reductions in sales, energy, CO₂, VAT or other taxes, investment or production tax credits, energy production payments, public investment, loans, grants, capital subsidies or rebates, from REN21 Policy Database.
- 182 Dentons, "The law on renewable energy sources has been adopted in Uzbekistan", 28 May 2019, <https://www.dentons.com/en/insights/alerts/2019/may/28/the-law-on-renewable-energy-sources-has-been-adopted-in-uzbekistan>.
- 183 Congressional Research Service, *The Renewable Electricity Production Tax Credit: In Brief* (Washington, DC: updated 29 April 2020), <https://fas.org/sgp/crs/misc/R43453.pdf>.
- 184 Laws and Regulations Database of the Republic of China, op. cit. note 148; Lin, op. cit. note 148.
- 185 IRENA, *Climate Change and Renewable Energy: National Policies and the Role of Communities, Cities and Regions* (Abu Dhabi: 2019), p. 27, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_climate_sustainability_2019.pdf.
- 186 Based on IEA, op. cit. note 88.
- 187 IRENA, *Innovation Landscape Brief: Market Integration of Distributed Energy Resources* (Abu Dhabi: 2019), p. 14, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Market_integration_2019.pdf.
- 188 P. Gunjan, "Distributed renewables offer a strong business case for behind-the-meter generation", Navigant Research, 8 April 2019, <https://www.navigantresearch.com/news-and-views/distributed-renewables-offer-a-strong-business-case-for-behind-the-meter-generation>.
- 189 M. Moench, "California solar mandate, gas bans take effect in 2020: What you need to know", *San Francisco Chronicle*, 26 December 2019, <https://www.sfchronicle.com/business/article/California-solar-mandate-gas-bans-take-effect-in-14931617.php>; T. Gillies, "Why California's new solar mandate could cost new homeowners up to an extra \$10,000", CNBC, 17 February 2019, <https://www.cnbc.com/2019/02/15/california-solar-panel-mandate-could-cost-new-homeowners-big.html>.
- 190 New York City Council, op. cit. note 49; Wetzell, op. cit. note 49; Hoffmann, op. cit. note 49.
- 191 A. Richter, "Geothermal to keep FIT in Japan, while auction system is introduced for solar and wind", Think GeoEnergy, 9 August 2019, <http://www.thinkgeoenergy.com/geothermal-to-keep-fit-in-japan-while-auction-system-is-introduced-for-solar-and-wind>.
- 192 Y. Rack, "UK to launch export payments for small renewables after scrapping feed-in tariff", Standard and Poors, 10 June 2019, https://www.spglobal.com/marketintelligence/en/news-insights/trending/FO1MSUX9blhB-TWoK_hnaA2.

- 193 C. Rollet, "Luxembourg raises solar FITs", pv magazine, 13 May 2019, <https://www.pv-magazine.com/2019/05/13/luxembourg-raises-solar-fits>.
- 194 C. Roselund, "Los Angeles still has a feed-in tariff. And it's growing." pv magazine, 27 September 2019, <https://pv-magazine-usa.com/2019/09/27/los-angeles-still-has-a-feed-in-tariff-and-its-growing>.
- 195 REN21 Policy Database.
- 196 E. Bellini, "Net metering introduced in Albania", pv magazine, 21 June 2019, <https://www.pv-magazine.com/2019/06/21/net-metering-introduced-in-albania>; E. Bellini, "Turkey introduces net metering for residential PV and new rules for unlicensed solar", pv magazine, 20 May 2019, <https://www.pv-magazine.com/2019/05/20/turkey-introduces-net-metering-for-residential-pv-and-new-rules-for-unlicensed-solar>.
- 197 Rödl and Partner, "Highlights of Kenya's Energy Act 2019", <https://www.roedl.com/insights/renewable-energy/2019-05/highlights-of-kenyas-energy-act-2019>, viewed 19 December 2019.
- 198 S. Prateek, "Goa issues net metering regulations for solar projects", Mercom India, 14 August 2019, <https://mercomindia.com/goa-net-metering-regulations-solar>.
- 199 A. Saran, "Uttar Pradesh deals blow to rooftop solar", Bridge to India, 22 February 2019, <https://bridgetoindia.com/uttar-pradesh-deals-a-blow-to-rooftop-solar>.
- 200 T. Sylvia, "DTE finally kills net metering", pv magazine, 2 May 2019, <https://pv-magazine-usa.com/2019/05/02/dte-finally-kills-net-metering>; C. Morehouse, "Louisiana utilities to pay less for rooftop solar power under new net metering rules", Utility Dive, 13 September 2019, <https://www.utilitydive.com/news/louisiana-utilities-to-pay-less-for-rooftop-solar-power-under-new-net-meter/562834>.
- 201 E. Pasiuk, "Solar companies face uncertain future after cancellation of net metering program", CBC News, 21 September 2019, <https://www.cbc.ca/news/canada/saskatchewan/solar-net-metering-program-saskatchewan-1.5291359>.
- 202 NREL, "Net metering", <https://www.nrel.gov/state-local-tribal/basics-net-metering.html>, viewed 21 November 2019.
- 203 P. Molina, "Spain's new rules for self-consumption come into force", pv magazine, 8 April 2019, <https://www.pv-magazine.com/2019/04/08/spains-new-rules-for-self-consumption-come-into-force>.
- 204 S. Prateek, "Delhi finalizes group and virtual net metering guidelines", Mercom India, 19 June 2019, <https://mercomindia.com/derc-group-virtual-net-metering>.
- 205 S. Golden, "What's new with community solar?" GreenBiz, 5 April 2019, <https://www.greenbiz.com/article/whats-new-community-solar>.
- 206 NREL, "Community solar", <https://www.nrel.gov/state-local-tribal/community-solar.html>, viewed 21 November 2019; J. Farrell, "Updated: States supporting virtual net metering", Institute for Local Self-Reliance, <https://ilsr.org/rule/net-metering/updated-states-supporting-virtual-net-metering/>, viewed 28 May 2020.
- 207 Rebates are granted for a maximum of PLN 5,000 (USD 1,325), from E. Bellini, "Poland launches €235 million solar rebate program", pv magazine, 23 July 2019, <https://www.pv-magazine.com/2019/07/23/poland-launches-235-million-solar-rebate-program>.
- 208 IEA, *Status of Power System Transformation 2019: System Flexibility* (Paris: 2019), p. 17, https://webstore.iea.org/download/direct/2782?fileName=Status_of_Power_System_Transformation_2019.pdf.
- 209 ACEEE, "Utility regulation and policy", 2016, <https://aceee.org/topics/utility-regulation-and-policy>.
- 210 For example, in 2019 the Ontario Energy Board (Canada) launched a policy initiative to identify ways to support the integration of distributed energy resources (including distributed renewable generation) into utility business, from Ontario Energy Board, "Utility Remuneration and Responding to Distributed Energy Resources. Consultation Initiation and Notice of Cost Awards Process. Board File Numbers: EB-2018-0287 and EB-2018-0288", 15 March 2019, <https://www.oeb.ca/sites/default/files/OEB-Ltr-Remuneration-DER-20190315.pdf>. Four US public utility commissions also enacted policies to shift utilities from traditional "cost of service" models, in which utilities are able to generate profit from investments in capital projects only, to performance-based remuneration models, which incorporate performance against metrics such as carbon abatement, distributed renewable energy integration and innovation. C. Girouard, "Top 10 utility regulation trends of 2019 — so far", GTM, 1 August 2019, <https://www.greentechmedia.com/articles/read/top-10-utility-regulation-trends-of-2019-so-far>. The four US states are Hawaii, Illinois, Oregon and Washington, from D. Roberts, "A closer look at Washington's superb new 100% clean electricity bill", Vox, 18 April 2019, <https://www.vox.com/energy-and-environment/2019/4/18/18363292/washington-clean-energy-bill>, and from H. Trabish, "3 state commissions upending the way utilities do business", Utility Dive, 2 October 2019, <https://www.utilitydive.com/news/3-state-commissions-upending-the-way-utilities-do-business/563949>.
- 211 REN21, op. cit. note 23; IRENA, *Community Energy: Broadening the Ownership of Renewables* (Abu Dhabi: 2018), p. 3, https://coalition.irena.org/-/media/Files/IRENA/Coalition-for-Action/Publication/Coalition-for-Action_Community-Energy_2018.pdf.
- 212 US Environmental Protection Agency, "Community choice aggregation", <https://www.epa.gov/greenpower/community-choice-aggregation>, viewed 2 February 2020.
- 213 H. Trabish, "As CCAs take over utility customers, local renewable generation emerges as the next big growth driver", Utility Dive, 8 October 2019, <https://www.utilitydive.com/news/as-ccas-take-over-utility-customers-local-generation-emerges-as-the-next-b/564422>.
- 214 IRENA, op. cit. note 185, p. 40.
- 215 City of San Diego, "Background on CCA: How we got here", <https://www.sandiego.gov/sustainability/clean-and-renewable-energy/community-choice-aggregation-program>, viewed 2 February 2020.
- 216 Spain's new community solar provisions include allowing apartment buildings to produce their own rooftop renewable electricity, allowing nearby buildings to exchange surplus renewable electricity with each other through "proximity" (virtual) self-consumption, and allowing citizens the right to gain revenue for surplus renewable electricity they inject into the grid, with simplified billing for small installations. Friends of the Earth Europe, "Renewables rise again in Spain", 23 April 2019, <https://www.foeeurope.org/Renewables-rise-again-Spain-230419>; D. Frieden et al., "Collective self-consumption and energy communities: Overview of emerging regulatory approaches in Europe", *Compile*, June 2019, p. 11, https://www.compile-project.eu/wp-content/uploads/COMPILE_Collective_self-consumption_EU_review_june_2019_FINAL-1.pdf.
- 217 Bellini, op. cit. note 142.
- 218 Frieden et al., op. cit. note 216, pp. 12-15.
- 219 J. Lavallo, "Good news for C&I solar – Maine passes new legislation", *National Law Review*, 24 June 2019, <https://www.natlawreview.com/article/good-news-ci-solar-maine-passes-new-legislation>; H. J. Mai, "Maryland passes energy storage pilot program to determine future regulatory framework", Utility Dive, 2 April 2019, <https://www.utilitydive.com/news/maryland-passes-energy-storage-pilot-program-to-determine-future-regulatory/551769>.
- 220 IEA, "System integration of renewables", <https://www.iea.org/topics/system-integration-of-renewables>, viewed 1 February 2020.
- 221 Government of New Jersey, *Draft 2019 New Jersey Energy Master Plan Policy Vision to 2050* (Trenton, NJ: June 2019), pp. 10-14, <https://nj.gov/emp/pdf/Draft%202019%20EMP%20Final.pdf>.
- 222 Ibid., pp. 10-14.
- 223 IEA, op. cit. note 208, p. 9.
- 224 EC, "Electricity market design", <https://ec.europa.eu/energy/en/topics/markets-and-consumers/market-legislation/electricity-market-design>, updated 30 October 2019; EC, "Clean Energy for All Europeans package completed: Good for consumers, good for growth and jobs, and good for the planet", 22 May 2019, https://ec.europa.eu/info/news/clean-energy-all-europeans-package-completed-good-consumers-good-growth-and-jobs-and-good-planet-2019-may-22_en.
- 225 IEA, op. cit. note 208, p. 3.
- 226 Ibid., p. 3.

- 227 California Independent System Operator, "Initiative: Extended day-ahead market", 3 October 2019, <http://www.caiso.com/informed/Pages/StakeholderProcesses/ExtendedDay-AheadMarket.aspx>; M. Lavillotti and Z. T. Smith, New York Independent System Operator, "DER energy & capacity market design", presentation, 17 April 2019, p. 7, <https://www.nyiso.com/documents/20142/6006612/BIC%20DER%20Market%20Design%20Presentation.pdf/9cdc8700-ab90-d741-c28d-0c29b3468807>.
- 228 NREL, *Sources of Operational Flexibility* (Golden, CO: May 2015), <https://www.nrel.gov/docs/fy15osti/63039.pdf>.
- 229 R. Ranganath, "Adani to build transmission lines in Gujarat and Rajasthan to facilitate renewables", Mercom India, 7 August 2019, <https://mercomindia.com/adani-transmission-gujarat-rajasthan-renewables>.
- 230 New York State, "Governor Cuomo announces \$15 million available to modernize New York's electric grid", press release (Albany, NY: 30 May 2019), <https://www.governor.ny.gov/news/governor-cuomo-announces-5-million-available-support-modernization-new-yorks-electric-grid>; R. Walton, "Michigan joins spate of state grid modernization initiatives", Utility Dive, 18 October 2019, <https://www.utilitydive.com/news/michigan-joins-spate-of-state-grid-modernization-initiatives/565301>.
- 231 NC Clean Energy Technology Centre, "Interconnection standards: Program overview", <https://programs.dsireusa.org/system/program/detail/951>, updated 10 September 2019; Bade, op. cit. note 161.
- 232 "SP Group eyes more links with region to tap clean power", *Straits Times*, 5 November 2019, <https://www.straitstimes.com/business/economy/sp-group-eyes-more-links-with-region-to-tap-clean-power>.
- 233 Deloitte, "2020 Renewable Energy Industry Outlook: Exploring renewable energy policy, innovation, and market trends", <https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/renewable-energy-outlook.html>, viewed 4 November 2019.
- 234 EC, "Clean Energy for All Europeans: Commission welcomes European Parliament's adoption of new electricity market design proposals", 25 March 2019, https://ec.europa.eu/commission/presscorner/detail/en/IP_19_1836.
- 235 J. Martín, "Exclusive: Portugal to hold 50-100MW energy storage auction in 2020", *Energy Storage News*, 1 March 2019, <https://www.energy-storage.news/news/exclusive-portugal-to-hold-50-100mw-energy-storage-auction-in-2020>; A. Colthorpe, "Portuguese 700MW solar auction includes price-capped energy storage option", *Energy Storage News*, 31 March 2020, <https://www.energy-storage.news/news/portuguese-700mw-solar-auction-includes-price-capped-energy-storage-option>.
- 236 IEA, op. cit. note 208, pp. 16-17.
- 237 NYSERDA, "During Earth Week, Governor Cuomo announces \$280 million available for energy storage projects to combat climate change", 25 April 2019, <https://www.nysesda.ny.gov/About/Newsroom/2019-Announcements/2019-04-25-Governor-Cuomo-Announces-280-Million-Available-for-Energy-Storage-Projects-to-Combat-Climate-Change>.
- 238 J. Weaver, "Massachusetts to pay energy storage its fair share", *pv magazine*, 5 February 2019, <https://pv-magazine-usa.com/2019/02/05/massachusetts-to-pay-energy-storage-its-fair-share>.
- 239 E. Bellini, "Another €4.4 million for solar-plus-storage incentives in northern Italy", *pv magazine*, 24 June 2019, <https://www.pv-magazine.com/2019/06/24/another-e4-4-million-for-solar-plus-storage-incentives-in-northern-italy>.
- 240 Oregon Department of Energy, "Oregon Solar + Storage Rebate Program", <https://www.oregon.gov/energy/Incentives/Pages/Solar-Storage-Rebate-Program.aspx>, viewed 13 December 2019.
- 241 Utilities Middle East, "Abu Dhabi launches world's largest virtual battery plant", 22 January 2019, <https://www.utilities-me.com/news/12329-abu-dhabi-launches-worlds-largest-virtual-battery-plant>.
- 242 C. Goldenberg and M. Dyson, "Pushing the limit: How demand flexibility can grow the market for renewable energy", Rocky Mountain Institute, 14 February 2019, <https://rmi.org/demand-flexibility-can-grow-market-renewable-energy>; IRENA, *Solutions to Integrate High Shares of Variable Renewable Energy* (Abu Dhabi: 2019), p. 15, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_grid_integration_2019.pdf.
- 243 EC, op. cit. note 234.
- 244 Australian Energy Market Commission, "Using demand management to take the pressure off the power system", 18 July 2019, <https://www.aemc.gov.au/news-centre/media-releases/using-demand-management-take-pressure-power-system>.
- 245 Montana State Legislature, "Bill HB0587", 16 May 2019, <https://leg.mt.gov/bills/2019/billpdf/HB0597.pdf>; G. Andersen and M. Cleveland, "Meeting energy needs with demand response", National Conference of State Legislatures, 9 July 2019, <http://www.ncsl.org/research/energy/meeting-energy-needs-with-demand-response.aspx>.
- 246 C. Girouard, "Top 10 utility regulation trends of 2019 – so far", *Advanced Energy Economy*, 18 July 2019, <https://blog.aee.net/top-10-utility-regulation-trends-of-2019-so-far>.
- 247 S. Baldwin, "Minnesota pioneers integration of new interconnection standard expected to propel DERs", *Utility Dive*, 9 December 2019, <https://www.utilitydive.com/news/minnesota-pioneers-integration-of-new-interconnection-standard-expected-to/568560>.
- 248 NYSERDA, "The Value Stack", <https://www.nysesda.ny.gov/All-Programs/Programs/NY-Sun/Contractors/Value-of-Distributed-Energy-Resources>, viewed 23 November 2019.

BIOENERGY

- 1 For a description of the various bioenergy options and their levels of maturity, see, for example, International Energy Agency (IEA), *Energy Technology Perspectives 2017* (Paris: 2017), <https://www.iea.org/etp>; for advanced biofuels, see International Renewable Energy Agency (IRENA), *Innovation Outlook: Advanced Biofuels* (Abu Dhabi: 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Advanced_Biofuels_2016_summary.pdf.
- 2 IEA, *Technology Roadmap: Delivering Sustainable Bioenergy* (Paris: 2017), p. 48, https://www.ieabioenergy.com/wp-content/uploads/2017/11/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf. Bioenergy is considered to be sustainable when its use reduces greenhouse gas emissions compared to the use of fossil fuels in the applications where it is used, and where its use avoids significant negative environmental, social or economic impacts and plays a positive role in the achievement of sustainable development objectives.
- 3 IEA, *Renewables 2019* (Paris: 2019), <https://www.iea.org/reports/renewables-2019>.
- 4 Based on analysis summarised in Figure 20 in endnote 5 for this section.
- 5 About half from IEA, *Renewables 2018* (Paris: 2018), <https://www.iea.org/reports/renewables-2018>. **Figure 20** estimated shares based on the following sources: total final energy consumption in 2018 (estimated at 378.0 EJ) is based on 370.1 EJ for 2017, from IEA, *World Energy Balances*, 2019 edition (Paris: 2019), <https://www.iea.org/reports/world-energy-balances-2019> and escalated by the 2.2% increase in estimated global total final consumption (including non-energy use) from 2017 to 2018, derived from IEA, *World Energy Outlook 2019* (Paris: 2019), <https://www.iea.org/reports/world-energy-outlook-2019>. Estimates of traditional biomass, modern bioenergy for heat and bioenergy contribution to district heating based on 2017 values from IEA, *World Energy Balances*, op. cit. this note and escalated to 2018 based on compound annual average growth rate from 2012 to 2017. Bioelectricity consumption based on estimates of 2017 generation from IEA, op. cit. note 3, and on global average electricity losses and estimated technology-specific industry own-use of bioelectricity in 2018 (estimated at 15.2% of generation), based on IEA, *World Energy Balances*, op. cit. this note.
- 6 See sources in endnote 5.
- 7 Based on analysis and references throughout this section.
- 8 **Figure 21** estimated shares in 2018 based on historical data from IEA, *World Energy Balances*, op. cit. note 5. Figure of 2.81 EJ of renewable electricity for heat in buildings in 2018 from IEA, op. cit. note 3, and for previous years based on compound annual growth rate of 5.3%, from idem. Total heat demand in buildings includes electricity for heating and cooling, derived from estimated renewable electricity for heat and calculated share of renewable energy in electricity production for target year. See also Global Overview chapter of this report, Figures 1 and 5.
- 9 IEA, op. cit. note 2.
- 10 Based on IEA, *World Energy Balances*, op. cit. note 5.
- 11 IEA et al., *Tracking SDG 7: The Energy Progress Report 2019* (Washington, DC: 2019), <https://trackingsdg7.esmap.org/downloads>. Household air pollution from polluting cook stoves is linked directly to 2.5 million premature deaths annually (equal to the combined total of deaths from malaria, tuberculosis and HIV/AIDS). In addition, the low efficiency in cooking stoves or in charcoal production means that fuel requirements are high and often exceed local sustainable supply, leading to pressure on local forestry resources and damage to local forests, with 27-34% of wood-fuel harvesting in tropical regions classified as unsustainable. The collection of biomass, such as firewood, for cooking is very time consuming and has a high opportunity cost, as the time spent gathering fuelwood takes time away from other income-generating activities and education. These issues disproportionately affect women and children, as they are the ones often tasked with the cooking and fuel collection.
- 12 Biogas is a mixture of methane, carbon dioxide and other gases produced when organic matter is broken down by bacteria in the absence of air (anaerobic digestion). The gas can be used for heating and for electricity production in engines or turbines. If the carbon dioxide and other gases are removed, a pure methane stream can be produced (biomethane). This can be used in the same way as natural gas, and pressurised and injected into gas distribution systems for use as a heating fuel or for transport applications.
- 13 Based on analysis from IEA, *World Energy Balances*, op. cit. note 5.
- 14 See sources in endnote 5.
- 15 Ibid.
- 16 IEA, op. cit. note 3, p. 147.
- 17 Ibid.
- 18 Data for 2018 based on Ibid.
- 19 Ibid. China is also an important user of biomass for heating in both buildings and industry, but this is not reflected in current statistics due to data collection and reporting challenges.
- 20 Bioenergy Europe, *Statistical Report 2019: Biomass for Heat* (Brussels: 2019), <https://bioenergyeurope.org/article.html/194>.
- 21 "Saica Group opens its first biomass plant in France", Bioenergy Insight, 13 September 2019, <https://www.bioenergy-news.com/news/saica-group-opens-its-first-biomass-plant-in-france>.
- 22 See sources in endnote 5.
- 23 Ibid.
- 24 While such uses of bioenergy are concentrated in developing and emerging economies, in more developed countries large quantities of wood are used to heat homes in inefficient and often polluting devices such as open grates, contributing to local air pollution problems. However, under the statistical conventions that define traditional biomass as that used for heating in countries outside the Organisation for Economic Co-operation and Development (OECD), such fuel use is classified as being "modern". See, for example, UK Department of Environment and Rural Affairs, *The Potential Air Quality Impacts of Biomass Combustion* (London: 2017), https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf.
- 25 Environment Agency Austria and International Institute for Applied Systems Analysis, *Measures to Address Air Pollution from Small Combustion Sources* (Vienna: 2018), p. 4, https://ec.europa.eu/environment/air/pdf/clean_air_outlook_combustion_sources_report.pdf.
- 26 P. Thornley et al., "Integrated assessment of bioelectricity technology options", *Energy Policy*, vol. 37, no. 3 (2009), pp. 890-903, <https://www.sciencedirect.com/science/article/abs/pii/S0301421508005740>; V. Loo and J. Koppejan, *The Handbook of Biomass Combustion and Co-firing* (London: Routledge, 2010), <https://www.routledge.com/The-Handbook-of-Biomass-Combustion-and-Co-firing-1st-Edition/Loo-Koppejan/p/book/9781849711043>.
- 27 Concentration in the EU is due in part to climatic reasons, as building heating requirements are limited in more southern countries, and bioenergy so far plays a very limited role in providing cooling. Also, note that by definition use of biomass for residential heating outside the OECD is classified as "traditional use of biomass" and so is not counted within the statistics as "modern use of biomass". IEA, op. cit. note 3, p. 136.
- 28 IEA, op. cit. note 3, p. 136.
- 29 Bioenergy Europe, op. cit. note 20.
- 30 For example, in Germany the use of biomass for heating in the residential and commercial sectors rose 8% and 6%, respectively, between 2018 and 2019, from Federal Ministry for Economic Affairs and Energy (BMWi), "Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, 1990-2019", Table 5, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html, updated March 2020.
- 31 Bioenergy Europe, *Statistical Report 2019: Pellet* (Brussels: 2019), <https://bioenergyeurope.org/article.html/211>.
- 32 Ibid.
- 33 Measures include a carbon tax on household energy in France (see Ministère de la Transition écologique et solidaire, "Fiscalité carbone", 21 September 2017, <https://www.ecologique-solidaire.gouv.fr/fiscalite-carbone>) and the phase-out of oil as a heating fuel in several countries including Denmark, Norway and Sweden. Restrictions on gas connections for new properties and developments also have been announced or implemented in the Netherlands, from IRENA, IEA and Renewable Energy Network for the 21st Century (REN21), *Renewable Energy Policies in a Time of Transition* (Paris: 2018), <https://www.ren21.net/2018-renewable-energy-policies-in-a-time-of-transition>.

- 34 Bioenergy Europe, op. cit. note 20.
- 35 US Energy Information Administration (EIA), *Winter Fuels Outlook* (Washington, DC: October 2019), https://www.eia.gov/outlooks/steo/special/winter/2019_winter_fuels.pdf.
- 36 Ibid.
- 37 Natural Resources Canada, "Renewable energy facts", <https://www.nrcan.gc.ca/science-and-data/data-and-analysis/energy-data-and-analysis/energy-facts/renewable-energy-facts/20069>, updated 3 April 2020.
- 38 Bioenergy Europe, op. cit. note 31.
- 39 See sources in endnote 8.
- 40 Based on data in IEA, op. cit. note 3, p. 131.
- 41 Euroheat & Power, *Country by Country 2019* (Brussels: 2019), <https://www.euroheat.org/cbc/2019/>.
- 42 Bioenergy Europe, op. cit. note 20.
- 43 "Danish power station uses wood chips to generate green power", Bioenergy Insight, 27 November 2019, <https://www.bioenergy-news.com/news/danish-power-station-uses-wood-chips-to-generate-green-power>.
- 44 E.ON is investing EUR 110 million (USD 123 million) in the project, from "E.ON to build biomass power plant at German paper mill", Bioenergy Insight, 29 November 2019, <https://www.bioenergy-news.com/news/e-on-to-build-biomass-power-plant-at-german-paper-mill/>; "Finnish company KPA Unicon to supply biomass heat plant to local town", Bioenergy Insight, 11 October 2019, <https://www.bioenergy-news.com/news/finnish-company-kpa-unicon-to-supply-biomass-heat-plant-to-local-town/>.
- 45 Based on biofuels data in IEA, *Oil 2020* (Paris: 2020), <https://www.iea.org/reports/oil-2020>, and supplemented by national data as referenced elsewhere.
- 46 Ibid.
- 47 Ibid.
- 48 IEA, op. cit. note 2, p. 35. Ethanol is produced principally from sugar- and starch-containing materials including maize, sugar cane, wheat and cassava. After pretreatment and fermentation, the ethanol is separated by distillation. Most biodiesel is made by chemically treating vegetable oils and fats (including palm, soy and canola oils, and some animal fats) to produce FAME biodiesel. Ethanol and biodiesel are collectively referred to as "conventional biofuels". While FAME fuels can be used in diesel engines, their properties depend on their origin and differ from those of fossil-based diesel, so they are usually used as a blend with fossil diesel products. See Difference.net, "Difference between corn and maize", <http://www.differencebetween.net/object/comparisons-of-food-items/difference-between-corn-and-maize>, viewed 13 May 2019.
- 49 IEA, op. cit. note 45, pp. 72-73 and supplemented by national data as referenced elsewhere. Another alternative is to take the oils and treat them with hydrogen to produce a hydrocarbon product that then can be refined to produce fuels with properties equivalent to those of a range of fuels derived from fossil fuels such as diesel or jet fuel. These fuels are described as HVO/HEFA and sometimes as renewable diesel. See, for example, Aviation Initiative for Renewable Fuels in Germany, "Hydroprocessed esters and fatty acids (HEFA)", <https://aireg.de/en/topics/alternative-aviation-fuels-from-regenerative-energies/production>, viewed 9 May 2020. In addition, a range of other biofuels are produced at a much smaller scale, including ethanol from cellulosic feedstocks, pyrolysis oils, etc. See Liquid Fuels Industry section of this chapter for further details and references.
- 50 **Figure 22** based on biofuels data in IEA, op. cit. note 45, supplemented by national data as referenced elsewhere; for previous years, see earlier editions of the GSR and related endnotes. Volumes of fuel converted to energy content using conversion factors from US Department of Energy, "Alternative Fuels Data Centre", <https://www.afdc.energy.gov>, viewed 4 April 2018. Lower caloric value for ethanol is 76,330 Btu/US gallon (21.27 MJ/litre) and for biodiesel is 119,550 Btu/US gallon (3.32 MJ/litre). Caloric value for HVO is 34.4 MJ/litre. See Neste, *Neste Renewable Diesel Handbook* (Espoo, Finland: 2016), p. 15, https://www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf.
- 51 Based on data on biomethane and other advanced biofuels referenced later in this section.
- 52 Based on data in IEA, op. cit. note 45, supplemented by national data as referenced elsewhere.
- 53 Ibid.
- 54 Ibid.
- 55 US EIA, *Monthly Energy Review* (Washington, DC: April 2020), "Table 10.3, Fuel ethanol overview", <https://www.eia.gov/totalenergy/data/monthly>.
- 56 Renewable Fuels Association (RFA), "Annual fuel ethanol production", <https://ethanolrfa.org/statistics/annual-ethanol-production>, viewed 21 March 2020.
- 57 IEA, op. cit. note 3; RFA, *2019 US Ethanol Exports and Imports: Statistical Summary* (Ellisville, MO: 2020), <https://files.constantcontact.com/a8800d13601/bedc9057-a440-470b-9a40-f1c88cff287b.pdf>; "US ethanol industry generated \$43 billion in 2019 despite policy challenges", Biofuels International, 14 February 2020, <https://biofuels-news.com/news/us-ethanol-industry-generated-43-billion-in-2019-despite-policy-challenges/>; K. Colombini, "RFA: EPA rule won't prevent further RFS erosion by waivers", RFA, 19 December 2019, <https://ethanolrfa.org/2019/12/rfa-epa-rule-wont-prevent-further-rfs-erosion-by-waivers>.
- 58 M. Thompson, "Siouxland Energy temporarily idles production", *Ethanol Producer Magazine*, 16 September 2019, <http://ethanolproducer.com/articles/16547/siouxland-energy-temporarily-idles-production/>; POET LLC, "Oil bailouts force POET to lower production", *Ethanol Producer Magazine*, 20 August 2019, <http://ethanolproducer.com/articles/16466/oil-bailouts-force-poet-to-lower-production>.
- 59 Agencia Nacional do Petróleo, Gas Natural e Biocombustíveis (ANP), "Dados estatísticos", <http://www.anp.gov.br/dados-estatisticos>, viewed 24 February 2020.
- 60 RenovaBio, "Brazilian president signs biofuels initiative into law", 3 January 2018, <https://www.renovabio.org/brazilian-president-signs-biofuels-initiative-into-law>.
- 61 US Department of Agriculture (USDA), Global Agricultural Information Network (GAIN), *Brazil Biofuels Annual 2019* (Washington, DC: 2019), p. 14, https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-9-2019.pdf.
- 62 E. Voegele, "Unica corn ethanol production continues to increase", *Ethanol Producer Magazine*, 11 February 2020, <http://ethanolproducer.com/articles/16909/unica-corn-ethanol-production-continues-to-increase/>; USDA, op. cit. note 61, p. 14.
- 63 IEA, op. cit. note 45, pp. 69-73, 114.
- 64 Ibid., pp. 69-73, 114.
- 65 T. Tsanova, "China's bioethanol capacity expanding to meet 2020 demand", *Renewables Now*, 14 December 2018, <https://renewablesnow.com/news/chinas-bioethanol-capacity-expanding-to-meet-2020-demand-report-636664/>; H. Gu, M. Xu and S. Singh, "Exclusive: China suspends national rollout of ethanol mandate – sources", *Reuters*, 8 January 2020, <https://www.reuters.com/article/us-china-ethanol-policy-exclusive-idUSKBN1Z1R8>.
- 66 S. Poundrik, "Transport and renewable energy policies in India", presentation, EU/India Conference on Biofuels, 7-8 March 2018, <https://ec.europa.eu/energy/en/content/conference-presentations-7-8-march-2018-eu-india-conference-advanced-biofuels>.
- 67 IEA, op. cit. note 45, pp. 69-73, 114.
- 68 RFA, op. cit. note 56, viewed April 2020; IEA, op. cit. note 3.
- 69 USDA, GAIN, *EU Biofuels Annual 2019* (Washington, DC: 2019), https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels%20Annual_The%20Hague_EU-28_7-15-2019.pdf.
- 70 Ethanol blending mandates were increased in a number of EU countries – including Greece, Hungary, the Netherlands, Poland, Romania and Spain – as the 2020 deadline approached for achieving the targets of the Renewable Energy Directive. USDA, op. cit. note 69; USDA, GAIN, *Biofuel Mandates in the EU by Member State in 2019* (Washington, DC: 2019), https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuel%20Mandates%20in%20the%20EU%20by%20Member%20State%20in%202019_Berlin_EU-28_6-27-2019.pdf.
- 71 IEA, op. cit. note 45.
- 72 Based on biofuels data in Ibid., supplemented by national data as referenced elsewhere in this section.
- 73 IEA, op. cit. note 45.

- 74 Based on biofuels data in Ibid., supplemented by national data as referenced elsewhere in this section.
- 75 IEA, op. cit. note 45.
- 76 Ibid.
- 77 F. T. R. Silalahi and T. Simatupang, "Biodiesel produced from palm oil in Indonesia: Current status and opportunities", *AIMS Energy*, vol. 8, no. 1 (2020), pp. 81-101, https://www.researchgate.net/publication/338693591_Biodiesel_produced_from_palm_oil_in_Indonesia_Current_status_and_opportunities; IEA, op. cit. note 45.
- 78 US EIA, *Monthly Energy Review* (Washington, DC: April 2020), "Table 10.4. Biodiesel and other renewable fuels overview", <https://www.eia.gov/totalenergy/data/monthly>. Eight US biodiesel plants were closed and other plants operated at reduced capacity. At the same time, several new plants came online or were being planned, including Cargill's 60 million gallons/year (230 million litres) project in Wichita, Kansas; the 7 million gallons/year (26 million litres) Green Biofuels plant in south Florida and SJV Biodiesel's 5 million gallons/year (19 million litres) plant in Pixley, California. R. Kotrba, "2020 biodiesel plant map reflections", *Biodiesel Magazine*, 7 January 2020, <http://biodieselmagazine.com/articles/2516872/2020-biodiesel-plant-map-reflections>.
- 79 R. Kotrba, "Historic 5 year extension of biodiesel tax credit signed into law", *Biodiesel Magazine*, 20 December 2019, <http://www.biodieselmagazine.com/articles/2516870/historic-5-year-extension-of-biodiesel-tax-credit-signed-into-law>.
- 80 ANP, op. cit. note 59, viewed 25 February 2020.
- 81 IEA, op. cit. note 3. As with ethanol, the RenovaBio initiative is stimulating growth in biodiesel production capacity in Brazil. For example, the local food company JBS announced that it would invest BRL 180 million (USD 48 million) to build another biodiesel plant in Santa Catarina, producing the fuel from pork and poultry fat as well as soy products, from JBS, "JBS to more than double biodiesel output with new plant in Brazil", *Biodiesel Magazine*, 31 July 2019, <http://biodieselmagazine.com/articles/2516745/jbs-to-more-than-double-biodiesel-output-with-new-plant-in-brazil>.
- 82 Ambito, "En 2019 cayó 4% la producción de bioetanol y se redujo 12% la de biodiesel", 17 February 2020, <https://www.ambito.com/economia/biocombustibles/en-2019-cayo-4-la-produccion-bioetanol-y-se-redujo-12-la-biodiesel-n5083366>.
- 83 Ibid.
- 84 IEA, op. cit. note 45.
- 85 Ibid.
- 86 IEA, *World Energy Outlook Special Report: Prospects for Biogas and Biomethane* (Paris: 2020), <https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth>.
- 87 S. Olson, "RNG, cellulosic fuels and the Renewable Fuel Standard", *BioCycle*, 17 February 2017, <https://www.biocycle.net/2017/02/14/rng-cellulosic-fuels-renewable-fuel-standard>.
- 88 Based on data in US Environmental Protection Agency (EPA), "RIN generation and renewable fuel volume production by fuel type from December 2019", <https://www.epa.gov/fuels-registration-reporting-and-compliance-help/spreadsheet-rin-generation-and-renewable-fuel-0>, updated March 2020.
- 89 Based on an analysis of the Eurostat SHARES database that includes data to 2017 for biogas use in the transport sector for each EU country. See Eurostat, "SHARES 2018 detailed results", Transport tab, <https://ec.europa.eu/eurostat/web/energy/data/shares>, viewed 26 February 2020.
- 90 Ibid.
- 91 CNG Fuels aims to have six refuelling stations, capable of refuelling up to 3,000 heavy goods vehicles a day, from "CNG fuels plans to become UK's first supplier of carbon neutral fuel for HGVs", *Bioenergy Insight*, 6 November 2019, <https://www.bioenergy-news.com/news/cng-fuels-plans-to-become-uks-first-supplier-of-carbon-neutral-fuel-for-hgvs>.
- 92 Gasum, which is building a network of biogas filling stations in the Nordic countries, already has 33 biogas filling stations in Finland (with 7 also serving long-distance heavy-duty transport) and 4 in Sweden; by the end of 2019, the company aimed to have 20 filling stations for heavy-duty vehicles (8 in Finland and 12 in Sweden), from "Major Nordic logistics supplier switches to biogas", *Bioenergy Insight*, 9 October 2019, <https://www.bioenergy-news.com/news/major-nordic-logistics-solutions-provider-switches-to-biogas>.
- 93 L. Cork, "Biogas bus order for Paris", *Transport Engineer*, 8 October 2019, <http://www.transportengineer.org.uk/transport-engineer-news/biogas-bus-order-for-paris/220031>.
- 94 "Norwegian city introduces 189 buses powered by biogas and biodiesel", *Bioenergy Insight*, 12 September 2019, <https://www.bioenergy-news.com/news/norwegian-city-introduces-189-buses-powered-by-biogas-and-biodiesel>.
- 95 L. Cork, "Bristol buses boosted by alternative fuel", *Transport Engineer*, 16 September 2019, <http://www.transportengineer.org.uk/transport-engineer-news/bristol-buses-boosted-by-alternative-fuel/219381>; L. Cork, "First West powers cleaner Bristol fleet with 77 biogas buses", *Transport Engineer*, 24 February 2020, <http://www.transportengineer.org.uk/transport-engineer-news/first-west-powers-cleaner-bristol-fleet-with-77-biogas-buses/224391>.
- 96 Based on data in US EPA, op. cit. note 88.
- 97 IEA, op. cit. note 3.
- 98 Overall bioelectricity capacity based on the following national data: US Federal Energy Regulatory Commission, "Office of Energy Projects Energy Infrastructure Update for December 2019" (Washington, DC: 2019), <https://www.ferc.gov/legal/staff-reports/2018/dec-energy-infrastructure.pdf>; BMWi, op. cit. note 30, Table 4; UK Department for Business, Energy and Industrial Strategy (BEIS), "Energy Trends: Renewables", Table 6.1, <https://www.gov.uk/government/statistics/energy-trends-section-6-renewables>, updated 26 March 2020; Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements) for 2018 and 2019", <https://mnre.gov.in/the-ministry/physical-progress>, viewed 23 February 2020; data for other countries based on forecast 2019 capacity figures from IEA, op. cit. note 3, datafiles.
- 99 Bioelectricity generation data based on national data from the following sources: US EIA, *Electric Power Monthly* (Washington, DC: March 2020), Table 1.1a, <https://www.eia.gov/electricity/data.php>, corrected for difference between net and gross electricity generation; BMWi, op. cit. note 30, Table 3; UK BEIS, op. cit. note 98; other countries based on forecast 2017 capacity figures from IEA, op. cit. note 3, datafiles. New Energy Network, "The installed capacity of biomass power generation in 2019 increased by 26.6% year-on-year", 12 March 2020, <https://newenergy.in-en.com/html/newenergy-2375278.shtml> (using Google Translate).
- 100 Ibid., all references.
- 101 Ibid., all references.
- 102 Ibid., all references.
- 103 Bioelectricity generation data based on analysis of national data from the following sources: US EIA, op. cit. note 99, corrected for difference between net and gross electricity generation; BMWi, op. cit. note 30, Table 3; UK BEIS, op. cit. note 98; other countries based on forecast 2017 capacity figures from IEA, op. cit. note 3, datafiles; China (National Energy Network), 2019 <https://newenergy.in-en.com/html/newenergy-2375278.shtml>.
- 104 See sources in endnote 99.
- 105 **Figure 23** based on analysis conducted using historical data from REN21 for years to 2015, and the results of analysis carried out for this report based on the national data referenced in endnotes 98 and 99.
- 106 New Energy Network, op. cit. note 99.
- 107 Ibid.
- 108 IEA, op. cit. note 3.
- 109 Ibid., datafiles.
- 110 Ibid., datafiles.
- 111 Ibid., datafiles.
- 112 Ibid., datafiles.
- 113 Government of India, MNRE, op. cit. note 98; IEA, op. cit. note 3, datafiles.
- 114 Based on analysis of relevant national data in endnote 99.
- 115 Ibid.
- 116 BMWi, op. cit. note 99.
- 117 UK BEIS, op. cit. note 98.
- 118 IEA, op. cit. note 3, datafiles; ECN, "Dutch renewable energy support scheme (SDE+)", <https://www.ecn.nl/collaboration/sde/index.html>, viewed 26 March 2020.

- 119 IEA, op. cit. note 3, datafiles.
- 120 US EIA, op. cit. note 99, corrected for difference between net and gross electricity generation.
- 121 Analysis based on Ibid.
- 122 IEA, op. cit. note 3.
- 123 IEA, op. cit. note 3, datafiles.
- 124 Projection for 2019 generation from Ibid.
- 125 Bioenergy Europe, op. cit. note 31.
- 126 World Biogas Association, *Global Potential of Biogas* (London: 2019), https://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-globalreport-56ppa4_digital-Sept-2019.pdf.
- 127 Ibid; Bioenergy Europe, *Statistical Report 2019: Biogas* (Brussels: 2019), <https://bioenergyeurope.org/article.html/103>; American Biogas Council, "Biogas market snapshot", <https://americanbiogascouncil.org/biogas-market-snapshot>, viewed 23 March 2020.
- 128 "Germany invests Euros 5 million in Ghanaian biogas project", Bioenergy Insight, 2 August 2019, <https://www.bioenergy-news.com/news/germany-invests-e5-million-in-ghanaian-biogas-project>.
- 129 Power Technology, "Bloom Energy to install solid oxide fuel cells at biogas plant", 7 October 2019, <https://www.power-technology.com/news/bloom-energy-solid-oxide-fuel-cells>; Bloom Energy, "Bloom Energy and EnergyPower to supply reliable, renewable, zero carbon electricity from India's BioWaste", press release (San Jose, CA and New Delhi: 4 October 2019), <https://www.bloomenergy.com/newsroom/press-releases/bloom-energy-and-energypower-supply-reliable-renewable-zero-carbon>.
- 130 "Biotech firm opens poultry waste-to-biogas facility in Mexico", Bioenergy Insight, 22 November 2019, <https://www.bioenergy-news.com/news/biotech-firm-opens-poultry-waste-to-biogas-facility-in-mexico>.
- 131 "Brazil's first biogas-fired plant using pig manure begins operations", Bioenergy Insight, 25 July 2019, <https://www.bioenergy-news.com/news/brazils-first-biogas-fired-plant-using-pig-manure-begins-operations>.
- 132 "Mazoon Dairy inaugurates first biogas plant in the region", Times of Oman, 12 October 2019, <https://timesofoman.com/article/2057059/Business/Mazoon-Dairy-inaugurates-first-biogas-plant-in-the-region>.
- 133 W. Abbas, "Coming soon: Dubai's first biogas plant", Khaleej Times, 29 September 2019, <https://www.khaleejtimes.com/coming-soon-dubais-first-biogas-plant>.
- 134 IEA, op. cit. note 2.
- 135 Bioenergy Europe, op. cit. note 31.
- 136 Ibid.
- 137 Ibid., p. 17.
- 138 Ibid.
- 139 Calculation based on: calorific value of pellets of 17 GJ per tonne, from Forest Research, "Typical calorific values of fuels", <https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/typical-calorific-values-of-fuels>; on 30% electricity generation efficiency for large-scale plant, from IEA, op. cit. note 2, p. 39; and on total bioelectricity generation for 2018 in Markets section of Bioenergy text.
- 140 Calculation based on calorific value of pellets of 17 GJ per tonne, from Forest Research, op. cit. note 139, and on total bio-heat for buildings for 2018 in Markets section of Bioenergy text.
- 141 Granuul Invest, "Frontpage", <https://www.graanulinvest.com/eng/frontpage>, viewed 9 May 2020; An Viet Phat, "Home", <https://anvietenergy.com/?lang=en>, viewed 9 May 2020; Highland Pellets, "Projects", <http://highland-pellets.com/projects/>, viewed 9 May 2020; Pacific Bioenergy, "Our products", <https://www.pacificbioenergy.ca/our-products>, viewed 9 May 2020.
- 142 See, for example, "Pinnacle inks wood pellet supply contracts in Japan and South Korea", Bioenergy Insight, 15 July 2019, <https://www.bioenergy-news.com/news/pinnacle-inks-wood-pellets-supply-contracts-in-japan-south-korea>.
- 143 Bioenergy Europe, op. cit. note 31.
- 144 Based on EIA, *Monthly Densified Biomass Fuel Report* (Washington, DC: 15 April 2020), https://www.eia.gov/biofuels/biomass/#table_data.
- 145 "Permit approved for Enviva's new wood pellet facility in Alabama", Bioenergy Insight, 3 December 2019, <https://www.bioenergy-news.com/news/permit-approved-for-envivas-new-wood-pellet-facility-in-alabama-us>.
- 146 Bioenergy Europe, op. cit. note 31, p. 24. Pellet use for power generation in Japan and the Republic of Korea started to grow in 2013-2014 when it was already well established in Europe, and especially in the UK where pellet consumption was already over 3 million tonnes.
- 147 IEA, op. cit. note 3, p. 34.
- 148 Bioenergy Europe, op. cit. note 31.
- 149 To finance a large-scale power plant fuelled with wood pellets, investors require certainty about the long-term availability and price of the fuel to reduce supply-side risks. These plants therefore usually need to secure long-term supply contracts. Similarly, investors in pellet plants and transport systems need assurance that there will be a market for their products, so they seek long-term off-take agreements with consumers. The capital cost of converting a coal-fired plant to allow co-firing is much lower than that of a new dedicated plant, and the supply risks are reduced. Such plants often seek shorter-term supply contracts that enable them to be more flexible and take advantage of lower cost materials when available. "Pinnacle inks wood pellet supply contracts in Japan and South Korea", op. cit. note 142.
- 150 Ibid.
- 151 Ibid.
- 152 See, for example, IEA Bioenergy, "The use of forest biomass for climate change mitigation: Response to statements by EASAC", December 2019, <https://www.ieabioenergy.com/publications/the-use-of-forest-biomass-for-climate-change-mitigation-response-to-statements-by-easac>.
- 153 EU Science Hub, "Renewable energy – Recast to 2030 (RED II), Sustainability Criteria", <https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii>, viewed 20 April 2020. In the original RED, sustainability criteria applied only to liquid biofuels, but in the revised directive this is extended to cover solid biomass feedstocks.
- 154 See, for example, Enviva Biomass, "Track & Trace™", <https://www.envivabiomass.com/sustainability/responsible-sourcing/track-trace>, viewed 20 April 2020.
- 155 Sustainable Bioenergy Programme, "SBP prepares for change", <https://sbp-cert.org/about-us/governance-transition-process>, viewed 20 April 2020.
- 156 "CEG delivers biocoal pellets to European customer", Bioenergy Insight, 7 May 2019, <https://www.bioenergy-news.com/news/ceg-delivers-biocoal-pellets-to-european-customer>.
- 157 M. Thompson, "Siouxland Energy temporarily idles production", *Ethanol Producer Magazine*, 16 September 2019, <http://ethanolproducer.com/articles/16547/siouxland-energy-temporarily-idles-production>; POET LLC, op. cit. note 58.
- 158 These included Cargill's 60 million gallons per year (230 million litres) project in Wichita, Kansas; the 7 million gallons per year (26 million litres) Green Biofuels plant in south Florida and SJV Biodiesel's 5 million gallons per year (19 million litres) plant in Pixley, California. Kotrba, op. cit. note 78.
- 159 IEA, op. cit. note 3.
- 160 Ibid.
- 161 IEA, op. cit. note 45.
- 162 IEA, op. cit. note 45.
- 163 World Energy, "World Energy invests \$350M to expand Paramount biofuel production", *Biomass Magazine*, 24 October 2018, <http://www.biomassmagazine.com/articles/15699/world-energy-invests-350m-to-expand-paramount-biofuel-production>.
- 164 Kotrba, op. cit. note 78.
- 165 Based on data from announced plants.
- 166 Total, "Total starts la Mede biorefinery", press release (Paris: 3 July 2019), <https://www.total.com/en/media/news/press-releases/total-starts-la-mede-biorefinery>; M. Sapp, "Total's La Mede biorefinery starts up production", *Biofuels Digest*, 3 July 2019, <https://www.biofuelsdigest.com/bdigest/2019/07/03/totals-la-mede-biorefinery-starts-up-production>.
- 167 M. Sapp, "Eni opens 750,000-ton biorefinery in Gela", *Biofuels Digest*, <https://www.biofuelsdigest.com/bdigest/2019/09/25/eni-opens-750000-ton-biorefinery-in-gela>.

- 168 M. Sapp, "St1 hires ÅF Pöyry to do engineering for hydrogen manufacturing at Gothenburg HVO plant", *Biofuels Digest*, 4 November 2019, <http://www.biofuelsdigest.com/bdigest/2019/11/04/st1-hires-af-poyry-to-do-engineering-for-hydrogen-manufacturing-at-gothenburg-hvo-plant>.
- 169 Petroplaza, "PKN ORLEN invests in biofuels of the future", 20 December 2018, <https://www.petroplaza.com/news/9863>.
- 170 Neste, "Neste hosts foundation stone ceremony for Singapore expansion", *Biodiesel Magazine*, 31 July 2019, <http://biodieselmagazine.com/articles/2516743/neste-hosts-foundation-stone-ceremony-for-singapore-expansion>.
- 171 "ECB Group hires UBS, Barclays as financial advisors for large HVO plant", *Reuters*, 11 November 2019, <https://uk.reuters.com/article/uk-biofuels-hvo/ecb-group-hires-ubs-barclays-as-financial-advisors-for-large-hvo-plant-idUKKBN1XL2KM>.
- 172 IEA, op. cit. note 3.
- 173 IEA, op. cit. note 2.
- 174 The aim of developing and commercialising advanced biofuels is threefold: first, to produce fuels that can provide more life-cycle carbon savings than some biofuels produced from sugar, starch and oils; second, to produce fuels with less impact on land use (e.g., from wastes and residues), thereby reducing indirect land-use change impacts and also reducing competition for food or for productive agricultural land; and finally, to produce biofuels with properties that enable them to directly replace fossil fuels in advanced transport systems such as aviation engines, or to be blended in high proportions with conventional fuels ("drop-in biofuels"), from IEA, op. cit. note 2.
- 175 I. Landalv, L. Waldheim and K. Maniatis, *Subgroup on Advanced Biofuels: Technology Status and Reliability of the Value Chains: 2018 Update* (Brussels: 2018), <http://artfuelsforum.eu/wp-content/uploads/2019/04/ART-Fuels-Forum-SGAB-Biofuels-Technology-report-2018-update.pdf>.
- 176 E. Voegelé, "POET-DSM halts Liberty project over RFS mismanagement", *Ethanol Producer Magazine*, 19 November 2019, <http://ethanolproducer.com/articles/16722/poet-dsm-halts-project-liberty-production-over-rfs-mismanagement>.
- 177 J. Lane, "VERBIO North America acquires Iowa cellulosic ethanol facility from DuPont", *Biodiesel Digest*, 11 September 2018, <https://www.biofuelsdigest.com/bdigest/2018/11/09/verbio-north-america-acquires-iowa-cellulosic-ethanol-facility-from-dupont/>.
- 178 J. Lane, "Looking deeper into Clariant cellulosic technology", *Biofuels Digest*, 16 September 2018, <https://www.biofuelsdigest.com/bdigest/2018/09/16/looking-deeper-into-clariant-cellulosic-technology-part-2-of-2-a-visit-to-craiova-romania-and-first-commercial-groundbreaking>.
- 179 J. Lane, "Clariant and Anhui Guoxhen Group and Chemtex chemical engineering ink deal for 30 million gallon cellulosic ethanol project in China", *Biofuels Digest*, 1 June 2019, <http://www.biofuelsdigest.com/bdigest/2020/01/06/clariant-anhui-guozhen-group-and-chemtex-chemical-engineering-ink-deal-for-30-million-gallon-cellulosic-ethanol-project-in-china>.
- 180 M. Sapp, "Eni's Versalis wins Biochemtex and Beta Renewables at auction", *Biofuels Digest*, 1 October 2018, <https://www.biofuelsdigest.com/bdigest/2018/10/01/eni-versalis-wins-biochemtex-and-beta-renewables-at-auction>.
- 181 H. Tavares Kennedy, "Granbio to resume ethanol plant commercial operations", *Biofuels Digest*, 25 January 2019, <http://www.biofuelsdigest.com/bdigest/2019/01/25/granbio-to-resume-ethanol-plant-commercial-operations>.
- 182 Landalv, Waldheim and Maniatis, op. cit. note 175.
- 183 M. Sapp, "Enerkem looking to Massachusetts to possibly site new WE plant", *Biofuels Digest*, 7 January 2019, <http://www.biofuelsdigest.com/bdigest/2019/01/07/enerkem-looking-at-massachusetts-to-possibly-site-new-wte-plant>; M. Sapp, "Enerkem agrees deal with twin cities allowing it to move forward with planning MSW to ethanol project", *Biofuels Digest*, 13 December 2018, <https://www.biofuelsdigest.com/bdigest/2018/12/13/enerkem-agrees-deal-with-twin-cities-allowing-it-to-move-forward-with-planning-msw-to-ethanol-project>.
- 184 Landalv, Waldheim and Maniatis, op. cit. note 175.
- 185 BTG, "Green Fuel Nordic Lieksa project", 2 April 2019, <https://www.btg-btl.com/en/company/projects/gfnl1>.
- 186 GoodFuels, "BTG and GoodFuels preparing for major investment in bio-refinery to support shipping's low carbon fuels demands", 14 November 2019, <https://goodfuels.com/btg-and-goodfuels-preparing-for-major-investment-in-bio-refinery-to-support-shippings-low-carbon-fuels-demands>.
- 187 A. Sherrard, "Pyrocell selects TechnipFMC and BTG-BTL to build Swedish bio-oil plant", *Bioenergy International*, 16 September 2019, <https://bioenergyinternational.com/technology-suppliers/pyrocell-selects-technipfmc-and-btg-btl-to-build-swedish-bio-oil-production-plant>.
- 188 "Shell to provide financial support for Norwegian refinery project", *Bioenergy International*, 24 November 2019, <https://bioenergyinternational.com/biofuels-oils/shell-to-provide-financial-support-for-norwegian-biorefinery-project>.
- 189 IEA, op. cit. note 2; P. Le Feuvre, "Commentary: Are aviation biofuels ready for take off?" IEA, 18 March 2019, <https://www.iea.org/newsroom/news/2019/march/are-aviation-biofuels-ready-for-take-off.html>. For industry carbon reduction commitments, see examples in text.
- 190 J. Lane, "KLM, SkyNRG and SHV Energy greenlight the world's largest stand-alone sustainable aviation fuels project", *Biofuels Digest*, 27 May 2019, <https://www.biofuelsdigest.com/bdigest/2019/05/27/klm-skyng-and-shv-energy-greenlight-the-worlds-largest-stand-alone-sustainable-aviation-fuels-project>.
- 191 Ibid.
- 192 M. Sapp, "Neste and Lufthansa extend collaboration on aviation biofuel", *Biofuels Digest*, 2 October 2019, <https://www.biofuelsdigest.com/bdigest/2019/10/02/neste-and-lufthansa-extends-collaboration-on-aviation-biofuel>.
- 193 "Norway's Avinor commits to biomass based sustainable aviation fuel", *Bioenergy Insight*, 27 June 2019, <https://www.bioenergy-news.com/news/norways-avinor-commits-to-biomass-based-sustainable-aviation-fuel>.
- 194 H. Tavares Kennedy, "Shell Aviation, World Energy to supply sustainable aviation fuel to Lufthansa at SFO; ink multi-year collaboration", 7 January 2020, <https://www.biofuelsdigest.com/bdigest/2020/01/07/shell-aviation-world-energy-to-supply-sustainable-aviation-fuel-to-lufthansa-at-sf>.
- 195 J. Lane, "Jet Blue starts aviation biofuels flights from SFO in 2020 and pledges to be carbon neutral by July through off-setting", *Biofuels Digest*, 6 January 2020, <https://www.biofuelsdigest.com/bdigest/2020/01/06/jetblue-starts-aviation-biofuels-flights-from-sfo-in-2020-pledges-carbon-neutral-by-july-through-offsetting>.
- 196 M. Sapp, "Delta to buy 10 million gallons per year of aviation biofuel from Gevo", *Biofuels Digest*, 17 December 2019, <https://www.biofuelsdigest.com/bdigest/2019/12/17/delta-to-buy-10-million-gallons-per-year-of-aviation-biofuel-from-gevo>.
- 197 Ibid.
- 198 M. Sapp, "United Airlines commits 40 million to new sustainable aviation fuel investment vehicle", *Biofuels Digest*, 28 October 2019, <https://www.biofuelsdigest.com/bdigest/2019/10/28/united-airlines-commits-40-million-to-new-sustainable-aviation-fuel-investment-vehicle>.
- 199 M. Sapp, "SkyNRG and Waterfall Group team with Vancouver airport on aviation biofuel", *Biofuels Digest*, 28 November 2019, <https://www.biofuelsdigest.com/bdigest/2019/11/28/skyng-and-waterfall-group-team-with-vancouver-airport-on-aviation-biofuel>.
- 200 IEA, op. cit. note 86.
- 201 Ibid.
- 202 Relevant quality standards are usually set by the gas grid operator where the connection is to take place; see, for example, SoCalGas, *Biomethane Gas Quality Standards* (no date), [https://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Gas/Natural_Gas_Market/PM%20May%2023%20_3%20Interconnect%20Commissioning%20\(May%20Lew\)%20FINAL.pdf](https://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Gas/Natural_Gas_Market/PM%20May%2023%20_3%20Interconnect%20Commissioning%20(May%20Lew)%20FINAL.pdf).
- 203 See, for example, Navigant and Ecofys, "Role of renewable gas in a decarbonized EU energy system", 31st Meeting of the European Gas Regulatory Forum, 16 October 2018, https://ec.europa.eu/energy/sites/ener/files/documents/01.c.01_mf31_presentation_ecofys_potential_resg_leun.pdf.
- 204 "Leyline Renewable Capital funds two new major AD facilities in US", *Bioenergy Insight*, 21 November 2019, <https://www.bioenergy-news.com/news/leyline-renewable-capital-funds-two-new-major-ad-facilities-in-us>.

- 205 "Two US firms announce \$200 million dairy waste to energy venture", Bioenergy Insight, 12 December 2019, <https://www.bioenergy-news.com/news/two-us-firms-announce-200-million-dairy-waste-to-energy-venture>.
- 206 "First dairy manure to RNG facility in Oregon, US celebrates opening", Bioenergy Insight, 5 December 2019, <https://www.bioenergy-news.com/news/first-dairy-manure-to-rng-facility-in-oregon-us-celebrates-opening>.
- 207 European Biogas Association, *Annual Report 2019* (Brussels: 2019), <https://www.europeanbiogas.eu/wp-content/uploads/2020/01/EBA-AR-2019-digital-version.pdf>.
- 208 "India to build 5,000 biogas plants by 2023", Bioenergy Insight, 17 December 2018, <https://www.bioenergy-news.com/news/india-to-build-5000-biogas-plants-by-2023>.
- 209 "ENGIE acquires biomethane producer", Bioenergy Insight, 28 February 2019, <https://www.bioenergy-news.com/news/engie-acquires-biomethane-producer>.
- 210 "Air Liquide's 2018 results show key role for biogas", Bioenergy Insight, 15 February 2019, <https://www.bioenergy-news.com/news/air-liquides-2018-results-show-key-role-for-biogas>.
- 211 "Plans for £150M UK bioresources to fuel facility approved", Bioenergy Insight, 6 November 2019, <https://www.bioenergy-news.com/news/plans-for-150m-uk-bio-resources-to-fuel-facility-approved>.
- 212 Global CCS Institute, *2019 Perspective: Bioenergy and Carbon Capture and Storage* (Melbourne: 2019), https://www.globalccsinstitute.com/wp-content/uploads/2019/03/BECCS-Perspective_FINAL_18-March.pdf; S. Budinis, "Going carbon negative – what are the technology options?" IEA, 20 January 2020, <https://www.iea.org/commentaries/going-carbon-negative-what-are-the-technology-options>.
- 213 IEA, op. cit. note 2.
- 214 Global CCS Institute, op. cit. note 212.
- 215 Ibid.
- 216 The project will benefit from a tax credit worth USD 20 per tonne of CO₂ stored, and has received USD 140 million in capital support from the US Department of Energy, from US Department of Energy, "DOE announces major milestone reached for Illinois industrial CCS project", 7 April 2017, <https://energy.gov/fe/articles/doe-announces-major-milestone-reached-illinois-industrial-ccs-project>. The other projects in the United States and Canada involve capturing CO₂ for enhanced oil recovery, including Kansas Arkalon (US), Bonanza CCS (US), Husky Energy CO₂ Injection (Canada) and Farnsworth (US). See Global CCS Institute, op. cit. note 212.
- 217 "Drax great biomass carbon capture experiment", Bioenergy Insight, 24 June 2019, <https://www.bioenergy-news.com/news/drax-great-biomass-carbon-capture-experiment>.
- 218 Midland Paper, "CO₂ Solutions begins commissioning of its carbon capture unit at the Resolute Pulp Mill in Saint-Félicien, Quebec", 20 March 2019, <https://www.midlandpaper.com/co2-solutions-begins-commissioning-of-its-carbon-capture-unit-at-the-resolute-pulp-mill-in-saint-felicien-quebec>.

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- 1 Estimates based on the following sources: power capacity data for Iceland, Japan and New Zealand from International Energy Agency (IEA) *Geothermal, 2019 Country Reports* (Taupo, New Zealand: February 2020), <http://iea-gia.org/publications-2/annual-reports>; power capacity data for Indonesia, the Philippines, Turkey and the United States from sources noted elsewhere in this section; capacity data for other countries from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2020* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_RE_Capacity_Statistics_2020.pdf; additional capacity data by country from Renewable Energy Network for the 21st Century (REN21), *Renewables 2019 Global Status Report* (Paris: 2019), http://www.ren21.net/gsr_2019_full_report_en; estimated electricity generation in 2019 of 95 TWh from G. W. Huttner, "Geothermal power generation in the world 2015-2020 update report", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01017.pdf>; and 93.6 TWh from Organisation for Economic Co-operation and Development (OECD) and IEA, *Market Report Series - Renewables 2019, Databook* (Paris: 2019). Heat capacity and output from J. W. Lund and A. N. Toth, "Direct utilization of geothermal energy 2020 worldwide review", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01018.pdf>.
- 2 End-2018 capacity data and capacity additions in 2019 from sources in endnote 1.
- 3 Capacity additions in 2019 by country from sources noted elsewhere in this section.
- 4 Ibid. **Figure 24** based on end-2018 capacity data and capacity additions in 2019 from sources in endnote 1 and sources noted elsewhere in this section. For the purpose of this figure, end-2018 capacity is assumed to be equal to end-2019 capacity less new capacity installed (or capacity expansion) during 2019.
- 5 End-2018 capacity data from sources in endnote 1; capacity additions in 2019, by country, from sources noted elsewhere in this section. **Figure 25** from idem.
- 6 Net summer capacity from US Energy Information Administration (EIA), *Electric Power Monthly*, February 2020, Table 6.2.B, <https://www.eia.gov/electricity/monthly>; nameplate capacity from US EIA, "Form EIA-860M (Preliminary Monthly Electric Generator Inventory)", December 2019, <https://www.eia.gov/electricity/data/eia860m>; US Department of Energy (DOE), Office of Scientific and Technical Information (OSTI), "GeoVision: Harnessing the heat beneath our feet" (Oak Ridge, TN: June 2019), p. 24 (footnote 34), <https://www.energy.gov/eere/geothermal/downloads/geovision-harnessing-heat-beneath-our-feet>.
- 7 See REN21, *Renewables Global Status Report* (Paris: 2017-2019 editions), <https://www.ren21.net/reports/global-status-report/>.
- 8 Capacity of 1,514.7 MW and 54 plants at end-2019, and 48 plants and 1,282.5 MW at end-2018, from Turkish Electricity Transmission Company (TEİAŞ), <http://www.teias.gov.tr>, viewed March 2020; for earlier additions, see REN21, op. cit. note 1.
- 9 A. Richter, "Celikler Holding has brought the 32 MW unit 6 addition to its Pamukören geothermal power plant complex in Turkey", ThinkGeoEnergy, 10 June 2019, <https://www.thinkgeoenergy.com/new-32-mw-pamukoren-unit-6-geothermal-plant-brought-online-in-turkey>.
- 10 MASPO, "Maspo Enerji Ala-2 JES Üretime Başladı", 5 October 2019, <http://www.maspoenerji.com/?Syf=26&Syz=687323&/Maspo-Enerji-Ala-2-JES-%C3%9Cretime-Ba%C5%9Fad%C4%B1>; "Maspo'nun 2'inci Faz Jeotermal Yatırımı 'ALA-2' Elektrik Satışına Başladı!" Enerji Gazetesi, 7 October 2019, <https://www.enerjigazetesi.ist/2inci-faz-jeotermal-enerji-yatirimi-ala-2-elektrik-satisina-basladi>.
- 11 Capacity of 1,514.7 MW and 54 plants at end-2019, and 48 plants and 1,282.5 MW at end-2018, from TEİAŞ, op. cit. note 8.
- 12 See REN21, op. cit. note 7; E. B. Erşen, "Turkey's renewable energy sector to continue enjoying European financier EBRD support", Daily Sabah, 26 February 2020, <https://www.dailysabah.com/business/energy/turkeys-renewable-energy-sector-to-continue-enjoying-european-financier-ebrd-support>.
- 13 "Milyar Dolarlık Jeotermal Yatırımı YEKDEM'i Bekliyor", Enerji Gazetesi, 20 June 2019, <https://www.enerjigazetesi.ist/milyar-dolarlik-jeotermal-yatirimi-yekdemi-bekliyor>; A. Richter, "IGC Turkey highlights optimism for geothermal energy", World Energy, 13 November 2019, <https://www.world-energy.org/article/3842.html>; E. Şengül, "Turkey to boost geothermal using support mechanisms", Anadolu Agency, 12 November 2019, <https://www.aa.com.tr/en/energy/investments/turkey-to-boost-geothermal-using-support-mechanisms/27343>.
- 14 "Milyar Dolarlık Jeotermal Yatırımı YEKDEM'i Bekliyor", op. cit. note 13.
- 15 "Jeotermalde Kurulu Güç Geçen Yıl Sonu İtibarıyla 1,525 MW'a Ulaştı!" Enerji Gazetesi, 16 February 2020, <https://www.enerjigazetesi.ist/jeotermalde-kurulu-guc-gecen-yil-sonu- itibariyla-1525-mwa-ulasti>.
- 16 H. Bintepe, "The local fightback against geothermal power", Inside Turkey, 16 January 2020, <https://insideturkey.news/2020/01/16/the-local-fightback-against-geothermal-power>; E. Yılmaz and M. A. Kaptan, "Environmental impact of geothermal power plants in Aydın, Turkey", *E3S Web of Conferences*, vol. 19, no. 2027 (October 2017), <https://doi.org/10.1051/e3sconf/20171902028>; T. O. Balaban, A. Bülbül and G. Tarcan, "Review of water and soil contamination in and around Salihli geothermal field (Manisa, Turkey)", *Arabian Journal of Geosciences*, vol. 10, no. 523 (2017), <https://doi.org/10.1007/s12517-017-3299-z>; S. Derya, "Jeotermalin etkileri uluslararası raporlarla aydınlanacak", Jesder, 7 July 2019, <https://jesder.org/jeotermalin-etkileri-uluslararası-raporlarla-aydinlanacak>.
- 17 "Türkiye'de Jeotermal Enerji Alanında Rekor Büyüme ve Sorunlar", Enerji Gazetesi, 21 September 2019, <https://www.enerjigazetesi.ist/turkiye-de-jeotermal-enerji-alaninda-rekor-buyume-ve-sorunlar>.
- 18 S. Akin, Y. Orucu and T. Fridriksson, "Characterizing the declining CO₂ emissions from Turkish geothermal power plant", *Proceedings of the 45th Workshop on Geothermal Reservoir Engineering*, Stanford University, Palo Alto, CA, 10-12 February 2020, <https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2020/Akin.pdf>.
- 19 Ibid.
- 20 Capacity at year-end 2018 and 2019 from Indonesian Ministry of Energy and Mineral Resources (ESDM), "Bahan Kementerian ESDM: Capaian kinerja 2019 dan program 2020" (Jakarta: 9 January 2020), <https://drive.esdm.go.id/wl/?id=65ffAEWB5lyElkXdfUxhtJaJrSWecPc0>.
- 21 ESDM, "PLTP Lumut Balai Unit 1 Ditargetkan COD Agustus 2019", 2 July 2019, <https://www.esdm.go.id/id/berita-unit/direktorat-jenderal-ebtke/pltp-lumut-balai-unit-1-ditargetkan-cod-agustus-2019>; ESDM, "Tahun 2019, Kapasitas Pembangkit Listrik EBT Capai 10 Ribu MW", 9 January 2020, <https://www.esdm.go.id/id/berita-unit/direktorat-jenderal-ebtke/tahun-2019-kapasitas-pembangkit-listrik-ebt-capai-10-ribu-mw>; ESDM, "Upaya Gigih Pengembangan Panas Bumi, PLTP Muara Laboh Kini Beroperasi", 19 February 2020, <https://www.esdm.go.id/id/berita-unit/direktorat-jenderal-ebtke/upaya-gigih-pengembangan-panas-bumi-pltp-muara-laboh-kini-beroperasi>.
- 22 ESDM, "PLTP Sorik Marapi, Proyek Panas Bumi Berdurasi Tercepat", 14 February 2020, <https://www.esdm.go.id/id/berita-unit/direktorat-jenderal-ebtke/pltp-sorik-marapi-proyek-panas-bumi-berdurasi-tercepat>.
- 23 World Bank, "Indonesia: Scaling up geothermal energy by reducing exploration risks", press release (Washington, DC: 26 September 2019), <https://www.worldbank.org/en/news/press-release/2019/09/26/indonesia-scaling-up-geothermal-energy-by-reducing-exploration-risks>.
- 24 V. N. Setiawan, "Tahun ini pemerintah Kerjakan pengeboran di tiga wilayah panas bumi", Katadata, 25 September 2019, <https://katadata.co.id/berita/2019/09/25/tahun-ini-pemerintah-kerjakan-pengeboran-di-tiga-wilayah-panas-bumi>; "Ministry of Finance encourages geothermal energy exploration", Antara News, 18 September 2019, <https://en.antaranews.com/news/133032/ministry-of-finance-encourages-geothermal-energy-exploration>.
- 25 World Bank, op. cit. note 23.
- 26 ESDM, *Handbook of Energy & Economic Statistics of Indonesia* (Jakarta: January 2019), <https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2018-final-edition.pdf>.
- 27 National Energy Council, *Indonesia Energy Outlook 2019* (Jakarta: 2019), p. 49, <https://www.esdm.go.id/assets/media/content/content-indonesia-energy-outlook-2019-english-version.pdf>.
- 28 Japan Oil, Gas and Metals National Corporation (JOGMEC),

- "Start of full-scale operation of Matsuo Hachimantai Geothermal Power Station", press release (Tokyo: 29 January 2019), http://www.jogmec.go.jp/news/release/news_10_000302.html (using Google Translate).
- 29 Ibid.; JOGMEC, "Large-scale geothermal power plant starts operation for the first time in 23 years", press release (Tokyo: 20 May 2019), http://www.jogmec.go.jp/news/release/news_03_000027.html (using Google Translate).
- 30 JOGMEC, op. cit. note 29; Toshiba, "Wasabizawa Geothermal Power Plant for which Toshiba Energy Systems & Solutions constructed power generation system goes into operation", press release (Kawasaki, Kanagawa: 20 May 2019), https://www.toshiba-energy.com/en/info/info2019_0520.htm.
- 31 JOGMEC, "About the adoption result of 'Research on resource amount of geothermal power generation project cost subsidy project'", press release (Tokyo: 25 December 2019), http://www.jogmec.go.jp/news/release/news_15_000001_00022.html (using Google Translate).
- 32 K. Yasukawa, 2019 *Japan Country Report* (Taupo, New Zealand: IEA Geothermal, February 2020), pp. 3-7, <http://iea-gia.org/about-us/members/japan>. Based on 279 MW of running capacity in 2018 and the addition of 54 MW of newly installed capacity in 2019.
- 33 Ibid., p. 4. Based on 279 MW of running capacity in 2018 and the addition of 54 MW of newly installed capacity in 2019.
- 34 Ibid.
- 35 A. D. Fronda et al., "Geothermal energy development: The Philippines country update", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org>.
- 36 J. L. Mayuga, "Lack of incentives crimps investments in geothermal", *Business Mirror*, 2 March 2020, <https://businessmirror.com.ph/2020/03/02/lack-of-incentives-crimps-investments-in-geothermal>.
- 37 A. Nortajuddin, "Revamping geothermal in the Philippines", *The ASEAN Post*, 13 March 2020, <https://theaseanpost.com/article/revamping-geothermal-philippines>.
- 38 Mayuga, op. cit. note 36.
- 39 IRENA, op. cit. note 1.
- 40 Steam Group, "Olkaria V – Unit 1 – Commissioned!" 29 July 2019, <https://www.steam-group.net/en/news-view.php?idnews=23>; Steam Group, "Olkaria V – Unit 1 and 2 – full load 160 MW", 26 September 2019, <https://www.steam-group.net/en/news-view.php?idnews=24>.
- 41 Geothermal Development Company (GDC), "GDC at the African Development Bank partial risk guarantee initializing ceremony", 17 December 2019, <http://www.gdc.co.ke/blog/gdc-at-the-african-development-bank-partial-risk-guarantee-initializing-ceremony>; A. Richter, "Construction on first 35 MW geothermal plant in Menengai to kick off in December 2019", *ThinkGeoEnergy*, 11 October 2019, <https://www.thinkgeoenergy.com/construction-on-first-35-mw-geothermal-plant-in-menengai-to-kick-off-in-december-2019>.
- 42 GDC, op. cit. note 41; Richter, op. cit. note 41.
- 43 GDC, "Baringo-Silali Project", <http://www.gdc.co.ke/baringo.php>, viewed April 2020; "GDC granted USD 18.6m for Baringo-Silali geothermal project", *Construction Review*, 10 December 2019, <https://constructionreviewonline.com/2019/12/gdc-granted-18-6m-for-baringo-silali-geothermal-project>; C. Muchira, "Geothermal strikes steam in Paka well", *Kenya Broadcasting Corporation*, 16 September 2019, <https://www.kbc.co.ke/gdc-steam-paka-well>; Geothermal Risk Mitigation Facility for Eastern Africa, <https://grmf-eastafrika.org>, viewed April 2020.
- 44 Presidencia de la República de Costa Rica, "Las Pailas II gana premio como mayor proyecto geotérmico de América Latina y el Caribe", press release (San José, Costa Rica: 17 July 2019), <https://www.presidencia.go.cr/comunicados/2019/07/las-pailas-ii-gana-premio-como-mejor-proyecto-geotermico-de-america-latina-y-el-caribe>; J. F. L. Salas, "ICE entrega planta geotérmica Pailas II con meses de atraso y sobrecosto de \$41 millones", *La Nación*, 23 July 2019, <https://www.nacion.com/el-pais/infraestructura/ice-entrega-planta-geotermica-pailas-ii-con-meses/APWJAGLX4FCDZAV5NKL3N5I5Y/story>.
- 45 Salas, op. cit. note 44.
- 46 Grupo ICE, "ICE adelanta integración de Las Pailas II al Sistema Eléctrico Nacional", 19 March 2019, <https://www.grupoice.com/wps/portal/ICE/acercadelgrupoice/sala-de-prensa/comunicados-oficiales/de850d3a-06c5-405f-9ea5-af49e6b9314e>.
- 47 Salas, op. cit. note 44.
- 48 Federal Energy Commission (CFE), "Inauguran el preidente Andrés Manuel López Obrador y el director general de la CFE Manuel Bartlett Díaz, la unidad 10 de la central geotermoeléctrica 'Los Azufres'", press release (Mexico City: 21 December 2019), <https://www.cfe.mx/salaprensa/Paginas/salaprensadetalle.aspx?iid=585&ilib=5>.
- 49 CFE, "Convocatoria: Concurso Abierto No. CFE-0036-CACON-0003-2019", 16 April 2019, http://dof.gob.mx/nota_detalle_popup.php?codigo=5557997.
- 50 A. Richter, "The sad state of affairs for geothermal energy development in Mexico", *ThinkGeoEnergy*, 2 September 2019, <https://www.thinkgeoenergy.com/the-sad-state-of-affairs-for-geothermal-energy-development-in-mexico>.
- 51 "Opera la geotérmica al 50% de capacidad", *La Voz*, 17 June 2019, <https://www.lavozdelafrontera.com.mx/local/opera-la-geotermica-al-50-de-capacidad-3775189.html>; historical account of declining enthalpy from R. M. Cárdenas and M. H. Rodríguez Rodríguez, "Cambios en la producción de vapor debido alas condiciones del yacimiento en Cerro Prieto, BC", *Geotermia*, vol. 24, no. 2 (2011), <https://biblat.unam.mx/hevila/Geotermia/2011/vol24/no2/1.pdf>; Richter, op. cit. note 50; installed capacity from IRENA, op. cit. note 1.
- 52 Enel Green Power, "EGP starts construction of 33 MW expansion of Cerro Pabellón geothermal plant", 30 August 2019, <https://www.enelgreenpower.com/media/news/d/2019/08/cerro-pabellon-expansion-geothermal-power-plant>.
- 53 Ibid.
- 54 Ibid.
- 55 Net generating capacity from US EIA, *Electric Power Monthly*, op. cit. note 6, Table 6.2.B; nameplate capacity from US EIA, "Preliminary monthly electric generator inventory", December 2018, <https://www.eia.gov/electricity/data/eia860M>.
- 56 Generation from US EIA, *Electric Power Monthly*, op. cit. note 6, Tables ES1.B, 1.1 and 1.1.A.
- 57 "Croatia's first geothermal power plant Velika 1 officially unveiled", *Balkan Green Energy News*, 19 November 2019, <https://balkangreenenergynews.com/croatias-first-geothermal-power-plant-velika-1-officially-unveiled>.
- 58 Turboden, "Turboden completed the commissioning of the 17.5 MWe Velika Ciglena Geothermal Plant", press release (Brescia, Italy: 11 December 2018), https://www.turboden.com/upload/blocchi/X12219allegato1-2X_5269_Turboden_Velika_Ciglena_ENG.pdf; first geothermal plant based on IRENA, *Renewable Energy Statistics 2018* (Abu Dhabi: March 2018), <http://irena.org/publications/2018/Mar/Renewable-Capacity-Statistics-2018>.
- 59 I. Ilic, "Croatia seeks to triple renewable energy output", *Reuters*, 11 April 2019, <https://www.reuters.com/article/croatia-energy/croatia-seeks-to-triple-renewable-energy-output-idUSL8N21T37L>; I. Ilic, "Croatia eyes more gas and oil production, use of geothermal sources", *Reuters*, 26 March 2019, <https://af.reuters.com/article/commoditiesNews/idAFL8N21D4AZ>.
- 60 I. Pavlova, "Turkey's MB Holding unit to build second geothermal power plant in Croatia – report", *SeeNews*, 6 September 2019, <https://seenews.com/news/turkeys-mb-holding-unit-to-build-second-geothermal-power-plant-in-croatia-report-668110>.
- 61 Gemeindewerke Holzkirchen, "Aktuelles vom Kraftwerk", <https://www.gw-holzkirchen.de/de/Geothermie/Presseberichte-und-Aktuelles>, viewed April 2020; Erdwerk GmbH, "Official commissioning of Holzkirchen geothermal plant", press release (Munich: 19 November 2019), <https://www.erdwerk.com/en/official-commissioning-holzkirchen-geothermal-plant>; Turboden, "Holzkirchen", <https://www.turboden.com/case-histories/1986/holzkirchen>, viewed April 2020.
- 62 Gemeindewerke Holzkirchen, op. cit. note 61; Turboden, op. cit. note 61.
- 63 Calculation based on Lund and Toth, op. cit. note 1. Growth of 2.2 GW in 2019 based on five-year compound annual growth rate of 7.8% from 2014 through 2019 (total capacity having grown from 20,627 MW in 2014 to 30,080 MW in 2019).
- 64 Calculation based on Lund and Toth, op. cit. note 1. Growth of 10 TWh in 2019 based on five-year compound annual growth rate of 9.6% from 2014 through 2019 (total output having grown from 265,790 TJ in 2014 to 420,906 TJ in 2019).
- 65 Calculation based on Lund and Toth, op. cit. note 1.

- 66 Ibid.
- 67 Ibid.
- 68 T. Tian et al., "Rapid development of China's geothermal industry – China National Report of the 2020 World Geothermal Conference", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org>.
- 69 Calculation based on Lund and Toth, op. cit. note 1.
- 70 Ibid.
- 71 O. Mertoglu et al., "Geothermal energy use: Projections and country update for Turkey", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org>.
- 72 A. Ragnarsson et al., "Geothermal development in Iceland 2015-2019", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org>.
- 73 K. Yasukawa et al., "Country update of Japan", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org>.
- 74 T. Garabetian, "Decarbonising cities with geothermal district heating: How to finance it?" (Brussels: 17 December 2019), <https://www.georisk-project.eu/decarbonising-cities-with-geothermal-district-heating-how-to-finance-it>.
- 75 Stadtwerke München, "Finale Pumpversuche nach Bohr-Ende", press release (Munich: 12 March 2020), <https://www.swm.de/dam/swm/pressemitteilungen/2020/03/energie20200312-geo-pumpversuche.pdf>.
- 76 Ibid.; Stadtwerke München, "Pumpversuche an vierter Bohrung", press release (Munich: 18 June 2019), <https://www.swm.de/dam/swm/pressemitteilungen/2019/06/swm20190618-vierte-geothermie-bohrung-hkw-sued-pumpversuche.pdf>.
- 77 Stadtwerke München, op. cit. note 75.
- 78 Stadtwerke München and Erdwärme Grünwald, "München und Grünwald kooperieren bei der Geothermie", press release (Munich: 7 November 2019), <https://www.swm.de/dam/swm/pressemitteilungen/2019/11/swm20191107swm-ewg.pdf>; Informationsportal Tiefe Geothermie, "Festakt zu 15 Jahre Geothermie in Pullach: Neues Projekt angekündigt", 22 November 2019, <https://www.tiefengeothermie.de/news/festakt-zu-15-jahre-geothermie-in-pullach-neues-projekt-angekuendigt>.
- 79 ENGIE, "The geothermal heating network in Champs-sur-Marne launches", 30 October 2019, <https://www.engie-solutions.com/en/news/geothermal-site-geomarne>.
- 80 Ibid.; GéoMarne, "Le réseau de chaleur GéoMarne, le futur réseau géothermique", 2 December 2019, <http://geomarne.reseau-chaaleur.com/le-reseau-de-chaaleur-geomarne-le-futur-reseau-geothermique>; Lumo SAS, "Géothermie de Champs-sur-Marne et Noisiel", <https://www.lumo-france.com/projets/geothermie-de-la-marne>, viewed March 2020.
- 81 La Ville de Drancy, "La géothermie à Drancy", <https://www.drancy.fr/la-ville-s-engage-pour-lenvironnement/energies-renouvelables-drancy-s-engage-pour-un-avenir-vertueux-et-durable/la-geothermie-a-drancy-525.html>, viewed March 2020; Sipperec, "Gényo: Un futur réseau de chaleur écologique pour Bobigny-Drancy", <https://sipperec.fr/developper/produire-localement-les-energies-de-demain/geothermie/genyo-un-futur-reseau-de-chaaleur-ecologique-pour-bobigny-drancy>, viewed March 2020.
- 82 "L'Alsace touchée par la fin des aides à la production d'électricité issue de la géothermie profonde", France 3, 7 March 2019, <https://france3-regions.francetvinfo.fr/grand-est/alsace/alsace-touchee-fin-aides-production-electricite-issu-geothermie-profonde-1634642.html>; "Géothermie en profondeur: Premiers résultats encourageants pour l'Eurométropole de Strasbourg", France 3, 18 April 2018, <https://france3-regions.francetvinfo.fr/grand-est/geothermie-profondeur-premiers-resultats-encourageants-eurometropole-strasbourg-1461229.html>.
- 83 "L'Alsace touchée par la fin des aides à la production d'électricité issue de la géothermie profonde", op. cit. note 82; G. Jolain, "Géothermie profonde: Des projets de centrales en suspens", L'Alsace, 22 January 2020, <https://www.lalsace.fr/economie/2020/01/22/geothermie-profonde-des-projets-de-centrales-en-suspens>.
- 84 "L'Alsace touchée par la fin des aides à la production d'électricité issue de la géothermie profonde", op. cit. note 83; "Un tremblement de terre de magnitude 3,3 ressenti à Strasbourg: La géothermie profonde est-elle responsable?" France 3, 12 November 2019, <https://france3-regions.francetvinfo.fr/grand-est/bas-rhin/strasbourg-0/strasbourg-tremblement-terre-magnitude-33-ressenti-centre-ville-cause-forage-geothermie-1748315.html>; "Séisme à Strasbourg: La géothermie n'est pas en cause, insiste Fonroche", La Croix, 13 November 2019, <https://www.la-croix.com/France/Seisme-Strasbourg-geothermie-pas-cause-insiste-Fonroche-2019-11-13-1301060210>; "Strasbourg: Le site de géothermie de Vendenheim-Reichstett doit suspendre ses essais", L'Alsace, 14 November 2019, <https://www.lalsace.fr/actualite/2019/11/14/strasbourg-une-nouvelle-secousse-mercredi-soir>; Fonroche, "Communiqué", press release (Pau, France: 15 November 2019), <https://www.fonroche-geothermie.com/copie-de-actualite-1>; Jolain, op. cit. note 83.
- 85 G. Bakema et al., "Netherlands country update", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org>.
- 86 Ibid.
- 87 Dutch Association of Geothermal Operators, "Forse stijging gebruik aardwarmte in de glastuinbouw", 16 March 2020, <https://www.dago.nu/forse-stijging-gebruik-aardwarmte-in-de-glastuinbouw>; Bakema et al., op. cit. note 85.
- 88 A. N. Toth, "Country update for Hungary", *Proceedings World Geothermal Congress 2020*, forthcoming, <https://www.geothermal-energy.org>; A. Richter, "Ambitious large scale geothermal district heating project kicking off in Szeged, Hungary", 6 September 2019, <https://www.thinkgeoenergy.com/ambitious-large-scale-geothermal-district-heating-project-kicking-off-in-szeged-hungary>.
- 89 Toth, op. cit. note 88.
- 90 J. Haffner, EPFL, "Reducing human-induced earthquake risk", 6 January 2020, <https://actu.epfl.ch/news/reducing-human-induced-earthquake-risk>.
- 91 Ibid.
- 92 S. Bentz et al., "Seismic moment evolution during hydraulic stimulations", *Geophysical Research Letters*, vol. 47, no. 5 (25 February 2020), <https://doi.org/10.1029/2019GL086185>.
- 93 US DOE, "DOE releases new study highlighting the untapped potential of geothermal energy in the United States", 30 May 2019, <https://www.energy.gov/articles/doe-releases-new-study-highlighting-untapped-potential-geothermal-energy-united-states>; US DOE, OSTI, op. cit. note 6.
- 94 US DOE, OSTI, op. cit. note 6, pp. 67-68.
- 95 US DOE, Office of Energy Efficiency & Renewable Energy (OEERE), "Energy Department announces \$18.8 million for hydrothermal and low temperature geothermal research", 4 February 2020, <https://www.energy.gov/eere/articles/energy-department-announces-188-million-hydrothermal-and-low-temperature-geothermal>.
- 96 US DOE, OEERE, "Energy Department awards \$5.5 million to apply machine learning to geothermal exploration", 3 May 2019, <https://www.energy.gov/eere/articles/energy-department-awards-55-million-apply-machine-learning-geothermal-exploration>; US DOE, OEERE, op. cit. note 95.
- 97 Eavor Technologies Inc., "The world's first truly scalable form of green baseload power demonstrated by Eavor Technologies Inc.", 5 February 2020, <https://eavor.com/press/#press16>; Natural Resources Canada, "Eavor-Loop demonstration project", <https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/eavor-loop-demonstration-project/21896>, viewed March 2020.
- 98 Eavor Technologies Inc., "Technology", <https://eavor.com/technology>, viewed March 2020.
- 99 "Top 20 geothermal power companies 2019", PR Newswire, 4 June 2019, <https://markets.businessinsider.com/news/stocks/top-20-geothermal-power-companies-2019-1028250552>.
- 100 T. Garabetian, European Geothermal Energy Council (EGEC), "EGEC geothermal market report 2018", presentation, 7 February 2019, https://www.egec.org/wp-content/uploads/media_publication/2-EGEC_Presentation-market-2018-TGA.pdf; P. Dumas, EGEC, "Geothermal energy in Europe – overview, market, business model", presentation at Norwegian Center for Geothermal Energy Research, 4 February 2019, http://cger.no/doc/pdf/presentations%20GeoEnergi2019/4%20februar/05-EGEC_Presentation%20market%202018-Philippe%20Dumas.pdf.

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- 1 Global capacity based on International Hydropower Association (IHA), *Hydropower Status Report* (London: 2020), https://www.hydropower.org/sites/default/files/publications-docs/2020_hydropower_status_report_-_28_may_2020.pdf, and on IHA, personal communications with Renewable Energy Policy Network for the 21st Century (REN21), April 2020. At end-2019, total installed capacity was 1,308 GW, less 158 GW of pumped storage. See IHA, *2020 Hydropower Status Report* (London: 2020), https://www.hydropower.org/sites/default/files/publications-docs/2020_hydropower_status_report_-_28_may_2020.pdf.
- 2 Country data from IHA, op. cit. note 1, and from the following sources: **China:** total capacity including pumped storage of 356.40 GW, capacity additions of 4.17 GW, utilisation and investment from China National Energy Administration (NEA), 2019 energy statistics, 20 January 2020, http://www.nea.gov.cn/2020-01/20/c_138720881.htm, and from China Electricity Council (CEC), 2019 electricity and other energy statistics, 21 January 2020, <http://www.cec.org.cn/guihuayutongji/tongjixinxi/niandushuju/2020-01-21/197077.html>; generation of 1,304.44 TWh and annual growth of 5.9% from National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2019 national economic and social development", press release (Beijing: 28 February 2020), http://www.stats.gov.cn/english/PressRelease/202002/t20200228_1728917.html. Total capacity including pumped storage of 356.4 GW, pumped storage capacity of 30.3 GW and hydropower capacity of 326.1 GW; capacity additions (excluding pumped storage) of 3.9 GW; and pumped storage additions of 0.3 GW from IHA, op. cit. note 1. **Brazil:** 4,950.9 MW (4,754.74 MW large-scale hydro, 184.14 MW small-scale hydro and 12 MW very small-scale hydro) added in 2019, from National Agency for Electrical Energy (ANEEL), "Acompanhamento da expansão da oferta de geração de energia elétrica", <http://www.aneel.gov.br/acompanhamento-da-expansao-da-oferta-de-geracao-de-energia-eletrica>, updated February 2020, from ANEEL, "Informações gerenciais", <http://www.aneel.gov.br/informacoes-gerenciais>, and from ANEEL, "Sistema de informações de geração da ANEEL – SIGA", <https://www.aneel.gov.br/siga>; year-end capacity of 109.03 GW from IHA, op. cit. note 1; generation of 418 TWh from National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed March 2020. **United States:** capacity from US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2019* (Washington, DC: February 2020), Tables 6.2.B and 6.3, <http://www.eia.gov/electricity/monthly>; generation from idem, Table 1.1. **Canada:** capacity and generation from IHA, op. cit. note 1. **Russian Federation:** capacity and generation from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2019* (Moscow: 31 January 2020), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2020/ups_rep2019.pdf. **India:** installed capacity in 2019 (units larger than 25 MW) of 40,614 MW (plus 4,786 MW of pumped storage) from Government of India, Ministry of Power, Central Electricity Authority (CEA), "Hydro reports", December 2019, <http://www.cea.nic.in/monthlyarchive.html>; installed small-scale (<25 MW) hydro capacity of 4,672 MW, net installed capacity expansion in 2019 of 154 MW and generation for plants larger than 25 MW (153 TWh) based on idem, "Installed capacity" and "Generation reports", viewed March 2020; output from hydro plants smaller than 25 MW (9 TWh) from idem, "Renewable energy generation report", viewed March 2020. **Norway:** generation from Statistics Norway, "Elektrisitet", <https://www.ssb.no/statbank/list/elektrisitet>, viewed March 2020; capacity from Norwegian Water Resources and Energy Directorate (NVE), "Ny kraftproduksjon", <https://www.nve.no/energiforsyning/kraftmarkedsdata-og-analyser/ny-kraftproduksjon/?ref=mainmenu>, viewed March 2020; additions of 134 MW and year-end capacity of 31.2 GW from IHA, op. cit. note 1. **Figure 26** based on capacity and generation sources provided in this note.
- 3 Estimated global hydropower generation and decrease from IHA, op. cit. note 1; share of estimated global generation from sources in endnote 210 of Global Overview chapter.
- 4 Capacity values by country from sources provided in endnote 2 and from IHA, op. cit. note 1. **Figure 27** based on idem.
- 5 REN21, *Renewables Global Status Report* (Paris: various years), <https://www.ren21.net/reports/global-status-report>.
- 6 IHA, op. cit. note 1, and sources on individual pumped storage projects noted elsewhere in this section.
- 7 ANEEL, op. cit. note 2, all references, and IHA, op. cit. note 1.
- 8 Norte Energia, "A história de Belo Monte – cronologia", <https://www.norteenergiasa.com.br/pt-br/uhe-belo-monte/historico>; Norte Energia, "Belo Monte é inaugurada e está pronta para a plena operação", press release (Brasília: 29 November 2019), <https://www.norteenergiasa.com.br/pt-br/imprensa/releases/belo-monte-e-inaugurada-e-esta-pronta-para-a-plena-operacao-100709>.
- 9 Ibid., both references; Norte Energia, "Unidade Geradora 15 liberada para operação commercial", press release (Brasília: 21 August 2019), <https://www.norteenergiasa.com.br/pt-br/imprensa/releases/unidade-geradora-15-liberada-para-operacao-comercial-100654>.
- 10 Generation from ONS, op. cit. note 2.
- 11 T. Barral, Empresa de Pesquisa Energética, Ministério de Minas e Energia, "What's next for hydropower? Perspectives for Brazilian market", presentation at IEA Hydropower Workshop, Paris, 10 February 2020.
- 12 Ibid.
- 13 Generation from ONS, op. cit. note 2.
- 14 Comisión Nacional de Energía, "Electricity statistics", <https://www.cne.cl/estadisticas/electricidad>, viewed March 2020.
- 15 Ibid.
- 16 Ibid.
- 17 Peruvian Electric System Operator (Comité de Operación Económica del Sistema), power plant database, <http://www.coes.org.pe/Portal/Planificacion/NuevosProyectos/OperacionComercial>, viewed March 2020; Andritz, "Bring back to life", *Hydro News*, no. 32 (2018), <https://www.andritz.com/hydro-en/hydronews/hn32/callahuanca-peru>.
- 18 Peruvian Electric System Operator, op. cit. note 17; Andritz, op. cit. note 17.
- 19 Peruvian Electric System Operator (Comité de Operación Económica del Sistema), "Monthly Generation Bulletin", December 2019, <http://www.coes.org.pe/Portal/Publicaciones/Boletines>.
- 20 National Electricity Company of Bolivia (ENDE), "Presidente Morales inauguró San José 2 sumando 69 MW al SIN", press release (Cochabamba: 9 June 2019), <https://www.ende.bo/noticia/noticia/165>.
- 21 ENDE, "Informe de situación de ENDE Corporación", January 2020, https://www.ende.bo/public/publicaciones/pdf/inf_situacion_enero_2020.pdf.
- 22 Ibid.
- 23 Capacity from Comité Nacional de Despacho de Carga (CNDC), "Effective capacity as of December 2019", <https://www.cndc.bo/agentes/generacion.php>; generation from CNDC, "Gross generation", https://www.cndc.bo/media/archivos/estadistica_anual/genbruta_2019.htm.
- 24 Total capacity including pumped storage of 356.4 GW, pumped storage capacity of 30.3 GW and hydropower capacity of 326.1 GW; capacity additions (excluding pumped storage) of 3.8 GW; and pumped storage additions of 0.3 GW from IHA, op. cit. note 1. Total capacity including pumped storage capacity of 356.4 GW, capacity additions of 4.17 GW and annual capacity growth of 1.1% from NEA, op. cit. note 2, and from CEC, op. cit. note 2.
- 25 NEA, op. cit. note 2, and CEC, op. cit. note 2.
- 26 Generation of 1,301.9 TWh and annual growth of 5.7% from CEC, op. cit. note 2.
- 27 Based on total electricity output in 2014 of 5,605 TWh, hydropower generation of 1,047 TWh and hydropower capacity in 2014 (excluding pumped storage) of 282.7 GW, from CEC, 2014 electricity statistics, 30 November 2015, <http://www.cec.org.cn/guihuayutongji/tongjixinxi/niandushuju/2015-11-30/146012.html>; total electricity output in 2019 of 7,325 TWh and hydropower generation of 1,302 TWh from CEC, op. cit. note 2.
- 28 Based on total electricity output in 2014 of 5,605 TWh and hydropower generation of 1,060 TWh (including pumped storage output for proper comparison; 1,047 TWh without pumped storage output), from CEC, op. cit. note 27; total electricity output in 2019 of 7,325 TWh and hydropower generation of 1,302 TWh (includes pumped storage output) from CEC, op. cit. note 2.

- 29 An Fengquan, "Drivers, status, challenges, and future of hydropower development in China", presentation at IEA Hydropower Workshop, Paris, 10 February 2020.
- 30 Ibid.; CEC, "China's hydropower development and construction shift to the west", 16 January 2020, <http://www.cec.org.cn/xinwenpingxi/2020-01-16/196961.html> (using Google Translate).
- 31 Fengquan, op. cit. note 29.
- 32 IHA, op. cit. note 1.
- 33 Xayaburi Hydroelectric Power Project, www.xayaburi.com, viewed March 2020.
- 34 T. Kang, "Don Sahong hydropower project comes online", *Laotian Times*, 18 November 2019, <https://laotiantimes.com/2019/11/18/don-sahong-hydropower-project-comes-online>; Nam Ngiep 1 Power Company, "Nam Ngiep 1 Project starts generation of electricity export to Thailand", 11 September 2019, <https://namngiepl.com/namngiep-1-project-starts-generation-of-electricity-export-to-thailand>; Kansai Electric Power, "Nam Ngiep 1 Hydropower Project in Laos", <https://www.kepcoco.jp/english/corporate/info/international/generate/laos.html>, viewed March 2020.
- 35 Nam Ngiep 1 Power Company, op. cit. note 34; Kansai Electric Power, op. cit. note 34.
- 36 P. Wongcha-um, "New Mekong dam in Laos opens to protests, dried-out downstream", *Reuters*, 29 October 2019, <https://www.reuters.com/article/us-mekong-river/new-mekong-dam-in-laos-opens-to-protests-dried-out-downstream-idUSKBN1X80VZ>.
- 37 Xayaburi Hydroelectric Power Project, op. cit. note 33; S. Cleary, "Xayaburi Dam dispels rumors of role in dry Mekong River", *Laotian Times*, 20 February 2020, <https://laotiantimes.com/2020/02/20/xayaburi-dam-dispels-rumors-of-role-in-dry-mekong-river>.
- 38 "Pilot programme to monitor impacts from Xayaburi, Don Sahong takes off", Lao News Agency, 26 February 2020, <http://kpl.gov.la/En/Detail.aspx?id=50822>.
- 39 Vietnam Electricity, "Operation of the power system in October 2019 and the tasks for the whole year 2019", press release (Hanoi City: 23 October 2019), <https://en.evn.com.vn/d6/news/Operation-of-the-power-system-in-October-2019-and-the-tasks-for-the-whole-year-2019-66-142-1658.aspx>; Vietnam Electricity, "Operating hydroelectric reservoirs to ensure multi-objective optimization", press release (Hanoi City: 14 January 2020), <https://en.evn.com.vn/d6/news/Operating-hydroelectric-reservoirs-to-ensure-multi-objective-optimization-66-142-1759.aspx>.
- 40 Vietnam Electricity, "Operating hydroelectric reservoirs to ensure multi-objective optimization", op. cit. note 39.
- 41 Vietnam Electricity, "EVN and Phongsbthavy Group (Laos) signs power purchase agreement", 28 June 2019, <https://en.evn.com.vn/d6/news/EVN-and-Phongsbthavy-Group-Laos-signs-Power-Purchase-Agreement-66-163-1557.aspx>.
- 42 IHA, op. cit. note 1.
- 43 Ibid.
- 44 Ibid.
- 45 Bharat Heavy Electricals Limited (BHEL), "Hon'ble Prime Minister of India inaugurates 4x180 MW Mangdechhu HEP, Bhutan, commissioned by BHEL", press release (New Delhi: 21 August 2019), http://www.bhel.com/assets/downloads/5d5ce31047386Hon%E2%80%99ble_Prime_Minister_of_India_inaugurates_4x180_MW_Mangdechhu_HEP_Bhutan_commissioned_by_BHEL.pdf; BHEL, "BHEL successfully commissions Chhukha Unit-1 in Bhutan; Customer commends efficient execution", press release (New Delhi: 19 June 2019), http://www.bhel.com/assets/downloads/5d09e3b14ede8BHEL_successfully_commissions_Chhukha_Unit-1_in_Bhutan_Customer_commends_efficient_execution.pdf.
- 46 "Tajikistan launches second turbine at Rogun megaproject", *Reuters*, 9 September 2019, <https://uk.reuters.com/article/tajikistan-hydro-rogun/tajikistan-launches-second-turbine-at-rogun-megaproject-idUKL5N2602OH>.
- 47 "Economy of Tajikistan following Rogun HPP construction", *Azer News*, 17 January 2019, <https://www.azernews.az/region/144141.html>; B. Aris, "Tajikistan's massive Rogun hydropower dam: A blessing or a curse?" *Eurasia*, 29 November 2019, <https://www.en.neweurasia.info/economy/1948-tajikistan-s-massive-rogun-hydropower-dam-a-blessing-or-a-curse>.
- 48 "Economy of Tajikistan following Rogun HPP construction", op. cit. note 47; Aris, op. cit. note 47.
- 49 Power Technology, "Rogun Hydropower Plant", <https://www.power-technology.com/projects/rogun-hydropower-plant>, viewed April 2020.
- 50 Energy Market Regulatory Authority of Turkey, "Elektrik Piyasası Aylık Sektör Raporu" (monthly electricity market sector report), <https://www.epdk.org.tr/Detay/Icerik/3-0-23-3/elektrikaylik-sektor-raporlar>, viewed March 2020.
- 51 Ibid.; "Turkey hits new renewable and hydro output records in 2019", Anadolu Agency, 3 January 2020, <https://www.dailysabah.com/energy/2020/01/03/turkey-hits-new-renewable-and-hydro-output-records-in-2019>.
- 52 "Erdogan says Turkey will start filling Ilisu dam in June", *Reuters*, 7 March 2019, <https://www.reuters.com/article/us-turkey-dam-erdogan-idUSKCN1Q01V5>; "Imminent danger of Turkish dam for Iran, Iraq", *Financial Tribune*, 15 November 2017, <https://financialtribune.com/articles/environment/76236/imminent-danger-of-turkish-dam-for-iran-iraq>; "Hasankeyf no more: Turkish government submerges 12,000-year-old town", *Ancient Origins*, 28 May 2019, <https://www.ancient-origins.net/news-general/destruction-hasankeyf-begins-ancient-caves-are-collapsed-explosives-008702>; "Last call for Hasankeyf as Ilisu Dam slowly engulfs it", ANF News, 16 February 2020, <https://anfenglish.com/rojava-syria/las-call-for-hasankeyf-as-ilisu-dam-slowly-engulfs-it-41656>; "They are barbaric: Turkey prepares to flood 12,000-year-old city to build dam", *The Guardian* (UK), 12 September 2019, <https://www.theguardian.com/cities/2019/sep/12/they-are-barbaric-turkey-prepares-to-flood-12000-year-old-city-to-build-dam>.
- 53 This total excludes pumped storage capacity. Installed capacity in 2019 (units larger than 25 MW) of 40,614 MW (plus 4,786 MW of pumped storage), installed small (<25 MW) hydro capacity of 4,672 MW and implied net capacity expansion in 2019 of 154 MW, from Government of India, Ministry of Power, CEA, "Hydro reports" and "Installed capacity", op. cit. note 2.
- 54 Generation for plants larger than 25 MW (152.8 TWh) from Government of India, Ministry of Power, CEA, "Generation reports", op. cit. note 2; output from hydropower plants smaller than 25 MW (9 TWh) from idem, "Renewable energy generation report".
- 55 S. Prateek, "Large hydro power projects now officially categorized under renewable energy sources", *Mercom India*, 8 March 2019, <https://mercomindia.com/large-hydro-projects-renewable-sources>; S. Dutta, "Is inclusion of large hydro power in India's renewable mix a good move?" *Mercom India*, 2 May 2019, <https://mercomindia.com/large-hydro-power-indias-renewable-mix-good>.
- 56 M. Aggarwal, "India pushes for its largest ever hydropower project despite concerns", *Mongabay*, 29 July 2019, <https://news.mongabay.com/2019/07/india-pushes-for-its-largest-ever-hydropower-project-despite-concerns>; U. Bhaskar, "Is hydropower back in play in India's energy mix?" *livemint.com*, 10 August 2019, <https://www.livemint.com/industry/energy/is-hydropower-back-in-play-in-india-s-energy-mix-1565407657407.html>.
- 57 Aggarwal, op. cit. note 56.
- 58 IHA, op. cit. note 1.
- 59 Ibid.
- 60 RusHydro, "RusHydro commissions third hydropower unit at Ust-Srednekanskaya HPP", press release (Moscow: 5 March 2019), <http://www.eng.rushydro.ru/press/news/107765.html>.
- 61 Ibid.
- 62 System Operator of the Unified Energy System of Russia, op. cit. note 2.
- 63 US EIA, op. cit. note 2, Table 6.2.B.
- 64 Ibid., Tables 6.3 and 6.4.
- 65 Ibid., Table 6.5.
- 66 Generation data from Ibid., Tables 1.1 and 1.10.B.
- 67 IHA, op. cit. note 1.
- 68 "Fifth turbine of Laúca dam enters into operation", *Angola Press News Agency*, 8 July 2019, https://www.angop.ao/angola/en_us/noticias/economia/2019/6/28/Fifth-turbine-LaUCA-dam-enters-into-operation,ete83d4d-7804-4521-a4b5-4ed548b5976c.html; Andritz, "Laúca, Angola – further milestones achieved", *Hydro News*, no. 33 (July 2019), <https://www.andritz.com/hydro-en/hydronews/hn33/lauca-angola>; Angola Ministry of Energy and

- Water, "Angola Energy 2025 – Angola power sector long term vision", June 2016, http://www.angolaenergia2025.com/sites/default/files/editor/livro_angola_energia_2025_baixa.pdf.
- 69 Andritz, op. cit. note 68.
- 70 J. M. Takouleu, "Ethiopia: CGGC to commission Genale Dawa III Dam", Afrik21, 29 September 2019, <https://www.afrik21.africa/en/ethiopia-cggc-to-commission-genale-dawa-iii-dam>; M. Teshome, "Genale Dawa III enters the national grid", Capital Ethiopia, 3 February 2020, <https://www.capitalethiopia.com/featured/genale-dawa-iii-enters-the-national-grid>; "254 MW Genale Dawa III Hydropower Plant Project", ZAWYA, 8 January 2020, <https://www.zawya.com/mena/en/project/091219025515/254-mw-genale-dawa-iii-hydropower-plant-project>.
- 71 Takouleu, op. cit. note 70; "Two Chinese-built hydro power projects in Ethiopia to be commissioned in Q2 2019", Devdiscourse, 24 April 2019, <https://www.devdiscourse.com/article/other/490683-two-chinese-built-hydro-power-projects-in-ethiopia-to-be-commissioned-in-q2-2019>.
- 72 J. Wandera, "Uganda's increased electricity generation", *The Independent*, 16 April 2019, <https://www.independent.co.ug/ugandas-increased-electricity-generation>.
- 73 Ibid.
- 74 J. Businge, "Why Karuma Dam commissioning has been extended again", *The Independent*, 29 January 2020, <https://www.independent.co.ug/karuma-dam-commissioning-extended-again>.
- 75 IHA, op. cit. note 1.
- 76 International Water Power & Dam Construction, "Gilkes commissions African project, received new order", 28 April 2020, <https://www.waterpowermagazine.com/news/newgilkes-commissions-african-project-7894735>; C. Mangazi, "New power firm to join market March", *The Times Group*, 27 February 2019, <https://times.mw/new-power-firm-to-join-market-march>; International Water Power & Dam Construction, "Mini hydro plant completed in Zambia", 8 October 2019, <https://www.waterpowermagazine.com/news/newsmini-hydro-plant-completed-in-zambia-7443942>; "Small hydro project boosts mini-grid impact", *ESI Africa*, 29 July 2019, <https://www.esi-africa.com/industry-sectors/renewable-energy/small-hydro-project-boosts-mini-grid-impact>.
- 77 "Small hydro project boosts mini-grid impact", op. cit. note 76.
- 78 M. C. Afful, "Ghana: Gov't to construct mini-hydropower plants across the country — Amewu", *Energy News Africa*, 30 September 2019, <https://energynewsafrika.com/index.php/2019/09/30/ghana-govt-to-construct-mini-hydropower-plants-across-the-country-amewu>; "BPA completes Ghana's first micro hydropower plant", *Renewable Energy Magazine*, 21 November 2019, https://www.renewableenergymagazine.com/small_hydro/bpa-completes-ghana-s-first-micro-hydropower-20191121; M. C. Afful, "Ghana: First 45kW micro hydropower project constructed on Tsatsadu River in Alavanyo-Abehenease", *Energy News Africa*, 30 September 2019, <https://energynewsafrika.com/index.php/2019/09/30/ghana-first-45kw-micro-hydropower-project-constructed-on-tsatsadu-river-in-alavanyo-abehenease>.
- 79 Afful, "Ghana: First 45kW micro hydropower project constructed on Tsatsadu River in Alavanyo-Abehenease", op. cit. note 78.
- 80 "The Emerging Africa Infrastructure Fund provides \$27 million loan for hydro power project", *Renewable Energy Magazine*, 4 March 2019, https://www.renewableenergymagazine.com/small_hydro/the-emerging-africa-infrastructure-fund-provides-27-20190304; M. C. Afful, "Burundi: AfDB's Sustainable Energy Fund for Africa approves \$1M support for solar-hydro hybrid project", *Energy News Africa*, 20 December 2019, <https://energynewsafrika.com/index.php/2019/12/20/burundi-afdb-s-sustainable-energy-fund-for-africa-approves-1m-support-for-solar-hydro-hybrid-project>.
- 81 Afful, op. cit. note 80.
- 82 IHA, op. cit. note 1; I. Tspouridis, "Naeras: A pumped storage clean energy plant on the island of Ikaria, Greece", *E=mc2*, 6 June 2019, <https://www.e-mc2.gr/el/news/naeras-pumped-storage-clean-energy-plant-island-ikaria-greece>.
- 83 IHA, op. cit. note 1.
- 84 An example of a new pumped hydro facility opened in 2019 that is integrating renewable energy was the Naeras pumped storage plant on the Greek Island of Ikaria, which couples 1.8 MW of wind power capacity with a 3.1 MW hydropower facility. See Tspouridis, op. cit. note 82. In the **United Arab Emirates**, a 250 MW pumped hydro facility due to enter operations in 2024 will make use of solar-powered pumps to charge its upper reservoir, from D. Proctor, "Group will build 'first of its kind' pumped-storage project in Dubai", *POWER*, 19 August 2019, <https://www.powermag.com/group-will-build-first-of-its-kind-pumped-storage-project-in-dubai>. In the **United States**, a 400 MW plant in the state of Montana, planned for 2020, will act as a peaking plant charged with excess renewable energy generated in the surrounding regions, from Institute for Energy Economics and Financial Analysis, "Major pumped hydro storage project moves forward in Montana", 15 July 2019, <https://ieefa.org/major-pumped-hydro-storage-project-moves-forward-in-montana>, and from J. Hettinger, "Montana's energy importers want renewables. Renewables require storage. A pumped hydro project in Meagher County aims to provide it." *Montana Free Press*, 20 September 2019, <https://montanafreepress.org/2019/09/20/montanas-energy-importers-want-renewables-renewables-require-storage-a-pumped-hydro-project-in-meagher-county-aims-to-provide-it>. In **Zimbabwe**, developers obtained water use approvals for a planned 2 GWh pumped storage plant with 300 MW of adjacent solar PV capacity, from B. Bungane, "Pumped storage hydro proposed for Zimbabwe", *ESI Africa*, 18 November 2019, <https://www.esi-africa.com/industry-sectors/generation/pumped-storage-hydro-proposed-for-zimbabwe/>.
- 85 "Snowy 2.0 Hydropower Project, New South Wales", *Power Technology*, <https://www.power-technology.com/projects/snowy-2-0-hydropower-project>, viewed April 2020; Snowy Hydro Limited, "Snowy 2.0", <https://www.snowyhydro.com.au/our-scheme/snowy20>, viewed April 2020; Voith, *Annual Report 2019* (Heidenheim, Germany: December 2019), pp. 5, 42-43, <http://voith.com/corp-en/about-us/annual-report-2019.html>.
- 86 N. Filatoff, "Eureka moment for Kidston Pumped Storage Hydro Project", *pv magazine*, 30 March 2020, <https://www.pv-magazine-australia.com/2020/03/30/eureka-moment-for-kidston-pumped-storage-hydro-project>; Australian Renewable Energy Agency, "Kidston Stage Two Hydro-Solar Project activities", <https://arena.gov.au/projects/project-development-activities-kidston-stage-two-hydro-solar-project>, viewed April 2020.
- 87 See, for example, World Hydropower Congress Secretariat and IHA, *World Hydropower Congress 2019 Report* (London: 2019), <https://www.hydropower.org/publications/world-hydropower-congress-report-2019>.
- 88 See, for example, the following: Andritz, *New Life for Hydro Assets: Modernization and Renovation of Hydropower Plants* (Graz, Austria: March 2019), <https://www.andritz.com/resource/blob/31840/5cab6294379100be61fdd75aa590769f/hydro-service-rehab-en-data.pdf>; concentration of modernisation efforts in Europe and North America in 2019 from Voith, op. cit. note 85, p. 42; World Hydropower Congress Secretariat and IHA, op. cit. note 87, pp. 36-37; L. La Pegna, Enel Green Power, "Existing assets management – refurbishment and modernization", presentation at IEA Hydropower Workshop, Paris, 10 February 2020.
- 89 See, for example, the following: Andritz, op. cit. note 88; World Hydropower Congress Secretariat and IHA, op. cit. note 87, pp. 25, 34-35.
- 90 RusHydro, *2018 Annual Report* (Moscow: 2019), <https://ar2018.rushydro.ru>.
- 91 RusHydro, "Boris Bogush, in the framework of REW, took part in the discussion of modernization of Russian hydropower", press release (Moscow: 4 October 2019), <http://www.rushydro.ru/press/news/109511.html> (using Google Translate).
- 92 Ibid.
- 93 S. Rivas Navarro, Alpiq, "Hydro pump-storage: roles & profitability", presentation at IEA Hydropower Workshop, Paris, 10 February 2020; B. Boesmans, ENGIE, presentation at IEA Hydropower Workshop, Paris, 10 February 2020; S. Racicot-Daignault, Hydro-Québec, "Managing existing assets: Drivers and challenges to refurbishment and modernization", presentation at IEA Hydropower Workshop, Paris, 10 February 2020.

- 94 General Electric Company, "Hydropower as an enabler to reliable renewable energy", presentation at IEA Hydropower Workshop, Paris, 10 February 2020; Rivas Navarro, op. cit. note 93.
- 95 See, for example, General Electric Company, op. cit. note 94.
- 96 Boesmans, op. cit. note 93; World Hydropower Congress Secretariat and IHA, op. cit. note 87, pp. 28-29; IHA, "The world's water battery: Pumped hydropower storage and the clean energy transition", 18 December 2018, <https://www.hydropower.org/publications/the-world%E2%80%99s-water-battery-pumped-hydropower-storage-and-the-clean-energy-transition>.
- 97 IHA, *Hydropower Sector Climate Resilience Guide* (London: 2019), <https://www.hydropower.org/publications/hydropower-sector-climate-resilience-guide>.
- 98 World Hydropower Congress Secretariat and IHA, op. cit. note 87; IHA, *How-to Guide: Hydropower Erosion and Sedimentation* (London: December 2019), <https://www.hydropower.org/publications/hydropower-erosion-and-sedimentation-how-to-guide>; B. Eckhouse, "Climate change wreaking havoc on the world's hydropower plants", *Bloomberg*, 2 May 2019, <https://www.bloomberg.com/news/articles/2019-05-02/climate-change-wreaking-havoc-on-the-world-s-hydropower-plants>; IHA, "Workshop Report: Climate resilience for hydropower projects", 2017 World Hydropower Congress, 8 May 2017, https://www.hydropower.org/sites/default/files/publications-docs/2017%20WHC_session%20report%20-%20WORKSHOP%20-%20Climate%20Resilience.pdf.
- 99 World Hydropower Congress Secretariat and IHA, op. cit. note 87; IHA, *How-to Guide: Hydropower Erosion and Sedimentation*, op. cit. note 98; Eckhouse, op. cit. note 98; IHA, "Workshop Report: Climate resilience for hydropower projects", op. cit. note 98.
- 100 IHA, op. cit. note 97.
- 101 World Hydropower Congress Secretariat and IHA, op. cit. note 87, pp. 12-13; IHA, *How-to Guide: Hydropower Benefit Sharing* (London: 2019), <https://www.hydropower.org/publications/hydropower-benefit-sharing-how-to-guide>.
- 102 IHA, op. cit. note 101; IHA, *How-to Guide: Hydropower Erosion and Sedimentation*, op. cit. note 98.
- 103 GE, *Form 10-K [as incorporated into 2019 Annual Report]* (Boston: February 2020), pp. 11, 13, <https://www.ge.com/investor-relations/annual-report>.
- 104 Ibid.
- 105 Andritz Group, *Annual Report 2019* (Graz, Austria: 2020), p. 1, 27, <https://www.andritz.com/group-en/investors/annual-reports>; Andritz, *Annual Report 2018* (Graz, Austria: 2019), <https://www.andritz.com/group-en/investors/annual-reports>.
- 106 Voith, op. cit. note 85, p. 42.
- 107 Ibid., p. 42.
- 108 XFLEX HYDRO, "Building a resilient, renewable power system with innovative hydropower technology", 10 December 2019, <https://xflexhydro.net/news/building-a-resilient-renewable-power-system-with-innovative-hydropower-technology>.
- 109 Ibid.

OCEAN POWER

- 1 **Sidebar 4** from the following sources: early history from J. M. Leishman and G. Scobie, *The Development of Wave Power – A Techno Economic Study* (Glasgow, Scotland: Economic Assessment Unit, National Engineering Laboratory, 1976), <https://web.archive.org/web/20110727162538/http://www.mech.ed.ac.uk/research/wavepower/0-Archive/EWPP%20archive/1976%20Leishman%20and%20Scobie%20NEL.pdf>, from "Power from the sea", *Popular Mechanics*, December 1930, pp. 881-82, https://books.google.ie/books?id=qOIDAAAAMBAJ&pg=PA881&source=gbs_toc_r&cad=2#v=onepage&q&f=false, and from W. H. Avery and C. Wu, *Renewable Energy from the Ocean: A Guide to OTEC* (New York: Oxford University Press, 1994), https://www.google.com/books/edition/Renewable_Energy_From_the_Ocean/HP3BXSWeQwIC?hl=en&gbpv=1&dq=Renewable+Energy+from+the+Ocean:+A+Guide+to+OTEC&printsec=frontcover; US OTEC investment from L. Meyer, D. Cooper and R. Varley, "Are we there yet? A developer's roadmap to OTEC commercialization", 2011, http://hinmrec.hnei.hawaii.edu/wp-content/uploads/2010/01/OTEC-Road-to-Commercialization-September-2011-_LM.pdf; UK studies from University of Edinburgh, "Edinburgh makes waves in power generation research" (Edinburgh, Scotland: 2016), <https://www.ed.ac.uk/files/atoms/files/engineering-wavemakers.pdf>; IEA programme from Ocean Energy Systems (OES), "Who is OES?" <https://www.ocean-energy-systems.org/about-us/who-is-oes->, viewed 27 March 2020; European Marine Energy Centre Ltd (EMEC), "Wave clients", <http://www.emec.org.uk/about-us/wave-clients>, viewed 27 March 2020; EMEC, "Tidal clients", <http://www.emec.org.uk/about-us/tidal-clients>, viewed 27 March 2020; SIMEC Atlantic Energy, "MeyGen", <https://simecatlantis.com/projects/meygen>, viewed 27 March 2020; EMEC, "Hydrogen production plant", <http://www.emec.org.uk/facilities/hydrogen>, viewed 27 March 2020; EMEC, "Naval Group deploy Microsoft underwater data centre at EMEC", press release (Orkney, Scotland: 7 June 2018), <http://www.emec.org.uk/press-release-naval-group-deploy-microsoft-underwater-data-centre-at-emec>; volatile from European Commission (EC), *Study on Lessons for Ocean Energy Development* (Brussels: 2017), https://publications.europa.eu/resource/cellar/03c9b48d-66af-11e7-b2f2-01aa75ed71a1.0001.01/DOC_1; EU attention from EC, "Blue growth", https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en, viewed 27 March 2020; government inconsistency from UK House of Commons Energy and Climate Change Committee, *The Future of Marine Renewables in the UK, Eleventh Report of Session 2010–12 (Volume II)* (London: 2012), pp. 85, 111, <https://publications.parliament.uk/pa/cm201012/cmselect/cmenergy/1624/1624vww.pdf>; EC, *Study on Lessons for Ocean Energy Development*, op. cit. this note, pp. 25, 37, 55; "Tidal energy is predicable, cheap and has great global potential", RenewableEnergyWorld.com, 13 November 2019, <https://www.renewableenergyworld.com/2019/11/13/tidal-energy-is-predicable-cheap-and-has-great-global-potential>; bankruptcies from G. Smart and M. Noonan, *Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit* (Glasgow, Scotland: Offshore Renewable Energy Catapult, 2018), <https://www.marineenergywales.co.uk/wp-content/uploads/2018/05/ORE-Catapult-Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Ind-Benefit-FINAL-v03.02.pdf>; lower costs from Low Carbon Energy Observatory (LCEO), *Ocean Energy Technology Development Report* (Luxembourg: EC Joint Research Centre, 2019), <https://ec.europa.eu/jrc/en/publication/ocean-energy-technology-development-report>; technological progress and development activity from Ocean Energy Europe (OEE), *Ocean Energy: Key Trends and Statistics 2019* (Brussels: March 2020), https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf.
- 2 Total 2018 capacity from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2019* (Abu Dhabi: March 2019), <http://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019>; 2019 capacity additions from OEE, op. cit. note 1.
- 3 Ibid., both references.
- 4 OEE, op. cit. note 1, p. 16.
- 5 EC, *Study on Lessons for Ocean Energy Development*, op. cit. note 1, p. iii.
- 6 Smart and Noonan, op. cit. note 1.
- 7 OES, *Annual Report 2019* (Lisbon: March 2020), <https://www.ocean-energy-systems.org/documents/49568-oes-annual-report-2019.pdf>, p. 4; OEE, op. cit. note 1, p. 4.
- 8 Smart and Noonan, op. cit. note 1, p. 4; EMEC, "Wave devices", <http://www.emec.org.uk/marine-energy/wave-devices>, viewed 27 March 2019.
- 9 OEE, op. cit. note 1, p. 10.
- 10 Naval Energies, "MRE: Naval Energies stops its investment in tidal-turbine energy and concentrates on floating wind turbines and ocean thermal energy conversion", press release (Paris: 27 July 2018), <https://www.naval-group.com/en/news/naval-energies-stops-its-investment-in-tidal-turbine-energy-and-concentrates-on-floating-wind-turbines-and-ocean-thermal-energy-conversion/>.
- 11 OEE, op. cit. note 1, p. 10.
- 12 Nova Scotia Canada, "Developmental Tidal Feed-in Tariff Program", <https://energy.novascotia.ca/renewables/programs-and-projects/tidal-fit>, viewed 27 March 2020.
- 13 OES, op. cit. note 7, p. 55.
- 14 Ibid.
- 15 Natural Resources Canada, "Minister Sohi announces major investment in renewable tidal energy that will power 2,500 homes in Nova Scotia", press release (Halifax, Nova Scotia: 20 September 2018), <https://www.canada.ca/en/natural-resources-canada/news/2018/09/minister-sohi-announces-major-investment-in-renewable-tidal-energy-that-will-power-2500-homes-in-nova-scotia.html>; OES, op. cit. note 7, p. 58.
- 16 Interreg, "Interreg's biggest ever project approved", press release (Norwich, UK: 16 October 2019), <https://www.channelmanche.com/en/news-and-media/latest-news/interregs-biggest-ever-project-approved>.
- 17 Ibid.
- 18 Ibid.
- 19 Atlantis Resources, "MeyGen Phase 1A completes construction phase and officially enters 25 year operations phase", press release (Edinburgh, Scotland: 12 April 2018), <https://simecatlantis.com/2018/04/12/meygen-phase-1a-completes-construction-phase-and-officially-enters-25-year-operations-phase>; SIMEC Atlantis Energy, "MeyGen operational update", 27 January 2020, <https://simecatlantis.com/2020/01/27/4036>.
- 20 Ibid.
- 21 Ibid.
- 22 SIMEC Atlantis Energy, "MeyGen granted £1.545m for pioneering subsea hub from the Scottish Government", press release (London: 25 March 2020), <https://simecatlantis.com/2020/03/25/meygen-granted-1-545m-for-pioneering-subsea-hub-from-the-scottish-government>.
- 23 OEE, op. cit. note 1.
- 24 Ibid.
- 25 "Abundance closes record £7m investment for Orbital Marine Power project", BusinessGreen, 11 January 2019, <https://www.businessgreen.com/news/3069167/abundance-closes-record-gbp7m-investment-for-orbital-marine-power-project>.
- 26 Minesto, "Minesto breaks new ground in the energy sector as it proves its subsea kite technology", press release (Västra Frölunda, Sweden: 30 August 2018), <https://minesto.com/news-media/minesto-breaks-new-ground-energy-sector-it-proves-its-subsea-kite-technology>; Minesto, "Minesto generates electricity for the first time with commercial-scale unit", press release (Västra Frölunda, Sweden: 9 October 2018), <https://minesto.com/news-media/minesto-generates-electricity-first-time-commercial-scale-unit>; Minesto, "Minesto signs PPA with electric utility SEV for utility-scale tidal energy installations", press release (Västra Frölunda, Sweden: 19 February 2020), <https://minesto.com/news-media/minesto-signs-ppa-electric-utility-sev-utility-scale-tidal-energy-installations>; Minesto, "Minesto secures all permits for Faroe Islands' installations", press release (Västra Frölunda, Sweden: 1 April 2020), <https://minesto.com/news-media/minesto-secures-all-permits-faroe-islands%E2%80%99-installations>.
- 27 Minesto, "Holyhead Deep", <https://minesto.com/projects/holyhead-deep>, viewed 27 March 2020.
- 28 Ibid.
- 29 I. Shumkov, "Update: Minesto gets EUR-2.4m EU grant for French tidal project", Renewables Now, 16 October 2019, <https://renewablesnow.com/news/update-minesto-gets-eur-24m-eu-grant-for-french-tidal-project-672838>.
- 30 OES, op. cit. note 7, p. 76.

- 31 HydroQuest, "6 months of operation", 30 January 2020, <https://www.hydroquest.net/2020/01/30/the-1-mw-turbine-oceanquest-achieves-6-months-of-effective-operation-on-paimpol-brehat-edf-site/>; Ouest France, "Brest. L'hydrolienne Guinard Énergies a été installée en Ria d'Étel", 1 March 2019, <https://www.ouest-france.fr/bretagne/brest-29200/brest-l-hydrolienne-guinard-energies-en-ria-d-etel-6243122>.
- 32 OEE, op. cit. note 1, p. 6.
- 33 Ocean Power Technologies, "Ocean Power Technologies announces the successful North Sea deployment of the PB3 PowerBuoy® for Premier Oil", press release (Monroe Township, NJ: 22 August 2019), <https://oceanpowertechnologies.gcs-web.com/news-releases/news-release-details/ocean-power-technologies-announces-successful-north-sea>.
- 34 Ocean Power Technologies, "PB3 PowerBuoy® celebrates one year of maintenance-free continuous operation in the Adriatic Sea", 16 January 2020, <https://oceanpowertechnologies.com/pb3-powerbuoy-celebrates-one-year-of-maintenance-free-continuous-operation-in-the-adriatic-sea>.
- 35 WaveRoller, "Portugal takes a step closer to commercial wave energy", 31 October 2019, <https://aw-energy.com/news/portugal-takes-a-step-closer-to-commercial-wave-energy>.
- 36 OEE, op. cit. note 1, p. 13.
- 37 University of Edinburgh Policy and Innovation Group, *UK Ocean Energy Review 2019* (Edinburgh, Scotland: 2019), p. 3, http://www.policyandinnovatedinburgh.org/uploads/3/1/4/1/31417803/policy_and_innovation_group_uk_oceanenergy_review_2019_final.pdf.
- 38 B. O'Donovan, "Irish company launches wave energy device in the US", RTE, 10 October 2019, <https://www.rte.ie/news/2019/10/10/1082377-ocean-energy-us>.
- 39 US Department of Energy (DOE), "U.S. Department of Energy awards \$25 million for next-generation marine energy research projects", press release (Washington, DC: 8 January 2019), <https://www.energy.gov/articles/us-department-energy-awards-25-million-next-generation-marine-energy-research-projects>; US DOE, Water Power Technologies Office, "A look back at water power in 2018", 22 January 2019, <https://www.energy.gov/eere/water/articles/look-back-water-power-2018>.
- 40 OES, op. cit. note 7, p. 60; S. Qiu et al., "A comprehensive review of ocean wave energy research and development in China", *Renewable and Sustainable Energy Reviews*, vol. 113 (October 2019), p. 109271, <https://www.sciencedirect.com/science/article/abs/pii/S1364032119304794>.
- 41 S. Vorrath, "Carnegie looks to boost CETO 6 wave power efficiency, reliability and smarts", *RenewEconomy*, 2 March 2020, <https://reneweconomy.com.au/carnegie-looks-to-boost-ceto-6-wave-power-efficiency-reliability-and-smarts-91891>.
- 42 S. Vorrath, "Milestone for Garden Island microgrid as Carnegie gets back on the wave", *RenewEconomy*, 6 February 2020, <https://reneweconomy.com.au/milestone-for-garden-island-microgrid-as-carnegie-gets-back-on-the-wave-82694>.
- 43 OES, op. cit. note 7, p. 8.
- 44 Bombora, "Two-thirds of contracts awarded for 1.5MW wave energy device project", 7 January 2020, <https://www.bomborawave.com/latest-news/two-thirds-of-contracts-awarded-for-1-5mw-wave-energy-device-project>.
- 45 Ibid.
- 46 LCEO, op. cit. note 1; OES, *Annual Report 2018* (Lisbon: March 2019), p. 5, <http://report2018.ocean-energy-systems.org>.
- 47 LCEO, op. cit. note 1; Directorate-General for Maritime Affairs and Fisheries of the European Commission, *Market Study on Ocean Energy* (Brussels: 20 June 2018), <https://publications.europa.eu/en/publication-detail/-/publication/e38ea9ce-74ff-11e8-9483-01aa75ed71a1/language-en/format-PDF/source-99081151>.
- 48 A. Copping, *The State of Knowledge for Environmental Effects Driving Consenting/Permitting for the Marine Renewable Energy Industry* (Richland, WA: OES and Pacific Northwest National Laboratory, January 2018), <https://tethys.pnnl.gov/publications/state-knowledge-environmental-effects-driving-consentingpermitting-marine-renewable>.
- 49 Ibid.
- 50 Directorate-General for Maritime Affairs and Fisheries of the European Commission, op. cit. note 47.
- 51 Directorate-General for Maritime Affairs and Fisheries of the European Commission, op. cit. note 47.
- 52 EC Strategies Energy Technologies Information System, *Ocean Energy – Implementation Plan* (Brussels: 2018), https://setis.ec.europa.eu/system/files/set_plan_ocean_implementation_plan.pdf.

SOLAR PV

- 1 Stable or contracted slightly in 2018 based on the following: 102.4 GW added to the world's grids in 2018, up from 98.5 GW installed in 2017, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023* (Brussels: 2019), p. 5, <https://www.solarpowereurope.org/global-market-outlook-2019-2023>; figures of 103,226 MW installed during 2018, down from 103,554 MW installed in 2017, from International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), *Trends in Photovoltaic Applications 2019* (Paris: 2019), p. 97, https://iea-pvps.org/trends_reports/2019-edition/; and 2018 saw first annual decline in 50 years (a result of policy changes in China), with total industry demand down 5%, to 89.1 GWp (compared with 93.9 GWp in 2017), from P. Mints, SPV Market Research, *The Solar Flare*, no. 4 (31 August 2019), p. 8. Figures of at least 114.9 GW added in 2019 for a total of at least 627 GW are preliminary estimates from IEA PVPS, *Snapshot of Global PV Markets 2020* (Paris: April 2020), <https://iea-pvps.org/snapshot-reports/snapshot-2020/>, and from Becquerel Institute, Brussels, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 10 April 2020; increase over 2018 market based on idem, both sources, and on additions of 103 GW in 2018, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. this note, pp. 96-97. Additions of 113.9 GW in 2019, and cumulative shipments of cells to first buyer over the period 1975-2019 reached 591 GW in 2019, from P. Mints, SVP Market Research, *Photovoltaic Manufacturer Shipments: Capacity, Price & Revenues 2019/2020* (San Francisco: April 2020), pp. 15, 34, and just over 110 GW for a global total exceeding 600 GW, from EurObserv'ER, *Photovoltaic Barometer* (Paris: April 2020), p. 2, <https://www.eurobserv-er.org/category/all-photovoltaic-barometers>. The numbers published by IEA PVPS are based on official data in reporting countries; many of these countries account for decommissioning of existing capacity, but not all countries track either decommissioning or repowering of solar PV capacity. IEA PVPS assumes that decommissioning is relatively uncommon at this stage, given that most global installations were commissioned in 2005 and later, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 13. A few countries report data officially in alternating current (AC) (e.g., Canada, Chile, India, Japan, Malaysia, Sweden and the United States); these data were converted to direct current (DC) by relevant sources provided in this section for consistency across countries. The difference between DC and AC power can range from as little as 5% (conversion losses, inverter set at DC level) to as much as 40% (due to some grid regulations limiting output or to the evolution of utility-scale solar PV plants), from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. this note, p. 9. Most utility-scale solar PV plants built in 2019 have an AC-DC ratio between 1.1 and 1.6, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 11. Conversions done by IEA PVPS and the Becquerel Institute use a multiplier of 1.3 for centralised capacity to convert capacity from AC to DC. In the United States, the median inverter loading ratio (ratio of DC nameplate rating to AC inverter nameplate rating) in 2018, for both tracked and fix-tilt utility-scale projects, was 1.33, but there is significant variation across projects, from M. Bolinger, J. Seel and D. Robson, *Utility-scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2019 Edition* (Berkeley, CA: Lawrence Berkeley National Laboratory, December 2019), p. ii, https://eta-publications.lbl.gov/sites/default/files/lbnl_utility_scale_solar_2019_edition_final.pdf. The argument is made that AC ratings are more appropriate for utility-scale capacity because other conventional and renewable utility-scale generating sources also are described in AC terms, and because the difference between a project's DC and AC capacity ratings is increasing in general (at least in the United States) due to a lower relative inverter rating, from M. Bolinger and J. Seel, *Utility-Scale Solar: Empirical Trends in Project Technology, Cost Performance, and PPA Pricing in the United States – 2018 Edition* (Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL), September 2018), p. 5, <https://emp.lbl.gov/utility-scale-solar>. However, most analysts, consultancies, industry groups, the IEA and many others report data in DC, from M. Schmela, SolarPower Europe, personal communication with REN21, 11 May 2019. In addition, DC capacity more accurately reflects the rating of panels, from C. Marcy, "Solar plants typically install more panel capacity relative to their inverter capacity", Today in Energy, US Energy Information Administration (EIA), 16 March 2018, <https://www.eia.gov/todayinenergy/detail.php?id=35372>. In order to maintain a consistent rating type
- 2 across all solar PV capacity, and because the AC capacity of most countries is not available, GSR 2020 attempts to report all solar PV data in DC units; in addition, the GSR reports only capacity that has entered into operation by year's end.
- 3 More than making up for China from P. Mints, SPV Market Research, *The Solar Flare*, no. 6 (23 December 2019), p. 6; G. Masson, Becquerel Institute and IEA PVPS, Brussels, personal communication with REN21, 20 February 2020; IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1; decline in China from China's National Energy Administration (NEA), "PV grid-connected operation in 2019", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827923.htm (using Google Translate).
- 4 Based on data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 97, and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6.
- 5 For total at end of 2019, see endnote 1. Figure of 23 GW at end of 2009 from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 96-97. **Figure 28** based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 96, 97, and from Becquerel Institute, op. cit. note 1.
- 6 SolarPower Europe, op. cit. note 1, pp. 9, 13. See also, for example, International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2018* (Abu Dhabi: 2019), p. 9, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf; B. Eckhouse, "Solar and wind cheapest source of power in most of the world", *Bloomberg*, 28 April 2020, <https://www.bloomberg.com/news/articles/2020-04-28/solar-and-wind-cheapest-sources-of-power-in-most-of-the-world>; BloombergNEF, "Solar, wind, batteries to attract \$10 trillion to 2050, but curbing emissions long-term will require other technologies too", 18 June 2019, <https://about.bnef.com/blog/solar-wind-batteries-attract-10-trillion-2050-curbing-emissions-long-term-will-require-technologies/>; M. Brown, "Solar energy prices hit tipping point as China reaches 'grid parity'", *Inverse*, 14 August 2019, <https://www.inverse.com/article/58495-solar-energy-prices-hit-tipping-point-as-china-reaches-grid-parity>; M. Brown, "Solar vs. coal: Why the '74 percent report' signals a new era for US energy", *Inverse*, 28 March 2019, <https://www.inverse.com/article/54399-solar-energy-cheaper-than-coal-whats-next>; <https://www.nature.com/articles/s41560-019-0441-z>; J. Weaver, "Solar price declines slowing, energy storage in the money", *pv magazine*, 8 November 2019, <https://pv-magazine-usa.com/2019/11/08/sola-price-declines-slowing-energy-storage-in-the-money>; M. Hutchins, "Solar 'could soon be UK's cheapest source of energy'", *pv magazine*, 12 December 2018, <https://www.pv-magazine.com/2018/12/12/solar-could-soon-be-uks-cheapest-source-of-energy>; K. Samanta, "India's renewable energy cost lowest in Asia Pacific: WoodMac", *Reuters*, 29 July 2019, <https://www.reuters.com/article/us-india-renewables-woodmac/indias-renewable-energy-cost-lowest-in-asia-pacific-woodmac-idUSKCN1U00L8>; J. Yan et al., "City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China", *Nature Geoscience* (2019), cited in J. Gabbatiss, "Solar now 'cheaper than grid electricity' in every Chinese city, study finds", *CarbonBrief*, 12 August 2019, <https://www.carbonbrief.org/solar-now-cheaper-than-grid-electricity-in-every-chinese-city-study-finds>.
- 7 N. Ford, "Europe solar-storage costs fall below markets as learnings kick in", *New Energy Update*, 2 October 2019, <https://analysis.newenergyupdate.com/pv-insider/europe-solar-storage-costs-fall-below-markets-learnings-kick>.
- 8 Estimated 18 countries (Australia, Brazil, China, Chinese Taipei, Egypt, Germany, India, Japan, the Republic of Korea, Mexico, the Netherlands, Pakistan, South Africa, Spain, Ukraine, United Arab Emirates, the United States and Vietnam) in 2019 based on preliminary estimates for IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, on data from Becquerel Institute, op. cit. note 1, and on data from country-specific sources provided throughout this section. Up from 11 countries (China, the United States, India, Japan, Australia, Germany, Mexico, the Republic of Korea, Turkey, the Netherlands and Brazil) in 2018 from SolarPower Europe, op. cit. note 1, p. 53; and up from 10 countries in 2018 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 9. There were nine countries in 2017 from IEA PVPS, *Trends in Photovoltaic Applications 2018: Survey Report of Selected IEA Countries Between 1992 and 2017* (Paris: 2018), p. 3, <http://www.iea-pvps.org/fileadmin/dam/public/report/>

- statistics/2018_iea_pvps_report_2018.pdf, and from SolarPower Europe, *Global Market Outlook for Solar Power 2018-2022* (Brussels: 2018), p. 5, <https://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf>; and seven countries in 2016 from idem, p. 5.
- 8 Figure of 39 countries in 2019 based on data from numerous sources, including preliminary data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from A. Detollenaere, Becquerel Institute, personal communication with REN21, 10 April 2020, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 96, and from numerous sources cited throughout this section. Figure of 31 countries in 2018 from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 6.
 - 9 IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, p. 80.
 - 10 IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 14. Based on cumulative capacity in operation at end-2019 and assumes close to optimum siting, orientation and long-term average weather conditions, from idem.
 - 11 **Honduras** sourced 10.7% of its gross electricity generation from solar PV, based on data from T. Vindel, Secretario de Estado en el Despacho de Energía de la República de Honduras, and provided by G. Bravo, Fundación Bariloche, personal communication with REN21, 27 April 2020; **Italy** generated 24,326 GWh of electricity with solar PV in 2019, and total net production in the system was 283,846 GWh, for a solar PV share of 8.57%, from Terna, *Rapporto mensile sul Sistema Elettrico December 2019* (Rome: 2019), p. 5, https://download.terna.it/terna/Rapporto_Mensile_Dicembre%202019_8d79d92a335c3f2.pdf; **Greece** from multiple original sources, all in Greek, and provided by I. Tsiouridis, R.E.D. Pro Consultants, Athens, personal communication with REN21, April 2020; **Germany's** solar PV generation accounted for 8.2% of Germany's gross electricity generation in 2019 (up from 7.7% in 2018), from Federal Ministry for Economic Affairs and Energy and Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Time Series for the Development of Renewable Energy Sources in Germany, Based on Statistical Data from the Working Group on Renewable Energy-Statistics (AGEE-Stat) (Status: February 2020)* (Dessau-Roßlau: February 2020), pp. 44, 45, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html; **Chile** share of generation from Asociación Chilena de Energías Renovables y Almacenamiento (ACERA), *Estadísticas Sector de Generación de Energía Eléctrica Renovable* (December 2019), p. 2, <https://acera.cl/wp-content/uploads/2020/01/2019-12-Bolet%C3%ADn-estad%C3%ADsticas.pdf>; **Australia** from Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), p. 9, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf>; **Japan** from Institute for Sustainable Energy Policies (ISEP), "Share of renewable energy electricity in Japan, 2019 (preliminary report)", 10 April 2020, <https://www.isep.or.jp/en/879>.
 - 12 Share of total global electricity generation based on the following: total global electricity generation in 2019 estimated at 27,011 TWh, based on 26,615 TWh in 2018 from BP, *Statistical Review of World Energy* (London: 2019), <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>, and on estimated 1.49% growth in global electricity generation in 2019. Growth rate in 2019 is based on the weighted average change in actual total generation for the following countries/regions (which together accounted for more than two-thirds of global generation in 2018): United States (-1.3% net generation), EU-28 (-1.2%), Russian Federation (+1.2%), India (+0.0%), China (+4.7%), Canada (-0.2%) and Brazil (+2.0%). Generation data for 2018 and 2019 by country or region from the following: US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2019* (Washington, DC: February 2020), Table 1.1, <https://www.eia.gov/electricity/monthly/archive/february2020.pdf>; European Commission (EC), Eurostat database, <http://ec.europa.eu/eurostat>, viewed April 2020; Ministry of Energy of the Russian Federation, "Statistics", <https://minenergo.gov.ru/en/activity/statistic>, viewed April 2020; Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly generation report", <http://www.cea.nic.in/monthlyarchive.html>, viewed April 2020; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2019 national economic and social development", press release (Beijing: 28 February 2020), http://www.stats.gov.cn/english/PressRelease/202002/t20200228_1728917.html (using Google Translate); Statistics Canada, "Electric Power Generation, monthly generation by type of electricity", <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501>, updated 11 May 2020; National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed April 2020. **Solar PV** worldwide production potential of 715.15 TWh, from Gaëtan Masson and Alice Detollenaere, Becquerel Institute and IEA PVPS, personal communication with REN21, 10 April 2020. Estimates for electricity generation from Masson and IEA PVPS are theoretical calculations based on average yield and installed solar PV capacity as of 31 December 2019..
 - 13 SolarPower Europe, op. cit. note 7, p. 42; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 91; IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, pp. 4, 80.
 - 14 Ibid.
 - 15 Lower than a decade ago but challenges remain, fossil and nuclear, from Masson, op. cit. note 2, 20 February 2020, and 4 May 2020. Regarding utilities, in Brazil, for example, utilities are restricting approval and authorization of solar PV systems, saying that they lack the capacity to make grid connections and to integrate solar energy into the grid, among other things, from R. Baitelo, Associação Brasileira de Energia Solar Fotovoltaica (ABSOLAR), personal communication with REN21, 7 April 2020; in Australia, the energy market operator has largely prevented attempts by electricity network operators to discriminate against and financially penalise solar customers, but network operators have imposed delays and conditions on the approval of grid connections, which leads to increases in the soft costs of solar deployment, from IEA PVPS, Australian Photovoltaic Institute (APVI) and Australian Renewable Energy Agency (ARENA), *National Survey Report of PV Power Applications in Australia 2018* (Paris: 2019), prepared by R. Egan, APVI, p. 36, https://iea-pvps.org/wp-content/uploads/2020/01/NSR_Australia_2018.pdf.
 - 16 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 48-56; IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, p. 43.
 - 17 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 48. Growth in grid-connected solar PV in particular has been due almost entirely to government support policies, mandates, and often a combination, from Mints, *Photovoltaic Manufacturer Shipments*, op. cit. note 1, p. 40.
 - 18 Corporate purchasing from information and sources elsewhere in this section; self-consumption from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 15.
 - 19 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 16; Schmela, op. cit. note 1; Masson, op. cit. note 2, 28 February 2019. See also E. Bellini, "Italy deployed 737 MW of solar in 2019", pv magazine, 21 April 2020, <https://www.pv-magazine.com/2020/04/21/italy-deployed-737-mw-of-solar-in-2019/>; L. Stoker, "WoodMac: UK will join the subsidy-free solar club in 2019", PV-Tech, 22 January 2019, <https://www.pv-tech.org/news/woodmac-uk-will-join-the-subsidy-free-solar-club-in-2019/>; T. Gualtieri, "Spanish developer plans 3.3 gigawatts of subsidy-free PV farms", *Bloomberg*, 28 October 2019, <https://www.bloomberg.com/news/articles/2019-10-28/spanish-developer-plans-3-3-gigawatts-of-subsidy-free-pv-farms>.
 - 20 Seventh consecutive year based on data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1; declines based on idem and from data and sources provided throughout this section; Asia accounted for half based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, 20 March 2020 and 10 April 2020, and from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1.
 - 21 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, 20 March 2020 and 10 April 2020, and from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1.
 - 22 Market and manufacturing from SolarPower Europe, op. cit. note 1, p. 89; share of additions in 2019 based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; 44% in 2018 (and 52% in 2017) from SolarPower Europe, op. cit. note 1, p. 89; China's share of

- total demand was 27% in 2014, 30% in 2015, 49% in 2016, 56% in 2017, 42% in 2018 and projected 29% in 2019, from P. Mints, SPV Market Research, *The Solar Flare*, no. 5 (31 October 2019), p. 5.
- 23 Top 10 countries and share of top 5 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; about 75% in 2018 from Becquerel Institute, op. cit. note 1, 10 May 2019, and from IEA PVPS, *2019 Snapshot of Global PV Markets* (Paris: April 2019), p. 8, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_T1_35_Snapshot2019-Report.pdf; less concentrated from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6. The share represented by the top 5 in 2017 was 84%, based on global additions of at least 98 GW_{DC}, and on additions of the top five countries (China, the United States, India, Japan and Turkey), from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018* (Paris: 2018), p. 4, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA_PVPS-A_Snapshot_of_Global_PV-1992-2017.pdf.
- 24 Figure for 2019 based on preliminary estimates for IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1. This was up from 1.3 GW in 2018, from Becquerel Institute, op. cit. note 1, 10 May 2019, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 23, p. 7, and from 954 MW in 2017, from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, p. 13. The market level to be among the top 10 for annual additions was 683 MW in 2016 and 675 MW in 2015, from IEA PVPS, idem.
- 25 Leading countries for total capacity based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1, 20 March 2020, and on data and sources provided throughout this section. Leaders per capita from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 7. **Figure 29** based on historical global and country-specific data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, and based on country-specific data and sources provided throughout this section for China, Germany, India, Japan and the United States. India data from the following: data for 2009 from European Photovoltaic Industry Association (EPIA), *Global Market Outlook for Photovoltaics Until 2015* (Brussels: 2011), p. 10, http://www.cogen.com.br/content/upload/1/documentos/Solar/Solar_COGEN/EPIA_Global_Market_Photovoltaics_2015.pdf; data for 2010 and 2011 from EPIA, *Global Market Outlook for Photovoltaics Until 2016* (Brussels: May 2012), p. 14, https://www.helapco.gr/pdf/Global_Market_Outlook_2015_-2019_lr_v23.pdf; data for 2012 from IEA PVPS, *PVPS Report, A Snapshot of Global PV 1992-2012* (Paris: 2013), https://iea-pvps.org/wp-content/uploads/2020/01/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2012_-_FINAL_4.pdf; data for 2013 from IEA-PVPS, *PVPS Report - Snapshot of Global PV 1992-2013: Preliminary Trends Information from the IEA PVPS Programme* (Paris: March 2014), https://iea-pvps.org/wp-content/uploads/2020/01/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2013_-_final_3.pdf; data for 2014 from Bridge to India, May 2015, provided by S. Orlandi, Becquerel Institute, Brussels, personal communication with REN21, 11 May 2015; data for 2015 from IEA PVPS, *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), https://iea-pvps.org/wp-content/uploads/2020/01/Trends_2016_-_mr.pdf; data for 2016 from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements)", data as on 31 December 2016, <http://www.mnre.gov.in/mission-and-vision-2/achievements>, viewed 19 January 2017; data for 2017 and 2018 from Becquerel Institute and IEA PVPS, personal communication with REN21, 3 June 2019 and 4 May 2020.
- 26 Year-end rally and 12.2 GW brought online from China Photovoltaic Industry Association (CPIA), cited in M. Hall, "China will add 35-38 GW of solar this year", *pv magazine*, 22 January 2020, <https://www.pv-magazine.com/2020/01/22/china-will-add-35-38-gw-of-solar-this-year>; a total of 30.11 GW was added in 2019, including 17.91 GW of utility-scale capacity and 12.2 GW of distributed, and representing a decline of 31.6% relative to 2018, from NEA, op. cit. note 2. Down more than 15% in 2018 based on 53,068 MW installed in 2017, and about 45 GW installed in 2018 (including unsubsidised capacity additions on top of official data for subsidised capacity), all from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1. An estimated 10 GW was installed in December 2019, from GlobalData Energy, "Solar PV capacity additions in China fell by 32% in 2019", *Power Technology*, 23 January 2020, <https://www.power-technology.com/comment/solar-pv-capacity-additions-china-2019>.
- 27 Second consecutive year based on data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6; down in almost every region (excluding Guizhou), from F. Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 6 April 2020, and from NEA, op. cit. note 2; 12 provinces based on grid-connected capacity data from China National Renewable Energy Center, cited in China NEA, "2019 PV installations utility and distributed by province", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827923.htm (using Google Translate) (data do not include Hong Kong SAR, Macao SAR or Chinese Taipei); and more than double the size of the next largest market based on data and sources throughout this section. **Figure 30** based on IEA PVPS, op. cit. note 1, both references, and on national data and references for top 10 countries provided throughout this section (or see endnote for Reference Table R16).
- 28 NEA, op. cit. note 2; Guizhou considered one of the poorest provinces, from F. Haugwitz, AECEA, "China solar PV – 2019/2020 – On the ground dynamics", email newsletter, 1 April 2020.
- 29 Cumulative capacity was 204.66 GW (including off-grid), from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6; cumulative capacity at end-2019 was 204.3 GW, up 17.3% over 2018, including 141.67 GW of utility-scale projects and 62.63 GW of distributed systems (all grid-connected), all from NEA, op. cit. note 2; year-end capacity was 204,680 MW, up 17.4% over 2018, from China Electricity Council (CEC), "2019 electricity & other energy statistics (preliminary)", 21 January 2020, <http://www.cec.org.cn/guihuayutongji/tongjinxin/niandushuju/2020-01-21/197077.html> (using Google Translate). The national target is part of the country's 13th Five-Year Plan (2016-2020), from Haugwitz, op. cit. note 28.
- 30 Schmela, op. cit. note 1, 12 May 2020; F. Haugwitz, "Towards a subsidy-free era for China's solar PV market", *Apricum*, 19 November 2019, <https://www.apricum-group.com/towards-a-subsidy-free-era-for-chinas-solar-pv-market>.
- 31 Haugwitz, op. cit. note 30.
- 32 V. Shaw, "Is China's market heading toward a cliff edge?" *pv magazine*, 30 December 2019, <https://www.pv-magazine.com/2019/12/30/is-chinas-market-heading-toward-a-cliff-edge>; C. Lin, "China's new solar FIT policy", *pv magazine*, 5 June 2019, <https://www.pv-magazine.com/2019/06/05/chinas-new-solar-fit-policy>; F. Haugwitz, AECEA, "China announced 15.99 GW during Jan-Sept 2019; 45% decrease YoY – AECEA revised full-year guidance to 20-24 GW", email newsletter, 29 October 2019.
- 33 Shaw, op. cit. note 32; Lin, op. cit. note 32; Haugwitz, op. cit. note 32; delayed release of policies, grid connection, land availability and challenges associated with mobilising finance also from Haugwitz, cited in R. Ranjan, "AECEA: China likely to install 23-31 GW of solar in 2020 as uncertainty grips", *Mercom India*, 7 January 2020, <https://mercomindia.com/aecea-china-likely-install-23-31-gw-solar-2020>.
- 34 Haugwitz, op. cit. note 28. See also Wood Mackenzie, "Global solar PV installations to reach record high in 2019", press release (25 July 2019), <https://www.woodmac.com/press-releases/global-solar-pv-installations-to-reach-record-high-in-2019>. Another source has the total at 22.7 GW, from M. Hall, "The year in solar, part III: Battery breakthroughs, inverter trouble, sustainable role models and new tech", *pv magazine*, 27 December 2019, <https://www.pv-magazine.com/2019/12/27/the-year-in-solar-part-iii-battery-breakthroughs-inverter-trouble-sustainable-role-models-and-new-tech>. Grid parity from Haugwitz, op. cit. note 27, 21 April 2020.
- 35 Haugwitz, op. cit. note 28. See also Wood Mackenzie, op. cit. note 34.
- 36 Based on data from NEA and from China PV Industry Association (CPIA), provided by Haugwitz, op. cit. note 27, 15 May 2020 and 27 May 2020; Target of 3.5 GW based on earmarked budget of RMB 750 million, which theoretically could support 3.5 GW, from Haugwitz, op. cit. note 27, 21 April 2020. See also Shaw, op. cit. note 32.
- 37 Shares of capacity added are based on 30.11 GW added to the grid in 2019, including 17.91 GW of utility-scale capacity (down 22.9% relative to 2018) and 12.2 GW of distributed capacity (up 41.3% over 2018), from NEA, op. cit. note 2. Share of cumulative capacity based on 141.67 GW of utility-scale capacity and 62.63 GW of distributed capacity (all grid-connected) at

- year's end, from idem, and on total grid-connected capacity of 204.3 GW. Centralised plants accounted for 53% of grid-connected installations in 2018, from NEA, "2018 added solar PV capacities," Finance World, 28 January 2019, <https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&for=pc> (using Google Translate).
- 38 NEA, op. cit. note 2.
- 39 In Qinghai, curtailment was up 2.5 percentage points over 2018 to 7.2%; others with significant average rates of curtailment during 2019 were Tibet, which curtailed 24.1% (down 19.5 percentage points relative to 2018), followed by Xinjiang (7.4%, down 8.2) and Gansu (4%, down 5.6), all from NEA, op. cit. note 2.
- 40 Figures for 2019 based on output from grid-connected systems was up 26.3% to 224.3 TWh, from NEA, op. cit. note 2, and on output up 26.5% to 223.8 TWh, from CEC, op. cit. note 29. For comparison, output was up 50%, to 177.5 TWh in 2018, from NEA, op. cit. note 37.
- 41 Share of generation based on 223.8 TWh of solar electricity and total generation from all sources of 7,325 TWh, from CEC, op. cit. note 29. Share of generation in 2018 (2.6%) from NEA, "Photovoltaic power generation statistics for 2018", 19 March 2019, http://www.nea.gov.cn/2019-03/19/c_137907428.htm (using Google Translate); the share was 2.5% based on 1,775 billion kWh of solar generation (note, however, that this may include a small amount of CSP) and 69,940 billion kWh of total power generation, from China Electricity Industry Development and Environmental Resources Department, cited by CEC, "2018 power statistics annual express basic data list", 19 January 2019, <http://www.cec.org.cn/guihuayutongji/tongjixinxi/nianrushuju/2019-01-22/188396.html>. Share of generation in 2017 was 1.9%, based on data from NEA, cited in "Energy Bureau conference informed of 2017 renewable energy grid operation", 24 January 2018, <http://shupeidian.bjx.com.cn/news/20180124/876448.shtml> (using Google Translate).
- 42 Based on preliminary data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 10, and on total capacity of 32.9 GW_{DC} at end 2018, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 10. IEA PVPS and Becquerel Institute use official estimates (in AC) with a multiplier of 1.3 for conversion of centralised capacity to DC, from IEA PVPS and Becquerel Institute, personal communication with REN21, 23 April 2020. India added 7,806.67 MW in 2019 based on end-2018 capacity of 26,869.08 MW and end-2019 capacity of 34,675.75 MW (mix of AC and DC), from Government of India, MNRE, "Physical progress (achievements)", <http://mnre.gov.in/mission-and-vision-2/achievements>, viewed 30 January 2019, and Government of India, MNRE, "Physical progress (achievements)", <https://mnre.gov.in/physical-progress-achievements>, viewed 9 January 2020. Totals from MNRE are for all solar power, so include some concentrating solar thermal power (CSP) capacity; India's CSP capacity is an estimated 225 MW (see Concentrating Solar Thermal Power section in this chapter for more details and sources). India added (all in AC) 7,346 MW (compared to 8,338 MW in 2018), for a year-end total of almost 35.7 GW; large-scale projects totalled 31.3 GW and rooftop installations for 4.4 GW, from "2019 Q4 and Annual India Solar Market Update – 7.3 GW installed in CY 2019", Mercom India, <https://mercomindia.com/product/2019-q4-annual-india-solar-market-update>, viewed 10 April 2020. Mercom India data were confirmed to be in AC by S. Prateek, Mercom India, New Delhi, personal communication with REN21, May 2019.
- 43 Total target from A. Parikh, "35 GW of solar installed, 65 GW more to go for India to reach its 100 GW solar target", Mercom India, 16 January 2019, <https://mercomindia.com/35-gw-solar-installed-65-gw-more-india>; rooftop target from K. Chandrasekaran, "Rooftop solar growth too slow to meet 2022 target", *Economic Times*, 26 February 2020, <https://economictimes.indiatimes.com/industry/energy/power/rooftop-solar-growth-too-slow-to-meet-2022-target/articleshow/74310428.cms>. India's targets for fiscal year 2019 were reduced early in calendar year 2019, from Saurabh, "India cuts solar capacity addition target by 23% for 2019-2020", CleanTechnica, 27 May 2019, <https://cleantechnica.com/2019/05/27/india-cuts-solar-capacity-addition-target-by-23-for-2019-20>.
- 44 The decline in the annual market was more than 8% based on data for 2018 (10.8 GW_{DC} added), from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 12, and estimate of 9.9 GW added in 2019, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6. Significant growth in 2018 from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 12. Note that the GSR 2019 reported a decrease in India's installations in 2018 relative to 2017 based on data from IEA PVPS; however, recalculations by IEA PVPS determined that 2018 additions were actually higher than those in 2017, from idem. The annual market decline was 12% (accounts for no conversions from AC to DC), from P. Sanjay, "At 7.3 GW, India's solar installations in 2019 declined by 12%", Mercom India, 19 February 2020, <https://mercomindia.com/india-solar-installations-2019-declined>. Annual investments in the solar sector were an estimated USD 8.2 billion in calendar year 2019, down from USD 9.8 billion in 2018, from "2019 Q4 and Annual India Solar Market Update – 7.3 GW installed in CY 2019", op. cit. note 42. The market declined by 15.6% in 2019 relative to 2018, based on data for year-end 2017 to year-end 2019 (also includes CSP capacity, but only 225 MW total), from Government of India, MNRE, "Physical progress (achievements)", <http://mnre.gov.in/mission-and-vision-2/achievements>, viewed 30 January 2018 and 30 January 2019, and idem, "Physical progress (achievements)", <https://mnre.gov.in/physical-progress-achievements>, viewed 9 January 2020. India's annual market increased by 27% based on end-2019 total of 34,831 MW, end-2018 total of 27,127 MW, and end-2017 total of 17,923 MW, all from IRENA, *Renewable Capacity Statistics 2020* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_RE_Capacity_Statistics_2020.pdf.
- 45 See, for example, Sanjay, op. cit. note 44; "2019 Q4 and Annual India Solar Market Update – 7.3 GW installed in CY 2019", op. cit. note 42; Pratheeksha, "Important news snippets from India's renewable industry in June 2019", Mercom India, 4 July 2019, <https://mercomindia.com/important-news-snippets-june-2019>; "India's transmission infrastructure struggles to keep up with wind and solar additions", Mercom India, 1 August 2019, <https://mercomindia.com/indias-transmission-infrastructure-struggles-wind-solar>; S. Prateek, "Power Grid to build transmission network in Gujarat & Rajasthan to evacuate renewables", Mercom India, 8 August 2019, <https://mercomindia.com/power-grid-transmission-gujarat-rajasthan>; A. Parikh, "Year in review: 2019 A lost year for India's solar sector", Mercom India, 20 December 2019, <https://mercomindia.com/2019-lost-year-for-india-solar-sector>; S. Bajaj, "Andhra Pradesh's decision to renegotiate solar and wind PPAs sets bad precedent", Mercom India, 22 July 2019, <https://mercomindia.com/andhra-pradesh-solar-wind-ppa-bad-precedent>; S. Bajaj, "DISCOMs mandated to maintain Letter of Credit as payment security mechanism to buy power", Mercom India, 29 June 2019, <https://mercomindia.com/discoms-lc-payment-security-mechanism>; S. Bajaj, "Land is still the biggest impediment for large-scale solar development", Mercom India, 13 June 2019, <https://mercomindia.com/land-impediment-large-scale-solar>; S. Bajaj, "Tariff adoption delays are hurting investments and jobs in the solar sector", Mercom India, 15 November 2019, <https://mercomindia.com/tariff-adoption-delays-investments-jobs-solar>; N. Dewan, "Solar revolution? Far from it, says industry", *Economic Times*, 29 October 2019, <https://economictimes.indiatimes.com/small-biz/sme-sector/solar-revolution-far-from-it-says-industry/articleshow/71734062.cms>.
- 46 "2019 Q4 and Annual India Solar Market Update – 7.3 GW installed in CY 2019", op. cit. note 42; Pratheeksha, "India's solar power generation grows slower year-over-year compared to 1H of last year", Mercom India, 19 August 2019, <https://mercomindia.com/india-solar-generation-slower-yoy>.
- 47 A. Parikh, "MNRE warns states: Honor 'must run' status of solar and wind energy", Mercom India, 6 August 2019, <https://mercomindia.com/mnre-states-solar-wind-energy>; Parikh, op. cit. note 45. The MNRE issued a letter on 1 August 2019 calling on all states and territories to accord "must run" status to all wind and solar power projects, but state governments continued to curtail generation, from idem, both sources.
- 48 "2019 Q4 and Annual India Solar Market Update – 7.3 GW installed in CY 2019", op. cit. note 42; R. Ranjan, "Solar power generation up by 12% in the fourth quarter of 2019", 10 February 2020, <https://mercomindia.com/solar-power-generation-fourth-quarter-2019>.
- 49 Figure of 85% from Sanjay, op. cit. note 44, and from "2019 Q4 and Annual India Solar Market Update – 7.3 GW Installed in CY 2019", op. cit. note 42; more than 85% based on data for total capacity added and rooftop installations from sources in India text below. Large-scale projects represented nearly 88% of total operating capacity, from Sanjay, op. cit. note 44, and from 2019 Q4 and Annual India Solar Market Update – 7.3 GW Installed in CY 2019", op. cit. note 42.

- 50 Sanjay, op. cit. note 44.
- 51 Several tenders were undersubscribed due to downwards pressure on bidding and unrealistic expectations, among other factors from, for example, S. Prateek, "Gujarat's 1 GW solar tender undersubscribed by 700 MW, second in a row to get tepid response", Mercom India, 8 May 2019, <https://mercomindia.com/gujarat-1-gw-solar-tender-undersubscribed-700-mw>; S. Prateek, "SECI's CPSU tender for 2 GW of solar projects left undersubscribed by 847 MW", Mercom India, 25 July 2019, <https://mercomindia.com/seci-solar-tender-2gw-undersubscribed>. Other factors in low participation include unreliable auction mechanisms and a costly administrative infrastructure, from P. Mints, SPV Market Research, *The Solar Flare*, no. 3 (28 June 2019), p. 8. Payment delays also increased project risk and reduced participation, and cancelled tenders from Parikh, op. cit. note 46. Cancelled tenders also from N. Kabeer, "Solar auction cancellations need a fix for market sentiment to improve", Mercom India, 25 April 2019, <https://mercomindia.com/solar-auction-cancellations-need-a-fix>; Bajaj, "Tariff adoption delays are hurting investments and jobs in the solar sector", op. cit. note 45; S. Bajaj, "Solar tender, auction & commissioning delays causing liquidity issues for developers", Mercom India, 28 November 2019, <https://mercomindia.com/solar-tender-auction-commissioning-delays-causing-liquidity-issues>.
- 52 Sanjay, op. cit. note 44.
- 53 Rooftop installations were down by 33% in 2019, from Sanjay, op. cit. note 44; "2019 Q4 and Annual India Solar Market Update – 7.3 GW installed in CY 2019", op. cit. note 42; the capacity of new rooftop installations in 2019 was down 7% relative to 2018, from Bridge to India, "India solar rooftop map – December 2019", <https://bridgetoindia.com/report/india-solar-rooftop-map-dec-2019>, viewed 27 April 2020. India's rooftop sector made up 15% of additions in 2019 and 12.4% of year-end capacity, from Sanjay, op. cit. note 44.
- 54 Sanjay, op. cit. note 44. Maharashtra, in particular, has tried to discourage net metering and has proposed a grid support charge for net-metered rooftop systems, from idem. See also S. Prateek, "Corporate segment key driver for rooftop solar: Interview with Manu Karan, CleanMax Solar", Mercom India, 29 May 2019, <https://mercomindia.com/rooftop-solar-interview-manu-karan-cleanmax-solar>; S. Bajaj, "Serious policy push needed to get India's rooftop solar market to the next level", Mercom India, 8 May 2019, <https://mercomindia.com/serious-policy-push-indias-rooftop-solar-market/>; A. Parikh, "Year in Review: 2019 a lost year for India's solar sector", Mercom India, 20 December 2019, <https://mercomindia.com/2019-lost-year-for-india-solar-sector/>; S. Bajaj, "Economic slowdown has taken a toll on Indian rooftop solar market: Solis interview", Mercom India, 4 November 2019, <https://mercomindia.com/economic-slowdown-taken-toll-indian-rooftop-solar-market-solis/>; S. Prateek, "Small rooftop solar companies in India struggle to find viable financing options", Mercom India, 24 January 2019, <https://mercomindia.com/small-rooftop-solar-companies-struggle-viable-financing>.
- 55 Figure of 1.1 GW (direct current) distributed and off-grid installed from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6. An estimated 1,104 MW of rooftop solar capacity was added in 2019, down 33% from 1,655 MW_{ac} in 2018, from "2019 Q4 and Annual India Solar Market Update – 7.3 GW installed in CY 2019", op. cit. note 42, and from Sanjay, op. cit. note 44.
- 56 Prateek, op. cit. note 54; N. Prasad, "Indian Railways has installed 95.67 MW of rooftop solar capacity: Piyush Goyal", Mercom India, 22 November 2019, <https://mercomindia.com/indian-railways-rooftop-solar>; Bajaj, "Serious policy push needed to get India's rooftop solar market to the next level", op. cit. note 54; K. Singh, "Pune has stolen a march over other cities in India's rooftop solar energy race", Quartz India, 6 November 2019, <https://qz.com/india/1742584/pune-has-stolen-a-march-over-other-cities-in-indias-rooftop-solar-energy-race>. Of the total rooftop capacity operating at year's end (5,440 MW), 1,116 MW (20.5%) was commercial, 2,848 MW (52.4%) was industrial, 728 MW (13.4%) was in the public sector, and 748 MW (13.8%) was in the residential sector, from Bridge to India, op. cit. note 53.
- 57 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 12. Japan's market has been trending downwards since 2015, from idem. Down 40% from peak year of 2015 based on 10 GW solar PV capacity installed in 2015, and 6 GW installed in 2019, from data of feed-in tariff scheme, Japanese Ministry of Economy, Trade and Industry (METI), provided by H. Matsubara, ISEP, Tokyo, personal communication with REN21, 14 April 2020.
- 58 E. Bellini, "Japan's fifth solar auction delivers final lowest price of \$0.10/kWh", pv magazine, 27 January 2020, <https://www.pv-magazine.com/2020/01/27/japans-fifth-solar-auction-delivers-final-lowest-price-of-0-10-kwh/>; M. Maisch, "Japan proposes 22% commercial solar FIT cut in latest move to trim costs", pv magazine, 20 February 2019, <https://www.pv-magazine.com/2019/02/20/japan-proposes-22-commercial-solar-fit-cut-in-latest-move-to-trim-costs>; E. Bellini, "Another disappointing solar auction for Japan as prices stay high", pv magazine, 24 January 2019, <https://www.pv-magazine.com/2019/01/24/another-disappointing-solar-auction-for-japan-as-prices-stay-high>; lack of low-cost financial resources from P. Fragkos, E3Modelling, personal communication with REN21, 6 April 2020. The costs of solar PV is higher in Japan than average international levels due primarily to high construction and soft costs, and the risk of curtailment and limited grid capacity are the main reasons for the downwards market trend since 2015, from SolarPower Europe, op. cit. note 1, p. 62. In the Kyushu region, output curtailment continued throughout 2019, although the regional utility introduced a program to reduce curtailment by 9%, from T. Ohigashi and I. Kaizuka, "The beginnings of a post FIT-market", pv magazine, 25 February 2020, <https://www.pv-magazine.com/2020/02/25/the-beginnings-of-a-post-fit-market>.
- 59 Target for 2030 from Masson, op. cit. note 2, 4 May 2020. Figures of 7 GW added for a total of 63 GW are preliminary estimates from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1; and also from RTS Corp, cited in Ohigashi and Kaizuka, op. cit. note 58. In AC, 5.7 GW of capacity was added in 2019 for a year-end total of 54 GW, based on data of grid-connected capacity of utilities, provided by Matsubara, op. cit. note 57.
- 60 ISEP, op. cit. note 11.
- 61 Figures of 530,000 and 2 GW, from METI, https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/008_03_00.pdf (in Japanese), p. 8, viewed 27 April 2020, provided by Matsubara, op. cit. note 57, 27 April 2020; self-consumption and net zero from idem. See also J. Movella, "End of the residential FIT in Japan. Post FIT RECs go to RE100 companies", Renewable Energy World, 19 November 2019, <https://www.renewableenergyworld.com/2019/11/19/end-of-the-residential-fit-in-japan-post-fit-recs-go-to-re100-companies>; Ohigashi and Kaizuka, op. cit. note 58.
- 62 Movella, op. cit. note 61.
- 63 See, for example: GlobalData Energy, "Vietnam's solar drive", Power Technology, 30 July 2019, <https://www.power-technology.com/comment/vietnam-solar-drive>; S. Djunicic, "B.Grimm brings online 677 MW of solar in Vietnam", Renewables Now, 17 June 2019, <https://renewablesnow.com/news/bgrimm-brings-online-677-mw-of-solar-in-vietnam-658285>; M. Maisch, "Vietnam overtakes Australia for commissioned utility scale solar following June FIT rush", pv magazine, 5 July 2019, <https://www.pv-magazine.com/2019/07/05/vietnam-overtakes-australia-for-commissioned-utility-scale-solar-following-june-fit-rush>; T. Kenning, "Close to 90 solar projects 'sprinting' for Vietnam's June FiT deadline", PV-Tech, 20 May 2019, <https://www.pv-tech.org/news/close-to-90-solar-projects-sprinting-for-vietnams-june-fit-deadline>.
- 64 E. Bellini, "Vietnam to stop licensing large-scale solar projects", pv magazine, 19 December 2019, <https://www.pv-magazine.com/2019/12/19/vietnam-to-stop-licensing-large-scale-solar-projects>. A total of 8.93 GW of utility-scale capacity had been approved for development by year's end, from Ministry of Industry and Trade, cited in idem. By one account, more than 4.3 GW were added in a mere 11 weeks, from Maisch, op. cit. note 63.
- 65 Figure of 4.8 GW added in 2019 for a total of 4.9 GW, based on preliminary data for IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Vietnam's additions in 2018 and 2017 from Maisch, op. cit. note 63. Vietnam ended 2018 with 106 MW and 2019 with 5,695 MW, meaning annual additions in 2019 of 5,589 MW, based on data from IRENA, op. cit. note 44.
- 66 To meet rising demand and figure of 10% from E. Bellini, "Vietnam introduces auction scheme for large-scale PV", pv magazine, 5 December 2019, <https://www.pv-magazine.com/2019/12/05/vietnam-introduces-auction-scheme-for-large-scale-pv>; population growth and economic expansion from GlobalData Energy, op. cit. note 63.
- 67 Post June from Kenning, op. cit. note 63; in December from Bellini, op. cit. note 64.

- 68 List of countries and preliminary data for Republic of Korea (added 3,109 MW for a total of 11,208 MW), Chinese Taipei (1,411 MW; 4,149 MW), Pakistan (1,300 MW; 3,420 MW), Malaysia (562 MW; 1,552 MW) and Kazakhstan (500 MW; 709 MW), all from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Numbers were significantly different for Pakistan (160 MW added for total of 1,329 MW), Malaysia (346 MW; 882 MW) and Kazakhstan (333 MW; 542 MW), based on data for end-2018 and end-2019, from IRENA, op. cit. note 44.
- 69 "Your guide to solar market growth in the global 'gigawatt club'", pv magazine, 18 January 2020 <https://pv-magazine-usa.com/2020/01/18/your-guide-to-solar-market-growth-in-the-global-gigawatt-club>.
- 70 Pakistan's additions are preliminary data from Becquerel Institute, op. cit. note 1. Pakistan's year-end total was about 5 GW, from A. Jäger-Waldau, EC, personal communication with REN21, 10 April 2020, and was 1.3 GW, from IRENA, op. cit. note 44.
- 71 Decline in 2019 and Turkey installed an estimated 932 MW for a total of 8,080 MW from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, pp. 6, 9, and from Becquerel Institute, op. cit. note 1; decline of 37% in 2018 from SolarPower Europe, "Strong solar growth in Europe, Germany largest market", press release (Brussels: 20 February 2019), <http://www.solarpowereurope.org/eu-solar-market-grows-36-in-2018>; reasons for 2019 decline from "Your guide to solar market growth in the global 'gigawatt club'", op. cit. note 69; E. Bellini, "Turkey introduces net metering for residential PV and new rules for unlicensed solar", pv magazine, 20 May 2019, <https://www.pv-magazine.com/2019/05/20/turkey-introduces-net-metering-for-residential-pv-and-new-rules-for-unlicensed-solar>. Turkey installed an estimated 923 MW in 2019, for a cumulative total of almost 6 GW, from J. Martín, "Turkish solar eyes 1GW-a-year growth after nearing cumulative 6GW", PV-Tech, 20 January 2020, <https://www.pv-tech.org/news/turkish-solar-eyes-1gw-a-year-growth-after-nearing-cumulative-6gw>.
- 72 Bellini, op. cit. note 71.
- 73 **Bangladesh** held at least one tender, from A. Bhambhani, "Bangladesh Power Development Board issues re-tender for 100 MW solar power development near Chuadanga & Netrokona substations; August 7, 2019 last date to submit bids", *TaiyangNews*, 10 July 2019, <http://taiyangnews.info/business/bangladesh-solar-pv-tender-for-2x50-mw>. Bangladesh also has several large-scale projects in the pipeline, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 30; Cambodia secured a record-low bid for Southeast Asia in a tender, from M. Hall, "Cambodia tender secures lowest solar power price in Southeast Asia", pv magazine, 6 September 2019, <https://www.pv-magazine.com/2019/09/06/cambodia-tender-secures-lowest-solar-power-price-in-southeast-asia>; **Mongolia** had a 30 MW plant come online in 2019, from SENS Energy, "Sainshand, Mongolia", STEAG Solar Energy Solutions, <https://www.sens-energy.com/en/portfolio/sainshand-mongolei>, viewed 10 April 2020; **Pakistan** launched a request for prequalification for a 40 MW tender, from A. Bhambhani, "Uzbekistan to tender 900 MW PV under PPP model", *TaiyangNews*, 22 October 2019, <http://taiyangnews.info/markets/uzbekistan-to-tender-900-mw-pv-under-ppp-model>; UNIDO tendered for a hybrid solar PV-storage-diesel project in the **Philippines**, from E. Bellini, "Aquavoltaics in the Philippines", pv magazine, 13 August 2019, <https://www.pv-magazine.com/2019/08/13/aquavoltaics-in-the-philippines>; **Singapore** launched a floating solar tender, from M. Hall, "Singapore preps SE Asia's 'largest public floating solar tender'", pv magazine, 4 July 2019, <https://www.pv-magazine.com/2019/07/04/singapore-preps-se-asias-largest-public-floating-solar-tender>; **Uzbekistan** signed a mandate with the International Finance Corporation to tender solar PV capacity under the World Bank's Scale Solar Program, from Bhambhani, op. cit. this note.
- 74 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 75 Ukraine added about 3.5 GW for a total of 4,840 MW, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, pp. 6, 12, and from Becquerel Institute, op. cit. note 1; first time over 1 GW and feed-in tariff, from SolarPower Europe, op. cit. note 1, p. 18. Ukraine commissioned a total of 3,537.3 MW in 2019 for cumulative capacity of 4,925 MW, and the cumulative capacity of residential solar PV installations reached 550 MW, from Ukrainian Wind Energy Association, *Wind Power Sector of Ukraine 2019* (Kyiv: February 2020), p. 18. The boom in installations was driven by a scheduled 25% reduction in the "green" tariff rate for solar power plants, from idem. Ukraine third in Europe from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6. Russian Federation from E. Bellini, "Russia's largest PV plant comes online", pv magazine, 22 May 2019, <https://www.pv-magazine.com/2019/05/22/russias-largest-pv-plant-comes-online>; the Russian Federation also commissioned a 60 MW project in the Astrakhan region, from T. Kenning, "Hevel commissions 60MW solar plant in Astrakhan, Russia", PV-Tech, 1 March 2019, <https://www.pv-tech.org/news/hevel-commissions-60mw-solar-plant-in-astrakhan-russia>.
- 76 Close to 16 GW added in the EU from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, pp. 6, 8. Figures of 16 GW and close to 131.7 GW (and data for EU not including the United Kingdom) are based on preliminary data from idem, and from Becquerel Institute, op. cit. note 1. The EU added 15,634.9 MW in 2019 for a year-end total of 130.7 GW (accounting for decommissioned capacity), and generation in 2019 was 131.8 TWh (up from 122.936 TWh in 2018), from EurObserv'ER, op. cit. note 1, pp. 2, 5, 7. Additions in 2018 from SolarPower Europe, *EU Market Outlook for Solar Power, 2019-2023* (Brussels: 2019), p. 6, <https://www.solarpowereurope.org/eu-market-outlook-for-solar-power-2019-2023>.
- 77 Self-consumption and corporate sourcing from SolarPower Europe, op. cit. note 76, p. 6; C. Gilligan, "A new era of sustained growth", pv magazine, 16 January 2020, <https://www.pv-magazine.com/2020/01/16/a-new-era-of-sustained-growth>; government targets through tenders from SolarPower Europe, op. cit. note 76, pp. 6, 12, 82-83; SolarPower Europe, "EU solar boom: Over 100% solar market increase in 2019", press release (Brussels: 10 December 2019), <https://www.solarpowereurope.org/eu-solar-boom-over-100-solar-market-increase-in-2019>.
- 78 All challenges except land availability from Gilligan, op. cit. note 77; land availability from, for example, "Your guide to solar market growth in the global 'gigawatt club'", op. cit. note 69; land availability and grid constraints from SolarPower Europe, op. cit. note 76, pp. 50, 76; *Dutch Solar Energy Market Seeking Space to Grow Further*, prepared for The Solar Future NL, Utrecht, 8-9 July 2020, <https://thesolarfuture.nl/nieuws-source/2020/3/2/dutch-solar-energy-market-seeking-space-to-grow-further>; Mints, *The Solar Flare*, op. cit. note 22, p. 28.
- 79 Figures 26 of 28 and three-fourths from SolarPower Europe, op. cit. note 76, p. 6. Note that all EU countries added at least some capacity in 2019 – although less than 10 MW each in Latvia (1 MW), Croatia (6 MW) and the Slovak Republic (7 MW) – and additions in the top five countries accounted for 77% of the EU total, based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 80 Country rankings and data for the Netherlands (estimated 2,400 MW), France (915 MW) and Poland (estimated 800 MW) from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. **France** added 889 MW of capacity in solar parks for a year-end total of 9,435 MW, from Le réseau de transport d'électricité (RTE), *Bilan Électrique 2019* (Paris: January 2020), p. 55, https://www.rte-france.com/sites/default/files/bilan-electrique-2019_0.pdf; added 890 MW for a total of 9,436 MW, from C. Rollet, "France installed 890 MW of solar in 2019", pv magazine, 11 February 2020, <https://www.pv-magazine.com/2020/02/11/france-installed-890-mw-of-solar-in-2019>, and connected 965.6 MW (and decommissioned 5.1 MW) for a total of 10,575.9 MW, from EurObserv'ER, op. cit. note 1, p. 11. **The Netherlands** added 2.3 GW to 2.5 GW in 2019 and France added 1,068 MW, from SolarPower Europe, op. cit. note 76, pp. 6, 49. **Poland** added 784 MW, from SolarPower Europe, op. cit. note 77.
- 81 The Netherlands from SolarPower Europe, op. cit. note 76, pp. 9, 11. The Netherlands' rooftop market included residential and commercial and industrial uses; the commercial rooftop market was the largest segment, at about 40%, from idem., pp. 9, 49. Poland's market quadrupled based on 203 MW installed in 2018, from SolarPower Europe, op. cit. note 76, p. 10; rising incentives and extension of net metering in Poland from E. Bellini, "Poland tops 1.3 GW of PV capacity", pv magazine, 14 January 2020, <https://www.pv-magazine.com/2020/01/14/poland-tops-1-3-gw-of-pv-capacity>.
- 82 Based on data from SolarPower Europe, op. cit. note 76, p. 11; preliminary estimates from IEA PVPS, *Snapshot of Global PV*

- Markets 2020*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, 20 March 2020, and data for 2018 from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 96. Poland also passed 1 GW cumulative capacity in 2019, from EurObserv'ER, op. cit. note 1, p. 6.
- 83 SolarPower Europe, op. cit. note 76, p. 11. Italy added about 0.6 GW for a total of 20.8 GW, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, pp. 8, 10, and from Becquerel Institute, op. cit. note 1; and added 737 MW, a near-69% increase over the 437 MW added in 2018, for a total of 20.9 GW at the end of 2019, from Italian renewables association Anie Rinnovabili and grid operator Terna, cited in Bellini, op. cit. note 19. For more on Italy, see E. Bellini, "Italy has 80 MW/168 MWh of storage linked to renewables", pv magazine, 2 October 2019, <https://www.pv-magazine.com/2019/10/02/italy-has-80-mw-168-mwh-of-storage-linked-to-renewables>.
- 84 Based on additions of 4,752 MW for a total of 9,913 MW, from Carlos De Sande, Unión Española Fotovoltaica (UNEF), Madrid, personal communication with REN21, 28 May 2020. UNEF numbers are based on data from the Spanish system operator RED Eléctrica de España (additions of 4,201 MW for total of 8,913 MW), which are in DC and for utility-scale plants only, plus UNEF's estimates of solar PV capacity for self-consumption. See also RED Eléctrica de España, "Potencia instalada nacional (MW) - nacional", data as of April 2020, <https://www.ree.es/es/datos/publicaciones/series-estadisticas-nacionales>. Additions in 2018 based on 288 MW from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 97, on 235 MW, from S. Letón, "Solar panel systems soar in Spain thanks to friendlier regulation", *El País*, 25 June 2019, https://elpais.com/elpais/2019/06/24/inenglish/1561389834_185650.html, and on 108 MW, from Becquerel Institute, op. cit. note 1, 28 May 2020.
- 85 Mostly tendered projects and to meet EU obligations from Masson, op. cit. note 2, 4 May 2020. Tendered projects, PPAs et al. from SolarPower Europe, op. cit. note 76, pp. 9, 14, 45; J. Parnell, "The Spanish solar market has reawakened, but not every project with a grid-connection approval will get built", GTM, 15 October 2019, <https://www.greentechmedia.com/articles/read/spain-grid-connects-more-solar-in-2019-than-last-decade-combined>; J. Deign, "Spain's other solar boom: Distributed systems for self-consumption", GTM, 3 March 2020, <https://www.greentechmedia.com/articles/read/spain-goes-from-zero-to-hero-on-solar-self-consumption>. Interest in PPAs or sale into wholesale market is due to the fact that spot market prices generally are above the LCOE of solar generation in Spain, from J. Deign, "Spain moves to prevent a second solar bubble", GTM, 15 August 2019, <https://www.greentechmedia.com/articles/read/spain-tightens-rules-for-solar-as-second-bubble-looms>, and to unwillingness by some investors to participate in auctions given retroactive policy changes of 2013, from J. Deign, "Spain grid-connects more solar in 2019 than last decade combined", GTM, 15 October 2019, <https://www.greentechmedia.com/articles/read/spain-grid-connects-more-solar-in-2019-than-last-decade-combined>. See also EurObserv'ER, op. cit. note 1, pp. 6-8.
- 86 About 1 GW of capacity was in place for self-consumption by early 2020, most of it for small commercial, industrial and public sector consumers as barriers remain for residential customers, from Deign, "Spain's other solar boom", op. cit. note 85. An estimated 459 MW of new capacity was added for self-consumption (of which about 10% was estimated to be off-grid), with most of this in the industrial sector, followed by the commercial sector and then the residential sector, from UNEF, "The new regulation boosts the deployment of self-consumption in Spain", 11 February 2020, <https://unef.es/2020/02/the-new-regulation-boosts-the-deployment-of-self-consumption-in-spain>. Despite removal of the so-called Sun Tax in Spain, several retroactive measures placed on solar PV owners were to remain in place; some of these measures reduced revenues to solar PV system owners by as much as 50%, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 16.
- 87 SolarPower Europe, op. cit. note 76, p. 13.
- 88 J. Deign, "Spain moves to prevent a second solar bubble", op. cit. note 85.
- 89 Based on 2,888 MW added in 2018 (year-end totals of 42,293 MW at end-2017 and 45,181 MW at end-2018), and 3,835 MW added in 2019 based on end-2019 total of 49,016 MW, from German Federal Ministry for Economic Affairs and Energy and AGEE-Stat, op. cit. note 11, p. 7. Germany added 3.94 GW for a total of 49.78 GW, from German network operator, cited in S. Enkhardt, "Germany added almost 4 GW of PV in 2019", pv magazine, 31 January 2020, <https://www.pv-magazine.com/2020/01/31/germany-added-almost-4-gw-of-pv-in-2019>; added 3.9 GW for a total of 49.2 GW, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 10; and added 3,856 MW (decommissioned 21 MW) for a total of 49,016 MW, from EurObserv'ER, op. cit. note 1, pp. 6, 8-9. The year 2019 was the third year running with a significant increase in new installations, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 8.
- 90 SolarPower Europe, op. cit. note 76, p. 9.
- 91 Bundesverband Solarwirtschaft e.V. (BSW-Solar), "Nearly 100.000 new PV prosumers in Germany", press release (Berlin: 30 March 2020), <https://www.solarwirtschaft.de/en/2020/03/30/nearly-100-000-new-pv-prosumers-in-germany>.
- 92 M. Keijser, "In Germany, solar-powered homes are really catching on", *Wired*, 25 March 2019, <https://www.wired.com/story/in-germany-solar-powered-homes-are-catching-on>. Another source says that there were about 180,000 solar power storage units installed by the end of 2019, from BSW-Solar, "Statistische Zahlen der Deutschen – Solarstrombranche (Photovoltaik)", March 2020, https://www.solarwirtschaft.de/datawall/uploads/2020/04/bsw_faktenblatt_photovoltaik.pdf.
- 93 Goal from SolarPower Europe, op. cit. note 76, p. 47, and from S. Enkhardt, "German government wants 98 GW of solar by 2030", pv magazine, 9 October 2019, <https://www.pv-magazine.com/2019/10/09/german-government-wants-98-gw-of-solar-by-2030>; removal of cap was still under discussion at year's end, from S. Hermann, German Environment Agency, personal communication with REN21, 12 April 2020. The cap is the level at which FIT payments to new systems (with capacity up to 750 kW) will stop; the country is expected to pass the 52 GW mark during 2020, from S. Enkhardt, "Germany lifts cap on solar FIT program with new Climate Change Act", pv magazine, 23 September 2020, <https://www.pv-magazine.com/2019/09/23/germany-lifts-cap-on-solar-fit-program-in-climate-change-act>. Germany's coalition government decided to lift the cap in May 2020, from J. Parnell, "Onshore wind compromise averts German solar market crisis", GTM, 18 May 2020, <https://www.greentechmedia.com/articles/read/onshore-wind-policy-dispute-could-decimate-germanys-distributed-solar-industry>.
- 94 Solar PV gross generation increased from 45.784 billion kWh in 2018 to 47.517 billion kWh in 2019, and accounted for 8.2% of Germany's electricity generation in 2019 (up from 7.7% in 2018), from Federal Ministry for Economic Affairs and Energy and AGEE-Stat, op. cit. note 11, pp. 6, 44, 45. Share of generation in 2019 was 9%, based on 46.54 TWh of solar PV generation out of a total 513.76 TWh during 2019, from Fraunhofer ISE, "Annual electricity generation in Germany in 2019", <https://www.energy-charts.de/energy.htm?source=all-sources&period=annual&year=2019>, updated 1 February 2020. Note that Fraunhofer ISE takes account only of electricity fed into the grid and does not include self-consumption, from Hermann, op. cit. note 93. Solar PV generated 46.7 TWh, or around 8% of Germany's gross electricity consumption, from BSW-Solar, op. cit. note 92. An estimated 11% of total solar PV generation (about 5.3 TWh) was attributable to self-consumption, from EurObserv'ER, op. cit. note 1, p. 9.
- 95 UK Department for Business, Energy & Industrial Strategy (BEIS), "Solar photovoltaics deployment in the UK", <https://www.gov.uk/government/statistics/solar-photovoltaics-deployment>, updated 30 January 2020; L. Stoker, "UK government confirms plan to end key rooftop solar support", PV-Tech, 18 December 2018, <https://www.pv-tech.org/news/uk-government-confirms-plan-to-end-key-rooftop-solar-support>. Plans for a new scheme were related in June with expectations that it would be launched in January 2020, from J. Thornhill, "Under new rules for selling solar power, is it still worth it?" *The Guardian* (UK), 30 June 2019, <https://www.theguardian.com/money/2019/jun/30/solar-panels-smart-export-guarantee-is-it-still-worth-it>.
- 96 J. Ambrose, "Home solar panel installations fall by 94% as subsidies cut", *The Guardian* (UK), 5 June 2019, <https://www.theguardian.com/environment/2019/jun/05/home-solar-panel-installations-fall-by-94-as-subsidies-cut>. See also A. Vaughan, "Solar households expected to give away power to energy firms", *The Guardian* (UK), 18 December 2018, <https://www.theguardian.com/business/2018/dec/18/solar-power-energy-firms-government>.

- 97 I. Tsagas, "Brexit paralysis and lack of incentives leave community energy facing uphill struggle in the UK", pv magazine, 16 September 2019, <https://www.pv-magazine.com/2019/09/16/brexit-paralysis-and-lack-of-incentives-leave-community-energy-facing-uphill-struggle-in-the-uk>.
- 98 Slowest year since 2010 from E. Bellini, "Official statistics show UK deployed just 233 MW of PV in 2019", pv magazine, 31 January 2020, <https://www.pv-magazine.com/2020/01/31/official-statistics-show-uk-deployed-just-233-mw-of-pv-in-2019>; also based on data from UK BEIS, op. cit. note 95, updated 27 February 2020. Annual additions and year-end total based on end-2018 capacity of 13,125 MW and end-2019 capacity of 13,398.3 MW (net increase of 273.3 MW), and data for earlier years, all from idem. Note that the official statistics are based on incomplete datasets that do not include unsubsidised systems with capacity below 1 MW that are not registered on the UK Microgeneration Certification Scheme database, from idem; also, the UK's Solar Trade Association says the market is stable and recovering, from Bellini, op. cit. this note. The UK added 497.7 MW in 2019 for a total of 13,616 MW, from EurObserv'ER, op. cit. note 1, p. 6.
- 99 F. Colville, "UK solar market to return to gigawatt demand status next year", PV-Tech, 3 December 2019, <https://www.pv-tech.org/editors-blog/uk-solar-market-to-return-to-gigawatt-demand-status-next-year>.
- 100 SolarPower Europe, op. cit. note 76, p. 13, 83. See also C. Rollet and S. Enkhardt, "Private solar PPAs signed in France and Germany", pv magazine, 4 December 2019, <https://www.pv-magazine.com/2019/12/04/private-solar-ppas-signed-in-france-and-germany>; E. Bellini, "PPA-linked solar park comes online in Sweden", pv magazine, 22 July 2019, <https://www.pv-magazine.com/2019/07/22/ppa-linked-solar-park-comes-online-in-sweden>.
- 101 SolarPower Europe, op. cit. note 76, p. 13; "Pan-European contract template unlocks financing for solar, wind", New Energy Update, 3 July 2019, <https://analysis.newenergyupdate.com/pv-insider/pan-european-contract-template-unlocks-financing-solar-wind>.
- 102 J. Deign, "New ground: Spanish firm signs PPA for crowdfunded solar plant", GTM, 11 June 2019, <https://www.greentechmedia.com/articles/read/spanish-firm-signs-ppa-for-crowdfunded-solar-plant>; "Europe solar investors adapt contracts to supply smaller, riskier firms", New Energy Update, 20 March 2019, <http://newenergyupdate.com/pv-insider/europe-solar-investors-adapt-contracts-supply-smaller-riskier-firms>.
- 103 S. Enkhardt, "Europe has now 8.4 GW of planned and built PV projects under PPAs", pv magazine, 29 January 2020, <https://www.pv-magazine.com/2020/01/29/europe-has-now-8-4-gw-of-planned-and-built-pv-projects-under-ppas>. Other European countries with PPAs in place include Portugal (444 MW), Denmark (338 MW), France (158 MW), Ukraine (44 MW), Poland (35 MW), Sweden (16 MW) and the United Kingdom (6 MW), from idem. See also EurObserv'ER, op. cit. note 1, p. 11.
- 104 America's share based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. **Figure 31** based on IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and on country-specific data and sources provided throughout this section (or see endnote for Reference Table R16).
- 105 Solar Energy Industries Association (SEIA) and Wood Mackenzie, *U.S. Solar Market Insight, 2019 Year in Review – Executive Summary* (Washington, DC: March 2020), p. 5, <https://www.woodmac.com/research/products/power-and-renewables/us-solar-market-insight>. The United States added an estimated 9,114.4 MW (3,663.7 MW of small-scale plus 5,450.7 MW of utility-scale facilities) of solar PV capacity in 2019, for a total of 58,782 MW at end-2019, from EIA, op. cit. note 12, Table 6.1. These data omit capacity from facilities with a total generator nameplate capacity less than 1 MW, from idem. US EIA reports solar PV capacity in AC because US electricity operations and sales generally are conducted on an AC basis, from Marcy, op. cit. note 1.
- 106 SEIA and Wood Mackenzie, op. cit. note 105, p. 5. If counting only capacity additions, solar PV accounted for 37% based on total wind power additions of 9,166.8 MW, followed by solar PV (9,114.4 MW), geothermal (14.8 MW), natural gas (net of 6,347.9 MW) and other (47.9 MW), all from US EIA, op. cit. note 12, Table 6.1. Note that more power capacity was taken offline (mostly coal-fired) in the country during 2019 than was added, from idem.
- 107 SEIA and Wood Mackenzie, op. cit. note 105, p. 10. California added 3,124.6 MW, Texas added 1,381.2 MW, and Florida added 1,377.1 MW, from idem.
- 108 D. Kovaleski, "Hawaiian Electric reports record increase in solar capacity", Daily Energy Insider, 21 January 2020, <https://dailyenergyinsider.com/news/23902-hawaiian-electric-sees-record-increase-in-solar-capacity>; followed by California and Arizona includes projects with up to 1 MW capacity, from W. Driscoll, "Ten sunniest US states added 1.8 GW of small-scale solar in 2019, as solar advocates press for more", pv magazine, 10 February 2020, <https://pv-magazine-usa.com/2020/02/10/ten-sunniest-us-states-added-1-8-gw-of-small-scale-solar-in-2019-as-solar-advocates-press-for-more>.
- 109 Preliminary utility-scale data from US EIA, "Frequently asked questions: What is U.S. electricity generation by energy source?" <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3>, updated 27 February 2020, and from US EIA, op. cit. note 12, Table 1.1.A. Generation from smaller-scale (mostly rooftop) systems based on 69 TWh of utility-scale generation from idem, both sources, and on generation from all solar PV facilities of 104.057 GWh in 2019, based on data from US EIA, op. cit. note 12, Tables 1.17.B and 1.3.B.
- 110 SEIA and Wood Mackenzie, op. cit. note 105, p. 5.
- 111 Ibid., p. 9.
- 112 Ibid., pp. 5, 6, 8, 14.
- 113 Ibid., pp. 7, 12; J. Spector and E. F. Merchant, "Fast times for the US residential solar market", GTM, 21 November 2019, <https://www.greentechmedia.com/articles/read/the-latest-trends-in-residential-solar-q3>; I. Ivanova, "After PG&E blackout, California homeowners shift to solar and batteries", CBS News, 21 October 2019, <https://www.cbsnews.com/news/after-pg-e-blackouts-california-homeowners-move-to-solar-and-batteries>; L. Milford, "California power shut-offs drive customers to solar and storage", Renewable Energy World, 8 November 2019, <https://www.renewableenergyworld.com/2019/11/08/california-power-shut-offs-drive-customers-to-solar-and-storage>.
- 114 K. Misbrenner, "California celebrates 1 million solar roofs", Solar Power World, 13 December 2019, <https://www.solarpowerworldonline.com/2019/12/california-solar-industry-celebrates-1-million-solar-roofs-sets-new-goal-for-storage>; J. Daniels, "California clears final hurdle for state's landmark solar panel mandate for new homes", CNBC, 6 December 2018, <https://www.cnbc.com/2018/12/06/california-clears-final-hurdle-for-state-solar-mandate-for-new-homes.html>; J. Pyper, "U.S. Department of Energy announces winners of Solar Prize and two new innovative solar initiatives", 25 September 2019, <https://www.energy.gov/eere/solar/articles/us-department-energy-announces-winners-solar-prize-and-two-new-innovative-solar>.
- 115 The programme was first launched in 2015 and operated through 2016; it was redesigned and relaunched in September 2019, from US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), "National Community Solar Partnership (FY2016)", <https://www.energy.gov/eere/solar/national-community-solar-partnership-fy2016>, viewed 28 April 2020, and from DOE, EERE, "U.S. Department of Energy announces winners of Solar Prize and two new innovative solar initiatives", 25 September 2019, <https://www.energy.gov/eere/solar/articles/us-department-energy-announces-winners-solar-prize-and-two-new-innovative-solar>.
- 116 SEIA and Wood Mackenzie, op. cit. note 105, p. 16; Solar ITC information from "Solar pipelines soar in new global markets; US lawmakers call for 30% ITC extension", New Energy Update, 31 July 2019, <https://analysis.newenergyupdate.com/pv-insider/solar-pipelines-soar-new-global-markets-us-lawmakers-call-30-itc-extension>; Bolinger, Seel and Robson, op. cit. note 1, p. 8; E. Merchant, "US solar industry braces for ITC stepdown while making the case for another extension", GTM, 14 May 2019, <https://www.greentechmedia.com/articles/read/solar-industry-makes-case-for-itc-extension-as-it-preps-for-phasedown>; Mints, *The Solar Flare*, op. cit. note 2, p. 22.
- 117 Stockpiled to take advantage of ITC from P. Mints, SPV Market Research, *The Solar Flare*, no. 1 (28 February 2020), p. 12; B. Eckhouse, "U.S. solar companies are stockpiling a massive amount of panels", *Bloomberg*, 13 November 2019, <https://www.bloomberg.com/news/articles/2019-11-12/u-s-solar-companies-are-stockpiling-a-massive-amount-of-panels>; installers at capacity from D. Renné, International Solar Energy Society, Boulder, CO, personal communication with REN21, 23 March 2020.

- 118 "Solar projects shoot up in US Midwest farm belt", New Energy Update, 16 January 2020, <https://analysis.newenergyupdate.com/pv-insider/solar-projects-shoot-us-midwest-farm-belt>.
- 119 SEIA and Wood Mackenzie, op. cit. note 105, p. 16. Of the 48,118 MW under contract, 9,988 MW was under construction by end-2019, from idem, p. 17.
- 120 Ibid., p. 16.
- 121 E. Merchant, "Corporate renewables procurement accounted for nearly a quarter of all deals in 2018", GTM, 5 February 2019, <https://www.greentechmedia.com/articles/read/corporate-renewables-procurements-quarter-ppa-2018>. See also N. Ford, "Microsoft's record solar purchase lowers risks for smaller offtakers", New Energy Update, 11 April 2018, <http://analysis.newenergyupdate.com/pv-insider/microsofts-record-solar-purchase-lowers-risks-smaller-offtakers>, and E. Merchant, "Bloomberg, Gap, Salesforce join others to spearhead novel small-scale solar deal", GTM, 28 January 2019, <https://www.greentechmedia.com/articles/read/bloomberg-gap-salesforce-aggregation-solar-deal>.
- 122 "US to install record 12.6 GW utility-scale PV in 2020; Los Angeles to buy solar at under \$20/MWh", New Energy Update, 18 September 2019, <https://analysis.newenergyupdate.com/pv-insider/us-install-record-126-gw-utility-scale-pv-2020-los-angeles-buy-solar-under-20mwh>. Solar-plus-storage projects began in the US Southwest and are spreading now to northern states, from idem.
- 123 Number of projects from "Trailblazing PV-storage contract shows growing dispatch skills", New Energy Update, 12 February 2020, <https://analysis.newenergyupdate.com/pv-insider/traiblazing-pv-storage-contract-shows-growing-dispatch-skills>. For comparison, note that seven utility-scale solar PV-plus-battery storage projects came online in 2018, from Bolinger, Seel and Robson, op. cit. note 1, p. ii. As of early 2020, the California Independent System Operator had a queue of active requests for 14.5 GW of solar PV, 10.5 GW of solar PV with storage as a secondary source of generation 14.9 GW of solar PV with storage with solar PV as the secondary source, and 16 GW of energy storage with no secondary source of generation, all from R. Canonica and K. Micek, "Rapid renewables growth brings challenges for US states: Part I – California", S&P Global Platts, 8 April 2020, <https://www.spglobal.com/en/research-insights/articles/rapid-renewables-growth-brings-challenges-for-us-states-part-i-california>. See also LBNL, "Hybrid power plants are growing rapidly: Are they a good idea?" 13 March 2020, <https://emp.lbl.gov/news/hybrid-power-plants-are-growing-rapidly-are>.
- 124 G. Barbose and N. Darghouth, *Tracking the Sun, Pricing and Design Trends for Distributed Photovoltaic Systems in the United States 2019 Edition* (Berkeley, CA: LBNL, October 2019), p. 2, https://emp.lbl.gov/sites/default/files/tracking_the_sun_2019_report.pdf; Milford, op. cit. note 113; Ivanova, op. cit. note 113.
- 125 Challenging economic conditions (among top solar installers) in Argentina and Brazil, in particular, from I. Sagardoy, Fundación Bariloche, personal communication with REN21, April 2020; F. Sabadini, RWTH – Aachen, personal communication with REN21, 1 April 2020; abundance of solar resources from M. Dorothal, "Top 30 Latin American solar PV plants (2018 update)", Unlocking Solar Capital, 22 May 2018, <https://lac.unlockingsolarcapital.com/news-english/2018/5/22/top-30-latin-american-solar-pv-plants-2018-update>; cost/price reductions are driving decisions, from E. Cruz, Climate Finance Solutions, personal communication with REN21, 13 April 2020; favourable political climates from Dorothal, op. cit. this note; favourable until 2019 from Sagardoy, op. cit. this note. Note that in 2019, Mexico cancelled its fourth long-term auction, which had already been announced, as well as tenders to two transmission lines; 2019 medium-term auctions were cancelled as well, from IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), p. 17, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_RE-Auctions_Status-and-trends_2019.pdf.
- 126 Brazil from ABSOLAR, "Infográfico ABSOLAR – Energia solar fotovoltaica no Brasil", 15 April 2020, <http://www.absolar.org.br/infografico-absolar.html>, viewed 20 April 2020. Mexico based on the following: year-end 2018 capacity of 3,075 MW, from Mexican Solar Energy Association (ASOLMEX), cited in J. Zarco, "Mexico reaches 4 GW milestone", pv magazine, 20 June 2019, <https://www.pv-magazine.com/2019/06/20/mexico-reaches-4-gw-milestone>; total of 5,000 MW capacity at end-2019 from ASOLMEX, cited in E. Mariano, "Energía Solar crece 62% en México: Asolmex", Energy and Commerce, 20 January 2020, <https://energyandcommerce.com.mx/energia-solar-crece-62-en-mexico-asolmex> (using Google Translate); total of 5,151 MW (4,333 MW of centralised capacity and 818 MW of distributed capacity), as of January 2020, from ASOLMEX, cited in J. Zarco, "Los números, las cifras de una energía que ilumina la República Mexicana", pv magazine, 12 February 2020, <https://www.pv-magazine-mexico.com/2020/02/12/los-numeros-las-cifras-de-una-energia-que-ilumina-la-republica-mexicana> (using Google Translate); and an estimated 1 GW in 2019 is preliminary data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6. Argentina from Becquerel Institute, op. cit. note 1, 20 March 2020.
- 127 J. Martín, "All systems go for Colombia's largest PV plant to date", PV-Tech, 8 April 2019, <https://www.pv-tech.org/news/all-systems-go-for-colombias-largest-pv-plant-to-date>; C. Rollet, "Neoen commissions a 51.5 MWp photovoltaic park in Jamaica", pv magazine, 4 October 2019, <https://www.pv-magazine.fr/2019/10/04/neoen-met-en-service-un-parc-photovoltaique-de-515-mwc-en-jamaique>; C. Rollet, "Solar delivers cheapest power in Jamaica", pv magazine, 4 October 2019, <https://www.pv-magazine.com/2019/10/04/solar-delivers-cheapest-power-in-jamaica>.
- 128 Argentina, Chile, Colombia and Ecuador from E. H. Gallego and N. G. Espinosa, "Latin America renewable energy: calls for public bids", GreenbergTraurig, 27 August 2019, <https://www.gtlaw.com/en/insights/2019/8/convocatorias-en-materia-de-energias-renovables-en-latinoamerica>; J. Martín, "Second tender inclusion sets Brazil's PV for three-year bonanza", PV-Tech, 10 May 2019, <https://www.pv-tech.org/news/second-tender-inclusion-sets-brazils-pv-for-three-year-bonanza>; Ecuador also from J. Martín, "Ecuador seeks developers of 200MW solar plant", PV-Tech, 31 July 2019, <https://www.pv-tech.org/news/ecuador-seeks-developers-of-200mw-solar-plant>; Bellini, "Guatemala launches tender for 110 MW solar project", pv magazine, 3 May 2019, <https://www.pv-magazine.com/2019/05/03/guatemala-launches-tender-for-110-mw-solar-project>; New Energy Events, "Jamaica issues call for tenders for solar and energy storage project", 31 January 2019, <http://newenergyevents.com/jamaica-issues-call-for-tenders-for-solar-and-energy-storage-project>. Colombia also from Office of the President, Government of Colombia, "Con nueva subasta, Gobierno Nacional superó en más del 50% la meta en energías renovables", <https://id.presidencia.gov.co/Paginas/prensa/2019/Con-nueva-subasta-Gobierno-Nacional-supero-en-mas-del-50-la-meta-en-energias-renovables-191022.aspx> (using Google Translate), from E. Bellini, "La subasta de Colombia termina con precio promedio final de \$0,027/kWh", pv magazine, 23 October 2019, <https://www.pv-magazine-latam.com/2019/10/23/la-subasta-de-colombia-termina-con-precio-promedio-final-de-0027-kwh> (using Google Translate), and from V. Volcovici, "Latin America pledges 70% renewable energy, surpassing EU: Colombia minister", *Reuters*, 25 September 2019, <https://www.reuters.com/article/us-climate-change-un-colombia-idUSKBN1WA26Y>. By early 2020, Colombia's solar project pipeline was 9.48 GW, from P. S. Molina, "Colombia's 9.48 GW solar project pipeline", pv magazine, 15 April 2020, <https://www.pv-magazine.com/2020/04/15/colombias-9-48-gw-solar-project-pipeline>. A private tender was called in Chile by copper miner Antofagasta Minerals, from "Antofagasta Minerals launches tender for Chile PV solar plant", bnamericas, 12 February 2019, <https://www.bnamericas.com/en/news/antofagasta-minerals-launches-tender-for-chile-pv-solar-plant>.
- 129 Brazil added 2,059 MW (including large-scale and rooftop installations) for a total year-end capacity of 4,470 MW, from ABSOLAR, "Energia Solar Fotovoltaica no Brasil Infográfico ABSOLAR", January and March 2020, <http://www.absolar.org.br/infografico-absolar.html>, provided by ABSOLAR, personal communication with REN21, 15 April 2020.
- 130 Figure of 650 MW based on data from ABSOLAR, "Energia Solar Fotovoltaica no Brasil Infográfico ABSOLAR", 15 April 2020, <http://www.absolar.org.br/infografico-absolar.html>. The 156 MW Juazeiro solar farm in Bahia is reportedly the first in Latin America to be built with a digital sub-station, from "Atlas fires up 156MW Brazil solar", reNEWS, 21 August 2019, <https://renews.biz/54902/atlas-fires-up-156mw-brazil-solar>. Also completed in 2019 was the 117 MW Sertão Solar Barreiras Complex, which was contracted after a 2017 auction under a 20-year PPA and is expected to provide electricity to 145,000 families annually, from Atlas Renewable Energy, "Atlas Renewable Energy announces fourth plant in Brazil reaches commercial operation, generating 275 GWh per year", press release (São Paulo, Brazil: 17 December 2019),

- <https://www.prnewswire.com/news-releases/atlas-renewable-energy-announces-fourth-plant-in-brazil-reaches-commercial-operation-generating-275-gwh-per-year-300975772.html>.
- 131 Figure of 5.7 GW from M. Takata, Greener, and provided by ABSOLAR, personal communication with REN21, 22 April 2020; interest in PPAs from ABSOLAR, personal communication, April 2020, from E. Bellini, "Private PPAs for solar are proliferating in Latin America", pv magazine, 4 October 2018, <https://www.pv-magazine.com/2018/10/04/private-ppas-for-solar-are-proliferating-in-latin-america>, and from E. Bellini and P. S. Molina, "Scratching the surface of Brazil's huge solar potential", pv magazine, 11 June 2019, <https://www.pv-magazine.com/2019/06/11/scratching-the-surface-of-brazils-huge-solar-potential>.
- 132 Record-setting low bid prices and sales into free market from E. Bellini, "Solar at \$17.30/MWh in Brazil's auction; is it a world record?" pv magazine, 22 July 2019, <https://www.pv-magazine.com/2019/07/22/solar-at-17-30-mw-in-brazils-auction-is-it-a-world-record?>, and from M. Willuhn, "Portuguese auction attracts world record bid of €14.8/MWh for solar", pv magazine, 31 July 2019, <https://www.pv-magazine.com/2019/07/31/portuguese-auction-attracts-world-record-bid-of-e14-8-mwh-for-solar>; at least 30%, based on official requirements from the Brazilian Electricity Regulatory Agency for electricity auctions, from ABSOLAR, personal communication, April 2020.
- 133 An estimated 1,409 MW of distributed capacity was added in 2019, for a year-end total of 1,997 MW, from ABSOLAR, op. cit. note 130; drivers from E. Bellini, "High power prices, falling PV costs and new regulations behind Brazil's solar carnival", pv magazine, 6 September 2019, <https://www.pv-magazine.com/2019/09/06/high-power-prices-falling-pv-costs-and-new-regulations-behind-brazils-solar-carnival>.
- 134 Residential consumers accounted for 72.6% of distributed generation capacity, followed by commercial (17.99%) and rural (6.25%) installations, from ABSOLAR, cited in L. Morais, "Brazil hits 2 GW of DG solar", Renewables Now, 22 January 2020, <https://renewablesnow.com/news/brazil-hits-2-gw-of-dg-solar-684361>; rising shares of commercial and industrial also from Bellini, op. cit. note 133.
- 135 Bellini, op. cit. note 133; E. Bellini, "Brazilian regulator wants to reduce net metering credit and introduce grid fee", pv magazine, 6 November 2019, <https://www.pv-magazine.com/2019/11/06/brazilian-regulator-wants-to-reduce-net-metering-credit-and-introduce-grid-fee>.
- 136 ASOLMEX, cited in "Solar power on the rise: Installations up 62% last year", Mexico News Daily, 28 January 2020, <https://mexiconewsdaily.com/news/solar-power-on-the-rise>, and in Mariano, op. cit. note 126. Mexico added almost 2 GW for a year-end total of about 5 GW based on the following: year-end 2018 capacity of 3,075 MW, from ASOLMEX, cited in Zarco, "Mexico reaches 4 GW milestone", op. cit. note 126; total of 5,000 MW at end-2019, from ASOLMEX, cited in Mariano, op. cit. note 126; total of 5,151 MW (4,333 MW of centralised capacity and 818 MW of distributed capacity), as of January 2020, from ASOLMEX, cited in Zarco, "Los números, las cifras de una energía que ilumina la República Mexicana", op. cit. note 126; added about 1 GW for a total of 5,102 MW, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6, and from Becquerel Institute, op. cit. note 1.
- 137 Enel, "Enel brings the power of green energy to the Mexican state of Tlaxcala by starting operations at 220 MW solar plant Magdalena II", 29 November 2019, <https://www.enel.pe/en/about-enel/media/news/d201911-enel-starts-operations-at-solar-plant-magdalena-ii.html>. Additional projects completed in 2019 include a 120 MW, from "EDF makes Mexican solar debut", reNEWS, 5 July 2019, <https://renews.biz/54113/edf-makes-mexican-solar-debut>, and a 350 MW plant, from I. Shumkov, "Cubico finalises 600 MW of renewable energy projects in Mexico", Renewables Now, 2 October 2019, <https://renewablesnow.com/news/cubico-finalises-600-mw-of-renewable-energy-projects-in-mexico-671263>.
- 138 P. Molina, "Region's first utility scale solar-plus-storage project comes online in Mexico", pv magazine, 2 May 2019, <https://www.pv-magazine.com/2019/05/02/regions-first-utility-scale-solar-plus-storage-project-comes-online-in-mexico>. The project has 32 MW of solar PV and 10.5 MW/7 MWh of lithium-ion battery storage, from idem.
- 139 SolarPower Europe, op. cit. note 1, p. 68; "Postponed Roundtables Mexico @ Solar Power Mexico 2020", pv magazine, <https://www.pv-magazine.com/pv-magazine-events/roundtables-south-america-solar-power-mexico-2020>, viewed 21 April 2020. In addition, the private market for PPAs remains in the infancy stage in Mexico, from idem.
- 140 Mexico had more than 112,660 contracts for solar rooftop systems, with total installed of 818 MW, including residential, commercial and industrial users, from ASOLMEX, cited in Mariano, op. cit. note 126.
- 141 Record additions from Clean Energy Council, op. cit. note 11, pp. 4, 6, 18, 69, 72, 76; ranked eighth based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and on data and sources throughout this section.
- 142 Figure of 3.7 GW added in 2019 for a year-end total of 14.7 GW from APVI, contribution to IEA PVPS, from Becquerel Institute, op. cit. note 1, 12 May 2020. Total additions of 3.8 GW based on 2,190 MW of small-scale (up to 100 kW), more than 162 MW of medium-scale (100 kW to 5 MW) and 1,416 MW of large-scale (>5 MW), and cumulative capacity of 13.6 GW based on a total 10,371.66 MW of small-scale, more than 400 MW of medium-scale and 2,807 MW of large-scale capacity (at least some of which is in AC), all from Clean Energy Council, op. cit. note 11, pp. 4, 6, 18, 69, 72, 76. Note that medium-scale total is an estimated based on a figure in idem, p. 72.
- 143 Output affected by bushfires from N. Filatoff, "Where there's smoke... there's reduced PV output", pv magazine, 21 January 2020, <https://www.pv-magazine.com/2020/01/21/where-theres-smoke-theres-reduced-pv-output>; generation of 18.1 TWh and share of 7.8% based on 12,269 GWh (5.3%) of generation by small-scale systems, 5,141 GWh (2.2%) by large-scale systems and 716 GWh (0.3%) by medium-scale systems, from Clean Energy Council, op. cit. note 11, p. 9. Increase of 54.7% based on generation of 11.7 TWh in 2018, from Clean Energy Council, *Clean Energy Australia Report 2019* (Melbourne: 2019), pp. 8, 9, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2019.pdf>.
- 144 APVI, "IEA PVPS Annual Report Australia 2019", 2020, http://apvi.org.au/wp-content/uploads/2020/02/PVPS-Annual-Report-2019-Aus_v2.pdf.
- 145 Clean Energy Council, op. cit. note 11, pp. 44-45. Note that the 400 MW is probably in alternating current (AC). Wind power accounted for the remaining 18%, from idem. Slower pace also from M. Maisch, "Global corporations set new record contracting 19.5 GW of wind and solar projects", pv magazine, 30 January 2020, <https://www.pv-magazine-australia.com/2020/01/30/global-corporations-set-new-record-contracting-19-5-gw-of-wind-and-solar-projects>. Solar PPAs represented a significant portion of the country's market for large-scale renewable energy projects, from idem. See also M. Maisch, "Coles signs PPA for three solar farms in Australia", pv magazine, 20 August 2019, <https://www.pv-magazine.com/2019/08/20/coles-signs-ppa-for-three-solar-farms-in-australia>.
- 146 Clean Energy Council, op. cit. note 11, p. 44.
- 147 Sydney Opera House, "Opera House marks World Environment Day with significant sustainability progress", press release (Sydney: 5 June 2019), <https://www.sydneyoperahouse.com/content/Non-Indexed/media/newsroom/MEDIA-RELEASE-world-environment-day.html>; S. Vorrath, "'Australian first' residential solar PPA a big hit with new home buyers", One Step Off the Grid, 3 July 2019, <https://onestepoffthegrid.com.au/australia-first-residential-solar-ppa-a-big-hit-with-new-home-buyers>.
- 148 M. Maisch, "Australia's move toward merchant solar", pv magazine, 21 October 2019, <https://www.pv-magazine.com/magazine-archive/australias-move-toward-merchant-solar>.
- 149 About 1,416 MW was added in 2019 for a year-end total of 2,807 MW, from Clean Energy Council, op. cit. note 11, pp. 6, 76. These numbers are believed to be in alternative current (AC). Note that average DC-AC ratio for the majority of solar PV plants installed up to April 2019 was estimated to be 1.27, from APVI, personal communication with REN21, 20 May 2020.
- 150 Ibid., pp. 64, 68-71. Average system size increased from 1.97 kW per system in 2010 to 7.62 kW per system in 2019, from idem.
- 151 Up 35% with 2,190.8 MW added in 2019 (and 1,616 MW added in 2018), in 287,504 newly installed systems, for a year-end total of 10,371.6 MW in 2.3 million systems, all from Ibid., pp. 7, 64, 68, 69. Note that additions were 2.13 GW (for systems under 100 kW) for a total of 10 GW, from SunWiz, cited in M. Maisch, "Australia

- installs 2.13 GW of rooftop solar in 2019", pv magazine, 15 January 2020, <https://www.pv-magazine-australia.com/2020/01/15/australia-installs-2-13-gw-of-rooftop-solar-in-2019/>; and household and commercial rooftop solar (up to 5 MW) installations were 2.4 GW in 2019, up 40% over the 1.7 GW installed in 2018, with 2.2 GW added being small-scale solar PV, all from Australian Government, *Clean Energy Regulator, Quarterly Carbon Market Report – December Quarter 2019* (Canberra: 2020), pp. 23, 36, <http://www.cleanenergyregulator.gov.au/DocumentAssets/Documents/Quarterly%20Carbon%20Market%20Report%20-%20December%20Quarter%202019.pdf>.
- 152 Ibid., p. 9. Estimated equivalent number of households powered over the year by small-scale solar PV systems was 2,669,440, from idem.
- 153 Ibid., p. 4. Estimates were a further 20,000 installed during 2019, about the same as in 2018, from APVI, op. cit. note 144.
- 154 Transforming landscape and pushing out coal plants from R. Verdonck, "Solar is beating out coal in Australia, pushing down emissions", *Bloomberg*, 10 February 2020, <https://www.bloomberg.com/news/articles/2020-02-10/solar-is-beating-out-coal-in-australia-pushing-down-emissions>. See also M. Maisch, "Solar and wind set new output record even as curtailment continues to bite", pv magazine, 12 February 2020, <https://www.pv-magazine-australia.com/2020/02/12/solar-and-wind-set-new-output-record-even-as-curtailment-continues-to-bite>. Coal plants unreliable and expensive to operate from Clean Energy Council, *Australia's Clean Energy Investment Outlook* (Melbourne: 11 September 2019), pp. 1, 4, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/CEC-briefing-paper-Australias-clean-energy-investment-outlook-September-2019.pdf>; SolarPower Europe, op. cit. note 1, p. 64. See also J. Thornhill, "A creaking grid jams up Australia's switch to green energy", *Bloomberg*, 2 August 2019, <https://www.bloomberg.com/news/articles/2019-08-01/creaking-grid-is-jamming-up-australia-s-switch-to-green-energy>.
- 155 Beyond expectations from G. Parkinson, "It's not easy to build a solar farm in Australia any more", *RenewEconomy*, 16 May 2019, <https://reneweconomy.com.au/its-not-easy-to-build-a-solar-farm-in-australia-any-more-59308>; M. Maisch, "5 things to watch in Australian solar sector in 2020", pv magazine, 15 February 2020, <https://www.pv-magazine-australia.com/2020/02/15/5-things-to-watch-in-australian-solar-sector-in-2020>; S. Hanley, "Renewable energy developers ready to quit Australia over idiotic government policies", *CleanTechnica*, 18 February 2020, <https://cleantechnica.com/2020/02/18/renewable-energy-developers-ready-to-quit-australia-over-idiotic-government-policies/>; overcrowded grid and connection delays from BloombergNEF, cited in G. Parkinson, "Australia wind and solar investment plunges as coalition turns blind eye to transition", *RenewEconomy*, 17 January 2020, <https://reneweconomy.com.au/australia-wind-and-solar-investment-plunges-as-coalition-turns-blind-eye-to-transition-75633>; G. Parkinson, "Wind and solar plants hit by massive de-ratings in congested grid", *RenewEconomy*, 8 March 2019, <https://reneweconomy.com.au/wind-and-solar-plants-hit-by-massive-de-ratings-in-congested-grid-96404>; K. Thornton, "Breaking Australia's vicious energy cycle", press release (Melbourne: Clean Energy Council, 16 March 2020), <https://www.cleanenergycouncil.org.au/news/breaking-australias-vicious-energy-cycle>. Investment failed to keep up from Clean Energy Council, op. cit. note 11, p. 7.
- 156 Time-consuming, costly and reducing revenue from G. Parkinson, "Grid queue for new generation totals 96GW, but will house full sign go up soon?" *RenewEconomy*, 30 July 2019, <https://reneweconomy.com.au/grid-queue-for-new-generation-totals-96gw-but-will-house-full-sign-go-up-soon-50693>; lack of policy and target clarity, and regulatory risks from Clean Energy Council, op. cit. note 154, pp. 1, 4; Mints, *The Solar Flare*, op. cit. note 22, p. 12; Parkinson, "It's not easy to build a solar farm in Australia any more", op. cit. note 155; Maisch, op. cit. note 155; Hanley, op. cit. note 155; Clean Energy Council, cited in M. Maisch, "Renewables investment collapses due to network woes and policy uncertainty", pv magazine, 1 February 2020, <https://www.pv-magazine-australia.com/2020/02/01/renewables-investment-collapses-due-to-network-woes-and-policy-uncertainty/>; Parkinson, "It's not easy to build a solar farm in Australia any more", op. cit. note 155; Maisch, op. cit. note 155; Hanley, op. cit. note 155; curtailment from BloombergNEF, cited in G. Parkinson, "Australia wind and solar investment plunges as coalition turns blind eye to transition", op. cit. note 155; barriers to investment, delayed and cancelled from Parkinson, "Grid queue for new generation totals 96GW, but will house full sign go up soon?" op. cit. this note. New investment commitments for large-scale renewable power projects fell more than 50% during the year, from Clean Energy Council, op. cit. note 11, p. 7. Investment in new large-scale renewable power projects fell 60% in 2019 relative to 2018, from BloombergNEF, cited in G. Parkinson, "Australia wind and solar investment plunges as coalition turns blind eye to transition", op. cit. note 155. See also Thornton, op. cit. note 155.
- 157 Thornton, op. cit. note 155.
- 158 Parkinson, "Grid queue for new generation totals 96GW, but will house full sign go up soon?" op. cit. note 156.
- 159 Australian Energy Market Operator, "Integrated System Plan (ISP)", <https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp>, viewed 16 April 2020.
- 160 B. Match, "Small-scale utility solar thriving on path of least resistance", pv magazine, 28 February 2020, <https://www.pv-magazine-australia.com/2020/02/28/small-scale-utility-solar-thriving-on-path-of-least-resistance>; M. Maisch, "Victoria decides to go it alone on transmission to unlock more large-scale renewables and batteries", pv magazine, 19 February 2020, <https://www.pv-magazine-australia.com/2020/02/19/victoria-decides-to-go-it-alone-on-transmission-to-unlock-more-large-scale-renewables-and-batteries>.
- 161 Based on 3.7 GW added in the Middle East and 2.95 GW added across Africa, for total additions of nearly 6.7 GW, and year-end capacity of over 7 GW in the Middle East and over 8 GW in Africa for cumulative of nearly 15.1 GW, based on data for individual countries in both regions from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. In 2018, the regions added an estimated 2,556 MW in 2018 for a total of 6,716 MW, from Becquerel Institute, op. cit. note 1, April 2019. Another source estimates that about 3.6 GW was added in 2018, up from less than 1 GW in 2017, from IHS Markit, cited in J. Berg, "MENA PV additions quadrupled in 2018", pv magazine, 17 January 2019, <https://www.pv-magazine.com/2019/01/17/mena-pv-additions-quadrupled-in-2018>.
- 162 Largest based on data from Middle East Solar Industry Association (MESIA), cited in B. Publicover, "Solar is gaining traction in MENA region – but plenty of obstacles remain", pv magazine, 17 January 2020, <https://www.pv-magazine.com/2020/01/17/mesia-outlines-past-progress-future-promise-in-sweeping-look-at-solar-across-middle-east-and-north-africa>, and from Becquerel Institute, op. cit. note 1; target from B. Asaba, "Abu Dhabi turns to solar for future power needs", *Arabian Industry*, 8 March 2020, <https://www.arabianindustry.com/utilities/news/2020/mar/8/abu-dhabi-turns-to-solar-for-future-power-needs-6344338>.
- 163 MESIA, cited in B. Publicover, op. cit. note 162; F. Todd, "World's largest 1.17GW solar project completed in Abu Dhabi", *NS Energy*, 4 July 2019, <https://www.nsenegybusiness.com/news/largest-solar-project-abu-dhabi>; M. Hall, "Noor solar park operational", pv magazine, 1 July 2019, <https://www.pv-magazine.com/2019/07/01/noor-limits-as-dubai-makes-extraordinary-carbon-emissions-claim>; Gulf News, "World's largest solar project, with power enough for 90,000 people, switched on in Abu Dhabi", 29 June 2019, <https://gulfnews.com/uae/worlds-largest-solar-project-with-power-enough-for-90000-people-switched-on-in-abu-dhabi-1.1561799168033>.
- 164 MESIA, cited in Publicover, op. cit. note 162.
- 165 At the end of 2019, the UAE had 1,730 MW in operation (including 1,177 MW at Sweihan, 413 MW at Sheikh Makrtoum and 125 MW through DEWA Shams and other smaller projects). Another 2 GW of solar projects was under tender in Abu Dhabi, but the opening of the tender was postponed due to the coronavirus, all from B. Schmuelling, UAE Ministry of Climate Change & Environment, personal communication with REN21, 8 April 2020. The UAE added an estimated 2 GW in 2019 (with some installed in 2018 but commissioned in 2019), for a year-end total of 2,978 MW, based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 9, and from Becquerel Institute, op. cit. note 1, 20 March 2020 and 10 April 2020. Dubai Shams initiative also from "DEWA's Shams Dubai connects 1,354 buildings totaling 125MW of power", Dubai Electricity and Water Authority, 8 October 2019, <https://www.dewa.gov.ae/en/about-us/media-publications/latest-news/2019/10/dewas-shams-dubai-connects-1354-buildings-totalling-125mw-of-power>.

- 166 **Saudi Arabia** from “300MW solar plugs into Saudi grid”, reNEWS, 26 November 2019, <https://renews.biz/56652/300mw-solar-plugs-into-saudi-grid>. **Jordan** added an estimated 600 MW for a year-end total of 1,030 MW, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 9, and from Becquerel Institute, op. cit. note 1; large plants in Jordan from L. Morais, “FRV switches on 67-MW PV plant in Jordan”, *Renewables Now*, 30 April 2019, <https://renewablesnow.com/news/frv-switches-on-67-mw-pv-plant-in-jordan-652377>, and from Pamelalargue, “ACWA Power commences commercial operations at Risha PV in Jordan”, *Power Engineering International*, 12 December 2019, <https://www.powerengineeringint.com/2019/12/12/acwa-power-commences-commercial-operations-at-risha-pv-in-jordan>; E. Bellini, “Jordan’s plan to have solar on all mosques moves forward”, *pv magazine*, 12 July 2019, <https://www.pv-magazine.com/2019/07/12/jordans-plan-to-have-solar-on-all-mosques-moves-forward>. As of mid-2019, some 500 of Jordan’s estimated 7,000 mosques had solar PV systems; this effort is part of a government plan that was launched in 2015, from idem. **Israel** added 759 MW based on 1,358 MW at end-2018 and 2,117 MW at end-2019 (forecast), from Israel Electricity Authority, *Report of Status of Economy 2018*, Chapter 4 – Renewable Energies, Tab 4.1, https://pua.gov.il/publications/documents/israel_e_market_state_n%20new_2020.xlsx, viewed 6 May 2020. Israel added 628 MW, based on 1,418 MW at end-2018 and 2,046 MW at end-2019, provided by E. Parnass, Green Energy Association of Israel, Jerusalem, personal communication with REN21, 6 May 2020. Israel’s largest solar PV plant from E. Bellini, “Israel’s largest solar park comes online”, *pv magazine*, 19 November 2019, <https://www.pv-magazine.com/2019/11/19/israels-largest-solar-park-comes-online>.
- 167 Kuwait and Oman from MESIA, cited in Publicover, op. cit. note 162; Iraq from E. Bellini, “Iraq kicks off huge 755 MW solar tender”, *pv magazine*, 3 May 2019, <https://www.pv-magazine.com/2019/05/03/iraq-kicks-off-huge-755-mw-solar-tender>.
- 168 MESIA, cited in Publicover, op. cit. note 162. Dubai aims for 25% of electricity from “clean sources” by 2030 and 75% by 2050, equivalent to a capacity of 42 GW, from T. Page and M. Burnell, “\$13.6B record-breaking solar park rises from Dubai desert”, <https://www.cnn.com/style/article/mbr-solar-park-dubai-desert-intl/index.html>.
- 169 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 45. See, for example, C. Mama, “On-grid solar in Nigeria: Two years after the PPAs”, *Solar Future*, 22 February 2018, <https://nigeria.thesolarfuture.com/news-source/2018/2/22/on-grid-solar-in-nigeria-two-years-after-the-ppas>; A. Rahagalala, “Sun-blessed Madagascar turns to solar to reduce energy costs”, *Bloomberg*, 4 July 2018, <https://www.bloomberg.com/news/articles/2018-07-04/sun-blessed-madagascar-turns-to-solar-to-reduce-energy-costs>; “Malawi: 60MW solar plant to end blackouts”, *ESI Africa*, 4 December 2018, <https://www.esi-africa.com/malawi-60mw-solar-plant-to-end-blackouts>; E. Bellini, “Algerian government approves 200 MW of PV tenders”, *pv magazine*, 11 June 2018, <https://www.pv-magazine.com/2018/06/11/algerian-government-approves-200-mw-of-pv-tenders>; limiting or reducing carbon dioxide emissions from P. Fragkos, op. cit. note 58.
- 170 Financing tools and tenders from Institut Montaigne, cited in E. Bellini, “Unrealistic price signals and an explosion of tenders hinder African PV”, *pv magazine*, 13 January 2020, <https://www.pv-magazine.com/2020/01/13/unrealistic-price-signals-and-an-explosion-of-tenders-hinder-african-pv>; fossil fuel subsidies from, for example, Publicover, op. cit. note 162; subsidies as well as social and political unrest from Mints, *The Solar Flare*, op. cit. note 22, p. 12. See also G. Schwerhoff and M. Sy, “Where the sun shines: Renewable energy sources, especially solar, are ideal for meeting Africa’s electrical power needs”, *International Monetary Fund, Finance & Development*, vol. 57, no. 1 (March 2020), <https://www.imf.org/external/pubs/ft/fandd/2020/03/powering-Africa-with-solar-energy-sy.htm>.
- 171 Kenya’s 50 MW Garissa plant contributed about 2% of the country’s electricity mix and has helped to reduce the country’s energy costs, from Rural Electrification and Renewable Energy Corporation, “The 50 MW Garissa Solar Power Plant”, https://www.rerec.co.ke/index.php?option=com_content&view=article&id=53&Itemid=234, viewed 17 April 2020; Kenya also from T. F. Ishugah, East African Centre for Renewable Energy & Energy Efficiency (EACREEE), personal communication with REN21, 13 April 2020. “Mozambique inaugurates 40MW solar plant”, *ESI Africa*, 14 August 2019, <https://www.esi-africa.com/industry-sectors/renewable-energy/mozambique-inaugurates-40mw-solar-plant>; “Alten to commission Namibia’s biggest PV plant”, *pv magazine*, 19 June 2019, <https://www.pv-magazine.com/2019/06/19/alten-to-commission-namibias-biggest-pv-plant>; Zambia commissioned a 54 MW plant, from C. Phiri, “Lungu commissions 54MW solar power plant”, *Zambia Reports*, 11 March 2019, <https://zambiareports.com/2019/03/11/lungu-commissions-54mw-solar-power-plant>, and from E. Mumba, “Bangweulu Power plant”, *Mining News Zambia*, 12 March 2019, <http://www.miningnewszambia.com/residential-commissioning-of-largest-facility/>; Zambia 34 MW plant from Enel, “Energy Green Power brings online its first power plant in Zambia”, press release (Rome: 29 April 2019), <https://www.enelgreenpower.com/media/press/d/2019/04/enel-green-power-brings-online-its-first-power-plant-in-zambia>. Sudan brought online a 5 MW solar PV plant, from “Renewable Energy in Sudan: Status and Potential – Part 2”, *Renewables in Africa*, 29 January 2020, <https://www.renewablesinafrica.com/renewable-energy-in-sudan-status-and-potential-part-2>; Tunisia grid-connected its first solar park, of 10 MW, from E. Bellini, “Tunisia announces grid-connection of its first solar park”, *pv magazine*, 9 August 2019, <https://www.pv-magazine.com/2019/08/09/tunisia-announces-grid-connection-of-its-first-solar-park>, and allocated about 500 MW of new solar capacity in December, from Publicover, op. cit. note 162; Uganda completed a 10 MW plant, from T. Kenning, “Metka completes 10MW solar plant in Uganda”, *PV-Tech*, 10 June 2019, <https://www.pv-tech.org/news/metka-completes-10mw-solar-plant-in-uganda>.
- 172 “Watch footage of Benban, the largest solar project in the world”, *Renewable Energy World*, 24 October 2019, <https://www.renewableenergyworld.com/2019/10/24/watch-footage-of-benban-the-largest-solar-project-in-the-world>.
- 173 South Africa had more than 94 MW of installed rooftop systems, from GreenCape, “Solar PV”, <https://www.greencape.co.za/content/focusarea/solar-pv>, viewed 17 April 2020; total capacity was much higher if including systems not yet registered with local municipalities, from S. Mthwecu, Solar Rais, Sandton, Guanteng, South Africa, personal communication with REN21, 10 April 2020; unofficial rooftop solar PV installations exceeded 300 MW, from PVGreenCard, “Some facts: Current status”, <https://www.pvgreencard.co.za>, viewed 17 April 2020.
- 174 E. Bellini, “Morocco opens 230 MW solar tender”, *pv magazine*, 11 July 2019, <https://www.pv-magazine.com/2019/07/11/morocco-opens-230-mw-solar-tender>; E. Bellini, “Morocco issues 200 MW PV tender”, *pv magazine*, 15 January 2019, <https://www.pv-magazine.com/2019/01/15/morocco-issues-200-mw-pv-tender>; E. Bellini, “Morocco kicks off tender for 400 MW solar park”, *pv magazine*, 31 January 2020, <https://www.pv-magazine.com/2020/01/31/morocco-kicks-off-tender-for-400-mw-solar-park>. Large plants from, for example, the following: MESIA, cited in Publicover, op. cit. note 162, and from E. Bellini, “Angola’s solar plans boosted by Italian oil giant Eni”, 14 November 2019, <https://www.pv-magazine.com/2019/11/14/angolas-solar-plans-boosted-by-italian-oil-giant-eni>; I. Shumkov, “Hanergy to build 400 MW of solar parks in DR Congo”, *Renewables Now*, 4 July 2019, <https://renewablesnow.com/news/hanergy-to-build-400-mw-of-solar-parks-in-dr-congo-660442>; C. Rollet, “Engie signs MoU in Djibouti for 30 MW solar plant”, *pv magazine*, 4 June 2019, <https://www.pv-magazine.com/2019/06/04/engie-signs-mou-in-djibouti-for-30-mw-solar-plant>; “13 IPPs pre-selected for solar and biomass projects in Eswatini”, *Construction Review*, 15 November 2019, <https://constructionreviewonline.com/2019/11/13-ipp-pre-selected-for-solar-and-biomass-projects-in-eswatini>; F. Jonh, “Ethiopia kicks off construction US \$300m solar power plants”, 25 October 2019, <https://constructionreviewonline.com/2019/10/ethiopia-kicks-off-construction-us-300m-solar-power-plants>; B. Koigi, “USTDA awards grant to OnePower Lesotho to develop 20MW solar power plant”, *Africa Business Communities*, press release (Lesotho: 17 May 2019), <https://africabusinesscommunities.com/news/ustda-awards-grant-to-onepower-lesotho-to-develop-20mw-solar-power-plant/>; World Bank, *International Development Association Project Appraisal Document on Proposed Grant in the amount of SDR 46.8 Million (US\$65.0 Million Equivalent) to the Central African Republic for the Emergency electricity Supply and Access Project (PURACEL)* (Washington, DC: 14 February 2019), <http://documents.worldbank.org/curated/en/307711551668592488/pdf/SIERRA-LEONE-PAD-02192019-63687247375315841.pdf>; “Togo

- secures its first IPP-developed utility-scale PV plant", ESI Africa, 4 December 2019, <https://www.esi-africa.com/industry-sectors/generation/solar/togo-secures-its-first-ipp-developed-utility-scale-pv-plant>. Tenders were held in several countries, from the following sources: E. Bellini, "Algerian diesel-solar tender concludes with lowest bid of 11 cents", pv magazine, 16 August 2019, <https://www.pv-magazine.com/2019/08/16/algerian-diesel-solar-tender-concludes-with-lowest-bid-of-11-cents>; E. Bellini, "Burkina Faso tenders for 30 MW of solar", pv magazine, 8 January 2019, <https://www.pv-magazine.com/2019/01/08/burkina-faso-tenders-for-30-mw-of-solar>; J. Takoueu, "BURKINA FASO: Six solar power plants to increase energy supply by 155 MW", Afrik 21, 10 April 2019, <https://www.afrik21.africa/en/burkina-faso-six-solar-power-plants-to-increase-energy-supply-by-155-mw>; T. Kenning, "Ethiopia adds 250MW to Scaling Solar Round 2", PV-Tech, 8 May 2019, <https://www.pv-tech.org/news/ethiopia-expands-scaling-solar-round-2-to-up-to-750mw>; T. Kenning, "Ethiopia eyes 500MW in Scaling Solar Round 2", PV-Tech, 17 April 2019, <https://www.pv-tech.org/news/ethiopia-eyes-500mw-in-scaling-solar-round-2>; T. Folaranmi, "Ethiopia launches tender for installation of solar PV mini-grids", 11 October 2019, <https://constructionreviewonline.com/2019/10/ethiopia-launches-tender-for-installation-of-solar-pv-mini-grids>; Gambia tender, launched by the United Nations Development Programme, from V. Petrova, "Eol for 10.5 MWp of solar released in Gambia", Renewables Now, 5 April 2019, <https://renewablesnow.com/news/eoi-for-105-mwp-of-solar-released-in-gambia-649504>; T. Kenning, "Tunisia awards remaining 10MW in solar tender", PV-Tech, 25 April 2019, <https://www.pv-tech.org/news/tunisia-awards-remaining-10mw-in-solar-tender>; V. Petrova, "Tunisia awaits bids in 70-MW tender for solar projects", Renewables Now, 16 July 2019, <https://renewablesnow.com/news/tunisia-awaits-bids-in-70-mw-tender-for-solar-projects-661790>; J. Parnell, "Zambia solar tender sets Sub-Saharan price record", PV-Tech, 8 April 2019, <https://www.pv-tech.org/news/zambia-solar-tender-sets-sub-saharan-price-record>. In addition, the government of Zimbabwe approved 39 projects with a total of up to 1.15 GW of future solar PV capacity, from "39 solar power projects get nod", *The Herald*, 26 September 2019, <https://www.herald.co.zw/39-solar-power-projects-get-nod>.
- 175 E. Bellini, "Namibia and Botswana mull 20-year, 5 GW solar push", pv magazine, 4 September 2019, <https://www.pv-magazine.com/2019/09/04/namibia-and-botswana-mull-20-year-5-gw-solar-push>; "New trans-Africa CSP, PV plan tests regional scaling skills", New Energy Update, 2 October 2019, <https://analysis.newenergyupdate.com/csp-today/new-trans-africa-csp-pv-plan-tests-regional-scaling-skills>. The World Economic Forum's Global Future Council on Energy is supporting this plan, from idem, both sources.
- 176 See, for example, J. R. Martin, "West African states press ahead with solar corridor", PV-Tech, 25 February 2019, <https://www.pv-tech.org/news/west-african-states-press-ahead-with-solar-corridor>; N. Kabeer, "West African countries propose a solar energy corridor", Mercom India, 5 March 2019, <https://mercomindia.com/west-african-countries-solar-corridor>; T. Kenning, "Halting desertification in the Sahel with solar power", PV-Tech, 14 December 2018, <https://www.pv-tech.org/long-reads/long-read-halting-desertification-in-the-sahel-with-solar-power>.
- 177 Additions and year-end totals are preliminary data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1, 20 March 2020 and 10 April 2020.
- 178 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 4, 9. Although preliminary data show that the market for distributed capacity increased in 2019, the share of capacity in large, centralised projects increased, due greatly to tendering schemes in many countries, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 11.
- 179 See, for example, Barbose and Darghouth, op. cit. note 124, p. 1; Clean Energy Council, op. cit. note 11, pp. 64, 68-71; Bellini, op. cit. note 19.
- 180 Tendering from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 11; tendering and PPAs from SolarPower Europe, op. cit. note 1, p. 25.
- 181 J. Petri, "Solar has finally gone off the scale", *Bloomberg*, 28 February 2020, <https://www.bloomberg.com/news/articles/2020-02-28/solar-power-has-finally-gone-off-the-scale-green-insight>.
- 182 D. Lenardič, pvresources, Jesenice, Slovenia, personal communications with REN21, 25 March 2020, 12 April 2020 and 17 April 2020. A total of 13 projects of 50 MW and larger were completed in Australia alone during 2019, based on Clean Energy Council, op. cit. note 11, p. 75.
- 183 Petri, op. cit. note 181.
- 184 S. Djunisic, "Vietnam inaugurates 420-MW Dau Tieng PV power complex", Renewables Now, 9 September 2019, <https://renewablesnow.com/news/vietnam-inaugurates-420-mw-dau-tieng-pv-power-complex-668299>; Spain from Grupo Cobra, "Central fotovoltaica Mula", <http://www.grupocobra.com/proyecto/central-fotovoltaica-mula>, viewed 23 March 2020. Spain's 500 MW Núñez de Balboa project also was completed at the end of 2019, but not fully operational by year's end. See, for example, J. Parnell, "Iberdrola completes Europe's largest solar plant (and yes, it's subsidy-free)", GTM, 3 January 2020, <https://www.greentechmedia.com/articles/read/iberdrola-completes-europes-largest-solar-plant-and-yes-its-subsidy-free>, and "Iberdrola completes construction on 500MW Nunez de Balboa solar project in Spain", NS Energy, 30 December 2019, <https://www.nsenergybusiness.com/news/iberdrola-nunez-de-balboa>. "China's biggest subsidy-free solar farm powers up in Liaoning", *Bloomberg*, 26 December 2019, <https://www.bloomberg.com/news/articles/2019-12-26/china-s-biggest-subsidy-free-solar-farm-powers-up-in-liaoning>; R. Ranjan, "World's largest solar park at Karnataka's Pavagada is not fully operational", Mercom India, 27 December 2019, <https://mercomindia.com/karnatakas-pavagada-solar-operational>. The Pavagada plant in Karnataka, India has 2,050 MW of capacity, from idem. Other large projects completed in 2019 include: "Atlas fires up 156MW Brazil solar", op. cit. note 130; "China firms complete building Argentina's largest solar farm: Xinhua", *Reuters*, 2 October 2019, <https://www.reuters.com/article/us-china-argentina-solar/china-firms-complete-building-argentina-s-largest-solar-farm-xinhua-idUSKBN1WH0WK>; Shumkov, op. cit. note 137; "Capital Dynamics sparks 131MW Springbok 3 solar", reNEWS, 15 October 2019, <https://renews.biz/55838/capital-dynamics-sparks-131mw-springbok-3-solar>; "Tennessee's largest solar facility is now online", Renewable Energy World, 29 April 2019, <https://www.renewableenergyworld.com/articles/2019/04/tennessees-largest-solar-facility-is-now-online.html>; A. Bhamhani, "Engie Fabricom completes 99.5 MW Kristal Solar Park in Belgium's Lommel City in Flanders in collaboration with Nyrstar, LRM NV & City of Lommel", TaiyangNews, 18 June 2019, <http://taiyangnews.info/business/99-5-mw-kristal-solar-park-complete-in-belgium>; B. Publicover, "Chint Solar connects 103 MW of solar to Dutch grid", pv magazine, 9 December 2019, <https://www.pv-magazine.com/2019/12/09/chint-solar-connects-103-mw-of-solar-to-dutch-grid>; "Iberdrola completes construction on 500MW Nunez de Balboa solar project in Spain", op. cit. this note; Bellini, op. cit. note 75; T. Kenning, "Ukraine's largest solar project completed with Chinese partners", PV-Tech, 23 April 2019, <https://www.pv-tech.org/news/ukraines-largest-solar-project-completed-with-chinese-partners>; Azure Power, "Azure Power commissions 150 MW SECI solar power project", press release (New Delhi: 29 April 2019), <http://investors.azurepower.com/press-releases/2019/04-29-2019>; E. Bellini, "50 MW solar park comes online in Malaysia", pv magazine, 12 September 2019, <https://www.pv-magazine.com/2019/09/12/50-mw-solar-park-comes-online-in-malaysia>; D. Loh, "Vietnam's solar opportunities shine bright", pv magazine, 23 December 2019 <https://www.pv-magazine.com/2019/12/23/vietnams-solar-opportunities-shine-bright>; "300MW solar plugs into Saudi grid", op. cit. note 166; G. Parkinson, "Two new solar farms connect to the grid in Queensland", RenewEconomy, 29 May 2019, <https://reneweconomy.com.au/two-new-solar-farms-connect-to-the-grid-in-queensland-33369>; Clean Energy Council, "Project tracker", <https://www.cleanenergycouncil.org.au/resources/project-tracker>, viewed 25 March 2020. Considering plants of 4 MW_{ac} and up, 2019 was another record year with new installations surpassing 45 GW_{ac}, for a global total exceeding 220 GW_{ac}, from Wiki-Solar, "Utility-scale solar sets new record", 17 March 2020, https://wiki-solar.org/library/public/200317_Utility-Solar_another_record_year_as%20total_tops_220GW.pdf.
- 185 See, for example, J. McCurry, "Japan's renewable energy puzzle: Solar push threatens environment", *The Guardian* (UK), 19 April 2018, <https://www.theguardian.com/world/2018/apr/19/japans-renewable-energy-puzzle-solar-push-threatens-environment>; IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note

- 7, p. 16.
- 186 Renné, op. cit. note 117, April 2020.
- 187 Wood Mackenzie Power & Renewables, cited in M. Cox, "The state of floating solar: Bigger projects, climbing capacity, new markets", GTM, 19 September, <https://www.greentechmedia.com/articles/read/the-state-of-floating-solar-bigger-projects-and-climbing-capacity>; World Bank, ESMAP and SERIS, *Where Sun Meets Water: Floating Solar Handbook for Practitioners* (Washington, DC: World Bank, 2019), <http://documents.worldbank.org/curated/en/418961572293438109/Where-Sun-Meets-Water-Floating-Solar-Handbook-for-Practitioners>; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 16-17.
- 188 Wood Mackenzie Power & Renewables, cited in Cox, op. cit. note 187.
- 189 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 16-17. Countries with projects in Asia include China, Republic of Korea, Malaysia, the Philippines, Singapore, Thailand, Vietnam and others, from CEC, "World's largest floating solar plant connected in China", press release, <http://english.cec.org.cn/No.106.1755.htm>, viewed 25 March 2020; T. Kenning, "World's largest floating solar plant connected in China", PV-Tech, 20 March 2019, <https://www.pv-tech.org/news/worlds-largest-floating-solar-plant-connected-in-china>; GCL System, "Floating solar: Philippines switches on its first hybrid floating photovoltaic hydro power project", pv magazine, 16 July 2019, <https://www.pv-magazine-australia.com/press-releases/floating-solar-philippines-switches-on-its-first-hybrid-floating-photovoltaic-hydro-power-project>; M. Patel, "Floating solar power plants: An idea whose time has come", *Economic Times*, 22 May 2019, <https://energy.economicstimes.indiatimes.com/energy-speak/floating-solar-power-plants-an-idea-whose-time-has-come/3582>; E. Bellini, "New alliance to expand floating PV in Southeast Asia", pv magazine, 8 August 2019, <https://www.pv-magazine.com/2019/08/08/new-alliance-to-expand-floating-pv-in-southeast-asia>; Maldives from A. A. Hadi, "World's largest floating solar energy systems installed in Maldives", Sun, 26 August 2019, <https://en.sun.mv/55072>. African countries include Malawi and the Seychelles, from J. Martín, "France powers up Europe's self-styled largest floating PV project", PV-Tech, 21 October 2019, <https://www.pv-tech.org/news/france-powers-up-europes-self-styled-largest-floating-pv-project>, and from BizCommunity, "Seychelles floating solar energy project moves into next phase", 13 June 2019, <https://www.bizcommunity.com/Article/189/640/191942.html>. Countries in Europe include France, Portugal and the Netherlands, from the following sources: J. Martín, "World Bank, SERIS take aim at floating PV hurdles with standardisation push", PV-Tech, 4 November 2019, <https://www.pv-tech.org/news/world-bank-seris-take-aim-at-floating-pv-hurdles-with-standardisation-push>; J. Martín, "France powers up Europe's self-styled largest floating PV project", op. cit. this note; E. Barbiroglio, "A new floating solar farm shows that renewables can be easy", *Forbes*, 7 November 2019, <https://www.forbes.com/sites/emanuelbarbiroglio/2019/11/07/a-new-floating-solar-farm-shows-that-renewables-can-be-easy>; M. Osborne, "BayWa r.e. planning over 100MW of floating solar projects in Europe for 2020", PV-Tech, 5 November 2019, <https://www.pv-tech.org/news/baywa-r-e-planning-over-100mw-of-floating-solar-projects-in-europe-for-2020>. Countries in the Americas include Brazil, from J. Martín, "France powers up Europe's self-styled largest floating PV project", op. cit. this note, and the United States, from T. Sylvia, "America's largest floating solar project completed", pv magazine, 23 October 2019, <https://pv-magazine-usa.com/2019/10/23/americas-largest-floating-solar-project-completed>.
- 190 China from CEC, op. cit. note 189, and from Kenning, op. cit. note 189; India from GCL System, op. cit. note 189, and from Patel, op. cit. note 189; Terrenus Energy, "Tender for 50 MW of floating solar launched in Portugal", press release (Singapore: 28 November 2019), <https://www.terrenusenergy.com/tender-for-50-mw-of-floating-solar-launched-in-portugal>; E. Bellini, "Vietnam to hold auctions for 400 MW of floating solar", pv magazine, 6 January 2020, <https://www.pv-magazine.com/2020/01/06/vietnam-to-hold-auctions-for-400-mw-of-floating-solar>.
- 191 Off Dutch coast from E. Bellini, "Offshore PV system goes online in North Sea", pv magazine, 12 December 2019, <https://www.pv-magazine.com/2019/12/12/offshore-pv-system-goes-online-in-north-sea>. See also J. Martín, "Storms Ciara, Dennis no match for offshore solar trailblazer", PV-Tech, 17 February 2020, <https://www.pv-tech.org/news/storms-ciara-dennis-no-match-for-offshore-solar-trailblazer>. United Arab Emirates and Singapore from J. Deign, "Floating solar gets ready for the high seas", GTM, 5 August 2019, <https://www.greentechmedia.com/articles/read/floating-solar-gears-up-for-the-high-seas>; D. Dudley, "Dubai joins the race to develop offshore solar power plants", *Forbes*, 12 June 2019, <https://www.forbes.com/sites/dominicdudley/2019/06/12/dubai-offshore-solar-power>; V. Ratcliffe, "Abu Dhabi island to host nation's first floating solar power plant", Bloomberg, 13 February 2020, <https://www.bloomberg.com/news/articles/2020-02-13/abu-dhabi-island-to-host-nation-s-first-floating-solar-power>. T. Kenning, "Firms align for 300MW wind and 2.7GW floating PV complex at Korean seawall", PV-Tech, 10 December 2019, <https://www.pv-tech.org/news/firms-align-for-300mw-offshore-wind-and-2.7gw-floating-pv-complex-at-korean>; E. Bellini, "South Korea's 2.1 GW floating solar project overcomes first hurdle", pv magazine, 4 November 2019, <https://www.pv-magazine.com/2019/11/04/south-koreas-2-1-gw-floating-solar-project-overcomes-first-hurdle>.
- 192 Figures of 2.4 GW in 35 countries from Wood Mackenzie Power & Renewables, cited in Cox, op. cit. note 187. Almost every region based on information and sources throughout this paragraph.
- 193 Building-integrated progressing but slowly, and auto manufacturers, from Masson, op. cit. note 2. The high-rise is a building in Nanchang City, in the Chinese province of Jiangxi, from M. Willuhn, "Hanergy wraps 460 kW of CIGS around Chinese skyscraper", pv magazine, 10 July 2019, <https://www.pv-magazine.com/2019/07/10/hanergy-wraps-460-kw-of-cigs-around-chinese-skyscraper>.
- 194 Bifacial systems from Renné, op. cit. note 117, 11 April 2020.
- 195 Advantages from, for example, C. Branam, "Solar arrays could be used as resources for plant productivity, study shows", press release (Corvallis, OR: Oregon State University, 2 November 2018), <https://today.oregonstate.edu/news/solar-arrays-could-be-used-resources-plant-productivity-study-shows>; E. Bellini, "Food crops do better in the shade of solar panels", pv magazine, 3 September 2019, <https://www.pv-magazine.com/2019/09/03/food-crops-do-better-in-the-shade-of-solar-panels>; P. Lal, "India prepares to embrace agrivoltaics", pv magazine, 27 September 2019, <https://www.pv-magazine-india.com/2019/09/27/india-prepares-to-embrace-agrivoltaics>; T. Tsanova, "German agro PV trial shows up to 186% land use efficiency", *Renewables Now*, 15 April 2019, <https://renewablesnow.com/news/german-agro-pv-trial-shows-up-to-186-land-use-efficiency-650768>. Improved yields and additional income from SolarPower Europe, op. cit. note 1, p. 51, and from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 17. Prevention of wind and soil erosion, and shade for livestock, from Lal, op. cit. this note; reduced evaporation and rainwater harvesting from Tsanova, op. cit. this note.
- 196 Figure of approximately 2.9 GW was as of end-2018, from Fraunhofer ISE, "Agrophotovoltaics", <https://www.ise.fraunhofer.de/en/key-topics/integrated-photovoltaics/agrophotovoltaics-apv.html>, viewed 17 April 2020. National funding programmes existed in several countries, including Japan (since 2013), China (about 2014), France (2017), the United States (2018) and most recently the Republic of Korea, from idem. In Japan, almost 1,900 agricultural PV facilities were already installed by the end of fiscal year 2017, and such projects have been included under Japan's FIT scheme since 2013, from Matsubara, op. cit. note 57; E. Bellini, "Ambitious 1 GW agrivoltaic livestock farming project announced in Malaysia", pv magazine, 6 December 2019, <https://www.pv-magazine.com/2019/12/06/ambitious-1-gw-agrivoltaic-livestock-farming-project-announced-in-malaysia>.
- 197 Masson, op. cit. note 2.
- 198 P. Mints, SPV Market Research, *The Solar Flare*, no. 2 (30 April 2020), pp. 10, 17.
- 199 Mints, *The Solar Flare*, op. cit. note 22, p. 13; Mints, *The Solar Flare*, op. cit. note 198, p. 16; Mints, *The Solar Flare*, op. cit. note 1, p. 22.
- 200 "US solar maintenance costs plummet as tech gains multiply", *New Energy Update*, 6 February 2019, <https://analysis.newenergyupdate.com/pv-insider/us-solar-maintenance-costs-plummet-tech-gains-multiply>.
- 201 Frankfurt School-UNEP Centre and BloombergNEF, *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020), pp. 27-29, <https://www.fs-unep-centre.org>.
- 202 IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 15; S. Henbest, "The first phase of the transition is about electricity, not primary energy", BloombergNEF, 28 January 2020, <https://about.bnef.com/blog/>

- the-first-phase-of-the-transition-is-about-electricity-not-primary-energy; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 83; M. Hall, "The year in solar, part IV: More storage and hydrogen advances as solar just kept getting cheaper", pv magazine, 30 December 2019, <https://www.pv-magazine.com/2019/12/30/the-year-in-solar-part-iv-more-storage-and-hydrogen-advances-as-solar-just-kept-getting-cheaper>. Regarding variations in energy costs, see, for example, G. Barbose and N. Darghouth, *Tracking the Sun VIII: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States* (Berkeley, CA: LBNL, September 2017), p. 2, https://emp.lbl.gov/sites/default/files/tracking_the_sun_10_report.pdf, G. Barbose and N. Darghouth, *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States, 2019 Edition* (Berkeley, CA: LBNL, October 2019), https://emp.lbl.gov/sites/default/files/tracking_the_sun_2019_report.pdf, and IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 77.
- 203 Mints, *The Solar Flare*, op. cit. note 2, p. 11.
- 204 Solar PV most competitive (including against wind power, the second lowest price) and average price from ABSOLAR, 2019, provided by R. Baitelo, ABSOLAR, personal communication with REN21, 15 April 2020. Similar information and natural gas from Willuhn, op. cit. note 132. Selected projects must be operational by 1 January 2025. The lowest electricity price bid in Brazil's A-4 auction in June 2019 was even lower, at USD 17.30 per MWh; at the time, it was the lowest price ever recorded for large-scale solar in an energy auction, from idem.
- 205 Dubai's tender was for the fifth phase of the 5 GW Mohammad bin Rashid Al Maktoum Solar Park, from MESIA, cited in Publicover, op. cit. note 162; A. Parikh, "Dubai's 900 MW solar auction sees record low tariffs", Mercom India, 15 October 2019, <https://mercomindia.com/dubai-solar-auction-record-low-tariffs>; E. Bellini, "Dubai confirms Saudi's ACWA won 900 MW solar project tender with \$0.016953/kWh bid", pv magazine, 22 November 2019, <https://www.pv-magazine.com/2019/11/22/dubai-confirms-saudis-acwa-won-900-mw-solar-project-tender-with-0-016953-kwh-bid>. Portugal figure of 1.29 GW from L. Ferreira, Portuguese Renewable Energy Association (APREN), 13 April 2020; bid prices and record lows from Mints, *The Solar Flare*, op. cit. note 1, p. 21; S. Djunic, "Portugal publishes full list of solar auction winners", Renewables Now, 8 August 2019, <https://renewablesnow.com/news/portugal-publishes-full-list-of-solar-auction-winners-664834>; Willuhn, op. cit. note 132; Wood Mackenzie, "Portugal's world record-breaking solar PV auction", press release, 12 August 2019, <https://www.woodmac.com/press-releases/portugals-world-record-breaking-solar-pv-auction>; J. Bowlus, "By adding solar, Portugal pushes all-in on renewables", Energy Reporters, 7 October 2019, <https://www.energy-reporters.com/opinion/by-adding-solar-portugal-pushes-all-in-on-renewables>. The low bid in Portugal was EUR 14.63/MWh, from B. Silva, "Solar auctions sink electricity prices to less than half", *dinheiro vivo*, 30 July 2019, <https://www.dinheirovivo.pt/outras/leiloes-do-solar-afundam-precos-para-menos-de-metade-iberdrola-vence-sete-lotes>.
- 206 Dubai records thanks to low cost of finance, cheap labour and excellent resources, from G. Parkinson, "Solar PV prices fall to record lows in tender for 900MW solar park in Dubai", *RenewEconomy*, 10 October 2019, <https://reneweconomy.com.au/solar-pv-prices-fall-to-record-lows-in-tender-for-900mw-solar-park-in-dubai-51069>; desert and resources also from Masson, op. cit. note 2; experts and low bids from Ferreira, op. cit. note 205, and from Masson, op. cit. note 2; E. Bellini, "Portugal's bid of €0.01470/kWh is not the price of PV", pv magazine, 2 August 2019, <https://www.pv-magazine.com/2019/08/02/portugals-bid-of-e0-01470-kwh-is-not-the-price-of-pv>. See also, for example, Bowlus, op. cit. note 205; J. Deign, "Key to those record-low solar bids? Rosy merchant income assumptions", *GTM*, 9 August 2019, <https://www.greentechmedia.com/articles/read/merchant-income-is-key-in-latest-record-solar-bids>; Willuhn, op. cit. note 132.
- 207 Bellini, op. cit. note 132; Willuhn, op. cit. note 132.
- 208 New lows in 2019 from Mints, *The Solar Flare*, op. cit. note 22, p. 29; pricing for utility-scale solar PPAs declined by 4.7% during the year, to an average of 2.74 cents/kWh, from LevelTen Energy, cited in J. Weaver, "Utility-scale solar PPA pricing down 4.7% in 2019, with 13.6 GW of corporate deals signed", pv magazine, 4 February 2020, <https://pv-magazine-usa.com/2020/02/04/utility-scale-solar-ppa-pricing-down-4-7-in-2019-with-13-6-gw-of-corporate-deals-signed>; into 2020 from "Oil group Galp becomes Spanish solar giant; Qatar signs PV contract below \$16/MWh", *New Energy Update*, 29 January 2020, <https://analysis.newenergyupdate.com/pv-insider/oil-group-galp-becomes-spanish-solar-giant-qatar-signs-pv-contract-below-16mwh>.
- 209 Range of PPA prices from SEIA and Wood Mackenzie, op. cit. note 105, p. 9. California's Eland project from Institute for Energy Economics and Financial Analysis, cited in F. Mayr, "Battery storage at US\$20/MWh? Breaking down low-cost solar-plus-storage PPAs in the USA", *Energy Storage News*, 23 March 2020, <https://www.energy-storage.news/blogs/battery-storage-at-us20-mwh-breaking-down-low-cost-solar-plus-storage-ppas>.
- 210 "Oil group Galp becomes Spanish solar giant", op. cit. note 208.
- 211 Shortening and shifting towards merchant model from C. Roselund, "Is the U.S. solar market slipping towards merchant?", pv magazine, 24 June 2019, <https://www.pv-magazine.com/2019/06/24/is-the-u-s-solar-market-slipping-towards-merchant>; IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 15. Agreement periods in the United States are shortening to 7-15 years, while these are longer than many PPA periods in Australia and Germany. In addition, the US market is starting to shift towards the merchant model, with this development further along in Chile and parts of Europe, especially Spain, all from idem. Utility-scale solar pricing in the United States is flattening and the price of PPAs actually increased somewhat during 2019, from LevelTen, cited in J. Weaver, "Utility scale solar pricing inches up", pv magazine, 20 February 2019, <https://pv-magazine-usa.com/2019/02/20/utility-scale-solar-pricing-inches-up>; flattening in Australia from SunWiz, "Australian solar power prices fall to record lows in 2019", 22 January 2020, <https://www.sunwiz.com.au/australian-solar-power-prices-fall-to-record-lows-in-2019>.
- 212 Low prices and constrained margins from Mints, *The Solar Flare*, op. cit. note 2; Henbest, op. cit. note 202. Bidding below marginal costs to win tenders from IRENA, op. cit. note 125, p. 31. See also information and sources throughout this section.
- 213 Hareon Solar from M. Osborne, "Hareon Solar's main manufacturing subsidiary forced into bankruptcy liquidation", PV-Tech, 3 January 2019, <https://www.pv-tech.org/news/hareon-solars-main-manufacturing-subsidiary-forced-into-bankruptcy-liquidat>; Suntech from Mints, *The Solar Flare*, op. cit. note 2, p. 18. See also A. Stevenson, "China's companies binged on debt. Now they can't pay the bill", *New York Times*, 12 December 2019, <https://www.nytimes.com/2019/12/12/business/china-default.html>; Yingli's several difficult years from M. Kanellos, "Yingli in trouble: The 'number one' curse in solar strikes again", *Forbes*, 18 May 2015, <https://www.forbes.com/sites/michaelkanellos/2015/05/18/yingli-in-trouble-the-number-one-curse-in-solar-strikes-again>; B. Beetz, "Yingli's financials go from bad to worse", pv magazine, 26 April 2018, <https://www.pv-magazine.com/2018/04/26/yinglis-financials-go-from-bad-to-worse>; 2019 challenges from M. Hall, "Yingli reveals the full extent of its huge debt mountain", pv magazine, 1 May 2019, <https://www.pv-magazine.com/2019/05/01/yingli-reveals-the-full-extent-of-its-huge-debt-mountain>; S. Lacey, "Yingli's troubles show the downside of relying on solar project development in China", *GTM*, 28 May 2015, <https://www.greentechmedia.com/articles/read/yinglis-troubles-show-the-downside-of-relying-on-solar-project-development>; E. Bellini, "Panasonic transfers solar manufacturing unit to GS-Solar and creates new research JV", pv magazine, 9 May 2019, <https://www.pv-magazine.com/2019/05/09/panasonic-transfers-solar-manufacturing-unit-to-gs-solar-and-creates-new-research-jv>; B. Kuroda and Y. Kawai, "Panasonic sells solar factory in Malaysia to new Chinese R&D ally", *Nikkei*, 10 May 2019, <https://asia.nikkei.com/Business/Business-deals/Panasonic-sells-solar-factory-in-Malaysia-to-new-Chinese-R-D-ally>; S. Prateek, "With no buyers, Moser Baer Solar heads towards liquidation", Mercom India, 24 June 2019, <https://mercomindia.com/moser-baer-solar-liquidation-no-buyers>; Chinese Taipei from Mints, *The Solar Flare*, op. cit. note 2, p. 32. In addition, REC Silicon (Norway) shut down much of its operations during the year, from M. Hall, "REC Silicon prepared to power down the rest of its operation", pv magazine, 3 October 2019, <https://www.pv-magazine.com/2019/10/03/rec-silicon-prepared-to-power-down-the-rest-of-its-operation>; Hanergy (China) announced large numbers of layoffs and stopped manufacturing at several locations, from E. Wesoff, "Hanergy: From thin-film solar savior to mass layoffs at MiaSolé, Alta, Solibro and Global Solar", pv magazine, 13 December 2019, <https://www.pv-magazine.com/2019/12/13/hanergy>.

- pv-magazine-usa.com/2019/12/13/hanergy-from-thin-film-solar-savior-to-mass-layoffs-at-miasole-alta-solibro-and-global-solar; Swiss-based ABB exited the solar space by selling its inverter business to Italian-based Fimer, from Hall, op. cit. note 34, and from ABB, "ABB to exit solar inverter business", press release (Zurich: 9 July 2019), <https://new.abb.com/news/detail/26838/abb-to-exit-solar-inverter-business>; inverter manufacturer KACO (Germany) became a subsidiary of Siemens (Germany), from KACO new energy, "Made in Germany – worldwide", <https://kaco-newenergy.com/company>, viewed 17 April 2020.
- 214 M. Osborne, "China-based solar manufacturers set to post big profit gains in 2019", PV-Tech, 27 January 2020, <https://www.pv-tech.org/news/china-base-solar-manufacturers-set-to-post-big-profit-gains-in-2019>; Shaw, op. cit. note 32. Falling demand in China, but increasing in Europe and elsewhere meant that Chinese manufacturers had markets for their excess capacity (and could avoid the United States and its tariffs), from Mints, *The Solar Flare*, op. cit. note 51, p. 5.
- 215 A. Bhambhani, "LONGi improved 2019 revenues by close to 50%", TaiyangNews, 24 April 2020, <http://taiyangnews.info/business/longi-improved-2019-revenues-by-close-to-50-annually>.
- 216 Able to cope, lower cost and economies of scale from Masson, op. cit. note 2, 4 May 2020; top-tier companies and partnerships from J. Chase et al., "On prices, technology and 2019 trends", pv magazine, 6 September 2019, <https://www.pv-magazine-australia.com/2019/09/06/on-prices-technology-and-2019-trends>.
- 217 Strategic co-operation and support supply chains in 2019 from V. Shaw, "Tongwei announces output tie-up with Longi", pv magazine, 4 June 2019, <https://www.pv-magazine.com/2019/06/04/tongwei-announces-tie-up-with-longi>, and from A. Bhambhani, "LONGi & Tongwei announce strategic cooperation agreement; Both to acquire 30% stake in each other's manufacturing facilities; further cooperation arenas to be explored", TaiyangNews, 5 June 2019, <http://taiyangnews.info/business/strategic-tie-up-between-longi-tongwei>; earlier ventures and agreements from, for example, M. Hutchins, "Tongwei subsidiary announces joint venture with Longi", pv magazine, 14 March 2017, <https://www.pv-magazine.com/2017/03/14/tongwei-subsi-dary-announces-joint-venture-with-longi>, and from B. Publicover, "Tongwei, Longi sign 55,000 MT polysilicon supply agreement", pv magazine, 24 May 2018 <https://www.pv-magazine.com/2018/05/24/tongwei-longi-sign-55000-mt-polysilicon-supply-agreement>. Zhonghuan Semiconductor and GCL-Poly from E. Bellini and M. Hutchins, "Zhonghuan Semiconductor and GCL-Poly to expand production of mono wafers by 25 GW", pv magazine, 4 June 2019, <https://www.pv-magazine.com/2019/06/04/zhonghuan-semiconductor-and-gcl-poly-to-expand-production-of-mono-wafers-by-25-gw>.
- 218 Masson, op. cit. note 2; M. Hall, "The year in solar, part II: A lively show season, more legal shenanigans and rising panel efficiencies abound", pv magazine, 26 December 2019, <https://www.pv-magazine.com/2019/12/26/the-year-in-solar-part-ii-a-lively-show-season-more-legal-shenanigans-and-rising-panel-efficiencies-abound>; EurObserv'ER, op. cit. note 1, p. 14; maintain market share from "China solar giants get bigger as glut ignites battle for share", *Bloomberg*, 4 March 2020, <https://www.bloomberg.com/news/articles/2020-03-04/china-solar-giants-get-bigger-as-glut-ignites-battle-for-share>, and from P. Mints, SPV Market Research, personal communication with REN21, 1 May 2020. Note that industry forecasts are based largely on government programmes, including auctions and tenders, from Mints, *The Solar Flare*, op. cit. note 117, p. 19. New facilities that began operation in 2019 included: Q Cells' new 1.7 GW per year module factory in the US state of Georgia, reportedly the largest in the Western hemisphere, from "New solar PV manufacturing facility is largest in Western Hemisphere", *Renewable Energy World*, 27 September 2019, <https://www.renewableenergyworld.com/2019/09/27/new-solar-pv-manufacturing-facility-is-largest-in-western-hemisphere>; First Solar, "First Solar becomes largest PV module manufacturer in the Western Hemisphere", press release (Tempe, AZ: 24 October 2019), <https://investor.firstsolar.com/news/press-release-details/2019/First-Solar-Becomes-Largest-PV-Module-Manufacturer-in-the-Western-Hemisphere/default.aspx>; C. Roselund, "Inside JinkoSolar's Jacksonville factory", pv magazine, 26 February 2019, <https://pv-magazine-usa.com/2019/02/26/inside-jinkosolars-jacksonville-factory>; Jinko Solar, "JinkoSolar expands mono wafer production capacity to 18 GW with added 5 GW capacity to Sichuan production facility", press release (Shanghai: 8 November 2019), <http://ir.jinkosolar.com/news-releases/news-release-details/jinkosolar-expands-mono-wafer-production-capacity-18-gw-added-5>; I. Shumkov, "Seraphim to open 1-GW Chinese solar factory in May", *Renewables Now*, 12 March 2019, <https://renewablesnow.com/news/seraphim-to-open-1-gw-chinese-solar-factory-in-may-646116>; LONGi, "LONGi launches new 5GW mono module plant, increases supply capacity", press release (Shaanxi, China: 8 March 2019), https://en.longi-solar.com/home/events/press_detail/id/98.html. Announcements of expansion plans included: M. Osborne, "LONGi planning new 10GW mono ingot production plant", PV-Tech, 28 November 2019, <https://www.pv-tech.org/news/longi-planning-new-10gw-mono-ingot-production-plant>; Bhambhani, op. cit. note 215; V. Shaw, "Risen shines: Manufacturer starts work on 2.5 GW cell and module factory", pv magazine, 20 August 2019, <https://www.pv-magazine.com/2019/08/20/risen-shines-manufacturer-starts-work-on-2-5-gw-cell-and-module-factory>; M. Osborne, "Canadian Solar taking module capacity to over 12GW in 2019", PV-Tech, 15 August 2019, <https://www.pv-tech.org/news/canadian-solar-taking-module-capacity-to-over-12gw-in-2019>; E. Bellini, "Ekore breaks ground on 1 GW vertically integrated module factory in Turkey", pv magazine, 11 March 2019, <https://www.pv-magazine.com/2019/03/11/ekore-breaks-ground-on-1-gw-vertically-integrated-module-factory-in-turkey>; P. Hannen, "Meyer Burger abandons plan to relocate operations to China", pv magazine, 15 August 2019, <https://www.pv-magazine.com/2019/08/15/meyer-burger-abandons-plan-to-relocate-operations-to-china>.
- 219 Commercial crystalline and thin-film manufacturing capacity increased 35% in 2019, from 113.3 GWp in 2018 to 153.1 GWp, and module assembly capacity increased 29% in 2019, from 143.9 GW in 2018 to 185 GWp, from Mints, op. cit. note 1, pp. 15, 25, 29. In spite of reduced demand in China, the upstream industry saw growth in 2019, with production increasing during the first half of the year for polysilicon (up 8.4%), wafers (26%), cells (30.8%) and modules (11.9%). Exports also increased by 50% for cells and 45.2% for modules, while wafer exports were down (by 34%) due to higher domestic demand for cell manufacturing, from Haugwitz, op. cit. note 30.
- 220 See endnote 223.
- 221 Mints, *The Solar Flare*, op. cit. note 117, p. 20. See also "China solar giants get bigger as glut ignites battle for share", op. cit. note 218.
- 222 Figure of 39% increase over 2018 from Mints, *The Solar Flare*, op. cit. note 198, pp. 4, 10. An estimated 89.1 GW of capacity was shipped in 2018, and 123.5 GW shipped in 2019; cumulative shipment of all solar PV technologies reached 591 GW peak by year's end, from idem, p. 13. Asia was home to 86% of global capacity to manufacture crystalline and thin-film solar cells; China was home to 63% of the world's total cell manufacturing capacity and to 58% of module manufacturing capacity, from Mints, *The Solar Flare*, op. cit. note 198, p. 5.
- 223 Based on data from Mints, *The Solar Flare*, op. cit. note 198, p. 11. Total shipments were 123.5 GWp, with shipment shares as follows: Tongwei 10%, LONGi 9%, Jinko Solar 8%, Canadian Solar (China/Canada) 7%, Aiko Solar 6%, JA Solar 6%, Trina Solar 5% (US), First Solar 4%, Hanwha Q-Cells 4% (Republic of Korea), UREC 4% (Chinese Taipei), all others 37%, based on shipments from in-house production of crystalline and thin-film cells shipped to first buyer from idem, and from Mints, *Photovoltaic Manufacturer Shipments*, op. cit. note 1, p. 107.
- 224 Mints, *The Solar Flare*, op. cit. note 117, p. 8; Mints, *The Solar Flare*, op. cit. note 1, p. 17; Mints, *The Solar Flare*, op. cit. note 22, p. 5. See also information and sources throughout this section.
- 225 Mints, *The Solar Flare*, op. cit. note 117, p. 8; Mints, *The Solar Flare*, op. cit. note 51, p. 13; Mints, *The Solar Flare*, op. cit. note 1, pp. 8, 10; Mints, *The Solar Flare*, op. cit. note 22, p. 28.
- 226 Grid infrastructure and emerging markets from Masson, op. cit. note 2; grid infrastructure also from Mints, *The Solar Flare*, op. cit. note 1, pp. 8, 10; Mints, *The Solar Flare*, op. cit. note 22, p. 28. See market text and references for more on policy-related impacts.
- 227 See, for example, IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 58, 70-71; N. Kabear, "Indian solar cell and module imports decline by 37% year-over-year in CY 2018", Mercom India, 21 February 2019, <https://mercomindia.com/solar-cell-module-imports-decline-2018>; Hall, "REC Silicon prepared to power down the rest of its operation", op. cit. note 213.
- 228 Parikh, op. cit. note 45; N. Kabear, "Duties and tariffs piling up in the Indian renewable industry", Mercom

- India, 22 April 2019, <https://mercomindia.com/duties-tariffs-piling-up-indian-renewable-industry>.
- 229 Solar PV imports from C. Marcy, "U.S. imports of solar photovoltaic modules mainly come from Asia", Today in Energy, US EIA, 14 February 2018, <https://www.eia.gov/todayinenergy/detail.php?id=34952>. The Section 201 tariffs are set to apply for four years to cells and modules using crystalline silicon panel chemistries; they start at 30% of the cell or module price, and decline annually by 5 percentage points, from idem. Steel and aluminium from B. Beetz, "3: PV's day of judgement", pv magazine, 27 December 2018, <https://www.pv-magazine.com/2018/12/27/3-pvs-day-of-judgement>; C. Roselund and J. Weaver, "2018 solar power year in review (part 1)", pv magazine, 20 December 2018, <https://pv-magazine-usa.com/2018/12/20/2018-solar-power-year-in-review-part-1>; E. F. Merchant, "Trump admin announces 25% tariff on Chinese inverters", GTM, 17 September 2018, <https://www.greentechmedia.com/articles/read/administration-announces-25-inverter-tariffs>. The United States accounted for about 0.24% of solar exports from China during 2018, down from 5.9% in 2017. Most of China's shipments overseas went to Europe, India and Southeast Asia, all from D. Stanway, "China installed 18 percent less solar power capacity in 2018", Reuters, 16 January 2019, <https://www.reuters.com/article/us-china-solarpower/china-installed-18-percent-less-solar-power-capacity-in-2018-idUSKCN1PB09G>. See also C. Roselund, "Trump tariff increase to have limited effect on U.S. solar market", pv magazine, 6 May 2019, <https://pv-magazine-usa.com/2019/05/06/trump-tariff-increase-to-have-limited-effect-on-the-u-s-solar-market>, and L. Stoker, "Trade tariffs have caused 'devastating harm' to US solar industry", PV-Tech, 3 December 2019, <https://www.pv-tech.org/news/trade-tariffs-have-caused-devastating-harm-to-us-solar-industry>.
- 230 E. Merchant, "Chinese solar inverters hit by latest US trade tariffs, but impact seen as muted", GTM, 13 May 2019, <https://www.greentechmedia.com/articles/read/chinese-solar-inverters-hit-by-latest-us-trade-tariffs-but-impact-seen-as-m>; Pratheeksha, op. cit. note 45. Tariffs on Chinese inverters were originally adopted in 2018 and scheduled to begin in January 2019, but they were delayed due to ongoing negotiations between the United States and China, from Merchant, op. cit. this note.
- 231 IEA PVPS, 2019 Snapshot of Global PV Markets, op. cit. note 23, p. 15.
- 232 E. Merchant, "Solar tariffs boosted US-produced modules, but industry remains split on their future", GTM, 10 February 2020, <https://www.greentechmedia.com/articles/read/solar-tariffs-put-wins-on-the-board-for-u-s-produced-modules-but-industry-remains-split-on-their-future>. See also J. Martín, "Trump solar tariffs failing to kickstart US upstream turnaround, review finds", PV-Tech, 10 February 2020, <https://www.pv-tech.org/news/trumps-pv-sanctions-more-boon-for-us-modules-than-cells-review-finds>; S. Higgins, "Two years after White House solar panel tariffs, industry outlook isn't brighter", Washington Examiner, 12 February 2020, <https://www.washingtonexaminer.com/policy/economy/two-years-after-white-house-solar-panel-tariffs-industry-outlook-isnt-brighter>.
- 233 Merchant, op. cit. note 232. See also Martín, op. cit. note 232; Higgins, op. cit. note 232.
- 234 Demand soared from "US exempts bifacial panels from import tariffs; Nevada PV project proposes US' largest battery", New Energy Update, 19 June 2019, <http://newenergyupdate.com/pv-insider/us-exempts-bifacial-panels-import-tariffs-nevada-pv-project-proposes-us-largest-battery>. On and off bifacial exception information from, for example: Mints, *The Solar Flare*, op. cit. note 22, p. 33; Mints, *The Solar Flare*, op. cit. note 2, p. 15; J. Parnell, "Bifacial modules now exempt from Trump's trade tariffs", PV-Tech, 13 June 2019, <https://www.pv-tech.org/news/bifacial-modules-now-exempt-from-trumps-trade-tariffs>; J. Martín, "Bifacial loses US tariff workaround as Section 201 exemption is axed", PV-Tech, 7 October 2019, <https://www.pv-tech.org/news/bifacial-loses-us-tariff-workaround-as-section-201-exemption-is-axed>; E. Merchant, "US reverses course on tariff exclusion for bifacial solar modules", GTM, 7 October 2019, <https://www.greentechmedia.com/articles/read/us-reverses-course-on-tariff-exclusion-for-bifacial-solar-modules>; Pratheeksha, op. cit. note 45; C. Lin, "12 GW bifacial demand in 2020", pv magazine, 31 December 2019, <https://www.pv-magazine.com/2019/12/31/12-gw-bifacial-demand-in-2020>; "US exempts bifacial panels from import tariffs", op. cit. this note; S. Bajaj, "Trump administration withdraws tariff exemption for bifacial solar modules", Mercom India, 7 October 2019, <https://mercomindia.com/trump-withdraws-tariff-exemption-bifacial-solar-modules>; A. Burger, "Reversal of U.S. bifacial solar tariff exemption will bite, but growth expected to continue", Solar Magazine, 17 October 2019, <https://solarmagazine.com/reversal-of-us-bifacial-solar-tariff-exemption-but-growth-continues>. Removal of exemption in early 2020 from E. F. Merchant, "Trump administration removes tariff exemption for bifacial solar panels – again", GTM, 17 April 2020, <https://www.greentechmedia.com/articles/read/trump-admin-removes-tariff-exemption-for-bifacial-solar-panels-again>.
- 235 Schmela, op. cit. note 1, 14 May 2020.
- 236 American Wind Energy Association, Washington, DC, personal communication with REN21, 8 May 2020; K. E. Stromsta, "US wind industry's response to solar's rise: Embrace it", GTM, 22 May 2019, <https://www.greentechmedia.com/articles/read/us-wind-industrys-response-to-solars-rise-embrace-it>; F. Zhao, Global Wind Energy Council, Copenhagen, personal communication with REN21, 4 May 2020.
- 237 See, for example, P. S. Molina, "Repsol set up renewables unit", pv magazine, 9 October 2019, <https://www.pv-magazine.com/2019/10/09/repsol-sets-up-renewables-unit>; E. Bellini, "Spain's oil giant Repsol turns to renewables", pv magazine, 17 May 2018, <https://www.pv-magazine.com/2018/05/17/spains-oil-giant-repsol-turns-to-renewables>; E. Wesoff, "Oil and gas giants Shell and Total get serious about solar", pv magazine, 9 February 2020, <https://pv-magazine-usa.com/2020/02/09/oil-and-gas-giants-shell-and-total-get-serious-about-solar>; E. Bellini, "Eni uses solar to power oil and gas fields in Pakistan and Tunisia", pv magazine, 13 March 2019, <https://www.pv-magazine.com/2019/03/13/eni-uses-solar-to-power-oil-and-gas-fields-in-pakistan-and-tunisia>; E. Bellini, "Angola's solar plans boosted by Italian oil giant Eni", pv magazine, 14 November 2019, <https://www.pv-magazine.com/2019/11/14/angolas-solar-plans-boosted-by-italian-oil-giant-eni>; M. Maisch, "Upstream majors to lead the charge in renewables investment", pv magazine, 28 May 2019, <https://www.pv-magazine-australia.com/2019/05/28/upstream-majors-to-lead-the-charge-in-renewables-investment>.
- 238 Solar cells and modules, value chain from Schmela, op. cit. note 1, 12 May 2020. See also, for example, S. Chunduri, "TaiyangNews first report on high efficiency cell technologies provides overview from PERC to passivated contacts and HJT", TaiyangNews, 21 November 2019, <http://taiyangnews.info/reports/high-efficiency-solar-cells-2019>; S. Chunduri, "The time for a new generation of solar modules has come – TaiyangNews presents in-depth report with product data on the most exciting new PV module technologies", TaiyangNews, 20 September 2018, <http://taiyangnews.info/reports/advanced-solar-module-technology-2018-report>, as well as information and related sources throughout this section.
- 239 See, for example, "ASU researchers break solar-cell efficiency record at 25.4 percent", Renewable Energy World, 14 January 2019, <https://www.renewableenergyworld.com/articles/2019/01/asu-researchers-break-solarcell-efficiency-record-at-25-4-percent.html>; Insolight, "Next-gen rooftop solar panels achieve record efficiency", press release (Lausanne, Switzerland: 19 February 2019), <https://insolight.ch/press-release-201902/>; Smart Energy Council, "LONGi Solar sets solar record", 1 February 2019, <https://www.smartenergy.org.au/news/longi-solar-sets-solar-record>; S. Dutta, "Global module suppliers Trina and Canadian Solar announce world record efficiencies", Mercom India, 31 May 2019, <https://mercomindia.com/trina-and-canadian-solar-record-efficiencies>; Fraunhofer ISE, "Ultrathin solar cells reach nearly 20% efficiency – 'Nature Energy' publishes paper by Centre de Nano-Sciences et de Nanotechnologies and Fraunhofer ISE", 6 August 2019, <https://www.ise.fraunhofer.de/de/presse-und-medien/news/2019/paper-in-nature-energy-ultrathin-solar-cells-reach-nearly-20-percent-efficiency.html>; K. Weinmann, "New record for flexible thin-film solar cells", Empa, 4 July 2019, <https://www.empa.ch/web/s604/cigs-record-2019>; Willuhn, op. cit. note 193; Fraunhofer ISE, "Fraunhofer ISE sets two records for the efficiency of silicon-based monolithic triple-junction solar cells", press release (Freiburg, Germany: 29 August 2019), <https://www.ise.fraunhofer.de/en/press-media/press-releases/2019/fraunhofer-ise-sets-two-records-for-the-efficiency-of-silicon-based-monolithic-triple-junction-solar-cells.html>; J. Martín, "Canadian Solar trumpets new cell conversion efficiency breakthrough", PV-Tech, 18 September 2019, <https://www.>

- pv-tech.org/news/canadian-solar-trumpets-new-cell-conversion-efficiency-breakthrough; E. Bellini, "Scientists hit 21.6% perovskite cell efficiency using concentrator PV", pv magazine, 22 November 2019, <https://www.pv-magazine.com/2019/11/22/scientists-hit-21-6-perovskite-cell-efficiency-using-concentrator-pv/>; R. Ranjan, "Hanergy achieves 25.11% conversion efficiency for its silicon heterojunction solar technology", Mercom India, 25 November 2019, <https://mercomindia.com/hanergy-achieves-conversion-efficiency/>; Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), "New efficiency world record for organic solar modules", 11 November 2019, <https://www.fau.eu/2019/11/11/wissenschaft/new-efficiency-world-record-for-organic-solar-modules>. Module efficiencies continued to increase in 2018 and through the first half 2019 (the time period covered by source), from Barbose and Darghouth, op. cit. note 124, p. 2.
- 240 Mints, *The Solar Flare*, op. cit. note 2, pp. 6, 12; Dutta, op. cit. note 239; Chase et al., op. cit. note 216. Expansions were monocrystalline, from SolarPower Europe, *Global Market Outlook for Solar Power 2019-2023* (Brussels: 2019), p. 49. In April, Chinese manufacturer LONGi announced plans to more than double its mono ingot/wafer output from 28 GW in 2018 to 65 GW by 2023, from idem. Details in endnote about crystalline cell technologies from the following: IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 7. For information on mono- versus multi-/poly-crystalline technologies, see, for example, Evergreen Solar, "January 2020 best type of solar panels", <https://evergreensolar.com/types>, viewed 20 March 2020; Gold Coast Solar Power Solutions, "Mono crystalline or poly / multi crystalline solar panels – does it matter?" <https://gold-coast-solar-power-solutions.com.au/posts/mono-crystalline-or-poly-multi-crystalline-solar-panels-does-it-matter>, viewed 20 March 2020; "Monocrystalline and polycrystalline solar panels: What you need to know", Energy Sage, 12 December 2019, <https://www.energysage.com/solar/101/monocrystalline-vs-polycrystalline-solar-panels>.
- 241 IEA, "Tracking power – solar PV", <https://www.iea.org/reports/tracking-power-2019/solar-pv>, viewed 17 April 2020.
- 242 New standard and reasons from Ibid. and from SolarPower Europe, op. cit. note 240, p. 49; Schmelz, op. cit. note 1, 1 April 2018; economically attractive for many projects from Dutta, op. cit. note 239.
- 243 PERC (especially mono-PERC) is now mainstream and role of LONGi, from Masson, op. cit. note 2; investment in commercialisation from Mints, *The Solar Flare*, op. cit. note 22, p. 17; LONGi also from M. Osborne, "LONGi Solar becomes world's largest module manufacturer with latest expansion", PV-Tech, 11 March 2019, <https://www.pv-tech.org/news/longi-solar-becomes-worlds-largest-module-manufacturer-with-latest-expansio>.
- 244 Mints, *Photovoltaic Manufacturer Shipments*, op. cit. note 1, pp. 87, 89; Chunduri, op. cit. note 238.
- 245 SolarPower Europe, op. cit. note 240, p. 49; converting factories from, for example, S. Chunduri, "Heterojunction solar technology 2019 report. TaiyangNews' first report on heterojunction technology (HJT) explores if this promising high-efficiency silicon cell species is the next big thing in solar cell/module manufacturing", TaiyangNews, 20 March 2019, <http://taiyangnews.info/reports/heterojunction-solar-technology-2019-report>; Recom Solar, "Heterojunction technology: The solar cell of the future", <https://recom-solar.com/innovation>, viewed 29 April 2019; low temperatures and fewer steps from G. Roters et al., *Heterojunction Technology: The Solar Cell of the Future* (Gwatt, Switzerland: Meyer Burger, undated), https://www.meyerburger.com/user_upload/dashboard_news_bundle/da4c7a0b7c33e8e21ccddace78c76513b12cc727.pdf. See also "Risen Energy introduces 3 new high-power modules with 440W, 450W & 500W based on different technologies, incl. HJT, M12", TaiyangNews, 13 December 2019, <http://taiyangnews.info/technology/risen-energy-announces-500-w-hjt-modules>, and K. Pickerel, "What are heterojunction technology (HJT) solar panels?" Solar Power World, 4 November 2019, <https://www.solarpowerworldonline.com/2019/11/what-are-heterojunction-technology-hjt-solar-panels>.
- 246 Haugwitz, op. cit. note 27, 6 April 2020.
- 247 Masson, op. cit. note 2, 4 May 2020. HJT offers the advantage of an existing base, good equipment manufacturers and some costs advantages, from idem.
- 248 REC, "REC Group kicks off mass production of its ground-breaking Alpha module in Singapore", press release (Tuas, Singapore: 10 October 2019), <https://usa.recgroup.com/news/rec-group-kicks-mass-production-its-ground-breaking-alpha-module-singapore>.
- 249 Silicon-based solar cells, which account for about 90% of the market and are ahead of the competition for stability and efficiency (20-22% for typical solar cells in the marketplace), are close to reaching their maximum theoretical efficiency, from "Silicon-perovskite solar cells achieve record efficiency of 25.2%", Solar Novus, 12 June 2018, https://www.solarnovus.com/silicon-perovskite-solar-cells-achieve-record-efficiency-of-25-2_N11561.html. The maximum theoretical efficiency of silicon solar cells is 32%, from Graphene Flagship, "Graphene, perovskites, and silicon—an ideal tandem for efficient solar cells", phys.org, 3 March 2020, <https://phys.org/news/2020-03-graphene-perovskites-siliconan-ideal-tandem.html>. One laboratory has developed a possible solution that would be economically competitive, integrating a perovskite cell directly onto a silicon-based cell, with efficiency of 25.2%, from idem. Developing new technologies based on information from references cited in this section.
- 250 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 8. Reports of about 3% in 2006 to more than 24% in 2019, from US DOE, EERE, "Perovskite solar cells", <https://www.energy.gov/eere/solar/perovskite-solar-cells>, viewed 15 March 2020, and from European Perovskite Initiative, "Perovskite solar cells: A new paradigm in Photovoltaics", PV-Tech, 17 October 2019, <https://www.pv-tech.org/corporate-updates/perovskite-solar-cells-a-new-paradigm-in-photovoltaics>; efficiency of 28% was achieved in a silicon-based tandem in 2019, from IEA PVPS, op. cit. this note, and from Oxford PV, "Oxford PV perovskite solar cell achieves 28% efficiency", press release (Oxford, UK: 20 December 2018), <https://www.oxfordpv.com/news/oxford-pv-perovskite-solar-cell-achieves-28-efficiency>.
- 251 Masson, op. cit. note 2; European Perovskite Initiative, op. cit. note 250. Research under way from, for example, US DOE, EERE, op. cit. note 250; J. Yoo et al., "An interface stabilized perovskite solar cell with high stabilized efficiency and low voltage loss", *Energy & Environmental Science*, vol. 12, no. 7 (2019), pp. 2192-99, <https://pubs.rsc.org/en/content/articlelanding/2019/ee/c9ee00751b>; Graphene Flagship, op. cit. note 249; "Perovskite solar cells made with peppermint oil and walnut aroma food additives, preventing lead leakage", *Science Daily*, 26 February 2020, <https://www.sciencedaily.com/releases/2020/02/20200226102144.htm>; I. Fadelli, "Inverted perovskite solar cells with a power conversion efficiency of 22.3%", TechXplore, 20 February 2020, <https://techxplore.com/news/2020-02-inverted-perovskite-solar-cells-power.html>; R. Sanders, "Blue diode illustrates limitations, promise of perovskite semiconductors", *Berkeley News*, 24 January 2020, <https://news.berkeley.edu/2020/01/24/blue-diode-illustrates-limitations-promise-of-perovskite-semiconductors>; NREL, "Researchers improve safety of lead-based perovskite solar cells", press release (Golden, CO: 19 February 2020), <https://www.nrel.gov/news/press/2020/researchers-improve-safety-lead-based-perovskite-solar-cells.html>; Sonnenseite, "Plants absorb lead from perovskite solar cells more than expected", 22 February 2020, <https://www.sonnenseite.com/en/science/plants-absorb-lead-from-perovskite-solar-cells-more-than-expected.html>.
- 252 A. Exntance, "The reality behind solar power's next star material", *Nature*, 25 June 2019, <https://www.nature.com/articles/d41586-019-01985-y>; J. Spector, "Tandem PV secures a rare fund raise for perovskite solar", GTM, 10 April 2019, <https://www.greentechmedia.com/articles/read/tandem-pv-secures-a-rare-fund-raise-for-perovskite-solar>. Saule Technologies (Poland) announced that it had succeeded in printing its perovskite modules with a consistent 10% efficiency, and that it was scheduled to launch prototype production of a single-junction panel later in 2019, from Saule Technologies, "Saule Technologies achieves significant milestones ahead of launching prototype production line in Q4 2019", press release (Warsaw: 13 June 2019), <https://drive.google.com/drive/folders/1FlkbXYsnE-YvITol6nnF60-hg0CclnkP>; B. Wang, "First commercial perovskite solar late in 2019 and the road to moving the energy needle", Nextbigfuture, 3 February 2019, <https://www.nextbigfuture.com/2019/02/first-commercial-perovskite-solar-late-in-2019-and-the-road-to-moving-the-energy-needle.html>. Perovskite company Oxford PV (United Kingdom) announced several developments, including: a strategic partnership with Swiss technology company Meyer Burger to accelerate the move into volume production, from Oxford PV, "Oxford PV to

- collaborate with Meyer Burger", press release (Oxford, UK: 21 March 2019), <https://www.oxfordpv.com/news/oxford-pv-collaborate-meyer-burger>; GBP 65 million (nearly USD 80 million) in funding, including a major investment by Chinese wind turbine manufacturer Goldwind, from Oxford PV, "Oxford PV secures £65 million in Series D funding round", press release (Oxford, UK: 3 July 2019), <https://www.oxfordpv.com/news/oxford-pv-secures-ps65-million-series-d-funding-round>, and from Oxford PV, "Oxford PV raises £31m funding", press release (Oxford, UK: 15 March 2019), <https://www.oxfordpv.com/news/oxford-pv-raises-ps31m-funding>; and plans to begin manufacturing perovskite-on-silicon tandem solar cells on a 250 MW line by the end of 2020, from Oxford PV, "Oxford PV continues to prepare for volume manufacturing", press release (Oxford, UK: 23 October 2019), <https://www.oxfordpv.com/news/oxford-pv-continues-prepare-volume-manufacturing>, from B. Publicover, "Oxford PV orders 100 MW production line from Meyer Burger", pv magazine 8 August 2019, <https://www.pv-magazine.com/2019/08/08/oxford-pv-orders-100-mw-production-line-from-meyer-burger>. See also BloombergNEF, "Solar's hot new thing nears production: Q&A", 11 June 2019, <https://about.bnef.com/blog/solar-hot-new-thing-nears-production-qa>.
- 253 SolarPower Europe, op. cit. note 240, p. 50.
- 254 J. Hill, "SunPower launches world's most powerful residential solar panels", CleanTechnica, 7 March 2019, <https://cleantechnica.com/2019/03/07/sunpower-launches-worlds-most-powerful-residential-solar-panels/>; J. Runyon, "SunPower releases most efficient residential solar panel on the market", Renewable Energy World, 3 May 2019, <https://www.renewableenergyworld.com/articles/2019/03/sunpower-releases-most-efficient-residential-solar-panel-on-the-market.html>; E. Bellini, "Canadian Solar unveils new 400+ Watt bifacial poly PERC black silicon module", pv magazine, 25 September 2018, <https://www.pv-magazine.com/2018/09/25/canadian-solar-unveils-new-400-watt-bifacial-poly-perc-black-silicon-module>. See also C. Roselund, "LONGi launches new high-powered half-cut bifacial module", pv magazine, 15 May 2019, <https://www.pv-magazine.com/2019/05/15/longi-launches-new-high-powered-half-cut-bifacial-module>. Trina Solar launched a 415 watt panel, from M. Hall, "The year in solar, part I: New modules, flat-pack solar and inverter turbulence", pv magazine, 23 December 2019, <https://www.pv-magazine.com/2019/12/23/the-year-in-solar-part-i-new-modules-flat-pack-solar-and-inverter-turbulence>.
- 255 SolarPower Europe, op. cit. note 240, p. 50.
- 256 "Bifacial solar plants can generate 7% higher returns, US model shows", New Energy Update, 15 May 2019, <https://analysis.newenergyupdate.com/pv-insider/bifacial-solar-plants-can-generate-7-higher-returns-us-model-shows/>; "Qatar expands bifacial PV tests as data shows 10% output gains", New Energy Update, 18 September 2019, <https://analysis.newenergyupdate.com/pv-insider/qatar-expands-bifacial-pv-tests-data-shows-10-output-gains/>; J. Crescenti, "Discussing bifacial project economics", pv magazine, 19 February 2020, <https://www.pv-magazine.com/2020/02/19/discussing-bifacial-project-economics>; potential for lower LCOE from Mints, *Photovoltaic Manufacturer Shipments*, op. cit. note 1, p. 57; gains with trackers from C. Barati, "A record year for trackers", pv magazine, 19 November 2019, <https://www.pv-magazine.com/2019/11/19/a-record-year-for-trackers>. Bifacial technology continues to be shunned by some investors due to concerns about data gaps around real-world performance and risks including panel overheating, from Wood Mackenzie, cited in Martín, op. cit. note 234; concerns about bifacial include lack of testing standardisation, components such as trackers must be specifically designed for bifacial, bifacial appropriate technologies have higher manufacturing costs, and others, from Mints, *Photovoltaic Manufacturer Shipments*, op. cit. note 1, pp. 57-58; quality-related uncertainties also from Masson, op. cit. note 2, 28 February 2019; general information on trackers from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 8; Masson, op. cit. note 2, 28 February 2019. Single-axis trackers can increase energy yield by 25-35% compared with fixed systems, from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, p. 6. Trackers can increase duration of the peak period for output, from S. Vorrath, "Changing shape of solar power: How tracking technology killed the solar bell curve", RenewEconomy, 5 February 2019, <https://reneweconomy.com.au/changing-shape-of-solar-power-how-tracking-technology-killed-the-solar-bell-curve-87089>.
- 257 V. Chaturvedi, DSM, cited in Power and Energy Solutions, "Backsheet or bust? The true cost of broken backsheets in the solar industry", PES Solar, February 2020, <https://cdn.pes.eu.com/v/20180916/wp-content/uploads/2020/02/PES-S-1-DSM-ask-the-experts-V2-1.pdf>; SolarPower Europe, op. cit. note 240, p. 49; Lin, op. cit. note 234; "Bifacial solar plants can generate 7% higher returns, US model shows", op. cit. note 256; "Qatar expands bifacial PV tests as data shows 10% output gains", op. cit. note 256; M. Maisch, "WoodMac: Bifacial module capacity will exceed 21 GW by 2024", pv magazine, 26 September 2019, <https://www.pv-magazine.com/2019/09/26/woodmac-bifacial-module-capacity-will-exceed-21-gw-by-2024>. Installed capacity of bifacial technologies has increased from 97 MW in 2016, to more than 2.6 GW in 2018, and an expected 5.4 GW by the end of 2019, from Wood Mackenzie Power & Renewables, cited in Maisch, op. cit. this note.
- 258 See, for example, M. Hutchins, "A common language for bifacial PV", pv magazine, 19 September 2019, <https://www.pv-magazine.com/2019/09/19/a-common-language-for-bifacial-pv/>; Crescenti, op. cit. note 256; Maisch, op. cit. note 257; C. Thurston, "Bifacial tracking grows on new designs", pv magazine, 31 October 2019, <https://www.pv-magazine.com/magazine-archive/bifacial-tracking-grows-on-new-designs/>; Barati, op. cit. note 256. New products launched in 2019 include: Jinko released a new light-weight bifacial module in collaboration with US chemical company DuPont, from E. Merchant, "JinkoSolar strikes upbeat tone on market signs in China and the US", GTM, 3 September 2019, <https://www.greentechmedia.com/articles/read/jinkosolar-sees-us-demand-shifting-to-tariff-exempt-bifacial-modules>; LONGi (China) unveiled a bifacial PERC module with power ratings up to 430 watts, from Roselund, op. cit. note 254; and Seraphim (China) announced a light-weight half-cell, bifacial PERC cell technology, from "Seraphim rolls out new Blade Bifacial solar module", NS Energy, 15 May 2019, <https://www.nsenerybusiness.com/news/seraphim-rolls-out-new-blade-bifacial-solar-module>.
- 259 "Solar operators steer new designs as performance demands grow", New Energy Update, 1 May 2019, <http://newenergyupdate.com/pv-insider/solar-operators-steer-new-designs-performance-demands-grow/>; "PV owners urged to use tech advances, retrofits to hike yield", New Energy Update, 16 October 2019, <https://analysis.newenergyupdate.com/pv-insider/pv-owners-urged-use-tech-advances-retrofits-hike-yield/>; "US solar maintenance costs plummet as tech gains multiply", op. cit. note 200.
- 260 EurObserv'ER, op. cit. note 1, p. 12.
- 261 Advances in inverter technology from SolarPower Europe, op. cit. note 240, p. 50; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 69; improve performance and grid services from SolarPower Europe, *Digitalisation & Solar in Emerging Markets* (Brussels: 5 November 2019), pp. 11, 16, 18, 29, <https://www.solarpowereurope.org/digitalisation-solar-in-emerging-markets>; forecasting schemes from Renné, op. cit. note 117, 11 April 2020.
- 262 See, for example, "US solar maintenance costs plummet as tech gains multiply", op. cit. note 200.
- 263 "PV owners urged to use tech advances, retrofits to hike yield", op. cit. note 259.
- 264 See, for example, R. Ranjan, "Robotic cleaning of solar modules gaining traction in India amid water scarcity", Mercom India, 4 February 2020, <https://mercomindia.com/robotic-cleaning-solar-modules-gaining-traction-india/>; "Miraikikai to commence dry-cleaning robot operation at Bhadla Solar Park, Rajasthan", pv magazine, 2 April 2019, <https://www.pv-magazine.com/press-releases/miraikikai-to-commence-dry-cleaning-robot-operation-at-bhadla-solar-park-rajasthan/>; "Solar panel cleaning services: From robots, kits to water jet pressure; here's all you need to know", *Economic Times*, 8 May 2019, <https://economictimes.indiatimes.com/small-biz/productline/power-generation/solar-panel-cleaning-services-from-robots-kits-to-water-jet-pressure-heres-all-you-need-to-know/articleshow/69230349.cms>; J. Udasin, "Israeli robotic PV cleaning system commissioned at mega solar park in India", *Jerusalem Post*, 11 December 2016, <https://www.jpost.com/Business-and-Innovation/Environment/Israeli-robotic-PV-cleaning-system-commissioned-at-mega-solar-park-in-India-475064>; Global Market Insights, *Solar Panel Cleaning Market by Technology*, report summary, October 2019, <https://www.gminsights.com/industry-analysis/solar-panel-cleaning-market>.

- 265 "The long read: The research behind dust mitigation", pv magazine India, 21 March 2020, <https://www.pv-magazine-india.com/2020/03/21/the-long-read-the-research-behind-dust-mitigation>. Some anti-soiling products are already available, from Schmela, op. cit. note 1, 12 May 2020.
- 266 Mints, *The Solar Flare*, op. cit. note 1, p. 21; Mints, *The Solar Flare*, op. cit. note 2, p. 11; Chaturvedi, op. cit. note 257.
- 267 Mints, *The Solar Flare*, op. cit. note 2, p. 11; Mints, *The Solar Flare*, op. cit. note 2, p. 31; Masson, op. cit. note 2. Examples of countries facing challenges: In Australia, the desire for cheap solar energy has resulted in poor-quality products; an audit in 2018 found that only 1.2% of rooftop installations had been inspected by the regulator, and one in six of these was substandard; failed panels still count towards Australia's renewable energy target, all from L. Hobday and S. Gross, "Australia's obsession with cheap solar is derailing the market, insiders say", ABS News, 27 May 2019, <https://www.abc.net.au/news/2019-05-27/australias-obsession-with-cheap-solar-derailing-market-insiders/11139856>. In Bangladesh, the pursuit of ever-lower bids has caused developers to overlook the quality of components, including imported panels; the government has created standards for panels, inverters, charge controllers and batteries, and has taken steps to mandate them, from S. Islam, "Sub-standard PV equipment worries Bangladeshi solar developers", pv magazine, 18 October 2019, <https://www.pv-magazine.com/2019/10/18/sub-standard-pv-equipment-worries-bangladeshi-solar-developers>. See also A. Gupta, "Substandard products slow down solar power development", EQ International, 4 October 2019, <https://www.eqmagpro.com/substandard-products-slow-down-solar-power-development>. In India, in response to low tariff caps and bid matching, and in order to maximise profits a growing number of developers has compromised quality of components, resulting in decreased output and efficiency of solar plants, from A. Rajeshwari, "Quality consciousness in Indian solar projects a mixed bag: DuPont interview", Mercom India, 3 October 2019, <https://mercomindia.com/quality-consciousness-solar-mixed-bag-dupont>; S. Bajaj, "Low tariffs pushing developers to cut costs and quality of solar mounting structures", Mercom India, 15 July 2019, <https://mercomindia.com/low-tariffs-developers-solar-mounting>. There also are growing concerns in India about the quality of mounting structures for both rooftop and ground-mounted systems, for which there are no regulatory authorities in place, from idem. In the United States, an independent testing lab found that cost pressures (as PPA rates decline) are forcing manufacturers to use cheaper modules, other materials and construction practices in order to offer competitive prices, from K. Pickerel, "Solar's silent killer: Backsheets are shortening some project lifespans", Solar Power World, 15 January 2020, <https://www.solarpowerworldonline.com/2020/01/solars-silent-killer-backsheets-are-shortening-project-lifespans>. Fake and substandard products have flooded the market in Zimbabwe as demand for solar PV has risen alongside rolling blackouts, from "Fake products slow down solar revolution", *The Herald*, 2 September 2019, <https://www.herald.co.zw/fake-products-slow-down-solar-revolution>, "China flooding Zim with substandard solar products", ZimEye, 7 October 2019, <https://www.zimeye.net/2019/10/07/china-flooding-zim-with-substandard-solar-products>. See also E. Bellini, "Lessons to be learnt from Italy's alleged PV fraud", pv magazine, 10 March 2020, <https://www.pv-magazine.com/2020/03/10/lessons-to-be-learnt-from-italys-alleged-pv-fraud>.
- 268 Masson, op. cit. note 2; weather and curtailment from Mints, *The Solar Flare*, op. cit. note 117, p. 22, and from Mints, *The Solar Flare*, op. cit. note 22, p. 31.
- 269 Masson, op. cit. note 2. To date, learning from field failures has relied mainly on anecdotal communication methods and rumor, from Mints, *The Solar Flare*, op. cit. note 117, p. 22.
- 270 S. Bajaj, "MNRE approves 'series' guidelines for quality testing of solar inverters", Mercom India, 27 August 2019, <https://mercomindia.com/mnre-approves-series-guidelines-solar-inverters>.
- 271 S. Islam, "Cheap Indian imports claim prompts Bangladesh to introduce solar standards", pv magazine India, 19 November 2019, <https://www.pv-magazine-india.com/2019/11/19/cheap-indian-imports-claim-prompts-bangladesh-to-introduce-solar-standards>; Islam, op. cit. note 267. Pakistan introduced similar standards for similar reasons a few years earlier, from Haugwitz, op. cit. note 27, 6 April 2020.
- 272 Clean Energy Council, op. cit. note 11, p. 18. The code was under review as of early 2020 and was expected to come into effect later in the year, from idem.
- 273 Renné, op. cit. note 117, 11 April 2020.
- 274 A solar PV system's useful lifetime is 25 to 40 years, from NREL, "Useful life", <https://www.nrel.gov/analysis/tech-footprint.html>, viewed 13 May 2020; there are no end dates per se for the productive life of a solar panel, but modules typically are warranted for 20-25 years, after which they still can produce electricity, from B. Mow, "STAT FAQs part 2: Lifetime of PV panels", NREL, 23 April 2018, <https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html>; volume of decommissioned panels from IRENA and IEA PVPS, *End-of-Life Management: Solar Photovoltaic Panels* (Abu Dhabi/Paris: 2016), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf; N. Hasham, "Waste crisis looms as thousands of solar panels reach end of life", *Sydney Morning Herald*, 13 January 2019, <https://www.smh.com.au/politics/federal/waste-crisis-looms-as-thousands-of-solar-panels-reach-end-of-life-20190112-p50qzd.html>; research from, for example, ARENA, *Research and Development Program Round 5: Addressing Solar PV End-of-Life Issues and Lowering the Cost of Solar PV, Guidelines* (Canberra: December 2019), <https://arena.gov.au/assets/2019/12/research-development-addressing-solar-pv-end-of-life-issues-and-cost.pdf>; S. Enkhardt, "A second life for disused modules and EV batteries", pv magazine, 19 March 2020, <https://www.pv-magazine.com/2020/03/19/a-second-life-for-disused-modules-and-ev-batteries>; E. Butler, "PV end-of-life management", SEIA, August 2019, <https://www.epa.gov/sites/production/files/2019-08/documents/butler.pdf>; SEIA, "End-of-life Considerations for Solar Photovoltaics" (Washington, DC: May 2019), <https://seia.org/sites/default/files/2020-01/SEIA-EOL-Considerations-PV-Factsheet-May2019.pdf>; S. Chowdhury, "An overview of solar photovoltaic panels' end-of-life material recycling", *Energy Strategy Reviews*, vol. 27 (January 2020), <https://www.sciencedirect.com/science/article/pii/S2211467X19301245>; K. Maile, "Shining a light on solar panel recycling", *Recycling Today*, 25 September 2019, <https://www.recyclingtoday.com/article/end-of-life-solar-panel-recycling>.
- 275 J. Spaes, "More than 5,000 tons of modules collected for recycling in France", pv magazine, 4 February 2020, <https://www.pv-magazine.com/2020/02/04/more-than-5000-tons-of-modules-collected-for-recycling-in-france>.
- 276 M. Hall, "Jinko becomes first solar manufacturer to make 100% renewable energy pledge", pv magazine, 24 September 2019, <https://www.pv-magazine.com/2019/09/24/jinko-becomes-first-solar-manufacturer-to-make-100-renewable-energy-pledge>.
- 277 LONGi, "LONGi joins the Global Initiative RE100, commits to 100% renewable power across its entire global operations by 2028", press release (Shaanxi, China: 12 March 2020), https://en.longi-solar.com/home/events/press_detail/id/201.html. For a full list of companies that have committed to 100% renewable energy, see RE 100, "230 RE100 companies have made a commitment to go '100% renewable'. Read about the actions they are taking and why", <http://there100.org/companies>.

CONCENTRATING SOLAR THERMAL POWER (CSP)

- 1 Data are compiled from the following sources: New Energy Update, "CSP Today global tracker", <http://tracker.newenergyupdate.com/tracker/projects>, viewed on numerous dates leading up to 27 April 2020; US National Renewable Energy Laboratory (NREL), "Concentrating solar power projects", <https://solarpaces.nrel.gov>, with the page and its subpages viewed on numerous dates leading up to 27 April 2020 (some subpages are referenced individually throughout this section) and references cited in the CSP section of Renewable Energy Policy Network for the 21st Century (REN21), *Renewables 2019 Global Status Report* (Paris: 2019), pp. 107-09, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf. In some cases, information from the above sources was verified against additional country-specific sources, as cited in the rest of the endnotes for this section. Global CSP data are based on commercial facilities only; demonstration and pilot facilities as well as facilities of 5 MW or less are excluded from capacity data, with the exception of certain plants in China that are described as "demonstration" plants by government but are nonetheless large- (utility-) scale, grid-connected plants that are operating or will operate commercially. Data discrepancies between REN21 and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals.
- 2 Ibid. **Figure 32** based on all sources in endnote 1.
- 3 See sources in endnote 1.
- 4 Ibid.
- 5 Ibid.
- 6 Ibid.
- 7 Ibid.
- 8 Ibid.
- 9 Ibid.
- 10 Ibid.
- 11 reve, "Israel's Megalim concentrated solar power plant starts operations", 11 April 2019, <https://www.evwind.es/2019/04/11/israels-megalim-concentrated-solar-power-plant-starts-operations/66737>; S. Djunic, "Negev Energy's 110-MW solar thermal plant brought online in Israel", *Renewables Now*, 12 April 2019, <https://renewablesnow.com/news/negev-energys-110-mw-solar-thermal-power-plant-brought-online-in-israel-650548>.
- 12 SolarPACES, "CSP projects around the world", <https://www.solarpaces.org/csp-technologies/csp-projects-around-the-world>, viewed 18 March 2020.
- 13 HeliosCSP, "Israel builds world's largest concentrated solar power tower", 5 April 2019, <http://helioscsp.com/israel-builds-worlds-largest-concentrated-solar-power-tower-3>; Focal Line Solar, "Israel inaugurates Negev concentrated solar power plant", 29 August 2019, <https://flsnova.com/2019/08/29/israel-inaugurates-negev-concentrated-solar-power-plant>.
- 14 See sources in endnote 1.
- 15 Ibid.
- 16 SolarPACES, "China announces the first group of CSP demonstration projects", 1 September 2017, <https://www.solarpaces.org/china-announces-the-first-group-of-csp-demonstration-projects>; reve, "Xinjiang's first concentrated solar power plant operational", 30 December 2019, <https://www.evwind.es/2019/12/30/xinjiangs-first-concentrated-solar-power-plant-operational/72831>. See also sources in endnote 1.
- 17 See sources in endnote 1.
- 18 Ibid.
- 19 Ibid.
- 20 "World Forum unveils Botswana-Namibia CSP plan; Israel completes 121 MW trough plant", *New Energy Update*, 11 September 2019, <https://analysis.newenergyupdate.com/csp-today/world-forum-unveils-botswana-namibia-csp-plan-israel-completes-121-mw-trough-plant>; G. Martín, Protermsolar, Madrid, personal communication with REN21, 12 April 2019.
- 21 GBA News Desk, "South Africa IRP: No allocation for concentrated solar power (CSP)", 19 October 2019, <https://www.greenbuildingafrica.co.za/south-africa-irp-no-allocation-for-concentrated-solar-power-csp>; Department of Energy, Republic of South Africa, *Integrated Resource Plan 2019* (Pretoria: 17 October 2019), <http://www.energy.gov.za/IRP/2019/IRP-2019.pdf>.
- 22 "Kuwait eyes up to 400 MW of CSP in expanded solar park", *New Energy Update*, 3 July 2019, <https://analysis.newenergyupdate.com/csp-today/kuwait-eyes-400-mw-csp-expanded-solar-park>. See also sources in endnote 1.
- 23 "Kuwait eyes up to 400 MW of CSP in expanded solar park", op. cit. note 22; Utilities Middle East, "First phase of Kuwait's Shagaya renewable energy park launched", 25 February 2019, <https://www.utilities-me.com/news/12453-first-phase-of-kuwaits-shagaya-renewable-energy-park-launched>. See also sources in endnote 1.
- 24 See sources in endnote 1.
- 25 J. Ball, "Construction progress for \$4.3bn Phase 4 of Dubai's MBR Solar Park", *Construction Week*, 30 December 2018, <https://www.constructionweekonline.com/168452-dewa-notes-progress-on-fourth-phase-of-950mw-mbr-solar-park>.
- 26 "World's largest CSP project achieves financial closure; US announces \$33mn CSP funding", *New Energy Update*, 3 April 2019, <http://newenergyupdate.com/csp-today/worlds-largest-csp-project-achieves-financial-closure-us-announces-33mn-csp-funding>.
- 27 NREL, "eLLO Solar Thermal Project", <https://solarpaces.nrel.gov/ello-solar-thermal-project>, updated 26 September 2019.
- 28 V. Petrova, "Chinese firms picked to build 50-MW CSP park in Greece", *Renewables Now*, 14 November 2019, <https://renewablesnow.com/news/chinese-firms-picked-to-build-50-mw-csp-park-in-greece-676316>; NREL, "Concentrating solar power projects: MINOS", <https://solarpaces.nrel.gov/minos>, updated 5 April 2017.
- 29 "Kuwait eyes up to 400 MW of CSP in expanded solar park", op. cit. note 22; Utilities Middle East, op. cit. note 23. See also sources in endnote 1.
- 30 N. A. Ramos Miranda, "In Chile's Atacama Desert, a cautionary tale for bold renewable energy vows", *Reuters*, 30 October 2019, <https://uk.reuters.com/article/us-chile-energy-solar/in-chiles-atacama-desert-a-cautionary-tale-for-bold-renewable-energy-vows-idUKKBN1X9132>.
- 31 reve, "Cerro Dominador concentrated solar power developer plans larger plants in Chile", 17 October 2019, <https://www.evwind.es/2019/10/17/cerro-dominador-concentrated-solar-power-developer-plans-larger-plants-in-chile/71372>.
- 32 See sources in endnote 1.
- 33 Ibid.
- 34 Ibid.
- 35 ESTELA, "Flexible renewable power: Spain to triple solar thermal capacity by 2030", *Energy Post*, 13 March 2019, <https://energypost.eu/flexible-renewable-power-spain-to-triple-solar-thermal-capacity-by-2030>.
- 36 See sources in endnote 1; Ministerio para la Transición Ecológica, "Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030", 20 January 2020, <https://www.miteco.gob.es/es/ministerio/default.aspx>.
- 37 See sources in endnote 1.
- 38 See, for example: D. Enescu et al., "Thermal energy storage for grid applications: Current status and emerging trends", *Energies*, vol. 13, no. 2 (2020), p. 340, <https://doi.org/10.3390/en13020340>; B. Bungane, "CSP with energy storage to ensure stable power supply", *ESI Africa*, 7 May 2019, <https://www.esi-africa.com/industry-sectors/renewable-energy/csp-with-energy-storage-to-ensure-stable-power-supply>; Power Technology, "Energy storage is key for the future of the concentrated solar power market", 24 April 2019, <https://www.power-technology.com/comment/csp-energy-storage>.
- 39 Based on data from sources in endnote 1. **Figure 33** from idem.
- 40 See sources in endnote 1.
- 41 Ibid.
- 42 Ibid.
- 43 Ibid.
- 44 Ibid.
- 45 Including developers and investors from China, France, Kuwait, Saudi Arabia, Spain and the United States. See sources in endnote 1.
- 46 See sources in endnote 1.
- 47 International Renewable Energy Agency (IRENA), *Renewable*

- Power Generation Costs in 2018* (Abu Dhabi: 2019), p. 25, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf. See Sidebar 5 for LCOE estimates of electricity from CSP in 2019.
- 48 Ibid., p. 26; J. Deign, "How have CSP costs managed to decrease so much", Energy Storage Report, 2 August 2018, <http://energystoragereport.info/csp-costs-decrease>.
- 49 IRENA, op. cit. note 47, p. 25.
- 50 Lazard, "Lazard's Levelised Cost of Energy Analysis – Version 13.0", November 2019, p. 2, <https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf>.
- 51 "Dubai CSP technology inventions accelerate industry cost reductions", New Energy Update, 17 April 2019, <http://newenergyupdate.com/csp-today/dubai-csp-technology-inventions-accelerate-industry-cost-reductions>.
- 52 reve, "Israel inaugurates Negev concentrated solar power plant", 29 August 2019, <https://www.evwind.es/2019/08/29/israel-inaugurates-negev-concentrated-solar-power-plant/70565>; reve, "6 concentrated solar power projects with 350 MW capacity will be newly built in China this year", 11 September 2019, <https://www.evwind.es/2019/09/11/6-concentrated-solar-power-solar-projects-with-350-mw-capacity-will-be-newly-built-in-china-this-year/70772>.
- 53 reve, op. cit. note 31.
- 54 Masdar, "Bid success for Noor Midelt Phase 1 hybrid solar power plant in Morocco", 23 May 2019, <https://news.masdar.ae/en/news/2019/05/23/10/46/noor-midelt-phase-1-hybrid-solar-power-plant>.
- 55 "Dubai CSP technology inventions accelerate industry cost reductions", op. cit. note 51; B. Schmuelling, Ministry of Climate Change & Environment, United Arab Emirates, personal communication with REN21, 12 April 2019; Dubai Electricity and Water Authority, "DEWA, ACWA Power, and Silk Road Fund reach financial closing on 950MW 4th phase of Mohammed bin Rashid Al Maktoum Solar Park", 24 March 2019, <https://www.dewa.gov.ae/en/about-us/media-publications/latest-news/2019/03/dewa-acwa-power-and-silk-road-fund-reach-financial-closing-on-950mw-4th-phase>.
- 56 S. Kraemer, "Shouhang and EDF to test s-CO₂ cycle in concentrated solar power", SolarPACES, 29 March 2019, <https://www.solarpaces.org/shouhang-and-edf-first-to-test-s-co2-cycle-in-concentrated-solar-power>.
- 57 J. Deign, "Why smaller might be better for concentrated solar power", GTM, 11 November 2019, <https://www.greentechmedia.com/articles/read/why-smaller-might-be-better-for-concentrated-solar-power>.
- 58 S. Kraemer, "US lists \$30 million in 2019 CSP research awards", SolarPACES, 7 November 2019, <https://www.solarpaces.org/us-lists-30-million-in-2019-csp-research-awards>.
- 59 A. Bolitho, "Quenching the thirst of concentrated solar power plants", Euronews, 23 May 2019, <https://www.euronews.com/2019/05/20/quenching-the-thirst-of-concentrated-solar-power-plants>.

SOLAR THERMAL HEATING AND COOLING

- 1 Solarthermalworld.org reported on solar thermal sales activities in at least 134 countries worldwide during 2008-2019, from B. Epp, solrico, Bielefeld, Germany, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), March 2020.
- 2 Global solar thermal capacity is based on the latest market data from Australia, Austria, Brazil, China, Germany, India, Israel, Mexico, Turkey and the United States, which represented 86% of cumulative installed capacity in operation in 2018. The other countries were projected according to their trend over the past two years, from M. Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Austria, personal communication with REN21, April 2020; W. Weiss and M. Spörk-Dür, *Solar Heat Worldwide. Global Market Development and Trends in 2019, Detailed Market Figures 2018* (Gleisdorf, Austria: International Energy Agency (IEA) Solar Heating and Cooling Programme, 2020), <https://www.iea-shc.org/solar-heat-worldwide>.
- 3 Spörk-Dür, op. cit. note 2. Equivalence of 395 TWh and 232 million barrels of oil equivalent from Kyle's Converter, <http://www.kylesconverter.com>.
- 4 **Figure 34** from Spörk-Dür, op. cit. note 2.
- 5 H. Cheng, Shandong SunVision Management Consulting, Dezhou, China, personal communications with REN21, January 2020.
- 6 Spörk-Dür, op. cit. note 2.
- 7 Ibid.
- 8 Ibid. PV-thermal systems capture the waste heat from solar PV modules, which utilise only 12% to 15% of the incoming sunlight, to provide heat for space and water, mostly in combination with heat pumps or bore holes.
- 9 Spörk-Dür, op. cit. note 2.
- 10 Ibid.
- 11 Ibid.
- 12 Ibid.
- 13 Global newly commissioned capacity from Spörk-Dür, op. cit. note 2; Chinese newly commissioned capacity from Cheng, op. cit. note 5.
- 14 **Figure 35** based on the latest market data available for glazed and unglazed water collectors (without concentrating collectors) at the time of publication for countries that together represent 94% of the world total. Data from original country sources include gross national additions and were provided to REN21 as follows: David Ferrari, Sustainability Victoria, Melbourne, Australia; Werner Weiss, AEE INTEC, Vienna, Austria; Danielle Johann, Brazilian Solar Thermal Energy Association (ABRASOL), São Paulo, Brazil; Hongzhi Cheng, Shandong SunVision Management Consulting, Dezhou, China; Panayiotis Kastanias, Cyprus Union of Solar Thermal Industrialists (EBHEK), Nicosia, Cyprus; Daniel Trier and Jan Erik Nielson, PlanEnergi, Skørping, Denmark; Andrea Liesen, BSW Solar, Berlin, Germany; Costas Travasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; Jaideep Malaviya, Solar Thermal Federation of India (STFI), Pune, India; Eli Shilton, Elsol, Kohar-yair, Israel; Federico Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milan, Italy; Daniel Garcia, Solar Thermal Manufacturers Organisation (FAMERAC), Mexico City, Mexico; Janusz Staroscik, Association of Manufacturers and Importers of Heating Appliances (SPIUG), Warsaw, Poland; Karin Kritzinger, Centre for Renewable and Sustainable Energy Studies, University of Stellenbosch, Stellenbosch, South Africa; Pascual Polo, Spanish Solar Thermal Association (ASIT), Madrid, Spain; Abdullah Azzam, Palestinian Central Bureau of Statistics, Ramallah, State of Palestine; David Stickelberger, Swissolar, Zurich, Switzerland; Abdelkader Baccouche, ANME, Tunis, Tunisia; Kutay Ülke, Bural Heating, Kayseri, Turkey; Les Nelson, Solar Heating & Cooling Programs at the International Association of Plumbing and Mechanical Officials (IAPMO), Ontario, California, United States, all personal communications with REN21, February-April 2020. Data for China and World Total assume that systems have a 10-year operational lifetime in China; national data for all other countries reflect a 25-year lifetime, with the exceptions of Turkey (14 years prior to 2018 and 15 years starting with 2018) and Germany (20 years).
- 15 Ibid.
- 16 Ibid.
- 17 Ibid.
- 18 Ibid.
- 19 Spörk-Dür, op. cit. note 2.
- 20 B. Epp, "Chinese market keeps shrinking, but exports on the rise", Solarthermalworld.org, 6 January 2020, <https://www.solarthermalworld.org/news/chinese-market-keeps-shrinking-exports-rise>.
- 21 Ibid.
- 22 Cheng, op. cit. note 5.
- 23 Epp, op. cit. note 20.
- 24 Cheng, op. cit. note 5.
- 25 B. Epp, "World's largest flat plate collector manufacturers in 2019", Solarthermalworld.org, 20 March 2020, <https://www.solarthermalworld.org/news/worlds-largest-flat-plate-collector-manufacturers-2019>.
- 26 Epp, op. cit. note 20.
- 27 B. Epp, "Green heat policies in China benefit heat pumps", Solarthermalworld.org, 23 October 2019, <https://www.solarthermalworld.org/news/green-heat-policies-china-benefit-heat-pumps>.
- 28 K. Ülke, Bural Heating, Kayseri, Turkey, personal communication with REN21, March 2020.
- 29 Ibid.
- 30 Market figures for 2019 from J. Malaviya, Malaviya Consultancy, Pune, India, personal communication with REN21, March 2020.
- 31 Ibid.
- 32 Ibid.
- 33 B. Epp, "Stable solar thermal sales despite booming PV sector", Solarthermalworld.org, 30 March 2020, <https://www.solarthermalworld.org/news/stable-solar-thermal-sales-despite-booming-pv-sector>.
- 34 Ibid.
- 35 Ibid.
- 36 D. Johann, ABRASOL, São Paulo, Brazil, personal communication with REN21, April 2020.
- 37 Ibid.
- 38 L. Nelson, Solar Heating & Cooling Programs, IAPMO, Ontario, CA, personal communication with REN21, March 2020.
- 39 Ibid.
- 40 Ibid.
- 41 Ibid.
- 42 P. Dias, Solar Heat Europe, Brussels, Belgium, personal communication with REN21, April 2020.
- 43 Ibid.
- 44 Ibid.
- 45 Ibid.
- 46 A. Liesen, BSW Solar, Berlin, Germany, personal communication with REN21, February 2020; C. Travasaros, EBHE, Greece, personal communication with REN21, March/April 2020.
- 47 Data from Germany delivered annually by BSW Solar; data from Greece delivered annually by EBHE. The Energy Savings in Households programme (EKSOIKONOMO) subsidises energy efficiency and renewable energy projects in Greek households and buildings, from P. Fragkos, E3Modelling, Athens, Greece, personal communication with REN21, April 2020.
- 48 B. Epp, "High scrappage bonus for oil boilers", Solarthermalworld.org, 3 March 2020, <https://www.solarthermalworld.org/news/high-scrappage-bonus-oil-boilers>.
- 49 Epp, op. cit. note 1.
- 50 L. Shaheen, "Cuts to electricity subsidies boost solar thermal in Saudi Arabia", Solarthermalworld.org, 9 April 2019, <https://www.solarthermalworld.org/news/cuts-electricity-subsidies-boost-solar-thermal-saudi-arabia>.
- 51 T. Dimas, Dimas Solar, Argos, Greece, personal communication with REN21, March 2020.
- 52 E. Arun, Ecobold, Kuwait, personal communication with REN21, March 2020.
- 53 Ibid.

- 54 D. Trier, PlanEnergi, Skørping, Denmark, personal communication with REN21, February/March 2020.
- 55 B. Epp, "Danish SDH market reaches new milestone", Solarthermalworld.org, 1 September 2020, <https://www.solarthermalworld.org/news/danish-sdh-market-reaches-new-milestone>.
- 56 Ibid.
- 57 Epp, op. cit. note 1.
- 58 B. Epp, "SDH system with parabolic troughs in Tibet", Solarthermalworld.org, 17 December 2019, <https://www.solarthermalworld.org/news/sdh-system-parabolic-troughs-tibet>.
- 59 B. Epp, "Second Arcon-Sunmark SDH system up and running in Tibet", Solarthermalworld.org, 25 November 2019, <https://www.solarthermalworld.org/news/second-arcon-sunmark-sdh-system-and-running-tibet>.
- 60 B. Epp, "Saga in Tibet tests solar heating in public buildings", Solarthermalworld.org, 25 March 2020, <https://www.solarthermalworld.org/news/saga-tibet-tests-solar-heating-public-buildings>.
- 61 Epp, op. cit. note 27; E. Shan, Linuo Ritter International, Jinan, China, personal communication with REN21, March 2020.
- 62 J. Berner, "Large-scale solar heat is cost-competitive in Germany", Solarthermalworld.org, 13 December 2019, <https://www.solarthermalworld.org/news/large-scale-solar-heat-cost-competitive-germany>.
- 63 Ibid.
- 64 B. Epp, "15 MW SDH plant inaugurated in Latvia", Solarthermalworld.org, 27 October 2019, <https://www.solarthermalworld.org/news/15-mw-sdh-plant-inaugurated-latvia>.
- 65 B. Epp, "SDH prefeasibility studies for Serbian cities", Solarthermalworld.org, 19 February 2019, <https://www.solarthermalworld.org/news/sdh-prefeasibility-studies-serbian-cities>.
- 66 H. Tao, China Academy of Building Research, Beijing, China, personal communication with REN21, February 2020.
- 67 B. Epp, "From S.O.L.I.D. to Solid: Differing views on a complicated story", Solarthermalworld.org, 4 December 2020, <https://www.solarthermalworld.org/news/solid-solid-differing-views-complicated-story>.
- 68 Survey among the largest flat plate collector manufacturers in China and Europe carried out by solrico in February and March 2020 resulting in the ranking of the largest flat plate collector manufacturers, as per Epp, op. cit. note 25.
- 69 Ibid.
- 70 **Figure 36** based on Spörk-Dür, op. cit. note 2, and on Weiss and Spörk-Dür, op. cit. note 2. Year-end total installations of concentrating collector technologies (linear Fresnel, parabolic trough and dish) were reported by aperture area and converted into solar thermal capacity using the internationally accepted convention for stationary collectors, 1 million m² = 0.7 GW_{th}.
- 71 B. Epp and M. Oropeza, *Solar Heat for Industry*, March 2017, <https://www.solar-payback.com/wp-content/uploads/2017/07/Solar-Heat-for-Industry-Solar-Payback-April-2017.pdf>.
- 72 B. Epp, "Industrial sector sees record-breaking capacity additions in 2019", Solarthermalworld.org, 26 April 2020, <https://www.solarthermalworld.org/news/industrial-sector-sees-record-breaking-capacity-additions-2019>.
- 73 Ibid.
- 74 Ibid.
- 75 Ibid.
- 76 R. Battisti, "Transportable Fresnel collectors to supply process heat in Spain", Solarthermalworld.org, 8 October 2018, <https://www.solarthermalworld.org/news/transportable-fresnel-collectors-supply-process-heat-spain>; Oman from J. O. Donnell, former Vice President Business Development, Glasspoint, Fremont, California, personal communication with REN21, November 2019; B. Epp, "Mexico: Solar process heat beats fossil-fuel boiler in energy cost", Solarthermalworld.org, 25 July 2016, <https://www.solarthermalworld.org/news/mexico-solar-process-heat-beats-fossil-fuel-boiler-energy-cost>.
- 77 Epp, op. cit. note 72.
- 78 B. Epp, "Highly efficient industrial solar heat showcase in southwest France", Solarthermalworld.org, 19 July 2019, <https://www.solarthermalworld.org/news/highly-efficient-industrial-solar-heat-showcase-southwest-france>; B. Epp, "10,000 m² of solar collectors to help freesias survive the cold", Solarthermalworld.org, 25 September 2018, <https://www.solarthermalworld.org/news/10000-m2-solar-collectors-help-freesias-survive-cold>.
- 79 B. Epp, "Kyotherm wins 2019 SHC Solar Award", Solarthermalworld.org, 14 November 2019, <https://www.solarthermalworld.org/news/kyotherm-wins-2019-shc-solar-award>.
- 80 Epp, op. cit. note 72.
- 81 MENA CSP KIP, short for The Middle East and North Africa Concentrating Solar Power Knowledge and Innovation Program, supports feasibility studies in, for example, Jordan, Tunisia and Morocco, from R. Battisti, "Initial pilot plants for industrial solar steam", Solarthermalworld.org, 3 January 2019, <https://www.solarthermalworld.org/news/initial-pilot-plants-industrial-solar-steam>.
- 82 Epp, op. cit. note 25.
- 83 One manufacturer observed that it had to drop the price to get more contracts (mostly in the apartment market) in order to utilise the new solar collector production lines put in operation in April 2019, from X. Wu, Haier Water Heater, Qingdao, China, personal communication with REN21, February 2020.
- 84 Epp, op. cit. note 25.
- 85 Epp, op. cit. note 1.
- 86 K. Mulligan-Bertholon, Kingspan, Ireland, personal communication with REN21, February 2020; KBB from B. Epp, "Berlin-based technology pioneer shuts down collector production", Solarthermalworld.org, 22 September 2019, <https://www.solarthermalworld.org/news/berlin-based-technology-pioneer-shuts-down-collector-production>.
- 87 Epp, op. cit. note 86.
- 88 I. Skjelland, Inaventa Solar, Billingstad, Norway, personal communication with REN21, January 2020; B. Epp, "Prefabricated Fresnel collectors used in Spanish SHIP plants", Solarthermalworld.org, 15 March 2020, <https://www.solarthermalworld.org/news/prefabricated-fresnel-collectors-used-spanish-ship-plants>.
- 89 Skjelland, op. cit. note 88.
- 90 Epp, op. cit. note 88.
- 91 Epp, op. cit. note 67.
- 92 Ibid.
- 93 Epp, op. cit. note 25.
- 94 B. Epp, "Demand for central solar water heating peaks in 2019", Solarthermalworld.org, 23 March 2020, <https://www.solarthermalworld.org/news/demand-central-solar-water-heating-peaks-2019>.
- 95 Linuo Paradigma from Ibid.; S. Gabriel, Glasspoint, Fremont, California, personal communication with REN21, April 2020.
- 96 Y. Akay, Solimpeks Solar Corp, Konya, Turkey, personal communication with REN21, February/March 2020.
- 97 B. Epp, "Acquisition of strategic importance", Solarthermalworld.org, 3 April 2020, <https://www.solarthermalworld.org/news/acquisition-strategic-importance>.
- 98 Ibid.; Arcon-Sunmark's newly commissioned systems from D. Trier, PlanEnergi, Skørping, Denmark, personal communication with REN21, February 2020.
- 99 Epp, op. cit. note 97.
- 100 Epp, op. cit. note 72.
- 101 B. Epp, "Production line for Solar Keymark-certified parabolic trough collectors", Solarthermalworld.org, 23 July 2019, <https://www.solarthermalworld.org/news/production-line-solar-keymark-certified-parabolic-trough-collectors>.
- 102 Ibid.; Absolicon, "Ariya Finergy signs framework agreement on acquisition of production line in Kenya", October 2019, <http://www.absolicon.com/ariya-finergy-signs-framework-agreement-on-acquisition-of-production-line-in-kenya/>.
- 103 J. Byström, Absolicon Solar Collector, Härnösand, Sweden, personal communication with REN21, February 2020. The benchmark costs refer to an average yield of 500 watts per m².

- 104 C. Raggi, Trivelli Energia, Gardone Val Trompia, Italy, personal communication with REN21, March 2020.
- 105 B. Epp, "Industrial Solar and Gasco join forces", Solarthermalworld.org, 13 May 2019, <https://www.solarthermalworld.org/news/industrial-solar-and-gasco-join-forces>.
- 106 Ibid.
- 107 B. Epp, "Water-energy nexus in industrial sector", Solarthermalworld.org, 9 July 2018, <https://www.solarthermalworld.org/news/water-energy-nexus-industrial-sector>.
- 108 B. Epp, "Using solar steam to clean wastewater", Solarthermalworld.org, 5 February 2020, <https://www.solarthermalworld.org/news/using-solar-steam-clean-wastewater>.
- 109 B. Epp, "Clean energy and clean water – a perfect match", Solarthermalworld.org, 2 February 2020, <https://www.solarthermalworld.org/news/clean-energy-and-clean-water-perfect-match>.
- 110 B. Epp, "SHC 2019: 15 expert interviews highlight technology and market trends on tape", Solarthermalworld.org, 23 December 2019, <https://www.solarthermalworld.org/news/shc-2019-15-expert-interviews-highlight-technology-and-market-trends-tape>.
- 111 Epp, op. cit. note 1.
- 112 B. Epp, "SHW system for Costa Rican hotel crowdfunded in 24 hours", Solarthermalworld.org, 18 September 2020, <https://www.solarthermalworld.org/news/shw-system-costa-rican-hotel-crowdfunded-24-hours>.
- 113 Ibid.
- 114 Epp, op. cit. note 79.
- 115 Ibid.
- 116 B. Epp, "Highly efficient industrial solar heat showcase in southwest France", Solarthermalworld.org, 19 July 2019, <https://www.solarthermalworld.org/news/highly-efficient-industrial-solar-heat-showcase-southwest-france>.
- 117 T. Zippler, Solarlite, Duckwitz, Germany, personal communication with REN21, March 2020.
- 118 H. Mikhi, Millenium Energy Industries, Amman, Jordan, personal communication with REN21, March 2020.
- 119 B. Rutter, Solar Wärme Austria, Klagenfurt, Austria, personal communication with REN21, March 2020.
- 120 F. Zhenzhen, Linuo Paradigma, Jinan, China, personal communication with REN21, February 2020.
- 121 B. Thirumalai, Aspiration Energy, Chennai, India, personal communication with REN21, March 2020.
- 122 Epp, op. cit. note 1.
- 123 B. Kanawati, Fahrenheit, Munich, Germany, personal communication with REN21, March 2020.
- 124 M. Colaiemma, Maya, Milano, Italy, personal communication with REN21, March 2020.
- 125 Ibid.
- 126 Malaviya, op. cit. note 30; S. Sampath, VSM, Bangalore, India, personal communication with REN21, March 2020.
- 127 Blue Star, "Introducing highly energy efficient solar air conditioning from Blue Star", April 2019, <https://www.bluestarindia.com/projects/solar-air-conditioning>.
- 128 C. Holter, Solid Solar Energy Systems, Graz, Austria, personal communication with REN21, February 2020.
- 129 G. Anand, Energy Concepts, Annapolis, MD, United States, personal communication with REN21, March 2020; V. Wu, Shuangliang Eco-Energy Systems, Jiangyin, China, personal communication with REN21, March 2020.
- 130 B. Epp, "A new solar cooling standard for Australia", Solarthermalworld.org, 15 July 2019, <https://www.solarthermalworld.org/news/new-solar-cooling-standard-australia>.
- 131 Ibid.

WIND POWER

- 1 Based on 60.4 GW added in 2019, including 54.2 GW onshore and 6.1 GW offshore, up from 50.7 GW onshore and 4.4 GW offshore in 2018, from Global Wind Energy Council (GWEC), *Global Wind Report 2019* (Brussels: March 2020), pp. 13, 42, <https://gwec.net/global-wind-report-2019>, and from GWEC, "Global Wind Statistics 2019: Status as End of 2019" (Brussels: March 2020), and on year-end 2019 total of 650,758 MW and year-end 2018 total of 591,091 MW, from World Wind Energy Association (WWEA), "Global wind installations", <https://library.wwea.org/global-statistics>, viewed 16 April 2020. Net additions were 58,884 MW based on end-2019 total of 622,704 MW and end-2018 total of 563,820 MW, from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2020* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_RE_Capacity_Statistics_2020.pdf.
- 2 GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 10, 42; GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 3 GWEC, *Global Wind Report 2019*, op. cit. note 1.
- 4 Increase of 10% and year-end total based on end-2018 capacity of 591 GW and end-2019 capacity of 651 GW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 43, and on 650,758 MW at end-2019 and 591,091 MW at end-2018, from WWEA, op. cit. note 1. Year-end capacity was 622,704 MW, including 594,396 MW onshore and 28,308 MW offshore, from IRENA, op. cit. note 1. China accounts for most of the difference between data from GWEC and IRENA. See endnote 24. **Figure 37** based on historical data from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 41-42, and from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Note that annual additions reported in this section may be gross additions for some countries, but net additions (reflecting decommissioning) are provided where available.
- 5 Based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 10, 25, 44, from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from J. D. Pitteloud, WWEA, "Webinar: Wind power markets around the world", 16 April 2020, <https://wwea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world>. See also S. Campbell, "China and US lead rise in global growth", *Windpower Monthly*, 28 February 2020, <https://www.windpowermonthly.com/article/1675010/signs-improvement-try-harder>.
- 6 Delayed tenders and stop-go tempo of policies from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 10, 27; notable growth includes Argentina and the Dominican Republic, which both more than doubled their installed capacities in 2019, as well as Ethiopia, Jordan, Morocco and Vietnam, which all installed more than they had in the past few years (if ever) and saw total capacity increase by at least 20% in 2019, based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 7 At least 55 countries in 2019 based on data from GWEC, *Global Wind Statistics 2019*, op. cit. note 1, and from F. Zhao, GWEC, Copenhagen, personal communication with REN21, 13 April 2020; at least 47 countries in 2018 based on data from GWEC, *Global Wind Report 2018* (Brussels: April 2019), <https://gwec.net/wp-content/uploads/2019/04/GWEC-Global-Wind-Report-2018.pdf>. Senegal installed 50 MW, from Zhao, op. cit. this note, from C. Richard, "First power from first West African wind farm", *Windpower Monthly*, 12 December 2019, <https://www.windpowermonthly.com/article/1668654/first-power-first-west-african-wind-farm>, and from A. Frangoul, "West Africa's first large-scale wind farm starts generating power", *CNBC Sustainable Energy*, 13 December 2019, <https://www.cnbc.com/2019/12/13/west-africas-first-large-scale-wind-farm-starts-generating-power.html>. During 2019, 53 countries or territories added capacity, while 6 saw a slight decline (including Denmark, resulting from decommissioning), and Mauritania installed commercial capacity for the first time, ending the year with 34 MW, from WWEA, op. cit. note 1; 53 countries added capacity with only Denmark seeing total capacity decline during 2019, and both Senegal (plus 50 MW) and Tonga (2 MW) added capacity for the first time, from IRENA, op. cit. note 1.
- 8 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from Zhao, op. cit. note 7. There were 126 countries with at least 1 MW of wind power capacity and 36 with at least 1 GW of operating capacity in place at the end of 2019, from IRENA, op. cit. note 1. Figures for 2018 were at least 103 countries and 33 countries, based on data from GWEC, op. cit. note 7.
- 9 B. Eckhouse, "Solar and wind cheapest source of power in most of the world", *Bloomberg*, 28 April 2020, <https://www.bloomberg.com/news/articles/2020-04-28/solar-and-wind-cheapest-sources-of-power-in-most-of-the-world>; IRENA, *Renewable Power Generation Costs in 2018* (Abu Dhabi: 2019), pp. 9-11, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf; GWEC and MEC Intelligence, *India Wind Outlook Towards 2022: Looking Beyond Headwinds* (Brussels and Gurugram, India: May 2020), pp. 9, 13, <https://gwec.net/india-wind-outlook-towards-2022-looking-beyond-headwinds>; Frankfurt School-UNEP Centre and BloombergNEF, *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020), pp. 27-29, <https://www.fs-unep-centre.org>. See also, for example: Clean Energy Council, *Clean Energy Australia Report 2019* (Melbourne: 2019), p. 72, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2019.pdf>; American Wind Energy Association (AWEA), "US wind power grew 8 percent amid record demand", press release (Washington, DC: 9 April 2019), https://www.awea.org/2018-market-report_us-wind-power-grew-8-percent-in-2018; B. Chapman, "Offshore wind energy price plunges 30 per cent to a new record low", *The Independent (UK)*, 20 September 2019, <https://www.independent.co.uk/news/business/news/offshore-wind-power-energy-price-falls-record-low-renewables-a9113876.html>.
- 10 S. Sawyer, GWEC, Brussels, personal communication with REN21, 13 March 2019. See also C. Bogmans, "Falling costs make wind, solar more affordable", IMF, 26 April 2019, <https://blogs.imf.org/2019/04/26/falling-costs-make-wind-solar-more-affordable>; Frankfurt School-UNEP Centre and BloombergNEF, op. cit. note 9, p. 29.
- 11 GWEC, *Global Wind Market Outlook Update Q3 2019* (Brussels: September 2019), p. 2; GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 37; Latin American Energy Organization (OLADE) and GWEC, cited in GWEC, "Public tenders and auctions have driven 80% of current renewable energy capacity in Latin America and the Caribbean", press release (Brussels: 4 March 2020), <https://gwec.net/public-tenders-and-auctions-have-driven-80-of-current-renewable-energy-capacity-in-latin-america-and-the-caribbean>.
- 12 Share in North America is an estimate from Zhao, op. cit. note 7; up nearly 30% (and totalled 9 GW) from BloombergNEF, cited in GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 13-14. Note, however, that 8.7 GW of new PPAs were signed in the United States, from AWEA, *U.S. Wind Industry Quarterly Market Report, Fourth Quarter 2019* (Washington, DC: January 2020), pp. 3, 4, <https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/4q2019-marketreport>, and 2.1 GW were signed in Europe, from I. Komusanac, WindEurope, Brussels, personal communication with REN21, 14 April 2020.
- 13 EU share and seven member states from WindEurope, *Wind Energy in Europe in 2019: Trends and Statistics* (Brussels: 2020), pp. 17, 18, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf>.
- 14 Denmark's share of consumption from Energinet, cited in J. Gronholt-Pedersen, "Denmark sources record 47% of power from wind in 2019", *Reuters*, 2 January 2020, <https://www.reuters.com/article/us-climate-change-denmark-windpower-idUSKBN1Z10KE>. Share of generation based on total of 16,150 GWh from wind energy in 2019 and 28,457 GWh of total net generation, from Danish Energy Agency, "Monthly energy statistics, <https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics>, viewed 24 April 2020.
- 15 **Ireland** based on EIRGRID, "Ireland fuel mix 2019", <http://www.eirgridgroup.com/site-files/library/EirGrid/Fuel20Mix.jpg>, updated January 2020; **Portugal** from Portugal Directorate General for Energy and Geology (DGEG), "Renováveis – Estatísticas Rápidas – janeiro 2020", 2 March 2020, <http://www.dgeg.gov.pt>, viewed 5 March 2020; **Germany** from Federal Ministry for Economic Affairs and Energy (BMWi) and Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Time Series for the Development of Renewable Energy Sources in Germany – based on statistical data from the Working Group on Renewable Energy-Statistics (AGEE-Stat) (Status: February 2020)* (Dessau-Roßlau: February 2020), p. 45, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html; **Spain** based on provisional data from Red Eléctrica de España (REE), *The Spanish Electricity System – Preliminary Report 2019* (Madrid: January 2020), with estimated data as of

- 10 January 2020, p. 16, https://www.ree.es/sites/default/files/11_PUBLICACIONES/Documentos/InformesSistemaElectrico/2020/avance_ISE_2019_EN.pdf. Other European countries with high shares included the **United Kingdom** (19.8%), based on 9.9% onshore wind plus 9.9% offshore wind, from UK Department for Business, Energy & Industrial Strategy (BEIS), "Energy Trends: Renewables", Table 6.1. Renewable electricity capacity and generation, <https://www.gov.uk/government/statistics/energy-trends-section-6-renewables>, updated 26 March 2020; **Greece** (15.2%) from multiple original sources, all in Greek and provided by I. Tsiouridis, R.E.D. Pro Consultants, Athens, personal communication with REN21, 17 April 2020.
- 16 **Uruguay** generated 29.5% of its electricity with wind energy in 2019, based on production of 4,752.8 GWh from wind energy and 16,088.4 GWh total, from Ministerio de Industria, Energía y Minería (MIEM), Balance Energético Nacional Uruguay, "Balance preliminar 2019", <https://ben.miem.gub.uy/preliminar.html>, viewed 15 April 2020. Uruguay's share of electricity consumption from wind power was over 36%, based on generation data and on exports of 3,011.0 GWh and imports of 0.2 GWh, from idem. **Nicaragua** generated 17.44% of total net electricity output with wind energy, from Instituto Nicaragüense de Energía (INE), Ente Regulador, "Generación neta sistema eléctrico nacional año 2019", https://www.ine.gob.ni/DGE/estadisticas/2019/generacion_neta_dic19_actmar20.pdf, viewed 17 April 2020. Another source for Nicaragua has a 17.9% share of its electricity with wind power in 2019, from National Cargo Dispatch Center (NCDC), SIN (National Interconnected System) Operation Report, Centro Nacional de Desapacho de Carga, Nicaragua, <http://www.cndc.org.ni>, viewed 11 April 2020, provided by G. Bravo, Fundación Bariloche, personal communication with REN21, 11 April 2020. This was down from 18.6% of net generation with wind energy in 2018, from INE, Ente Regulador, "Generación neta de energía eléctrica sistema eléctrico nacional año 2018", https://www.ine.gob.ni/DGE/estadisticas/2018/generacion_neta_2018_actfeb19.pdf, viewed 14 April 2019, and 15.1% in 2017, from INE, Ente Regulador, "Generación neta sistema eléctrico nacional año 2017", http://www.ine.gob.ni/DGE/estadisticas/2017/generacion_neta_2017_actmar18.pdf, viewed 12 April 2018. **Costa Rica** based on wind generated 1,796.34 GWh out of a total generation of 11,312.85 GWh, providing 15.85% of total generation (and 15.8% of total demand (11,334.11 GWh)), from Centro Nacional de Control de Energía, Instituto Costarricense de Electricidad, *Generación y Demanda Informe Anual, 2019* (San José: 2020), p. 4, <https://apps.grupoice.com/CenceWeb/CenceDescargaArchivos.jsf?init=true&categoria=3&codigoTipoArchivo=3008>.
- 17 Share of generation based on the following: total global electricity generation in 2019 estimated at 27,011 TWh, based on 26,615 TWh in 2018 from BP, *Statistical Review of World Energy* (London: 2019), <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>, and on estimated 1.49% growth in global electricity generation in 2019. Growth rate in 2019 is based on the weighted average change in actual total generation for the following countries/regions (which together accounted for more than two-thirds of global generation in 2018): United States (-1.3% net generation), EU-28 (-1.2%), Russian Federation (+1.2%), India (+0.0%), China (+4.7%), Canada (-0.2%) and Brazil (+2.0%). Generation data for 2018 and 2019 by country or region from the following: US EIA, *Electric Power Monthly with Data for December 2019* (Washington, DC: February 2020), Table 1.1, <https://www.eia.gov/electricity/monthly/archive/february2020.pdf>; European Commission, Eurostat database, <http://ec.europa.eu/eurostat>, viewed April 2020; Ministry of Energy of the Russian Federation, "Statistics", <https://minenergo.gov.ru/en/activity/statistic>, viewed April 2020, Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly generation report", <http://www.cea.nic.in/monthlyarchive.html>, viewed April 2020; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2019 national economic and social development", press release (Beijing: 28 February 2020), http://www.stats.gov.cn/english/PressRelease/202002/t20200228_1728917.html (using Google Translate); Statistics Canada, "Electric power generation, monthly generation by type of electricity", <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501>, updated 11 May 2020; National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed April 2020. Wind power estimated wind generation of 1,600 TWh, based on wind power capacity at end-2019 from the following sources:
- Europe (excluding Turkey) from WindEurope, *Wind in Europe in 2019* (Brussels: 2020), p. 7, <https://windeurope.org/about-wind/statistics/european/wind-energy-in-europe-in-2019/>; United States from AWEA, op. cit. note 12, p. 3; remaining countries and regions from GWEC, "Global Wind Statistics 2019", op. cit. note 1; generation estimated with selected weighted average capacity factors by region, and for both onshore and offshore wind power, from the following sources: Asia and China offshore for 2018 (latest data available) from Zhao, op. cit. note 7, 14 May 2019; Brazil from ONS, *Boletim Mensal de Geração Eólica Março 2020* (Brasília: 2020), p. 20, http://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/Boletim_Geracao_Eolica_202003.pdf; China estimated at 0.24 using national average productivity of 2082 full-load hours for wind turbines from China Energy Portal, "2019 wind power installations and production by province", 28 February 2020, <https://chinaenergyportal.org/en/2019-wind-power-installations-and-production-by-province>; Europe from WindEurope op. cit. this note, p. 18; United States for 2018 (latest available) from US Department of Energy (DOE), Office of Energy Efficiency & Renewable Energy (EERE), *2018 Wind Technologies Market Report* (Washington, DC: August 2019), p. ix, <https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Wind%20Technologies%20Market%20Report%20FINAL.pdf>; remaining countries and regions from A. Whiteman, IRENA, personal communications with REN21, May 2020.
- 18 Share of total in 2019 (50.5%) and in 2018 (51.9%), and total regional capacity at end-2019 (all including Turkey), based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. The share in 2017 was 48%, based on data from GWEC, *Global Wind Report – Annual Market Update 2017* (Brussels: April 2018), p. 17, <https://gwec.net/publications/global-wind-report-2/>.
- 19 Regional shares based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from WindEurope, op. cit. note 13, p. 10. Numbers here are based on regional groupings that include Turkey as part of Asia, rather than Europe, and Mexico as part of Central America or Latin America, rather than North America.
- 20 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 36.
- 21 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 22 Based on data from Ibid. and from WindEurope, op. cit. note 13, p. 10. **Figure 38** based on country-specific data and sources provided throughout this section (see also endnote for Reference Table R19).
- 23 China's increase in 2019 relative to 2018 and data for 2019 based on data from H. Yu, Chinese Wind Energy Association (CWEA) and from GWEC, "Global Wind Statistics 2019", op. cit. note 1; China added 26,785 MW, including 24,292 MW onshore and 2,493 MW offshore), from Hui, op. cit. this note; and from China added 23,760 MW onshore and 2,395 MW offshore for a year-end total of 236,401.7 MW, from GWEC, "Global Wind Statistics 2019", op. cit. note 1; note that figure of 2.4 GW offshore was preliminary data provided to GWEC by the CWEA. China added 27.5 GW in 2019 for total of 237,029 MW, from WWEA, op. cit. note 1, and China added a net of 25,813 MW for a total of 210,478 MW, based on data from IRENA, op. cit. note 1. See also endnote 24.
- 24 Newly installed grid-connected wind power capacity was 25.74 GW, including 23.76 GW onshore and 1.98 GW offshore, for cumulative total of 210.05 GW (204 GW onshore and 5.93 GW offshore), based on 2019 data from China National Energy Administration (NEA), "Wind power grid-connected operation in 2019", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827910.htm (using Google Translate), and from China NEA and China Electricity Council (CEC), cited in China Energy Portal, op. cit. note 17, and on year-end 2018 data (184 GW cumulative), from NEA, "2018 wind power grid operation", 28 January 2019, http://www.nea.gov.cn/2019-01/28/c_137780779.htm (using Google Translate), and from China NEA and CEC, cited in China Energy Portal, op. cit. note 17. Additions of 25.74 GW were up 21% over the 21.27 GW added in 2018, and cumulative capacity increased 14%, from 184.27 GW at end-2018 to 210.05 GW at end-2019, from CEC, "Statistics of China Power Industry 2019", <http://english.cec.org.cn/No.110.1941.htm>, viewed 13 March 2020. The difference in statistics among Chinese organisations and agencies results from the fact that they count different things: installed capacity refers to capacity that is constructed and usually has wires carrying electricity from the turbines to a substation (i.e., CWEA annual statistics); capacity qualifies as grid-connected (i.e., included in CEC statistics) once certification is granted and

- operators begin receiving the feed-in tariff (FIT) premium payment, which can take weeks or even months. Due to transmission constraints in China, there is still often a several-month lag from when turbines are wire-connected to the substation until the process of certification and payment of the FIT premium is complete. No Chinese statistics provide actual grid-connected capacity, and discrepancies among available statistics can be large. Data cited by CWEA include some capacity that is not 100% grid-connected by year's end, but they are believed to most closely reflect the status of the market in China, from L. Qiao, GWEC, personal communication with REN21, 2 May 2018 and confirmed by Yu, op. cit. note 23, 19 May 2020. For the year, investment in new wind power projects in China was up more than 81%, to RMB 117.1 billion (USD 16.5 billion), from CEC, op. cit. this note.
- 25 GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 8; GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 37.
- 26 EurObserv'ER, *Wind Energy Barometer* (Paris: March 2020), p. 3, <https://www.eurobserv-er.org/wind-energy-barometer-2020>.
- 27 Ibid., p. 3.
- 28 Ibid., p. 3.
- 29 Majority based on additions in 2019 as well as on 72% at the end of 2018, from the following: share of cumulative based on central and eastern share of 27.9% and "three north" region share of 72.1%; share of additions based on 47% of total, all from NEA, "2018 added solar PV capacities", *Finance World*, 28 January 2019, <https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&for=pc> (using Google Translate). Henan added 3,260 MW followed by Hebei (2,480 MW), Shanxi and Shandong (both 2,080 MW), based on cumulative capacity for end-2018 and end-2019, from China Energy Portal, op. cit. note 17; Jiangsu added 1,596 MW, from Yu, op. cit. note 24. Also, note that the top installers in 2019 were Shanxi, Inner Mongolia, Henan, Hebei and Jiangsu, from idem. Curtailment rates from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24. Curtailment rates during 2019 were 0% in Henan, 4.8% in Hebei, 1.1% in Shanxi and 0.1% in Shandong, compared with rates of 7.1% to 14% in the northern and western provinces of Inner Mongolia, Gansu and Xinjiang, from idem.
- 30 Curtailed generation and curtailment rates in 2019 and 2018 based on data from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24. In late 2018, China re-emphasised its aim to keep curtailment of wind generation below 10% in 2019 and 5% in 2020, from Bloomberg News Editors, "China hopes to lessen solar, wind curtailment in 2019", *Renewable Energy World*, 3 December 2018, <https://www.renewableenergyworld.com/articles/2018/12/china-hopes-to-lesser-solar-wind-curtailment-in-2019.html>; "China targets cut in wind-, solar-power blocked from grid access", *Bloomberg*, 1 December 2018, <https://www.bloomberg.com/news/articles/2018-12-01/china-targets-cut-in-wind-solar-power-blocked-from-grid-access>. National curtailment in 2017 was 12% (41.9 TWh), from China National Energy Board, cited in NEA, "Wind grid operation in 2017", 1 February 2018, http://www.nea.gov.cn/2018-02/01/c_136942234.htm (using Google Translate); national curtailment in 2016 was 17% (49.7 TWh), from NEA and CEC, provided by S. Pengfei, CWEA, personal communication with REN21, 21 March 2017, and from NEA, "Wind power grid operation in 2016", 26 January 2017, http://www.nea.gov.cn/2017-01/26/c_136014615.htm (using Google Translate).
- 31 In Xinjiang, the curtailment rate fell more than 9 percentage points relative to 2018, to 14%; Gansu's declined 11.4 percentage points, to 7.6%; Inner Mongolia's fell nearly 3 percentage points, to 7.1%, based on 2019 data from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24, and on 2018 data from NEA, "2018 added solar PV capacities", op. cit. note 29.
- 32 Generation in 2019 from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24; increase in generation was about 10.9%, based on generation of 365.8 TWh in 2018, and 2019 share of total output based on wind generation relative to total generation (405.6 TWh) from CEC, op. cit. note 24. Figure of 5.2% in 2018 from China Energy Portal, "2018 wind power installations and production by province", 28 January 2019, <https://chinaenergyportal.org/en/2018-wind-power-installations-and-production-by-province>, and also based on data from China Electricity Council Express, cited in NEA, "National Energy Administration released statistics on national power industry in 2018", 18 January 2019, http://www.nea.gov.cn/2019-01/18/c_137754977.htm (using Google Translate). In 2017, wind energy generation was 305.7 TWh and its share of total generation was 4.8%, from China National Energy Board, cited in NEA, "Wind grid operation in 2017", 1 February 2018, http://www.nea.gov.cn/2018-02/01/c_136942234.htm (using Google Translate).
- 33 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 34 Figure of 8.5% based on 2,377 MW installed in 2019 and 2,191 MW added in 2018, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44; down nearly 50% in 2018 based on 2018 additions from Idem and 4,148 MW added in 2017, from GWEC, op. cit. note 7, p. 29. In 2017, India saw a rush to capitalise on national incentives before they expired and on FIT-based power purchase agreements (PPAs) before a shift to auctions. Reverse auctions from A. Parikh, "India's wind power installations flat in 2019 with 2.4 GW", Mercom India, 20 February 2020, <https://mercomindia.com/india-wind-installations-flat-2019>; R. Ranjan, "India's wind sector failed to gain speed in 2019", Mercom India, 23 December 2019, <https://mercomindia.com/india-wind-failed-gain-speed>.
- 35 Year-end capacity of 37,505.18 MW, from Government of India, Ministry of New and Renewable Energy (MNRE), cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2019) (Utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2020/installed_capacity-01.pdf; net additions of 2,367.03 based on Idem, and on end-2018 capacity of 35,138.15, from Government of India, MNRE, cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2018) (Utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2018/installed_capacity-12.pdf. India added 2.4 GW in 2019 for a total of 37.5 GW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 18; added 2.4 GW for a total of 37,529 MW, from WWEA, op. cit. note 1; added 2,217 MW for a total of 37,505 MW, from IRENA, op. cit. note 1; added 2.9 GW for a total of almost 38 GW, from Campbell, op. cit. note 5; and ended 2019 with 37,733.16 MW, from J. Hossain, Renewable Energy Welfare Society, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, <https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world>.
- 36 Figure of around 8.6 GW was the total active pipeline as of year-end 2019, from GWEC and MEC Intelligence, op. cit. note 9, p. 15. Of the 8.6 GW, nearly 3 GW was scheduled to be commissioned in 2020, 5.2 GW in 2021 and the remainder during 2022, from idem. Note that 9.355 GW of capacity was under implementation at year's end, from Government of India, MNRE, *Annual Report 2019-20* (New Delhi: 2020), p. 8, https://mnre.gov.in/img/documents/uploads/file_f-1585710569965.pdf. For delays, see sources for the following paragraph.
- 37 Undersubscribed from, for example, Ranjan, op. cit. note 34, and from "Undersubscription becoming a norm", Bridge to India, 3 September 2019, <https://bridgetoindia.com/undersubscription-becoming-a-norm>; delays and renegotiate tariffs from "Investors losing interest in troubled Indian market", *Windpower Monthly*, 7 October 2019, <https://www.windpowermonthly.com/article/1661651/investors-losing-interest-troubled-indian-market>; withdrawal from existing PPAs from A. Parikh, "Even with court's stay order in place, Andhra Pradesh to cancel 21 wind PPAs", Mercom India, 30 July 2019, <https://mercomindia.com/stay-order-andhra-pradesh-cancel-wind-ppas>. See also GWEC and MEC Intelligence, op. cit. note 9, p. 13, and IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), p. 14, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_RE-Auctions_Status-and-trends_2019.pdf. Over the past three years, more than 17 GW of capacity has been auctioned, but more than one-third of this has gone unsubscribed or been cancelled after being awarded; meanwhile, more than 80% of awarded projects have been delayed by 6-12 months, from MEC Intelligence, cited in GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 18. Andhra Pradesh severely curtailed wind generation, despite the national government's "must run" status for renewables, shifting from wind to coal generation, from S. Prateek, "After high court's stay, Andhra Pradesh begins curtailing wind power severely", Mercom India, 26 July 2019, <https://mercomindia.com/wind-curtailment-andhra-ppa-revision>; the state decided to renegotiate PPAs, from Parikh, op. cit. note 34, and it withdrew existing PPAs with 21 wind power projects, amounting to nearly 0.8 GW of capacity, from Parikh, op. cit. this note. Turbine deliveries and domestic manufacturing from S. Tendulkar, "Indian downturn hits manufacturing production", *Windpower Monthly*, 26 April 2019, <https://www.windpowermonthly.com/article/1583075/indian-downturn-hits-manufacturing-production>.

- 38 Challenges from, for example, GWEC and MEC Intelligence, op. cit. note 9, p. 9; Ranjan, op. cit. note 34; Parikh, op. cit. note 34; R. K. Singh, "Developers struggle to actually build low-cost wind farms in India", *Renewable Energy World*, 6 December 2019, <https://www.renewableenergyworld.com/2019/12/06/developers-struggle-to-actually-build-low-cost-wind-farms-in-india>; Campbell, op. cit. note 5; Tendulkar, op. cit. note 37. Projects have become financially unattractive due to low tariff caps, and most of the wind resource-rich sites are no longer available, making it difficult to acquire land; in addition, the windiest states are also those with the highest rates of curtailment, from Ranjan, op. cit. note 34. In addition, disputes between federal and state governments on the level of support needed for older wind farms have stalled India's repowering potential, from Campbell, op. cit. note 5.
- 39 S. Gsänger, "A dangerous trend is challenging the success of wind power around the globe: Concentration and monopolization", *WindTech International*, 4 February 2020, <https://www.windtech-international.com/view-from-inside/a-dangerous-trend-is-challenging-the-success-of-wind-power-around-the-globe-concentration-and-monopolization>; geographically concentrated from J. Hossain, WWEA, "Experience with auctions in India", from WWEA, "Webinar: Wind power and renewable energy policies: What is best to reach 100% RE", 14 May 2020, <https://wwindea.org/blog/2020/05/07/wwewebinar-wind-power-and-renewable-energy-policies-what-is-best-to-reach-100-re-14-may>.
- 40 Turkey installed 687 MW onshore, for a total of 8,056 MW at end-2019, and added 497 MW in 2018, all from Turkish Wind Energy Association (TWEA), *Turkish Wind Energy Statistic Report* (Ankara: January 2020), p. 9, http://www.tureb.com.tr/files/bilgi_bankasi/turkiye_res_durumu/istatistik_raporu_ocak_2020.pdf. Turkey added 686 MW for a total of 8,056 MW, from WindEurope, op. cit. note 13, p. 10; added 687 MW for a total of 8,056 MW, from WWEA, op. cit. note 1; and added 586 MW for a total of 7,591 MW, from IRENA, op. cit. note 1. op. cit. note 40, p. 11.
- 41 Fourth and capacity based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 44, 53; drop in FIT rates and investor confidence, from GWEC, "Market to watch: Thailand", press release (Brussels: 28 February 2020), <https://gwec.net/market-to-watch-thailand>. Thailand added 322 MW in 2019, down from 567.5 MW in 2018, for a total of 1,532 MW, from idem, both sources; added 323 MW for a total of 1,538 MW, from WWEA, op. cit. note 1; and added 404 MW for a total of 1,507 MW, from IRENA, op. cit. note 1.
- 42 Based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44. Pakistan added 396.6 MW in 2019 for a total of 1,185 MW, from I. Mirza, WWEA Pakistan, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, <https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world>.
- 43 T. Leonard, "Wind market storming ahead in Vietnam, but possible obstacles remain", *DNV GL*, 24 June 2019, <https://blogs.dnvgl.com/energy/wind-market-storming-ahead-in-vietnam-but-possible-obstacles-remain>.
- 44 Vietnam had a total of 228 MW at the end of 2018; the government targets 800 MW by 2020, 2 GW by 2025, and 6 GW by 2030, from idem. Vietnam added 160 MW for a total of 388 MW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 44, 51, and from WWEA, op. cit. note 1; and added 138 MW for a total of 375 MW, from IRENA, op. cit. note 1.
- 45 GWEC, "Industry pulse: South East Asia energy transition", press release (Brussels: 28 February 2020), <https://gwec.net/industry-pulse-south-east-asia-energy-transition>; GWEC, op. cit. note 42.
- 46 All Europe (not including Turkey) added 11,056 MW onshore and 3,627 MW offshore (14,683 MW total), for a year-end total of 196,758 MW (174,687 MW onshore and 22,071 MW offshore), based on data from WindEurope, op. cit. note 13, p. 10. Europe added 14,023 MW for a total of 195,908 MW, from IRENA, op. cit. note 1.
- 47 WindEurope, op. cit. note 13, pp. 8, 10. Based on additions of 9,552 MW onshore and 3,627 MW offshore (less 178 MW of decommissioned capacity), for a year-end total of 192,231 MW, of which 170,162 MW was onshore and 22,069 MW was offshore, from idem, pp. 8, 10. The EU installed 12,238.3 MW in 2019 (including 3,050 MW offshore), and decommissioned 208 MW, for a year-end total of 191,509.3 MW (including 21,803.6 MW offshore), from EurObserv'ER, op. cit. note 26, pp. 4, 10. Figure for EU-27 cumulative capacity (168,716 MW) based on data from WindEurope, op. cit. note 13, pp. 10, 14. Cumulative capacity for EU-27 was 167,578 MW, from EurObserv'ER, op. cit. note 26, p. 4.
- 48 Up 34% based on net additions of 13,001 MW in 2019, from WindEurope, op. cit. note 13, pp. 10, 16, and on net additions in 2018 of 9,690 MW (7,450 MW added onshore and 2,661 MW offshore, less 421 MW decommissioned), from WindEurope, *Wind Energy in Europe in 2018: Trends and Statistics* (Brussels: 2019), p. 10, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf>.
- 49 Greece, Spain and Sweden from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 13. Greece additions of 727 MW, and Sweden additions of 1,588 MW and year-end total of 8,985 MW, from WindEurope, op. cit. note 13, pp. 10, 11, 13. Wind power installations reached a record 727.5 MW in Greece during 2019, more than double the previous annual high of 311 MW, from I. Tsiouridis, RED PRO Consultants, personal communication with REN21, April 2020. Greece added 732 MW and Sweden added 1,579 MW from WWEA, op. cit. note 1; and Greece added 670 MW and Sweden added 1,588 MW from IRENA, op. cit. note 1.
- 50 Figure of 19 countries in 2019 based on data (9 EU member states added no new capacity) from WindEurope, op. cit. note 13, p. 13; figure of 16 countries in 2018 based on data from WindEurope, op. cit. note 48, p. 10.
- 51 Top countries in 2019 from WindEurope, op. cit. note 13, p. 12, and share of installations based on data from idem., pp. 10, 16. The share was down from 80% in 2018, from WindEurope, op. cit. note 48, p. 10. France contraction from WindEurope, op. cit. note 13; for Germany, see text and sources below.
- 52 WindEurope, op. cit. note 13, pp. 10, 15. Also based on data from IRENA, op. cit. note 1. France added 1,336 MW for total of 16,646 MW (all but 2 MW onshore), and Italy added 456 MW for a total of 10,512 MW, from WindEurope, op. cit. note 13, p. 10. France added 1,360 MW for a total of 16,494 MW, from Réseau de transport d'électricité (RTE), *Bilan Électrique 2019* (Paris: 2020), p. 27, https://www.rte-france.com/sites/default/files/bilan-electrique-2019_1.pdf. Italy added 456 MW for a year-end total of 10,512 MW, from WindEurope, op. cit. this note, and added 450 MW for a total of 10,600 MW, from D. A. Garcia, Italian Wind Energy Association, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, <https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world>.
- 53 The United Kingdom added 629 MW onshore and 1,764 MW offshore, and decommissioned 17 MW of capacity, for net additions of 2,376 MW and a year-end total of 23,515 MW, based on data from WindEurope, op. cit. note 13, pp. 8, 16. The UK ended 2018 with 21,771 MW (including 8,217 MW offshore) and ended 2019 with an estimated 23,975 MW (including 9,792 MW offshore), for total additions in 2019 of 2,204 MW, from UK BEIS, op. cit. note 15. The UK added 2,358 MW (1,728 MW added offshore) in 2019, for a total of 24,128 MW, from IRENA, op. cit. note 1; and added 2,772 MW for a total of 23,515 MW, from WWEA, op. cit. note 1.
- 54 WindEurope, op. cit. note 13, p. 12.
- 55 Ibid., p. 12.
- 56 Lows for coal and rise of wind, from A. Lee, "UK coal power hits 19th century lows as offshore wind roars on", *Recharge*, 26 September 2019, <https://www.rechargenews.com/wind/1855732/uk-coal-power-hits-19th-century-lows-as-offshore-wind-roars-on>; share of generation from wind energy was 19.8% (half of which was from onshore capacity and half from offshore wind power capacity), from UK BEIS, *Energy Trends* report, cited in D. Snieckus, "Wind delivers 'more than half' of record UK renewables power output", *Recharge*, 26 March 2020, <https://www.rechargenews.com/transition/wind-delivers-more-than-half-of-record-uk-renewables-power-output/2-1-781960>.
- 57 Spain added 2,319 MW for a total of 25,808 MW, from REE, cited in WindEurope, op. cit. note 13, pp. 8, 10; more than five times 2018 installations of 392 MW, from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from WindEurope, op. cit. note 48, p. 10. Spain added 2,243 MW for a total of 25.7 GW, from Spanish wind energy association, AEE, cited in D. Weston, "Spain surpasses 25GW after 'intense' 2019", *Windpower Monthly*, 25 February 2020, <https://www.windpowermonthly.com/article/1675099/spain-surpasses-25gw-intense-2019>, and added 2,148 MW based on year-end 2019 capacity of 25,742 MW and year-end 2018 capacity of 23,594 MW, from REE, "Potencia instalada nacional (MW)", as of 31 December 2019, <https://www.ree.es/es/datos/publicaciones/series-estadisticas-nacionales>.
- 58 WindEurope, op. cit. note 13, p. 8.
- 59 P. Dorronsoro, "Spain's new renewable energy 'reasonable return' law", *Pinsent Masons*, 4 December 2019,

- <https://www.pinsentmasons.com/out-law/analysis/spains-new-renewable-energy-reasonable-return-law>.
- 60 WindEurope, op. cit. note 13, p. 7; Germany was the leading installer in Europe from 2011 through 2018; Spain added slightly more capacity than Germany did during 2010, based on data from past editions of the REN21 *Renewables Global Status Report*.
- 61 Added 2,189 MW (1,078 gross onshore and 1,111 MW offshore) and decommissioned 97 MW (onshore), for net additions of 2,092 MW (981 MW onshore and 1,111 MW offshore), for a total of 61,357 MW (53,912 MW onshore and 7,445 MW offshore) at end-2019, from WindEurope, op. cit. note 13, p. 10. Similar numbers for onshore and offshore, with the exception of a year-end total of 7,516 MW offshore, from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, <https://www.windguard.com/year-2019.html>, and from Deutsche Windguard, *Status of Offshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, <https://www.windguard.com/year-2019.html>. Also, similar numbers for onshore and offshore additions, but 7.77 GW total offshore at end-2019, from Windpower Intelligence, cited in Campbell, op. cit. note 5. Official data are net additions of 886 MW onshore and 1,111 MW offshore for net total additions of 1,997 MW, and cumulative year-end capacity of 60.8 GW (including 53.3 GW onshore and 7.5 GW offshore), based on data from BMWi and AGEE-Stat, op. cit. note 15, p. 7. Note that Germany data from WindEurope are used in text, figures and reference table for consistent methodology across all countries in Europe.
- 62 WindEurope, op. cit. note 13, p. 13; U. Hessler, "German wind energy stalls amid public resistance and regulatory hurdles", DW, 4 September 2019, <https://www.dw.com/en/german-wind-energy-stalls-amid-public-resistance-and-regulatory-hurdles/a-50280676>; D. Weston, "Why Enercon is struggling and Senvion has gone under", Windpower Monthly, 14 November 2019, <https://www.windpowermonthly.com/article/1665862/why-enercon-struggling-senvion-gone>; J. S. Hill, "'Collapse' of Germany onshore wind is 'jeopardizing' German & EU renewable targets", CleanTechnica, 13 May 2020, <https://cleantechnica.com/2019/05/13/collapse-of-german-onshore-wind-is-jeopardizing-german-eu-renewable-targets>; R. Hinrichs-Rahlwes, European Renewable Energies Federation and German Renewable Energy Federation (BEE), personal communication with REN21, 3 April 2020. Figure of 16% of the 2017 volume from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 24; auction model introduced in 2017, from WWEA and Landesverband Erneuerbare Energien Nordrhein-Westfalen (LEE NRW), *Community Wind Under the Auctions Model: A Critical Appraisal* (Bonn/Düsseldorf: September 2019), WWEA Policy Paper Series, p. 8, <https://wwindea.org/download/community-power-study-september-2019>. The downturn results from a number of so-called citizen-owned projects that secured contracts in 2017 without permits and with longer lead times before needing to be online, and many of these have been held up by legal proceedings, from Weston, op. cit. this note. The onshore market has been stalled by permitting, legal and administrative delays as well as NIMBY-ism and the rise of a climate-sceptic political party, from GWEC op. cit. this note, pp. 24, 25.
- 63 Figure of more than 10 GW stuck in the permitted process based on more than 10 GW from FA Wind, cited in GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25; an estimated 11 GW from reve, "Germany wind power industry in crisis", 17 December 2019, <https://www.evwind.es/2019/12/17/germany-wind-power-industry-in-crisis/72559>; increase from 10 months to more than two years from EurObserv'ER, op. cit. note 26, p. 7. The time required to get through the permitting process has nearly tripled since 2010, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25. See also WindEurope, "Collapse in wind energy growth jeopardises German and EU renewables targets", press release (Brussels: 10 May 2019), <https://windeurope.org/newsroom/press-releases/collapse-in-wind-energy-growth-jeopardises-german-and-eu-renewables-targets>.
- 64 Aviation and military from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25; public resistance and setback from idem, p. 25. Public resistance also from GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 9., and due to projects believed to be too close to residential areas or to concerns about impacts on birds and other wildlife, from Hessler, op. cit. note 62; D. Wetzel, "Collapse of wind power threatens Germany's green energy transition", *Die Welt*, 26 July 2019, <https://www.thegwpf.com/collapse-of-wind-power-threatens-germanys-green-energy-transition>; setback distance also from Campbell, op. cit. note 5. See also WWEA and LEE NRW, op. cit. note 62. The proposed setback was pending as of early 2020 and the legislative process had stalled, but already the proposed setback was having a significant impact on development of wind power projects in Germany, from Hinrichs-Rahlwes, op. cit. note 62. In May 2020, Germany's coalition government decided to leave the decision on turbine setbacks up to individual regions, from J. Parnell, "Onshore wind compromise averts German solar market crisis", GTM, 18 May 2020, <https://www.greentechmedia.com/articles/read/onshore-wind-policy-dispute-could-decimate-germanys-distributed-solar-industry>.
- 65 Deterrents and impacts on community wind from WWEA, "German government clearly misses all three self-imposed goals associated with auctions", press release (Bonn/Düsseldorf/Berlin: 2 September 2019), <https://wwindea.org/blog/2019/09/02/german-government-clearly-misses-all-three-self-imposed-goals-associated-with-auctions>, and from WWEA and LEE NRW, op. cit. note 62; deterring investors also from Wetzel, op. cit. note 64; privileges for community projects from Institute for Energy Research, "Wind power is collapsing in Germany", 20 August 2019, <https://www.instituteforenergyresearch.org/international-issues/wind-power-is-collapsing-in-germany>.
- 66 WindEurope, op. cit. note 13, pp. 13, 21; GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25. Five of six onshore wind auctions were undersubscribed, from idem, both sources. Volume tendered was 3,675 MW and only 1,847 MW was awarded, and undersubscription was due to difficulties obtaining necessary permits, from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany, Year 2019*, op. cit. note 61, p. 8. A tender held in December was Germany's first onshore wind power tender to be oversubscribed since August 2018, from C. Richard, "Oversubscribed tender brings glimmer of hope to beleaguered German onshore sector", Windpower Monthly, 20 December 2019, <https://www.windpowermonthly.com/article/1669738/oversubscribed-tender-brings-glimmer-hope-beleaguered-german-onshore-sector>. For more on tenders during the year, see C. Richard, "German tender undersubscribed again", Windpower Monthly, 9 August 2019, <https://www.windpowermonthly.com/article/1593487/german-tender-undersubscribed-again>; reve, op. cit. note 63.
- 67 J. Harper, "German wind power blown off course", DW, 21 November 2019, <https://www.dw.com/en/german-wind-power-blown-off-course/a-51341340>; J. Harper, "Winds of change push German power grid to brink", DW, 3 November 2019, <https://www.dw.com/en/winds-of-change-push-german-power-grid-to-brink/a-52701005>.
- 68 Up almost 12% on land and 27% offshore, and total generation in 2019 was 125,975 GWh (101,270 GWh onshore and 24,705 GWh offshore), and share of total gross generation was 21.8% (17.5% onshore and 4.3% offshore), all based on data from BMWi and AGEE-Stat, op. cit. note 15, pp. 44-45. Net generation was up 13% on land (to 106 TWh), from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany*, op. cit. note 61, p. 11; up about 25% offshore (to 25.8 TWh) from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany*, op. cit. note 61, p. 11; 24.8% share of net generation, based on 127.23 TWh total net generation from wind energy and 513.76 TWh total net generation from all sources, from Fraunhofer ISE, "Annual electricity generation in Germany in 2019", <https://www.energy-charts.de/energy.htm?source=all-sources&period=annual&year=2019>, updated 1 February 2020.
- 69 J. Deign, "Germany's maxed-out grid is causing trouble across Europe", GTM, 31 March 2020, <https://www.greentechmedia.com/articles/read/germanys-stressed-grid-is-causing-trouble-across-europe>; Harper, "Winds of change push German power grid to brink", op. cit. note 67.
- 70 Curtailment decline from I. Komusanac, WindEurope, Brussels, personal communication with REN21, 29 April 2020; electricity exports declined from 48 TWh in 2018 to about 30 TWh in 2019, and were mostly to Austria and Poland, from Fraunhofer ISE, "Public net electricity generation in Germany 2019: Share from renewables exceeds fossil fuels", press release (Freiburg: 15 January 2020), p. 4, https://www.ise.fraunhofer.de/content/dam/ise/en/documents/News/0120_e_ISE_News_Electricity%20Generation_2019.pdf; transmission target and completion from Bundesnetzagentur, "Bundesnetzagentur veröffentlicht Jahresbericht 2019", press release (Bonn: 30 April 2020), https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2020/20200429_Jahresbericht.html.
- 71 Deign, op. cit. note 69; Komusanac, op. cit. note 70.

- 72 WindEurope, op. cit. note 13, pp. 18, 19. Wind energy generated an estimated 417 TWh in the EU during the year, from idem, p. 8. Wind energy generated an estimated 425.984 TWh in the EU-28 during 2019, from EurObserv'ER, op. cit. note 26, p. 6.
- 73 WindEurope, op. cit. note 13, p. 17.
- 74 Norway added 780 MW for a total of 2,444 MW, from WindEurope, op. cit. note 13, p. 10; Norway added 769 MW for a total of 2,444 MW, from WWEA, op. cit. note 1; and Norway added 734 MW for a total of 2,444 MW, from IRENA, op. cit. note 1.
- 75 D. Weston, "Local protests kill Norway's wind plans", *Windpower Monthly*, 17 October 2019, <https://www.windpowermonthly.com/article/1662940/local-protests-kill-norways-wind-plans>.
- 76 Ukraine added 637.1 MW in 2019, up from 67.8 MW in 2018, for a year-end total of 1169.9 MW (including occupied territories in the east), and policy transition all from Ukrainian Wind Energy Association (UWEA), *Wind Power Sector of Ukraine 2019* (Kyiv: 2020), pp. 8, 9, 21. Wind generation was curtailed for the first time in Ukraine in November 2019, due to imports of electricity from the Russian Federation and Belarus; also in 2019, Ukraine transitioned to a new wholesale electricity market in July, based on bilateral, day-ahead, intra-day balancing and ancillary services, compared with the previous single buyer model, all from idem, pp. 15, 29. Ukraine added 577 MW for a total of 1,170 MW, from WWEA, op. cit. note 1; and added 637 MW for a total of 1,258 MW, from IRENA, op. cit. note 1.
- 77 Capacity of PPAs in Europe during 2019 from Komusanac, op. cit. note 12; auctions from WindEurope, op. cit. note 13, p. 21.
- 78 Americas added 13,427 MW for a total exceeding 148 GW, from GWEC, "Americas wind installations rise 12% in 2019 to 13.4GW", 4 February 2020, <https://gwec.net/americas-wind-installations-rise-12-in-2019-to-13-4gw/>; regional share of new capacity based on idem, and on data for 2018 (11,891 MW added) from GWEC, "Global Wind Statistics 2019", op. cit. note 1. The Americas (including North and South America, Central America and Caribbean) added 13,233 MW for a total of 146,187 MW, based on data from IRENA, op. cit. note 1.
- 79 US share based on total regional additions and US-only installations of 9,143 MW, from AWEA, op. cit. note 12, p. 3; third biggest year from idem. The top years were 2012 (13 GW added) and 2009 (10 GW), from GWEC, op. cit. note 78.
- 80 Additions were 9,143 MW for a year-end total of 105,583 MW, from AWEA, op. cit. note 12, p. 3; additions were 9,137 MW for a year-end total of 105,591, from AWEA, "Wind Powers America Annual Report", press release (Washington, DC: 16 April 2020), <https://www.awea.org/resources/news/2020/wind-is-now-america%E2%80%99s-largest-renewable-energy-pro>. Total US year-end wind power summer capacity at end-2019 was 103,584.5 MW, including 29.3 MW offshore, not including capacity from facilities with a total generator nameplate capacity of less than 1 MW, from US EIA, op. cit. note 17, Table 6.1; and annual additions totalled 7,165 MW for total available installed US generating capacity at end-2019 of 101.93 GW, from Federal Energy Regulatory Commission, Office of Energy Projects, *Energy Infrastructure Update for December 2019* (Washington, DC: 2019), <https://www.ferc.gov/legal/staff-reports/2019/dec-energy-infrastructure.pdf>.
- 81 Figure of 22,115 MW, from AWEA, op. cit. note 12, pp. 3, 4.
- 82 GWEC, op. cit. note 78. The USD 0.015 per kWh production tax credit (or 18% investment tax credit) is available for wind power projects that begin construction during 2020 and come into operation before the end of 2023, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 60.
- 83 AWEA, Washington, DC, personal communication with REN21, 8 May 2020. Corporate and utility wind PPAs reached 8,726 MW in 2019, of which 5,266 MW was with utilities, all from AWEA, op. cit. note 12, pp. 3, 4. RPS mandates and corporates also from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 37.
- 84 AWEA, op. cit. note 12, pp. 3, 4. Utilities signed 5,085 MW, their second highest amount, out of a record total of 8,726 MW of PPAs, from AWEA, *Wind Powers America – Annual Report 2019*, Executive Summary (Washington, DC: 2020), p. 5, https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/amr2019_executivesummary. Most of the projects under construction were expected to come online in 2020 to receive the full PTC value, from AWEA, op. cit. note 12, pp. 3, 4.
- 85 AWEA, op. cit. note 12, p. 7.
- 86 The six states were Texas with 28,843 MW, Iowa (10,190 MW), Oklahoma (8,172 MW), Kansas (6,128), California (5,973 MW) and Illinois (5,350 MW), and cumulative capacity in Texas, all from AWEA, op. cit. note 12, pp. 7, 8. Another 13 states had more than 1 GW at year's end, from idem.
- 87 The Southwest Power Pool, the grid throughout much of the US Midwest, saw wind's share of generation reach 66.5% in April 2019, from C. Walter, "Wind breaks a new record in Southwest Power Pool", AWEA, 26 April 2019, <https://www.aweablog.org/wind-breaks-new-record-southwest-power-pool>. Several other regional grids also broke wind output or penetration records in 2018 and 2019, from idem. See, for example: G. Alvarez, "2018 highlights: Six trends shaping the future of wind power", AWEA, 10 January 2019, <https://www.aweablog.org/2018-highlights-six-trends-shaping-future-wind-power>; E. Douglas, "Texas wind generation breaks record, ERCOT reports", *Houston Chronicle*, 20 December 2018, <https://www.chron.com/business/energy/article/Texas-wind-generation-breaks-record-ERCOT-13481063.php>; R. Druzin, "Texas grid operator reports record amount of wind generation", *Houston Chronicle*, 16 November 2018, <https://www.chron.com/business/energy/article/Texas-grid-operator-reports-record-amount-of-wind-13398202.php>; G. Alvarez, "A huge record in the Southwest Power Pool", AWEA, 22 March 2018, <http://www.aweablog.org/huge-new-record-southwest-power-pool>.
- 88 K. Balaraman, "Wind plants can provide grid services similar to gas, hydro, easing renewables integration: CAISO", *Utility Dive*, 13 March 2020, <https://www.utilitydive.com/news/wind-plants-can-provide-grid-services-similar-to-gas-hydro-easing-renewab/574070/>; C. Loutan et al., *Avangrid Renewables Tule Wind Farm: Demonstration of Capability to Provide Essential Grid Services* (Folsom, CA: California ISO, Avangrid Renewables, General Electric, 11 March 2020), <http://www.caiso.com/Documents/WindPowerPlantTestResults.pdf>.
- 89 Based on data from US EIA, op. cit. note 17, Tables 1.14.B and 1.3.B.
- 90 States include Iowa (42%), Kansas (41.4%), Oklahoma (34.6%), North Dakota (26.8%), South Dakota (23.9%), Maine (23.8%), Nebraska (19.9%), New Mexico (19.5%), Colorado (19.4%), Minnesota (19.1%), Vermont (17.6%), Texas (17.5%) and Idaho (16.2%), all based on data from US EIA, op. cit. note 17, Tables 1.14.B and 1.3.B. Figures of 7.3% in 2019 and 6.5% of US total generation in 2018 based on data for utility-scale facilities net generation during 2018 from idem, Table ES1.B.
- 91 US EIA, "Wind has surpassed hydro as most-used renewable electricity generation source in U.S.", 26 February 2020, <https://www.eia.gov/todayinenergy/detail.php?id=42955>.
- 92 The region added 3,686.5 MW in 2019 based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Added 3,470 MW for a total of 29,190 MW, based on data for Central America and the Caribbean, South America and Mexico, from IRENA, op. cit. note 1.
- 93 The decline in installations relative to 2018 was about 1.3%, based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1; due to decline in Brazil and others made up for Brazil's decline based on data from idem, and from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 39.
- 94 Figure of 29.2 GW based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44; number of countries based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 95 Mexico added 1,284 MW, followed by Argentina (931 MW), Brazil (745 MW), and Chile added a record 526 MW, all from GWEC, op. cit. note 78. Data align for every country except Chile, which added only 170 MW in 2019, from Windpower Intelligence, cited in Campbell, op. cit. note 5. Argentina ended the year with a total of 1,571 MW, Chile with a total of 1,889 MW, and Uruguay added no new capacity and ended the year with a total of 1,647 MW, all from Windpower Intelligence, op. cit. this note. Mexico added 1,716 MW for a total of 6,591 MW, Argentina added 859 MW for a total of 1,609 MW, Brazil added 531 MW for a total of 15,364 MW, and Chile added 96 MW for a total of 1,620 MW, from IRENA, op. cit. note 1; and Mexico added 1,280 MW for a total of 6,215 MW, Argentina added 882 MW for a total of 1,604 MW, Brazil added 745 MW for a total of 15,452 MW, and Chile added 529 MW for a total of 2,150 MW, from WWEA, op. cit. note 1.
- 96 GWEC, op. cit. note 78; a total of 1,174 MW of wind power capacity, in seven projects, received 15-year PPAs, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 46. Ecuador also launched a tender for wind power, in July 2019, from G. Fenés, "Exclusivo: los pliegos de la subasta de energías renovables que lanzó el Gobierno de Ecuador", 2 August 2019, *Energía Estratégica*, <https://www.energiastراتيجية.com>.

- energiaestrategica.com/exclusivo-los-pliegos-de-la-subasta-de-energias-renovables-que-lanza-el-gobierno-de-ecuador (using Google Translate).
- 97 OLADE and GWEC, cited in GWEC, "Public tenders and auctions have driven 80% of current renewable energy capacity in Latin America and the Caribbean", op. cit. note 11; OLADE, "Public tenders and auctions have boosted 80% of the current renewable energy capacity in Latin America and the Caribbean", 19 March 2020, <http://www.olade.org/noticias/public-tenders-and-auctions-have-boosted-80-of-the-current-renewable-energy-capacity-in-latin-america-and-the-caribbean/?lang=en>. Role of auctions also from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 48.
- 98 Rankings, Mexico's additions (1,281 MW) and cumulative capacity of 6,215 MW based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Mexico had a total of nearly 6 GW at year's end, from Windpower Intelligence, cited in Campbell, op. cit. note 5. Wind power grew 26%, adding a record 1,280 MW, from Mexican Association of Wind Energy, cited in "Las energías renovables baten su récord en México pese a las tensiones con el Gobierno", *El País*, 26 February 2020, https://elpais.com/economia/2020/02/26/actualidad/1582694040_481642.html (using Google Translate). In 2019, about 65% of production resulted from long-term power auction, especially the first and second auctions, in 2015 and 2016; the third auction was in 2017, and about half of contracted capacity was under construction as of early 2020, from idem. Note that Mexico had 6,590 MW of wind power capacity at the end of 2019, up from 4,875 MW (net additions of 1,715 MW), and wind energy accounted for 8% of Mexico's electricity generation during the year, from "Sector eólico alerta: riesgo en empleos", *Heraldo de México*, 12 March 2020, <https://heraldodemexico.com.mx/mer-k-2/sector-eolico-alerta-riesgo-en-empleos> (using Google Translate).
- 99 GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 4; GWEC, op. cit. note 78.
- 100 On-off policies and auctions, from GWEC, *Global Wind Report 2019*, op. cit. note 1, and from Zhao, op. cit. note 7, 4 May 2020. Doubling and year-end capacity based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Argentina added 931 MW in 2019 for a year-end total of nearly 1,604 MW, from idem. See also S. Marcacci, "Argentina may be the hottest renewable energy market you haven't heard of. Can it spur a global boom?" *Forbes*, 15 October 2019, <https://www.forbes.com/sites/energyinnovation/2019/10/15/argentina-may-be-the-hottest-renewable-energy-market-you-havent-heard-of-can-it-spur-a-global-boom>.
- 101 Reve, "Wind energy in Argentina: The largest wind farm begins to operate", *EV Wind*, 26 September 2019, <https://www.evwind.es/2019/09/26/wind-energy-in-argentina-the-largest-wind-farm-begins-to-operate/71068>. It has been estimated that the project will generate some 987 GWh annually, from idem.
- 102 Lowest since 2011 based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from Windpower Intelligence, cited in Campbell, op. cit. note 5; break in auction schedule from Zhao, op. cit. note 7; Brazil added more wind (971 MW) than thermal (776 MW) power capacity in 2019, from Reve, "75% of Brazil's new power comes from hydroelectric, wind energy and solar power", 19 January 2020, <https://www.evwind.es/2020/01/19/75-of-brazils-new-power-comes-from-hydroelectric-wind-energy-and-solar-power/73131>. Note, however, that GWEC data provide a lower number for wind power additions in 2019, of 745 MW, from GWEC, op. cit. this note.
- 103 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 23. About 70% has been sold for private PPAs compared with 30% for private auctions, from E. Feitosa, *Eólica Tecnología*, Brazil, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, <https://www.wwea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world>.
- 104 Brazil added 745 MW to end 2019 with 15,452.4 MW of wind power capacity, compared with a regional total (including Mexico) of 29,223 MW, based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Brazil had a total of 15,418 GW of wind power capacity in place as of mid-December 2019, up from 14,704 MW at the end of 2018, from Associação Brasileira de Energia Eólica (ABEEólica), *Infowind Brazil* (No. 14, 13 December 2019), http://abeeolica.org.br/wp-content/uploads/2020/02/Infovento-14_ENG.pdf. Brazil added a net of 855 MW in 2019, based on year-end capacity of 6,385 MW, from ONS, "Geração de energia – composição", for period 1 January 2019 to 31 December 2019, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx; and on end-2018 capacity of 5,530 MW, from ONS, "Geração de energia – composição", for period 1 January 2018 to 31 December 2018, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx. Brazil added 971 MW in 2019, from Reve, "75% of Brazil's new power comes from hydroelectric, wind energy and solar power", 19 January 2020, <https://www.evwind.es/2020/01/19/75-of-brazils-new-power-comes-from-hydroelectric-wind-energy-and-solar-power/73131>.
- 105 Data for 2019 based on total annual generation of 593,591 GWh and annual wind energy generation of 55,932 GWh, and 2018 based on total annual generation of 581,923 GWh and annual wind energy generation of 48,443 GWh, all from ONS, "Geração de energia – composição", for period 1 January 2019 to 31 December 2019, op. cit. note 104.
- 106 Figures of 597 MW added and year-end total of 13,413 MW, from Canadian Wind Energy Association (CanWEA), "Installed capacity", December 2019", <https://canwea.ca/wind-energy/installed-capacity>, viewed 5 March 2020. Canada added a modest 537 MW for total of about 13.5 GW, Campbell, op. cit. note 5.
- 107 CanWEA, "National", <https://canwea.ca/wind-energy/national>, viewed 25 March 2020; drivers from P. McKay, CanWEA, cited in N. Hendley, "Windfall in wind energy?" *Canadian Metal Working*, 1 April 2020, <https://www.canadianmetalworking.com/canadianmetalworking/article/metalworking/windfall-in-wind-energy>.
- 108 Ontario ended the year with 5,436 MW, followed by Quebec (3,882 MW) and Alberta (1,685 MW), from CanWEA, op. cit. note 106.
- 109 Zhao, op. cit. note 7.
- 110 Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), pp. 78-82, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf>.
- 111 Australia added 837.1 MW across eight projects for a total of 6,279.4 MW, from *Ibid.*, pp. 9, 78, 79, 82. Australia added 837 MW for a total of 6,199 MW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44.
- 112 Wind power generated 19.487 TWh in 2019, accounting for 8.5% of Australia's total generation, followed (among renewables) by hydropower (14.166 TWh) and large-scale solar power (5.141 TWh), from Clean Energy Council, op. cit. note 110, pp. 6, 9, 79, 81.
- 113 Based on data for South Australia (29.2%), Victoria (27.8%) and New South Wales (22.9%), from Green Energy Markets, cited in Clean Energy Council, op. cit. note 110, p. 80; shares in 2018 were South Australia (35%), Victoria (28%) and New South Wales (19%), from Clean Energy Council, op. cit. note 9, pp. 72-76.
- 114 Clean Energy Council, op. cit. note 110, pp. 4, 7. See also Solar PV section in this chapter for more on challenges in Australia, and S. Paul, "Australia's solar, wind boom to power past grid woes in 2019", *Reuters*, 20 January 2019, <https://www.reuters.com/article/us-australia-renewables-idUSKCN1PE0V8>. Australia is seeing an increasing number of large-scale projects (both wind and solar) that need connection to a 5,000-kilometre transmission line that was built to carry electricity from coal plants near three large mining areas, and not designed to carry electricity from variability and remote wind and solar projects. Delays in project approvals and grid connections are causing project delays and unanticipated costs for developers who fail to account for grid-related issues (e.g., congestion, curtailment), all from Paul, op. cit. this note.
- 115 Clean Energy Council, op. cit. note 110, p. 78.
- 116 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 117 Figure of 2.6% from GWEC, "Over 60GW of wind energy capacity installed in 2019, the second-biggest year in history", 25 March 2020, <https://gwec.net/gwec-over-60gw-of-wind-energy-capacity-installed-in-2019-the-second-biggest-year-in-history>. An estimated 894 MW was added in 2019, from GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019, market expected to grow by over 10GW by 2024", 12 February 2020, <https://gwec.net/africa-and-middle-east-add-894mw-of-wind-energy-capacity-in-2019-market-expected-to-grow-by-over-10gw-by-2024>. All Africa added 300 MW and the Middle East added 109 MW, for total additions of 409 MW in 2019, bringing the year-end totals for 5,765 MW in Africa and 723 MW in the Middle East, for combined cumulative capacity of 6,488 MW at end-2019, based on data from IRENA, op. cit. note 1.
- 118 Numbers of countries by region from Zhao, op. cit. note 7, and

- capacities based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44, and GWEC, "Global Wind Statistics 2019", op. cit. note 1. Similar year-end capacities for these countries (2,094 MW in South Africa, 1,220 MW in Morocco, and 1,375 MW in Egypt) from IRENA, op. cit. note 1. Capacity also was added during 2019 in Israel (89 MW for a total of 374 MW) and Iran (20 MW for a total of 302 MW), with a total of 19 countries in Africa and 9 in the Middle East having wind capacity in operation (although many of the additional countries have fewer than 5 MW), all from idem.
- 119 GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019", op. cit. note 117.
- 120 GWEC, "Global Wind Statistics 2019", op. cit. note 1; GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019", op. cit. note 117. All of Ethiopia's new capacity was in the Aysha II Wind Farm project. Data were supplied by Chinese Dongfang to GWEC, from Zhao, op. cit. note 7. Egypt added 363 MW for a total of 1,573 MW, from Campbell, op. cit. note 5. Note that several sources say the Lake Turkana wind project in Kenya commenced operations during 2019. See, for example, "Kenya launches largest wind power plant in Africa", CNN Marketplace Africa, 20 July 2019, <https://edition.cnn.com/2019/07/20/africa/africas-largest-wind-farm-intl>. However, the project was announced by Vestas (Denmark) in 2018, so was included in GWEC's data for 2018, from Zhao, op. cit. note 7, and was reported as connected to the national grid as of December 2018, from Lake Turkana Wind Power, "Lake Turkana wind power connected to the national grid", 9 December 2018, <https://ltwp.co.ke/ltwp-connected-to-grid>. As a result, the project was included as newly installed capacity in GSR 2019. Data also conflict for South Africa, probably due to differences in timing of reporting: the local wind energy association in South Africa reported to GWEC that no new capacity came online in 2019, from Zhao, op. cit. note 7, whereas the country added 120 MW in 2019, from Campbell, op. cit. note 5. Per IRENA, Africa added capacity during 2019 only in Egypt (250 MW) and Senegal (50 MW), from IRENA, op. cit. note 1.
- 121 R. Ranjan, "ENGIE Africa commissions Egypt's largest wind farm", Mercom India, 12 November 2019, <https://mercomindia.com/engie-africa-commissions-egypt-largest-wind-farm>.
- 122 Egypt's target from Campbell, op. cit. note 5; pipeline from K. Benhamou, Sahara Wind, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, <https://windeea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world>.
- 123 C. Richard, "First power from first West African wind farm", Windpower Monthly, 12 December 2019, <https://www.windpowermonthly.com/article/1668654/first-power-first-west-african-wind-farm>; A. Frangoul, "West Africa's first large-scale wind farm starts generating power", CNBC Sustainable Energy, 13 December 2019, <https://www.cnbc.com/2019/12/13/west-africas-first-large-scale-wind-farm-starts-generating-power.html>; A. O. Diallo, "Sénégal: le plus grand parc éolien d'Afrique de l'Ouest prend forme à Taïba Ndiaye", Jeune Afrique, 27 May 2019, <https://www.jeuneafrique.com/780416/economie/senegal-le-plus-grand-parc-eolien-dafrique-de-louest-prend-forme-a-taiba-ndiaye>.
- 124 Jordan added 190 MW and Iran added 50 MW, from GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019", op. cit. note 117.
- 125 "Oil giant Saudi Arabia set to build first wind-power plant", Bloomberg, 26 July 2019, <https://www.bloomberg.com/professional/blog/oil-giant-saudi-arabia>.
- 126 Ibid.
- 127 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 13, GWEC, "Record 6.1 GW of new offshore wind capacity installed globally in 2019", 19 March 2019, <https://gwec.net/record-6-1-gw-of-new-offshore-wind-capacity-installed-globally-in-2019>; Europe data also from WindEurope, op. cit. note 13, p. 10. Note that 16 new offshore windfarms went into operation (meaning all turbines in the project were installed and first electricity had been generated by end-2019) in six countries (China, United Kingdom, Germany, Denmark, Belgium and Chinese Taipei) for record annual additions of 5,194 GW in 2019, bringing total capacity to 27,213 MW, from World Forum Offshore Wind, *Global Offshore Wind Report 2019* (Hamburg: February 2020), pp. 3, 4, https://x6a3i7a8.stackpathcdn.com/wp-content/uploads/2020/02/WFO_WindReport2019.pdf. This compares with 2018, when seven countries in Europe and two in Asia connected 4.5 GW (same capacity as in 2017), increasing cumulative global capacity by 24% to 23.1 GW, based on data from GWEC, op. cit. note 7. Note that offshore capacity increased by 4,679 MW in 2019, to a total of 28,308 MW, based on data from IRENA, op. cit. note 1.
- 128 Figure of less than 5% of capacity based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1; figures of 10% of global installations in 2019, up from 5% in 2015, from GWEC, op. cit. note 127. Offshore accounted for 12% of commissioned wind power capacity in 2019, up from 8% in 2018, from C. Richard, "Vestas leads the pack with squeezed market share", Windpower Monthly, 18 February 2020, <https://www.windpowermonthly.com/article/1674420/vestas-leads-pack-squeezed-market-share>. Investment from C. Richard, "Offshore wind spending reaches record high in 2019", Windpower Monthly, 16 January 2020, <https://www.windpowermonthly.com/article/1671093/offshore-wind-spending-reaches-record-high-2019>; "Late surge in offshore wind financings helps 2019 renewables investment to overtake 2018", BloombergNEF, 16 January 2020, <https://about.bnef.com/blog/late-surge-in-offshore-wind-financings-helps-2019-renewables-investment-to-overtake-2018>.
- 129 GWEC, op. cit. note 127.
- 130 China completed 2,395 MW of capacity in 2019, from GWEC, op. cit. note 127; total of 6,838 MW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 44, 61. China completed nine projects for a total of 2,450 MW, from Campbell, op. cit. note 5. National target from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 61.
- 131 Record installations and policy drivers from GWEC, "Webcast on wind: Market update and outlook for global offshore wind", 19 March 2020; reductions in the FIT from L. Yuanyuan, "China drops electricity subsidy price for offshore wind power", Renewable Energy World, 1 July 2019, <https://www.renewableenergyworld.com/articles/2019/07/china-drops-electricity-subsidy-price-for-offshore-wind-power.html>; take advantage before it expires from Richard, "Offshore wind spending reaches record high in 2019", op. cit. note 128.
- 132 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 61.
- 133 Ibid., p. 63. More than 40 GW of projects had been approved by national or provincial governments by year's end, with half located in Guangdong, from idem, p. 62.
- 134 Commissioned 120 MW and 2025 target, from Campbell, op. cit. note 5; figure of 120 MW and first utility-scale offshore project from GWEC, op. cit. note 131; further 10 GW target from "Taiwan plans additional 10GW offshore", reNEWS, 12 November 2019, <https://renews.biz/56366/taiwan-plans-additional-10gw-offshore>, and from GWEC, "Market to watch: Taiwan offshore wind", 16 January 2020, <https://gwec.net/market-to-watch-taiwan-offshore-wind>.
- 135 Japan's 3 MW of floating capacity from GWEC, op. cit. note 127; Japan had 65.6 MW of offshore capacity including 19 MW of floating capacity in five turbines, from B. Backwell, GWEC, "Take offshore wind global", presentation for Renewable Energy Institute, REvision – Webinar, 4 March 2020, Slide 16, https://www.renewable-ei.org/pdfdownload/activities/11_BenBackwell.pdf; capacity in the pipeline (14 GW) from Japan Wind Power Association, "Total capacity of wind in Japan by end of 2019" (Japanese only), provided by H. Matsubara, Institute for Sustainable Energy Policies, personal communication with REN21, April 2020. Capacity in pipeline was 13 GW, from Japan's Ministry of Economy, Trade and Industry, cited in O. Tsukimori, "With coal under fire, 2020 could be a big year for wind power in Japan", *Japan Times*, 2 January 2020, <https://www.japantimes.co.jp/news/2020/01/02/business/wind-power-2020-japan>. Getting through Japan's environmental assessment process takes 4-5 years; as of January 2020, there was 14.8 GW of offshore wind capacity in the pipeline, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 64. Vietnam from GWEC, op. cit. note 131, and from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 50; India from GWEC, *Global Offshore Wind Report 2019* (Brussels: 2019), p. 9.
- 136 Europe added 3,627 MW for total of 22,069 MW, and national data all from WindEurope, op. cit. note 13, pp. 8, 10. Up 36% based on 2,661 MW added in 2018, from Komusanac, op. cit. note 12, and increase of 36.5% over 2018, from Zhao, op. cit. note 7. Europe added a gross capacity of 3,627 MW (3,623 MW net), and two turbines of 2 MW each were decommissioned in the United Kingdom, for a cumulative total of 22,072 MW offshore, from WindEurope, *Offshore Wind in Europe: Key Trends and Statistics 2019* (Brussels: February 2020), pp. 7, 8, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2019.pdf>.
- 137 WindEurope, op. cit. note 13, pp. 8, 10. Denmark's 407 MW Horns Rev 3, completed in 2019, is reportedly the country's largest wind

- farm and was expected to increase wind generation in Denmark by 12%, from “Denmark opens country’s largest wind farm with royal inauguration”, Smart Energy International, 23 August 2019, <https://www.smart-energy.com/renewable-energy/denmark-opens-countrys-largest-wind-farm-with-royal-inauguration>, and from A. Frangoul, “Scandinavia’s biggest offshore wind farm is officially open”, CNBC, 23 August 2019, <https://www.cnbc.com/2019/08/23/scandinavias-biggest-offshore-wind-farm-is-officially-open.html>.
- 138 The United Kingdom added 1,764 MW for total of 9,945 GW, and about half of Europe’s total installations, all from WindEurope, op. cit. note 13, pp. 10, 12.
- 139 World’s largest (at 1,218 MW) from WindEurope, op. cit. note 13, p. 12; first to exceed 1 GW and farthest from shore (120 kilometres from the Yorkshire coast) from I. Shumkov, “Hornsea One begins commercial operations ahead of full completion”, Renewables Now, 3 June 2019, <https://renewablesnow.com/news/hornsea-one-begins-commercial-operations-ahead-of-full-completion-656423>.
- 140 For first time from B. Radowitz, “Germany adds more new wind offshore than on land for first time”, Recharge, 23 January 2020, <https://www.rechargenews.com/wind/germany-adds-more-new-wind-offshore-than-on-land-for-first-time/2-1-743221>; overachieved 2020 target, and approaching national cap of 7.7 GW for that year from S. Knight, “Is Germany’s offshore sector about to hit the buffers too?” Windpower Monthly, 23 January 2020, <https://www.windpowermonthly.com/article/1671820/germanys-offshore-sector-hit-buffers-too>.
- 141 Falling prices from EurObserv’ER, op. cit. note 26, p. 9. Increased targets and targeted capacity for 2030 from WindEurope, “Europe installs a record 3.6 GW of offshore wind in 2019”, press release (Brussels: 6 February 2020), <https://windeurope.org/newsroom/press-releases/europe-installs-a-record-3-6-gw-of-offshore-wind-in-2019>. For example, the United Kingdom increased its target to 40 GW by 2030 and Germany raised its target to 20 GW by 2030, from GWEC, op. cit. note 131. The United Kingdom also from J. Parnell, “The U.K. offshore wind industry wants annual tenders and faster permits to fulfill its role in delivering the country’s net-zero target”, GTM, 3 February 2020, <https://www.greentechmedia.com/articles/read/the-uks-offshore-wind-program-is-working-well-is-it-time-for-an-overhaul>. Germany’s previous target was for 15 GW by 2030, from EurObserv’ER, op. cit. this note. The Netherlands agreed on a climate deal in 2019 that foresees a total of 11.5 GW of wind power capacity in the North Sea, from A. Lee, “Vattenfall winds 760MW of Dutch zero-subsidy offshore wind”, Recharge, 10 July 2019, <https://www.rechargenews.com/wind/vattenfall-wins-760mw-of-dutch-zero-subsidy-offshore-wind/2-1-636547>.
- 142 WindEurope, op. cit. note 136, p. 37.
- 143 Ibid., p. 36.
- 144 “Vattenfall and Wallenstam cancel major offshore wind park plan in Sweden”, *Reuters*, 21 October 2019, <https://af.reuters.com/article/commoditiesNews/idAFL5N2763XU>.
- 145 Remained at 30 MW from GWEC, “Global Wind Statistics 2019”, op. cit. note 1; procurement targets from GWEC Market Intelligence, cited in GWEC, op. cit. note 131. During the year, six east coast states announced 16.3 GW of new offshore wind power targets, during 2019, from C. Wanner, “Put it in the books: Final 2019 numbers show wind power on the rise”, 30 January 2020, AWEA, <https://www.aweablog.org/put-books-final-2019-numbers-show-wind-power-rise>.
- 146 J. A. Dlouhy, “Why it’s so hard to build offshore wind power in the U.S.”, *Bloomberg*, 1 October 2019, <https://www.bloomberg.com/news/articles/2019-10-01/why-it-s-so-hard-to-build-offshore-wind-farms-in-the-u-s>. See also B. Storrow, “Interior delays finding on large offshore wind project”, E&E News, 9 August 2019, <https://www.eenews.net/stories/1060898805>; N. Groom, “Exclusive: First big U.S. offshore wind project hits snag due to fishing-industry concerns”, *Reuters*, 29 July 2019, <https://www.reuters.com/article/us-usa-wind-fishing-exclusive/exclusive-first-big-u-s-offshore-wind-project-hits-snag-due-to-fishing-industry-concerns-idUSKCN1U00EK>; E. Knickmeyer and R. Ngowi, “Things are going quite well for Trump’s nemesis industry”, *Associated Press*, 30 September 2019, <https://www.mercurynews.com/2019/09/30/things-are-going-quite-well-for-trumps-nemesis-industry>; R. Davidson, “New schedule for delayed Vineyard site”, Windpower Monthly, 12 February 2020, <https://www.windpowermonthly.com/article/1673761/new-schedule-delayed-vineyard-site>.
- 147 Storrow, op. cit. note 146; K.-E. Stromsta, “Two months later, Vineyard Wind’s delay still clouds US offshore picture”, GTM, 23 October 2019, <https://www.greentechmedia.com/articles/read/vineyard-wind-delay-still-clouds-us-offshore-market>.
- 148 Construction off Virginia coast from E. Ingram, “Dominion Energy begins construction on Coastal Virginia Offshore Wind project”, Renewable Energy World, 3 July 2019, <https://www.renewableenergyworld.com/articles/2019/07/dominion-energy-begins-construction-on-coastal-virginia-offshore-wind-project.html>; an estimated 7,483 MW, 17% of the US total, was under construction or advanced development, from Wanner, op. cit. note 145; AWEA’s definition of advanced development from K.-E. Stromsta, “The hot new US wind market: Crowded east coast states”, GTM, 29 January 2020, <https://www.greentechmedia.com/articles/read/the-hot-new-us-wind-market-crowded-east-coast-states>.
- 149 The east coast states were Connecticut, Maryland, Massachusetts, New Jersey, New York and Virginia, from D. Weston, “US offshore wind: Pipeline or pipe dream?” Windpower Monthly, 22 October 2019, <https://www.windpowermonthly.com/article/1663260/us-offshore-wind-pipeline-pipe-dream>; California coalition from B. Lillian, “New coalition pushes for 10 GW of California offshore wind”, North American Wind Power, 1 October 2019, <https://nawindpower.com/new-coalition-pushes-for-10-gw-of-california-offshore-wind>. See also AWEA, “Wind industry experiences third strongest year on record with 9,143 MW of wind power added to U.S. grid”, press release (Washington, DC: 29 January 2020), <https://www.awea.org/resources/news/2020/wind-industry-experiences-third-strongest-year-on>; D. K. Rubin, “NY makes long-awaited record offshore wind power awards”, ENR, 18 July 2019, <https://www.enr.com/articles/47227-ny-makes-long-awaited-record-offshore-wind-power-awards>. Connecticut figure of 2 GW by 2030 from J. Runyon, “Offshore wind experts jockey for position as industry heats up in the US Northeast”, Renewable Energy World, 7 June 2019, <https://www.renewableenergyworld.com/articles/2019/06/offshore-wind-experts-jockey-for-position-as-industry-heats-up-in-the-us-northeast.html>, and 30% of the state’s demand from L. Morton, “Connecticut and Virginia lead a huge month for offshore wind”, AWEA, 1 October 2019, <https://www.aweablog.org/connecticut-virginia-lead-huge-month-offshore-wind>; Maryland from B. Lillian, “Maryland Legislature passes clean energy bill with offshore provisions”, North American Wind Power, 9 April 2019, <https://nawindpower.com/maryland-legislature-passes-clean-energy-bill-with-offshore-provisions>; New Jersey from R. Davidson, “New Jersey doubles offshore goal”, Windpower Monthly, 20 November 2019, <https://www.windpowermonthly.com/article/1666427/new-jersey-doubles-offshore-goal>. New York State already had a goal of 9 GW by 2035, and in 2019 the state finalised contracts for offshore wind power, from B. Lillian, “New York finalizes offshore wind contracts”, North American Wind Power, 24 October 2019, <https://nawindpower.com/new-york-finalizes-offshore-wind-contracts>.
- 150 T. Casey, “Who’s gonna win the race for floating offshore wind turbines, Maine or California?” CleanTechnica, 23 December 2019, <https://cleantechnica.com/2019/12/23/whos-gonna-win-the-race-for-floating-offshore-wind-turbines-maine-or-california>.
- 151 Total of 18 includes Germany, Spain, the United Kingdom, France, Sweden, Denmark, the Netherlands, Ireland, Belgium, Norway, Finland and Portugal in Europe, from WindEurope, op. cit. note 136, p. 7; China, Japan, Chinese Taipei, the Republic of Korea and Vietnam in Asia; and the United States, all based on data from GWEC, “Global Wind Statistics 2019”, op. cit. note 1, and from WindEurope, op. cit. note 136, p. 10. European countries with demonstration projects only were France (including the Floatgen floating demonstrator), Norway (2.3 MW Hywind project) and Spain, and all other European countries with offshore wind power capacity had demonstration projects, from L. Ramirez, WindEurope, Brussels, personal communication with REN21, 16 April 2019.
- 152 European countries and capacities from WindEurope, op. cit. note 13, p. 10, with the exception of Germany, from BMWi and AGEE-Stat, op. cit. note 15, p. 7, and from GWEC, “Global Wind Statistics 2019”, op. cit. note 1; rest of world, including China, from idem.
- 153 Europe home to 75% and Asia nearly all the rest, based on data from GWEC, op. cit. note 131; 79% in 2018, down from 84% in 2017 and 88% in 2016, based on data from GWEC, op. cit. note 7. **Figure 39** based on data from the following: GWEC, *Global Wind Report – Annual Market Update 2015* (Brussels: April 2016), pp. 50-51, http://www.gwec.net/wp-content/uploads/vip/GWEC-Global-Wind-2015-Report_April-2016_19_04.pdf; GWEC, *Global*

- Wind Report – Annual Market Update 2016 (Brussels: April 2017), p. 58, <http://www.gwec.net/strong-outlook-for-wind-power>; GWEC, op. cit. note 18, p. 55; GWEC, op. cit. note 7, pp. 29, 33; GWEC, "Global Wind Statistics 2019, op. cit. note 1; S. Pengfei, CWEA, personal communication with REN21, April 2010 and March 2017; FTI Consulting, *Global Wind Market Update – Demand & Supply 2016, Part Two – Demand Side Analysis* (London: March 2017), p. 60; WindEurope, *The European Offshore Wind Industry – Key Trends and Statistics 2016* (Brussels: January 2017), p. 17, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2016.pdf>; WindEurope, *Offshore Wind in Europe – Key Trends and Statistics 2017* (Brussels: February 2018), p. 6, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2017.pdf>; WindEurope, op. cit. note 136, p. 11, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2019.pdf>; AWEA, "First US offshore wind farm unlocks vast new ocean energy resource", press release (Block Island, RI: 12 December 2016), <https://www.awea.org/resources/news/2016/first-us-offshore-wind-farm-unlocks-vast-new-ocean>.
- 154 Additional countries from, for example, S. Vorrath, "Australia's first offshore wind project heads to 'next phase' with new CEO", *RenewEconomy*, 21 November 2019, <https://reneweconomy.com.au/australias-first-offshore-wind-project-heads-to-next-phase-with-new-ceo-26094>; reve, "Turkey has 70 GW of offshore wind power potential", *EV Wind*, 2 November 2019, <https://www.evwind.es/2019/11/02/turkey-has-70-gw-of-offshore-wind-power-potential/71614>; Saurabh, "India plans first ever 1 gigawatt offshore wind tender for Gujarat", *CleanTechnica*, 16 February 2019, <https://cleantechnica.com/2019/02/16/india-plans-first-ever-1-gigawatt-offshore-wind-tender-for-gujarat/>; World Bank, "New program to accelerate expansion of offshore wind power in developing countries", press release (Washington, DC: 6 March 2019), <https://www.worldbank.org/en/news/press-release/2019/03/06/new-program-to-accelerate-expansion-of-offshore-wind-power-in-developing-countries>. See also World Bank, "Expanding offshore wind to emerging markets", 31 October 2019, <https://www.worldbank.org/en/topic/energy/publication/expanding-offshore-wind-in-emerging-markets>, and World Bank, *Going Global Expanding Offshore Wind to Emerging Markets* (Washington, DC: October 2019), <http://documents.worldbank.org/curated/en/716891572457609829/pdf/Going-Global-Expanding-Offshore-Wind-To-Emerging-Markets.pdf>.
- 155 Total based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. In addition to countries mentioned in this paragraph, Japan (5 MW), Chinese Taipei (2.3 MW), Peru (2 MW) and Mexico (0.6 MW) decommissioned capacity during 2019, from idem. Number of countries based on idem and on WindEurope, op. cit. note 13, p. 16.
- 156 GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 157 An estimated 178 MW of capacity was decommissioned in Europe, from WindEurope, op. cit. note 13, p. 16. Austria and Denmark decommissioned 32 MW each, the United Kingdom 17 MW and France 0.2 MW; 174 MW of the total was onshore capacity and 4 MW was offshore, all from idem. An estimated 174 MW was decommissioned in Europe, including in Germany (97 MW), Austria (32 MW), Denmark (31.9 MW) and the United Kingdom (13 MW), based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.
- 158 IRENA, op. cit. note 9, p. 9; Eckhouse, op. cit. note 9; Frankfurt School/UNEP Collaborating Centre and BloombergNEF, *Global Trends in Renewable Energy Investment 2018* (Frankfurt: 2019), pp. 16-17, https://www.fs-unep-centre.org/wp-content/uploads/2019/11/Global_Trends_Report_2018.pdf; S. Sawyer, GWEC, personal communication with REN21, 13 December 2017; W. Steel, "Bigger turbines, better economics, more digitization on deck for 2018 wind power market", *Renewable Energy World*, 14 February 2018, <http://www.renewableenergyworld.com/articles/print/volume-21/issue-1/features/wind/bigger-turbines-better-economics-more-digitization-on-deck-for-2018-wind-power-market.html>.
- 159 See, for example, GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 11; M. Martin, "German wind turbine maker Senvion files for insolvency", *Reuters*, 9 April 2019, <https://uk.reuters.com/article/us-germany-senvion/german-wind-turbine-maker-senvion-files-for-insolvency-idUUKCN1RL271>; "Wind margin pressures shift from turbines to service market", *New Energy Update*, 7 March 2019, <https://analysis.newenergyupdate.com/wind-energy-update/wind-margin-p pressures-shift-turbines-service-market>.
- 160 GWEC, *Global Wind Report 2019*, op. cit. note 1; B. Backwell, "Editorial", *GWEC Newsletter*, September 2018; S. Sawyer, GWEC, personal communication with REN21, 30 March 2019. In India, for example, intense competition led to very low bid prices, which were used to benchmark bids for subsequent auctions, all of which were undersubscribed. Other barriers to project implementation (such as unavailability of grid access and land) increased in parallel, raising risks and costs. The result has been a slowdown in installations, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 18. Developers in Germany have experienced permitting delays, due to technological changes such as higher hub heights, and public acceptance issues, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25. Across Europe, developers increasingly face more expensive and longer permitting procedures, from A. Robert and F. Simon, "French wind energy 'in limbo' for more than a year", *Euractiv*, 17 January 2019, <https://www.euractiv.com/section/energy/news/french-wind-energy-in-limbo-for-more-than-a-year>.
- 161 Technology advances from L. Kellner, "Report confirms wind technology advancements continue to drive down the cost of wind energy", *Lawrence Berkeley National Laboratory*, 26 August 2019, <https://newscenter.lbl.gov/2019/08/26/report-confirms-technology-advancements-continue-to-drive-down-the-cost-of-wind-energy/>; technology advances and supply chain efficiencies from GWEC, *Global Wind Report 2019*, op. cit. note 1, and from Navigant Research, "Global wind power development and policy, wind turbine OEM market shares, and capacity market forecasts", newsletter, 7 August 2018; Backwell, op. cit. note 160; R. B. Zeller, Vestas, personal communication with REN21, 12 April 2019; integration from EurObserv'ER, op. cit. note 26, p. 11, and from K. Ohlenforst, GWEC, personal communication with REN21, 22 April 2019 and from information and sources throughout this section.
- 162 Frankfurt School-UNEP Centre and BloombergNEF, op. cit. note 9, p. 28. LCOE estimates vary widely from place to place and are influenced by resources and local regulatory, finance and labour cost characteristics, from idem. Note that in India the LCOE of wind energy fell about 40% between 2015 and 2019, and was priced nearly 35% below conventional fuels, from GWEC and MEC Intelligence, op. cit. note 9, p. 13.
- 163 Frankfurt School-UNEP Centre and BloombergNEF, op. cit. note 9, p. 28.
- 164 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 13. Allocated capacity was 14.5 GW onshore and 3.3 GW offshore in 2018, for a total of 17.8 GW, which includes wind-specific auctions/tenders (e.g., in Germany, India) and broader renewable energy auctions/tenders (e.g., Brazil), from GWEC Market Intelligence, *Global Wind Market Development – Supply Side Data 2018* (Brussels: April 2019). Note that 9.3 GW of this was in Europe, from WindEurope, op. cit. note 48, p. 21. The year 2019 saw a new record, and peak in 2017, with 18,088 MW onshore and 5,426 MW offshore, for a total of 23,514 MW, from Backwell, op. cit. note 135, Slide 8. Number of countries was 18, including China, and a mix of wind-specific and technology-neutral/renewable energy auctions, all from Zhao, op. cit. note 7 and 12 May 2020.
- 165 See, for example, WindEurope, op. cit. note 13, pp. 8, 21; IRENA, op. cit. note 37.
- 166 WindEurope, op. cit. note 13, p. 21; S. Gsänger, WWEA, Bonn, personal communication with REN21, 7 May 2020.
- 167 Zhao, op. cit. note 7.
- 168 J. S. Hill, "Saudi Arabia wind farm claims world record low energy cost", *RenewEconomy*, 13 August 2019, <https://reneweconomy.com.au/saudi-arabia-wind-farm-claims-world-record-low-energy-cost-99966>.
- 169 OLADE and GWEC, cited in GWEC, "Public tenders and auctions have driven 80% of current renewable energy capacity in Latin America and the Caribbean", op. cit. note 11. See also OLADE, op. cit. note 97.
- 170 GWEC, *Global Wind Report*, op. cit. note 1, p. 46; GWEC, "Wind industry to invest \$1.8bn in Colombia next three years following successful tender", press release (Bogota: 14 November 2019), <https://gwec.net/wind-industry-to-invest-1-8bn-in-colombia-in-next-three-years-following-successful-tender>. Three solar projects and five wind power facilities were contracted at a final energy electricity price of US 27 per MWh, from E. Bellini, "Colombia's first solar and wind power auction brings average price of \$0.027/kWh", *pv magazine*, 23 October 2019, <https://www.pv-magazine.com>.

- [com/2019/10/23/colombias-first-solar-and-wind-power-auction-brings-average-price-of-0-027-kwh](https://www.renewablesnow.com/news/colombian-renewables-auction-closes-with-1298-mw-of-wind-solar-673555). See also S. Djunicic, "Colombian renewables auction closes with 1,298 MW of wind, solar", *Renewables Now*, 23 October 2019, <https://renewablesnow.com/news/colombian-renewables-auction-closes-with-1298-mw-of-wind-solar-673555>.
- 171 Based on 15.4 GW (8.6 GW onshore and 6.8 GW offshore) reported less 1 GW onshore in Turkey, which the GSR does not include as part of Europe, from *WindEurope*, op. cit. note 13, pp. 8, 21.
- 172 *WindEurope*, op. cit. note 13, p. 21.
- 173 The range for onshore projects was EUR 38-69 per MWh, from *Komusanac*, op. cit. note 12. However, the lowest bid was probably in Lithuania, where a zero-subsidy bid won, or in Denmark, where a fixed feed-in premium was awarded at EUR 1.34 per MWh, but these are not comparable to other winning projects, from *idem*.
- 174 Bid prices based on data from *WindEurope*, op. cit. note 48, p. 21, and from *WindEurope*, op. cit. note 13, p. 21; five of six onshore auctions undersubscribed, from *idem*, p. 21; and Germany also from *WindEurope*, "Permitting issues behind yet another under-subscribed German onshore wind auction round", 9 August 2019, <https://windeurope.org/newsroom/news/permitting-issues-behind-yet-another-under-subscribed-german-onshore-wind-auction-round>, and from *WWEA* and *LEE NRW*, op. cit. note 62. Awarded bid prices fell significantly in first year of auctions in Germany, but increased in 2018 and 2019, to above the statutory tariffs of the old EEG, or Germany's FIT, from *idem*, pp. 7, 11, and from *Gsänger*, op. cit. note 166.
- 175 Auctions in France, the Netherlands and the United Kingdom from *WindEurope*, op. cit. note 13, p. 21; prices continued to fall, from *GWEC*, *Global Wind Report 2019*, op. cit. note 1, p. 38. Offshore wind is already cost-competitive in Europe, with a levelised cost of electricity in Northwest Europe below the averages for natural gas, coal and nuclear power, from S. H. Buhl, Ørsted, "Global offshore wind growth and Japan outlook", presentation for Renewable Energy Institute, REvision – Webinar, 4 March 2020, slide 9, https://www.renewable-ei.org/pdfdownload/activities/13_SebastianHaldBuhl.pdf. France held a tender in June (Dunkirk) that resulted in 44 EUR per MWh, from *GWEC*, op. cit. note 135, p. 31.
- 176 The United Kingdom awarded 5.5 GW at price of EUR 43.8-46 per MWh, from *WindEurope*, op. cit. note 13, p. 21; *Chapman*, op. cit. note 9. According to the UK BEIS, prices for the third round fell by around 30% compared to the second round, held in 2017, and have fallen by as much as 66% compared to the first round, held in 2015. The lowest price awarded – GBP 39.65 per MWh (in 2012 prices) – was awarded for several different projects, all from BEIS, cited in J. S. Hill, "UK offshore wind prices reach new record low in latest CfD auction", *CleanTechnica*, 23 September 2019, <https://cleantechnica.com/2019/09/23/uk-offshore-wind-prices-reach-new-record-low-in-latest-cfd-auction>. The UK's CfD3 resulted in record low price of GBP 39.65 per MWh for delivery years 2023-24 and GBP 41.611 per MWh for 2024-25 (in 2012 prices), from S. Virley, "Blown away, CfD Round 3 delivers record low price for offshore wind", *KPMG*, 20 September 2019, <https://home.kpmg/uk/en/home/insights/2019/09/contract-for-difference-subsidiary-auction.html>.
- 177 *GWEC*, *Global Wind Report 2019*, op. cit. note 1, p. 38; A. Lee, "Vattenfall wins 760MW of Dutch zero-subsidy offshore wind", *Recharge*, 10 July 2019, <https://www.rechargenews.com/wind/vattenfall-wins-760mw-of-dutch-zero-subsidy-offshore-wind/2-1-636547>. The first such tender was held in 2018, from *WindEurope*, "World's first offshore wind farm without subsidies to be built in the Netherlands", press release (Brussels: 20 March 2018), <https://windeurope.org/newsroom/press-releases/worlds-first-offshore-wind-farm-without-subsidies-to-be-built-in-the-netherlands>.
- 178 B. Lillian, "Report: Wind PPA prices are on the rise", *North American Wind Power*, 17 October 2019, <https://nawindpower.com/report-wind-ppa-prices-are-on-the-rise>; E. Holbrook, "Majority of wind developers feel PPA prices will stay the same in 2020: Report", *Environmental Leader*, 22 January 2020, <https://www.environmentalleader.com/2020/01/majority-of-wind-developers-feel-ppa-prices-will-stay-the-same-in-2020-report/>; *LevelTen Energy*, "LevelTen Q4 2019 PPA Price Index reveals increasing wind, decreasing solar PPA offer prices", 22 January 2020, <https://leveltenenergy.com/blog/ppa-price-index/q4-2019/>; historic lows in 2018, PTC phase-out and tariffs, from *AWEA*, personal communication with *REN21*, 8 May 2020.
- 179 C. Richard, "Trade wars hit Vestas' profit margin in 'busy 2019'", *Windpower Monthly*, 5 February 2020, <https://www.windpowermonthly.com/article/1673055/trade-wars-hit-vestas-profit-margin-busy-2019>; United States is the most important market for Vestas and cascading effect, from K.-E. Stromsta, "Vestas profit falls as trade tariffs bite wind supply chain", *GTM*, 15 August 2019, <https://www.greentechmedia.com/articles/read/vestas-profit-falls-as-trade-tariffs-bite-wind-supply-chain>.
- 180 Figure of 90% from B. Lillian, "Report: Wind PPA prices are on the rise", *North American Wind Power*, 17 October 2019, <https://nawindpower.com/report-wind-ppa-prices-are-on-the-rise>; steel makes up 71-79% and aluminum 0-2%, from *US Geological Survey*, "What materials are used to make wind turbines?" <https://www.usgs.gov/faqs/what-materials-are-used-make-wind-turbines>, viewed 24 March 2020; permanent magnets from R. Davidson, "China trade deal no help for rising US wind costs", *Windpower Monthly*, 20 January 2020, <https://www.windpowermonthly.com/article/1671264/china-trade-deal-no-help-rising-us-wind-costs>; pressure on supply chain from B. Backwell, CEO of *GWEC*, cited in *GWEC*, op. cit. note 78; R. Davidson, "China trade deal no help for rising US wind costs", *Windpower Monthly*, 20 January 2020, <https://www.windpowermonthly.com/article/1671264/china-trade-deal-no-help-rising-us-wind-costs>. For more on tariffs on steel and aluminium, and impacts on the US wind industry, see J. Jackson, "How to develop the US offshore wind supply chain", *Maritime Executive*, 10 March 2020, <https://maritime-executive.com/features/how-to-develop-the-us-offshore-wind-supply-chain-1>.
- 181 R. Davidson, "China trade deal no help for rising US wind costs", *Windpower Monthly*, 20 January 2020, <https://www.windpowermonthly.com/article/1671264/china-trade-deal-no-help-rising-us-wind-costs>.
- 182 Other countries have introduced, from "Trade barriers 'hitting wind industry'", *reNEWS*, 21 October 2019, <https://renews.biz/55928/trade-barriers-hitting-wind-industry>; impacts on wind industry from Vestas senior vice president Morten Dyrholm, cited in *idem*.
- 183 *GWEC*, *Global Wind Report 2019*, op. cit. note 1, p. 11.
- 184 *Ibid.*, p. 11; "Wind margin pressures shift from turbines to service market", *New Energy Update*, 7 March 2019, <http://www.newenergyupdate.com/wind-energy-update/wind-margin-p pressures-shift-turbines-service-market>.
- 185 *Windtech International*, "A dangerous trend is challenging the success of wind power around the globe: Concentration and monopolisation", 4 February 2020, <https://www.windtech-international.com/view-from-inside/a-dangerous-trend-is-challenging-the-success-of-wind-power-around-the-globe-concentration-and-monopolisation>. Low and zero-subsidy bids have largely reduced the number of industry players, favouring larger companies, from *IRENA*, op. cit. note 37; number and diversity from *Gsänger*, op. cit. note 166, and from *WWEA* and *LEE NRW*, op. cit. note 62; K. E. Stromsta, "WoodMac: 'Final wave' of consolidation hits onshore wind as market approaches maturity", *GTM*, 5 February 2020, <https://www.greentechmedia.com/articles/read/woodmac-wind>. Also see J. Hossain, *WWEA* & R. Kannan, *OGPL*, "Experience with auctions in India", from *WWEA*, "Webinar: Wind power and renewable energy policies: What is best to reach 100% RE", 14 May 2020, <https://windea.org/blog/2020/05/07/wwewebinar-wind-power-and-renewable-energy-policies-what-is-best-to-reach-100-re-14-may>.
- 186 Zhao, op. cit. note 7, 15 May 2020; figure of more than 100 suppliers from *GWEC*, *Global Wind Report*, op. cit. note 1, p. 18.
- 187 Figure of 85.5% share from Zhao, op. cit. note 7, 15 May 2020, and from *GWEC*, *Global Wind Market Development – Supply Side Data 2019* (Brussels: May 2020); data for 2018 from *GWEC Market Intelligence*, op. cit. note 164, p. 3; 80% for 2017 from *FTI Consulting*, *Global Wind Market Update – Demand & Supply 2017, Part One – Supply Side Analysis* (London: April 2018), pp. 6, 10, 11, <https://fti-intelligence.com/gwmu2017-supply-side-analysis>, viewed April 2018; 75% in 2016 based on data from *FTI Consulting*, *Global Wind Market Update – Demand & Supply 2016, Part One – Supply Side Analysis* (London: 2017), p. 10, <https://fti-intelligence.com/global-wind-market-update-2016-supply-side-analysis>. The market share of the top 10 manufacturers increased from 70% in 2015 to 85% in 2018, from *BloombergNEF*, cited in "Wind margin pressures shift from turbines to service market", *New Energy Update*, 7 March 2019, <http://www.newenergyupdate.com/wind-energy-update/wind-margin-p pressures-shift-turbines-service-market>. The number of wind turbine manufacturers declined from around 100 a few years

- ago, from Zhao, op. cit. note 7, May 2019, and from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 18; and declined from 200 a few years ago to 37 in 2018, according to Intelstor, a market intelligence platform for renewable energy, in its report *Global Wind Energy Innovation Trend – 2019*, cited in EurObserv'ER, op. cit. note 26, p. 11.
- 188 BloombergNEF, "Vestas still rules turbine market, but challengers are closing in", 18 February 2020, <https://about.bnef.com/blog/vestas-still-rules-turbine-market-but-challengers-are-closing-in/>; GWEC, op. cit. note 187; Richard, "Vestas leads the pack with squeezed market share", op. cit. note 128. The top five (Vestas, Siemens Gamesa, Goldwind, GE Renewable Energy and China's Envision), accounted for two-thirds of new global installations in 2019, from S. Campbell, "Vestas holds first as leading OEM as China challenges for top spots", *Windpower Monthly*, 1 April 2020, <https://www.windpowermonthly.com/article/1678247/vestas-holds-firm-leading-oem-china-challenges-top-spots>; and the top five were Vestas, Siemens Gamesa, GE, Goldwind and Envision, from Wood Mackenzie, cited in "Vestas 'tops 2019 turbine charts'", ReNEWS, 11 May 2020, <https://renews.biz/60186/vestas-tops-2019-turbine-charts>.
- 189 GWEC, op. cit. note 187; BloombergNEF, op. cit. note 188; Richard, "Vestas leads the pack with squeezed market share", op. cit. note 128; GE and Goldwind specifics from Campbell, op. cit. note 188.
- 190 GWEC, op. cit. note 187; BloombergNEF, op. cit. note 188.
- 191 GWEC, op. cit. note 187, and Zhao, GWEC, personal communication with REN21, 18 May 2020. Nordex-Acciona took the eighth spot, and the remaining companies among the top 10 (all Chinese – Ming Yang, Windey, Shanghai Electric and CSIC) moved up in ranking thanks to a strong domestic market, from BloombergNEF, op. cit. note 188, and from Richard, "Vestas leads the pack with squeezed market share", op. cit. note 128.
- 192 Top 10 in 2017 based on data from FTI Consulting, *Global Wind Market Update – Demand & Supply 2017, Part One – Supply Side Analysis*, op. cit. note 187, pp. 6, 10, 11. Declining home markets from, for example, BloombergNEF, op. cit. note 188; Richard, "Vestas leads the pack with squeezed market share", op. cit. note 128; Weston, op. cit. note 62. Enercon's installations in 2019 were mostly outside of Germany, and the company, which used to be the largest supplier in Germany, lost market share domestically to Vestas and Siemens Gamesa, from GWEC, op. cit. note 187, and Zhao, op. cit. note 7, 18 May 2020.
- 193 S. Knight, "Enercon troubled by second year of losses", *Windpower Monthly*, 28 January 2020, <https://www.windpowermonthly.com/article/1672237/enercon-troubled-second-year-losses>; S. Knight, "Enercon braced for change following dramatic German collapse", *Windpower Monthly*, 12 April 2019, <https://www.windpowermonthly.com/article/1581941/enercon-braced-change-following-dramatic-german-collapse>; S. Knight and C. Richard, "Enercon cuts back, seeing 'no chance' of German recovery", *Windpower Monthly*, 29 November 2019, <https://www.windpowermonthly.com/article/1666659/enercon-cuts-back-seeing-no-chance-german-recovery>; Weston, op. cit. note 62; B. Radowitz, "Thousands to lose jobs as German wind crisis hits Enercon", *Recharge*, 11 November 2019, <https://www.rechargenews.com/wind/thousands-to-lose-jobs-as-german-wind-crisis-hits-enercon/2-1-704074>; "Enercon sends up distress flare as Germany's wind market collapses", *Windpower Monthly*, 8 November 2019, <https://www.windpowermonthly.com/article/1665213/enercon-sends-distress-flare-germanys-wind-market-collapses>; A. Spatuzza, "Enercon's Wobben lays off 370 at Brazilian wind plant", *Recharge*, 3 October 2019, <https://www.rechargenews.com/wind/enercons-wobben-lays-off-370-at-brazilian-wind-plant/2-1-682694>.
- 194 A. Hübner and M. Martin, "German wind turbine maker Senvion files for insolvency", *Reuters*, 9 April 2019, <https://in.reuters.com/article/us-germany-senvion/german-wind-turbine-maker-senvion-files-for-insolvency-idINKCN1RL271?il=0>; Radowitz, op. cit. note 193; "Siemens Gamesa to buy assets from wind turbine maker Senvion", *Reuters*, 21 October 2019, <https://www.reuters.com/article/us-senvion-a-siemens-gamesa/siemens-gamesa-to-buy-assets-from-wind-turbine-maker-senvion-idUSKBN1X00JO>; C. Richard, "SGRE completes Senvion purchase", *Windpower Monthly*, 9 January 2020, <https://www.windpowermonthly.com/article/1670368/sgre-completes-senvion-purchase>; E. de Vries, "The rise and fall of Senvion", *Windpower Monthly*, 18 September 2019, <https://www.windpowermonthly.com/article/1654013/rise-fall-senvion>.
- 195 Outstanding debt from A. Parikh, "Suzlon's outstanding debt reaches ₹127.85 billion", *Mercom India*, 9 January 2020, <https://mercomindia.com/suzlon-outstanding-debt/>; debt restructuring from C. Richard, "Key Suzlon lender accepts restructuring plan", *Windpower Monthly*, 20 February 2020, <https://www.windpowermonthly.com/article/1674590/key-suzlon-lender-accepts-restructuring-plan>. See also Tendulkar, op. cit. note 37.
- 196 Global turbine orders reached a record high in 2019, at almost 100 GW, from A. Dimitrova, "Global wind turbine orders hit all-time high in 2019 – WoodMac", *Renewables Now*, 6 March 2020, <https://renewablesnow.com/news/global-wind-turbine-orders-hit-all-time-high-in-2019-woodmac-689927>; Enercon, Senvion, Siemens Gamesa and Vestas all closed factories in Europe and laid off thousands of workers, from B. Radowitz, "Jobs axe swings as Europe's wind workers face perfect storm", *Recharge*, 30 September 2019, <https://www.rechargenews.com/wind/1856777/jobs-axe-swings-as-europes-wind-workers-face-perfect-storm>; "Wind turbine maker Vestas cuts 600 staff in Denmark and Germany", *Reuters*, 27 September 2019, <https://www.reuters.com/article/us-vestas-wind-strategy/wind-turbine-maker-vestas-cuts-600-staff-in-denmark-and-germany-idUSKBN1WCORW>; D. Snieckus, "Last of the line rolls out, as Senvion shuts Bremerhaven", *Recharge*, 14 November 2019, <https://www.rechargenews.com/wind/last-of-the-line-rolls-out-as-senvion-shutters-bremerhaven/2-1-704752>; Knight, "Enercon braced for change following dramatic German collapse", op. cit. note 193; Weston, op. cit. note 62; Radowitz, op. cit. note 193. Vestas had a record order intake (passing 17 GW for the year, from A. Lee, "New order record in the bag as wind giant Vestas busts 15GW", *Recharge*, 12 December 2019, <https://www.rechargenews.com/wind/new-order-record-in-the-bag-as-wind-giant-vestas-busts-15gw/2-1-723398>; V. Petrova, "Vestas' Q4 announced order intake nears 3 GW", *Renewables Now*, 3 January 2020, <https://renewablesnow.com/news/vestas-q4-announced-order-intake-nears-3-gw-682110>; V. Petrova, "Vestas' 2019 profits grow, order intake reaches all-time high", *Renewables Now*, 5 February 2020, <https://renewablesnow.com/news/vestas-2019-profits-grow-order-intake-reaches-all-time-high-686117>; the company also increased its revenue and operating profit, but Vestas' profit margin shrank due to rising costs, including trade-related tariffs, from Richard, op. cit. note 179; "Wind turbine maker Vestas benefits from climate change action, sees orders jump", *Reuters*, 7 November 2019, <https://www.reuters.com/article/us-vestas-wind-results/wind-turbine-maker-vestas-benefits-from-climate-change-action-sees-orders-jump-idUSKBN1XH1CW>. Nordex (Germany) suffered significant losses in 2019, despite a 31% increase in sales relative to 2018, from "Loss-making continues at bullish Nordex", *Windpower Monthly*, 13 November 2019, <https://www.windpowermonthly.com/article/1665651/loss-making-continues-bullish-nordex>; M. Bates, "Nordex Group touts 2019 wind turbine activity", *North American Wind Power*, 15 January 2020, <https://nawindpower.com/nordex-group-touts-2019-wind-turbine-activity>. GE also had losses for all four quarters of 2019, despite increased revenue and turbine orders, partly because of research and development investment for its 12 MW Haliade-X turbine, from D. Weston, "Haliade-X R&D hits GE Renewable Energy profit", *Windpower Monthly*, 30 April 2019, <https://www.windpowermonthly.com/article/1583328/haliade-x-r-d-hits-ge-renewable-energy-profit>; D. Weston, "GE remains in the red", *Windpower Monthly*, 29 January 2020, <https://www.windpowermonthly.com/article/1672324/ge-remains-red>.
- 197 See, for example, A. Lee, "Siemens Gamesa confirms Taiwan offshore wind factory", *Recharge*, 16 September 2019, <https://www.rechargenews.com/wind/1851361/siemens-gamesa-confirms-taiwan-offshore-wind-factory>. For more on challenges of transport, see, for example, L. Baker, "Shipping wind turbines is not a breeze", *Freight Waves*, 27 August 2019, <https://www.freightwaves.com/news/shipping-wind-turbines-is-not-a-breeze>.
- 198 V. Petrova, "Vestas cuts ribbon on new turbine factory in Brazil", *Renewables Now*, 13 November 2019, <https://renewablesnow.com/news/vestas-cuts-ribbon-on-new-turbine-factory-in-brazil-676116>; MHI Vestas, "MHI Vestas Offshore Wind inks contract for blade materials in Taiwan", press release (Chinese Taipei: 3 July 2019), <https://www.mhivestasoffshore.com/mhi-vestas-offshore-wind-inks-contract-for-blade-materials-in-taiwan/>; S. Djunicic, "Nordex to make own rotor blades in Mexico", *Renewables Now*, 12 February 2019, <https://renewablesnow.com/news/nordex-to-make-own-rotor-blades-in-mexico-642726>; "SGRE ramps up production, but investors seek more clarity", *Windpower Monthly*, 29 November 2019, <https://www.windpowermonthly.com/article/1666700/sgre-ramps-production-investors-seek-clarity>; A. Lee, "Siemens Gamesa confirms Taiwan offshore wind factory", *Recharge*, 16 September 2019, <https://www.rechargenews.com/wind/1851361/siemens-gamesa-confirms-taiwan-offshore-wind-factory>; Siemens Gamesa,

- "Siemens Gamesa reinforces offshore foothold in Asia Pacific with launch of nacelle assembly facility in Taiwan", press release (Chinese Taipei: 16 September 2019), <https://www.siemensgamesa.com/en-int/newsroom/2019/09/190616-siemens-gamesa-offshore-facility-taiwan>; GE from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 63.
- 199 K.-E. Stromsta, "US wind industry's response to solar's rise: Embrace it", *GTM*, 22 May 2019, <https://www.greentechmedia.com/articles/read/us-wind-industrys-response-to-solars-rise-embrace-it>; hybrid projects from Komusanac, op. cit. note 12. Most of the largest developers in the United States have expanded into solar PV and energy storage, from AWEA, personal communication with REN21, 8 May 2020; this also is occurring in China, India and wherever leading developers operate both wind and solar power, from Zhao, op. cit. note 7, 4 May 2020.
- 200 Ibid.; Australia from G. Parkinson, "South Australia's biggest wind solar hybrid project gets financial green light", *RenewEconomy*, 15 January 2020, <https://reneweconomy.com.au/south-australias-biggest-wind-solar-hybrid-project-gets-financial-green-light-58154>; other countries and drivers from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 30; H. K. Trabish, "Utilities take note: Hybrid renewables projects are coming" *Utility Dive*, 3 April 2018, <https://www.utilitydive.com/news/utilities-take-note-hybrid-renewables-projects-are-coming/520319>; J. Spector, "'Cheaper than a peaker': NextEra inks massive wind+solar+storage deal in Oklahoma", *GTM*, 25 July 2019, <https://www.greentechmedia.com/articles/read/nextera-inks-even-bigger-windsolarstorage-deal-with-oklahoma-cooperative>; A. Eller, "A new wave of renewable energy emerges with hybrid wind, solar, and storage Projects", *Navigant Research*, 24 September 2019, <https://www.navigantresearch.com/news-and-views/a-new-wave-of-renewable-energy-emerges-with-hybrid-wind-solar-and-storage-projects>; several countries in Europe from Zhao, op. cit. note 7, and from WindEurope, "Renewable hybrid power plants", <https://windeurope.org/about-wind/database-for-wind-and-storage-colocated-projects>, viewed 14 April 2020. See also World Bank, *International Bank for Reconstruction and Development Project Appraisal Document* (Washington, DC: 7 March 2019), <http://documents.worldbank.org/curated/en/523301554170679058/pdf/India-Innovation-in-Solar-Power-and-Hybrid-Technologies-Project.pdf>, and W. Gorman et al., "Motivations and options for deploying hybrid generator-plus-battery projects within the bulk power system", *Electricity Journal*, vol. 33 (2020), <https://www.sciencedirect.com/science/article/pii/S1040619020300312?via%3Dihub>. Despite the advantages of hybrid systems that pair variable renewable energy with battery storage, batteries that are sited independently (with no limitations on grid charging or interconnection limits associated with renewable capacity) can capture more value, from idem., p. 11.
- 201 Acciona, "ACCIONA, a pioneer in the hybridization of solar panels with wind power towers", press release (Madrid: 16 May 2019), <https://www.acciona.com/news/acciona-pioneer-hybridization-solar-panels-wind-power-towers>; C. Richard, "Acciona trials solar modules to power wind turbine", *Windpower Monthly*, 16 May 2019, <https://www.windpowermonthly.com/article/1584900/acciona-trials-solar-modules-power-wind-turbine>.
- 202 M. Hughlett, "Minnesota wind-solar hybrid project could be new frontier for renewable energy", *Star Tribune*, 23 September 2019, <http://www.startribune.com/minnesota-wind-solar-hybrid-project-could-be-new-frontier-for-renewable-energy/560906672>. A combined GE and Atria (India) team converted a wind project in India for a similar hybrid solution, from T. Kellner, "India needs plenty of wind and solar power to meet ambitious renewables goals. This hybrid farm can harvest both", *GE Reports*, 1 December 2018, <https://www.ge.com/reports/india-needs-plenty-wind-solar-power-meet-ambitious-renewables-goals-hybrid-farm-can-harvest>. See also B. Coffey, "The rise of the hybrids: New GE unit blends batteries and renewables to boost wind and solar power output", *GE Reports*, 23 September 2019, <https://www.ge.com/reports/the-rise-of-the-hybrids-new-ge-unit-blends-batteries-and-renewables-to-boost-wind-and-solar-power-output>.
- 203 F. Jossi, "Wind-solar pairing cuts equipment costs while ramping up output", *Energy News*, 7 March 2019, <https://energynews.us/2019/03/07/midwest/wind-solar-pairing-c>; Trabish, op. cit. note 200. See also Hughlett, op. cit. note 202.
- 204 Jossi, op. cit. note 203. See also Hughlett, op. cit. note 202.
- 205 S. Campbell, "The rise and rise of the super-size wind farm", *Windpower Monthly*, 28 February 2019, <https://www.windpowermonthly.com/article/1562622/rise-rise-super-size-wind-farm>; WindEurope, op. cit. note 136, p. 18. See also Buhl, op. cit. note 175.
- 206 WindEurope, op. cit. note 136, pp. 8, 18. The average size of projects off Europe's coast rose from 79.6 MW in 2007 to 621 MW in 2019, from WindEurope, *Offshore Wind in Europe: Key Trends and Statistics 2018* (Brussels: February 2019), pp. 7, 21, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2018.pdf>.
- 207 Reduce costs through scale and standardization, from WindEurope, op. cit. note 136, p. 8; reduce costs also from D. Iaconangelo, "Longer turbine blades have slashed wind energy costs", *E&E News*, 5 March 2020, <https://www.scientificamerican.com/article/longer-turbine-blades-have-slashed-wind-energy-costs>; costs of capital, etc. decline, from Campbell, op. cit. note 205. See also Buhl, op. cit. note 175.
- 208 Backwell, op. cit. note 135, Slide 10. Note that longer wind turbine blades have helped to reduce wind energy costs, from M. Bolinger, Lawrence Berkeley National Laboratory, cited in Iaconangelo, op. cit. note 207.
- 209 Average rated capacity of turbines delivered to market worldwide in 2019 was 2,755 kW (averages of 2,603 kW onshore and 5,653 kW offshore), from GWEC, *Global Wind Market Development – Supply Side Data 2019*, op. cit. note 187, and figure of 12% based on 2019 data from idem. and on average rated capacity of 2.45 MW in 2018, from GWEC Market Intelligence, *Global Wind Market Development – Supply Side Data 2018* (Brussels: April 2019).
- 210 Morocco (4,200 kW), Finland (4,182 kW) and Norway (3,825 kW) from Zhao, op. cit. note 7, 17 May 2020; exceeding 2 MW and Brazil (2,580 kW), the United States (2,549 kW) and China (onshore average of 2,355 kW, with overall average of 2,457 kW and offshore average of 4,240 kW), from GWEC, *Global Wind Market Development – Supply Side Data 2019*, op. cit. note 187. Note that Ukraine also was close to 3.8 MW, from WindEurope, op. cit. note 13, p. 20, and the US average was nearly 2.6 MW, from AWEA, personal communication with REN21, 8 May 2020.
- 211 Belgium, Portugal and Denmark from WindEurope, op. cit. note 136, p. 20, and from GWEC, *Global Wind Market Development – Supply Side Data 2019*, op. cit. note 187. Note that Germany's average offshore was 6,942 kW (down 2% relative to 2018, although the ratio of nominal capacity to rotor area still increased), from Deutsche Windguard, op. cit. note 61, p. 4.
- 212 WindEurope, op. cit. note 136, p. 20.
- 213 Launched in 2019 from US DOE, EERE, *2018 Offshore Wind Technologies Market Report* (Washington, DC: August 2019), p. xiii, <https://www.energy.gov/eere/wind/downloads/2018-offshore-wind-market-report>, and from D. Snieckus, "Siemens Gamesa unveils digitally souped-up 11MW offshore turbine", *Recharge*, 26 November 2019, <https://www.rechargenews.com/wind/siemens-gamesa-unveils-digitally-souped-up-11mw-offshore-turbine/2-1-711795>; on the market in 2022 from W. Musial et al., "2018 Offshore Wind Technologies Market Report", presentation, Washington, DC, August 2019, slide 38, <https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Offshore%20Wind%20Market%20Report%20Presentation.pdf>.
- 214 M. Bates, "MHI Vestas 10 MW turbines to power floating offshore project", *North American Wind Power*, 18 November 2019, <https://nawindpower.com/mhi-vestas-10-mw-turbines-to-power-floating-offshore-project>; <http://www.mhivestasoffshore.com/category/v164-10-0-mw>.
- 215 Y. Yu, "Second Chinese OEM unveils 10MW offshore wind turbine", *Recharge*, 27 October 2019, <https://www.rechargenews.com/wind/second-chinese-oem-unveils-10mw-offshore-wind-turbine/2-1-695389>; B. Radowitz, "Cost drops to 'open space' in Chinese offshore wind for global firms", *Recharge*, 15 November 2019, <https://www.rechargenews.com/wind/1877663/cost-drops-to-open-space-in-chinese-offshore-wind-for-global-firms>; Y. Yu, "China's Dongfang poised to launch 10MW offshore wind turbine", *Recharge*, 22 August 2019, <https://www.rechargenews.com/wind/chinas-dongfang-poised-to-launch-10mw-offshore-wind-turbine/2-1-659264>. Dongfang released a prototype and CSIC unveiled only a plan, from Zhao, op. cit. note 7.
- 216 Installed at Port of Rotterdam from WindEurope, op. cit. note 136, p. 8; started generating from D. Snieckus, "First power flows from world's biggest offshore wind turbine", *Recharge*, 7 November 2019, <https://www.rechargenews.com/wind/1874783/first-power-flows-from-worlds-biggest-offshore-wind-turbine>; serial production from S. Djunicic, "GE's Haliade-X generates record-breaking 288 MWh in 24 hours", *Renewables Now*, 7 February

- 2020, <https://www.renewablesnow.com/news/ges-haliade-x-generates-record-breaking-288-mwh-in-24-hours-686457>.
- 217 Longest made, at 107 metres, from B. Lillian, "LM Wind claims world's longest turbine blade", North American Wind Power, 18 April 2019, <https://nawindpower.com/lm-wind-claims-worlds-longest-turbine-blade>; length of football pitch from Bluebulb Projects, "The Measure of Things", <https://www.bluebulbprojects.com/measureofthings/results.php?comp=distance&unit=m&amt=100&sort=pr&p=1>, viewed 23 March 2020; number of European homes from Morton, op. cit. note 149.
- 218 For example, GreenSpur Wind Limited (United Kingdom) is fine-tuning new generators with magnets that are free of rare-earths, and with a per unit capacity of 20 GW, from EurObserv'ER, op. cit. note 26, p. 9; D. Snieckus, "Offshore wind turbine 20MW generator ready 'within three years'", Recharge, 22 November 2019, <https://www.rechargenews.com/wind/offshore-wind-turbine-20mw-generator-ready-within-three-years/2-1-711845>.
- 219 Become available from S. Sawyer, GWEC, personal communication with REN21, 20 April 2018; WindEurope, *Wind in Power 2017: Annual Combined Onshore and Offshore Wind Statistics* (Brussels: February 2018), p. 23, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf>. Orders came in for the MHI Vestas 10 MW machine in late 2019 for a French floating wind pilot project, from Bates, op. cit. note 214; Siemens Gamesa received orders soon after upgrading its turbine to 11 MW, from D. Weston, "WindEurope Offshore 2019: SGRE 'flexes' offshore turbine to 11MW", Windpower Monthly, 29 November 2019, <https://www.windpowermonthly.com/article/1666881/windeurope-offshore-2019-sgre-flexes-offshore-turbine-11mw>; B. Radowitz, "Siemens Gamesa's 1,000th offshore wind turbine up as 10MW+ era dawns", Recharge, 5 December 2019, <https://www.rechargenews.com/wind/siemens-gamesas-1-000th-offshore-wind-turbine-up-as-10mw-era-dawns/2-1-719148>; the first orders for the Haliade-X were placed for projects off the east coast of the United States, from K.-E. Stromsta, "GE lands first orders for 12MW offshore wind turbine, and they're huge", GTM, 19 September 2019, <https://www.greentechmedia.com/articles/read/ge-wins-lands-first-big-deals-for-12mw-offshore-wind-turbine>; Morton, op. cit. note 149, and off the coast of the UK for a 3.6 GW project, from M. Scott, "Giant offshore turbines set to take centre stage in global power markets", *Forbes*, 4 October 2019, <https://www.forbes.com/sites/mikescott/2019/10/04/ges-offshore-giants-set-to-take-centre-stage-in-power-markets>.
- 220 Backwell, op. cit. note 135, slide 10; WindEurope, Brussels, personal communication with REN21, 29 March 2018; P. N. Jensen, "Offshore wind: Big is beautiful", The Switch, 28 February 2018, <http://theswitch.com/2018/02/28/offshore-wind-big-beautiful>; "Offshore wind operators use scale, analytics to cut vessel trips", New Energy Update, 7 March 2019, <http://www.newenergyupdate.com/wind-energy-update/offshore-wind-operators-use-scale-analytics-cut-vessel-trips>; S. Sawyer, GWEC, personal communication with REN21, 30 March 2019; lower grid-connection costs from P. Pragkos, E3 Modelling, personal communication with REN21, 7 April 2019.
- 221 Challenges associated with larger turbines include lengthened permitting processes, more land required per turbine, and the potential for increased public opposition, from laconangelo, op. cit. note 207. Note that average distance to shore of Europe's offshore wind power projects under construction increased from 35 kilometres in 2018 to 59 kilometres in 2019, and average depth increased from 30 metres in 2018 to 33 metres in 2019, from WindEurope, op. cit. note 136, p. 19.
- 222 GE Reports, "GE's largest onshore wind turbine prototype installed and operating in the Netherlands", press release (Paris: 13 March 2019), <https://www.genewsroom.com/press-releases/ges-largest-onshore-wind-turbine-prototype-installed-and-operating-netherlands>; "US wind suppliers in transport grab as bottleneck looms", New Energy Update, 20 February 2019, <http://www.newenergyupdate.com/wind-energy-update/us-wind-suppliers-transport-grab-bottleneck-loats>; GE's largest onshore turbine from "GE scores 132.5-MW onshore wind win in Brazil with EDF", Renewable Energy World, 9 October 2019, <https://www.renewableenergyworld.com/2019/10/09/ge-scores-132-5-mw-onshore-wind-win-in-brazil-with-edf>. See also B. Lillian, "Study: Mitigating the challenges of ever-growing wind turbines", North American Wind Power, 7 March 2019, <https://nawindpower.com/study-mitigating-the-challenges-of-ever-growing-wind-turbines>.
- 223 Reducing outage time from Buhl, op. cit. note 175; reduced number of trips, from "Offshore wind operators use scale, analytics to cut vessel trips", op. cit. note 220.
- 224 D. Weston, "Vestas unveils drone technology partnership to aid blade installation", Windpower Monthly, 25 March 2019, <https://www.windpowermonthly.com/article/1580016/vestas-unveils-drone-technology-partnership-aid-blade-installation>; C. Richard, "Using drones for offshore spare parts delivery", Windpower Monthly, 21 January 2020, <https://www.windpowermonthly.com/article/1671982/using-drones-offshore-spare-parts-delivery>.
- 225 "Offshore wind leaders expand land, sea hubs to future-proof operations", New Energy Update, 21 November 2018, <http://www.newenergyupdate.com/wind-energy-update/offshore-wind-leaders-expand-land-sea-hubs-future-proof-operations>.
- 226 M. J. Coren, "Floating wind farms just became a serious business", Quartz, 22 June 2019, <https://qz.com/1650433/hywind-scotland-makes-floating-wind-farms-a-serious-business>; viable and economically attractive from WindEurope, "Floating offshore wind vision statement" (Brussels: June 2017), <https://windeurope.org/wp-content/uploads/files/about-wind/reports/Floating-offshore-statement.pdf>; stronger and more consistent from Statoil, "World class performance by world's first floating wind farm", press release (Stavanger, Norway: 15 February 2018), <https://www.statoil.com/en/news/15feb2018-world-class-performance.html>; best winds rather than suitable topography from S. Sawyer, GWEC, personal communication with REN21, 20 April 2018.
- 227 GWEC, "The growth of the global offshore wind market driven by Asia", 23 September 2019, <https://gwec.net/the-growth-of-the-global-offshore-wind-market-will-be-driven-by-asia>; WindEurope, op. cit. note 136, p. 21. For example, the European Union (EU) launched FLOTANT, a three-year project to develop a hybrid concrete-plastic floating structure, from EU, "Flotant Project", <http://flotantproject.eu/overview/shedule>, viewed 23 March 2020 and from EU, "Flotant Project", <http://flotantproject.eu/overview/objectives>, viewed 23 March 2020.
- 228 Portugal from "EDP reports first WindFloat Atlantic wind turbine connected to grid", Renewable Energy World, 3 January 2020, <https://www.renewableenergyworld.com/2020/01/03/edp-reports-first-windfloat-atlantic-wind-turbine-connected-to-grid>, and from "WindFloat Atlantic begins the installation of the first floating wind farm", edp renewables, 21 October 2019, <https://www.edpr.com/en/news/2019/10/21/windfloat-atlantic-begins-installation-first-floating-wind-farm>; Portugal and Spain from WindEurope, op. cit. note 136, p. 13.
- 229 Innogy, "Shell, Innogy and Stiesdal Offshore Technologies to build new floating wind demonstration plant", press release (Essen, Germany: 13 February 2019), <https://news.innogy.com/shell-innogy-and-stiesdal-offshore-technologies-to-build-new-floating-wind-demonstration-project#>; H. Stiesdal, "Stiesdal Offshore Technologies TetraSpar and TetraBase – Industrialized Offshore Wind Turbines Foundations", presentation, 1 February 2019, <https://www.stiesdal.com/material/2019/02/Stiesdal-Tetra-01.02.19.pdf>.
- 230 Europe's fleet from WindEurope, op. cit. note 136, p. 21; global estimate from Backwell, op. cit. note 135, slide 13. Floating turbines were operating in 10 countries, led by the United Kingdom, Portugal and Japan, and another 1,308 MW was in the planning stages (mostly in Europe) to be built by 2026, from idem.
- 231 "Whatever became of the vertical axis wind turbine?" Modern Power Systems, 16 May 2019, <https://www.modernpowersystems.com/features/featurewhatever-became-of-the-vertical-axis-wind-turbine-7183833>; G. Twining, "Vertical axis turbines could change floating offshore market", Dredging and Ports Construction, 23 May 2019, <https://dredgingandports.com/news/2019/vertical-axis-turbines-could-change-floating-offshore-market>.
- 232 "Whatever became of the vertical axis wind turbine?" op. cit. note 231.
- 233 SeaTwirl, "SeaTwirl is granted a Chinese patent on divisible wind turbine", press release (Gothenberg, Sweden: 9 May 2019), <https://seatwirl.com/news/seatwirl-is-granted-a-chinese-patent-on-divisible-wind-turbine>; SeaTwirl, "SeaTwirl is granted a European patent", press release (Gothenberg, Sweden: 14 January 2020), <https://seatwirl.com/news/seatwirl-is-granted-a-european-patent>; SeaTwirl, "SeaTwirl to be granted patent in the USA", press release (Gothenberg, Sweden: 31 January 2020), <https://seatwirl.com/news/seatwirl-to-be-granted-patent-in-the-usa>.
- 234 SeaTwirl, "SeaTwirl launches EU project", press release (Gothenberg, Sweden: 2 September 2019), <https://seatwirl.com/news/seatwirl-launches-eu-project>.

- 235 J. Deign, "Floating offshore wind holds promise for vertical-axis turbines", GTM, 10 May 2019, <https://www.greentechmedia.com/articles/read/floating-offshore-wind-holds-promise-for-vertical-axis-turbines>; Sandia National Laboratories, "Offshore wind", <https://energy.sandia.gov/programs/renewable-energy/wind-power/offshore-wind/#float-vawt>, viewed 22 March 2020; M. Fowler, D. Bull and A. Goupee, *A Comparison of Platform Options for Deep-water Floating Offshore Vertical Axis Wind Turbines: An Initial Study* (Albuquerque, NM: Sandia National Laboratories, 2014), <https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2014/1416800.pdf>; US DOE, EERE, "Offshore floating vertical-axis wind turbine project identifies promising platform design", 17 October 2017, <https://www.energy.gov/eere/wind/articles/offshore-floating-vertical-axis-wind-turbine-project-identifies-promising>.
- 236 P. Fairley, "Europe stores electricity in gas pipes", *Scientific American*, 1 April 2019, <https://www.scientificamerican.com/article/europe-stores-electricity-in-gas-pipes>. See also D. Thomas, "Hydrogen production from offshore wind power", presentation for MHI Vestas Thought Leaders Forum, WindEurope Exhibition, Bilbao, Spain, 2 April 2019, <https://windeurope.org/confex2019/wp-content/uploads/files/networking/tlf/day-1/13.30-14.00-Denis-Thomas-Hydrogenics.pdf>; C. Richard, "Offshore wind-to-hydrogen plant plans revealed", *Windpower Monthly*, 27 January 2020, <https://www.windpowermonthly.com/article/1672014/offshore-wind-to-hydrogen-plant-plans-revealed>.
- 237 "Shell aims to be world's largest power company; Orsted bundles hydrogen sales into offshore bid", *New Energy Update*, 20 March 2019, <http://newenergyupdate.com/wind-energy-update/shell-aims-be-worlds-largest-power-company-orsted-bundles-hydrogen-sales-offshore/>; B. Bedeschi, "Offshore wind hydrogen could be subsidy-free within 10 years", *New Energy Update*, 1 May 2019, <https://analysis.newenergyupdate.com/wind-energy-update/offshore-wind-hydrogen-could-be-subsidy-free-within-10-years/>; Ørsted, "Ørsted and partners secure funding for renewable hydrogen project", press release (Fredericia, Denmark: 20 December 2019), <https://orsted.com/en/media/newsroom/news/2019/12/945369984118407>.
- 238 Siemens in Australia from J. Deign, "10 countries moving toward a green hydrogen economy", GTM, 14 October 2019, <https://www.greentechmedia.com/articles/read/10-countries-moving-towards-a-green-hydrogen-economy>; Siemens with Shell and TenneT from Bedeschi, op. cit. note 237. For more on Shell, see also "Shell consortium eyes 10GW offshore wind-hydrogen giant", *reNEWS*, 27 February 2020, <https://renews.biz/58847/dutch-unveil-green-hydrogen-offshore-wind-mega-project>.
- 239 GWEC, op. cit. note 131. See also Equinor, "The future of offshore wind is afloat", 20 March 2020, <https://www.equinor.com/en/what-we-do/floating-wind.html>; Equinor, "Floating offshore wind project in South Korea", 11 July 2019, <https://www.equinor.com/en/news/2019-07-11-floating-offshore-wind-project-in-south-korea.html>; J. Parnell, "Equinor: Floating wind farms a natural fit for oil and gas companies", 6 February 2020, <https://www.greentechmedia.com/articles/read/floating-wind-is-cutting-costs-faster-than-regular-offshore-wind>; B. Magill, "Oil industry eyed as catalyst for floating offshore wind", *Bloomberg Environment*, 13 June 2019, <https://news.bloombergenvironment.com/environment-and-energy/oil-industry-eyed-as-catalyst-for-floating-offshore-wind>; "Aker Solutions brings its oil and gas skills into offshore floating wind", *Offshore Energy Today*, 7 February 2018, <https://www.offshoreenergytoday.com/aker-solutions-brings-its-oil-and-gas-skills-into-offshore-floating-wind>; L. Gilpin, "Oil giants see a future in offshore wind power. Their suppliers are investing, too", *Inside Climate News*, 11 January 2018, <https://insideclimatenews.org/news/11012018/offshore-wind-turbines-oil-gas-industry-renewable-energy-investment-shell-statoil-block-island>.
- 240 Saipem from J. Deign, "Revealed: Saipem's floating offshore wind bet", GTM, 3 April 2019, <https://www.greentechmedia.com/articles/read/revealed-saipems-floating-offshore-wind-platform-bet>; ExxonMobil from Magill, op. cit. note 239; Chinese market from D. Weston, "Equinor enters Chinese offshore wind", *Windpower Monthly*, 25 September 2019, <https://www.windpoweroffshore.com/article/1660579/equinor-enters-chinese-offshore-wind>; construct by 2022 and reduce costs from "Equinor cuts floating wind costs by 40% in design revamp", *New Energy Update*, 4 December 2019, <https://analysis.newenergyupdate.com/wind-energy-update/equinor-cuts-floating-wind-costs-40-design-revamp>.
- 241 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 60; S. Sawyer, "Global wind energy insight: Offshore breakthrough", *Renewable Energy World*, 21 June 2017, <http://www.renewableenergyworld.com/ugc/articles/2017/06/20/offshore-breakthrough.html>; R. Shrestha, "Elemental forces at play in APAC wind and solar markets", *Wood Mackenzie*, 26 October 2018, <https://www.woodmac.com/news/editorial/understanding-forces-in-asia-pacific-wind-and-solar-markets>; N. Ford, "Orsted deal with US utility sets up offshore growth surge", *New Energy Update*, 20 February 2019, <http://www.newenergyupdate.com/wind-energy-update/orsted-deal-us-utility-sets-offshore-growth-surge>.
- 242 GWEC, op. cit. note 135, p. 9.
- 243 S. Dutta, "India and Denmark to work together in the offshore wind sector", *Mercom India*, 16 April 2019, <https://mercomindia.com/india-and-denmark-offshore-wind-sector>; "Turkey, Denmark work closely on offshore wind growth", *Daily Sabah*, 13 November 2019, <https://www.dailysabah.com/energy/2019/11/13/turkey-denmark-work-closely-on-offshore-wind-growth>; *Power Insider*, "Denmark to assist Vietnam with offshore wind", press release, 16 October 2019, <https://www.pimagazine-asia.com/denmark-to-assist-vietnam-with-offshore-wind>.
- 244 GWEC, op. cit. note 135, p. 11. For more on the US offshore supply chain, see, for example, J. Jackson, "How to develop the US offshore wind supply chain", *Maritime Executive*, 10 March 2020, <https://maritime-executive.com/features/how-to-develop-the-us-offshore-wind-supply-chain-1>.
- 245 Partnering with European developers from "Orsted deal with US utility sets up offshore growth surge", *New Energy Update*, 20 February 2019, <http://www.newenergyupdate.com/wind-energy-update/orsted-deal-us-utility-sets-offshore-growth-surge>; C. Papavizas, "Forming joint ventures to construct US offshore wind farms", *Renewable Energy World*, 21 March 2019, <https://www.renewableenergyworld.com/2019/03/21/forming-joint-ventures-to-construct-us-offshore-wind-farms>; D. Weston, "US offshore wind: Pipeline or pipe dream?" *Windpower Monthly*, 22 October 2019, <https://www.windpowermonthly.com/article/1663260/us-offshore-wind-pipeline-pipe-dream>; for example, in 2019, Denmark's Ørsted and a German steelmaker reached an agreement to establish a facility in New Jersey to finish turbine foundation, from K. Moore, "Offshore wind developers building Northeast supply chain", *WorkBoat*, 26 September 2019, <https://www.workboat.com/news/offshore/offshore-wind-developers-building-northeast-supply-chain>. In early 2020, Ørsted and utility Eversource announced an agreement to establish an industry hub in New London, Connecticut, from K.-E. Stromsta, "Vineyard Wind's timeline slips as Trump administration further delays permits", GTM, 11 February 2020, <https://www.greentechmedia.com/articles/read/vineyard-winds-timeline-slips-as-trump-administration-further-delays-permits>. Also in 2019, the site of a former coal-fired power plant in Massachusetts was being redeveloped for offshore turbine assembly, from S. Mizes-Tan, "Former coal powerplant Brayton Point to make way for renewable energy", *WCAI*, 23 April 2019, <https://www.capeandislands.org/post/former-coal-powerplant-brayton-point-make-way-renewable-energy>. Working with agencies and others to address impacts from B. Lillian, "Equinor Wind US joins effort to protect whales in New York bight", *North American Wind Power*, 9 April 2019, <https://nawindpower.com/equinor-wind-us-joins-effort-to-protect-whales-in-new-york-bight>; B. Lillian, "Responsible offshore science alliance launches", *North American Wind Power*, 8 April 2019, <https://nawindpower.com/responsible-offshore-science-alliance-launches>; "Major developers bid to build offshore wind farm for Connecticut", *Renewable Energy World*, 1 October 2019, <https://www.renewableenergyworld.com/2019/10/01/major-developers-bid-to-build-offshore-wind-farm-for-connecticut>.
- 246 See other endnotes for this paragraph.
- 247 See, for example, CanWEA, "Decommissioning/Repowering a wind farm", <https://canwea.ca/communities/decommissioningrepowering-wind-farm>, viewed 9 May 2020; GE Renewable Energy, "Upgrades and refurbishment for your onshore wind assets: repowering and life extension for older onshore wind turbines", <https://www.ge.com/renewableenergy/wind-energy/onshore-wind/services/upgrades-refurbishment>, viewed 9 May 2020; K. Centera, "Six factors to consider before repowering a wind site", *Windpower Engineering & Development*, 25 February 2019, <https://www.windpowerengineering.com/business-news-projects/>

- six-factors-to-consider-before-repowering-a-wind-site.
- 248 See, for example, GE Renewable Energy, "Digital optimization and analytics for your wind assets", <https://www.ge.com/renewableenergy/wind-energy/onshore-wind/services/digital-optimization>, viewed 9 May 2020; "Vestas wins repowering order with Danish auction win", Energy Northern Perspective, 6 March 2020, <https://energynorthern.com/2020/03/06/vestas-wins-repowering-order-with-danish-auction-win>; L. Gilpin, "Aging wind farms are repowering with longer blades, more efficient turbines", Inside Climate News, 28 March 2018, <https://insideclimatenews.org/news/27032018/wind-power-blades-capacity-clean-energy-technology-jobs-ge-siemens-leeward-midamerican-repowering>; M. Motyka, A. Slaughter and C. Amon, "Global renewable energy trends: solar and wind move from mainstream to preferred", Deloitte Insights, 13 September 2018, <https://www2.deloitte.com/insights/us/en/industry/power-and-utilities/global-renewable-energy-trends.html>; GE estimates that repowering can increase fleet output by up to 25%, from GE, "GE adds value to the US wind turbine industry with its repower offering", press release (Anaheim, CA: 23 May 2017), <https://www.genewsroom.com/press-releases/ge-adds-value-us-wind-turbine-industry-its-repower-offering-283781>.
- 249 B. Zeller, Vestas, personal communication with REN21, 12 April 2019. See, for example, Vestas, "Fleet optimization", <https://www.vestas.com/en/services/fleet%20optimisation>, viewed 9 May 2020; Siemens Gamesa, "Life extension: Lifetime upgrade", <https://www.siemensgamesa.com/en-int/products-and-services/service-wind/life-extension>, viewed 9 May 2020; GE Renewable Energy, "Upgrades and refurbishment for your onshore wind assets: repowering and life extension for older onshore wind turbines", <https://www.ge.com/renewableenergy/wind-energy/onshore-wind/services/upgrades-refurbishment>, viewed 9 May 2020.
- 250 Project owners partially repowered a combined 2,803 MW of existing wind projects in 2019, up 129% from the 1,226 MW repowered in 2018, from AWEA, personal communication with REN21, 8 May 2020. Examples of specific projects include: Mortenson, "Clearway completes its first wind repowering project in Texas", press release (San Francisco: 4 December 2019), <https://www.mortenson.com/company/news-and-insights/2019/elbow-creek-repowering-complete>; Kallanish Energy, "E.ON secures financing for Texas wind repowering project", 27 September 2019, <https://www.kallanishenergy.com/2019/09/27/e-on-secures-financing-for-texas-wind-repowering-project>; "Siemens Gamesa wins largest wind farm repowering order in US history", Smart Energy International, 4 July 2019, <https://www.smart-energy.com/industry-sectors/business-finance-regulation/siemens-gamesa-wins-largest-wind-farm-repowering-order-in-us-history>; GE Reports, GE Renewable Energy has repowered more than 4 GWs of wind turbines in the US", 21 May 2019, <https://www.genewsroom.com/press-releases/ge-renewable-energy-has-repowered-more-4-gws-wind-turbines-us>.
- 251 WindEurope, op. cit. note 13, p. 16; B. Bedeschi, "Europe's new permit, grid rules set to hike wind repowering spending", New Energy Update, 23 January 2019, <http://newenergyupdate.com/wind-energy-update/europes-new-permit-grid-rules-set-hike-wind-repowering-spending>; Komusanac, op. cit. note 70.
- 252 WindEurope, op. cit. note 13, p. 16. In late December 2019, Vestas received an order for 38 MW to repower a project in Norway, from Reve, "Wind power in Norway: Vestas' wind turbines for repowering", Evwind, 21 December 2019, <https://www.evwind.es/2019/12/23/wind-power-in-norway-vestas-wind-turbines-for-repowering/72716>.
- 253 Reve, "Wind energy in China, repowering with larger wind turbines", Evwind, 17 December 2019, <https://www.evwind.es/2019/12/17/wind-energy-in-china-repowering-with-larger-wind-turbines/72555>.
- 254 Most blades are made of resin and fiberglass from C. Stella, "As wind energy thrives, so does its waste problem", NET News and Harvest Public Media, 31 August 2019, <http://netnebraska.org/article/news/1188411/wind-energy-thrives-so-does-its-waste-problem>; difficult and expensive from US National Renewable Energy Laboratory (NREL), "Greening industry: Building recyclable, next-generation turbine blades", 21 April 2020, <https://www.nrel.gov/news/program/2020/greening-industry.html>.
- 255 Partnership from S. Francis, "Decommissioned wind turbine blades used for cement co-processing", CompositesWorld, 18 July 2019, <https://www.compositesworld.com/blog/post/recycled-composites-from-wind-turbine-blades-used-for-cement-co-processing>; P. Shrestha, "New cross-sector project targets wind turbine blades recycling", Energy Live News, 3 July 2019, <https://www.energylivenews.com/2019/07/03/new-cross-sector-project-targets-wind-turbine-blades-recycling>. The European initiative proposes grinding glass fiber composite blades for use as filler in the manufacture of cement, but is exploring alternative technologies for materials other than glass-reinforced composites, from M. Donlon, "Initiative proposes turning old wind turbine blades into composite for cement", GlobalSpec, 18 July 2019, <https://insights.globalspec.com/article/12274/initiative-proposes-turning-old-wind-turbine-blades-into-composite-for-cement>. Miljoskarm from L. M. Lombrana, "A recycling plan to clear wind turbine blades from graveyards", Bloomberg, 9 March 2020, <https://www.bloomberg.com/news/articles/2020-03-09/a-recycling-plan-to-clear-wind-turbine-blades-from-graveyards>; M. Donlon, "Startup to turn decommissioned wind turbines into noise pollution barriers", GlobalSpec, 9 March 2020, <https://insights.globalspec.com/article/13688/startup-to-turn-decommissioned-wind-turbines-into-noise-pollution-barriers>. Markets Insider, "Global Fiberglass Solutions becomes the first US-based company to commercially recycle wind turbine blades into viable products", press release (Sweetwater, TX: 29 January 2019), <https://markets.businessinsider.com/news/stocks/global-fiberglass-solutions-becomes-the-first-us-based-company-to-commercially-recycle-wind-turbine-blades-into-viable-products-1027906087>; C. Martin, "Wind turbine blades can't be recycled, so they're piling up in landfills", Bloomberg, 5 February 2020, <https://www.bloomberg.com/news/features/2020-02-05/wind-turbine-blades-can-t-be-recycled-so-they-re-piling-up-in-landfills>.
- 256 NREL, "Greening industry: Building recyclable, next-generation turbine blades", 21 April 2020, <https://www.nrel.gov/news/program/2020/greening-industry.html>; NREL, "New materials could lead to recyclable blades", 19 March 2019, <https://www.nrel.gov/news/program/2019/new-materials-could-lead-to-recyclable-wind-blades.html>.
- 257 GE will achieve this goal by reducing emissions through improved operational efficiency, securing renewable electricity to supply all operations, and purchasing carbon offsets to cover any remaining emissions, from GE Reports, "GE Renewable Energy announces its plan to become carbon neutral In 2020", press release (Paris: 24 September 2019), <https://www.genewsroom.com/press-releases/ge-renewable-energy-announces-its-plan-become-carbon-neutral-2020>.
- 258 Siemens Gamesa Renewable Energy (SGRE), "Achieving a better future - committed to sustainable development", <https://www.siemensgamesa.com/sustainability>, viewed 4 May 2020; SGRE, *Consolidated Non-Financial Statement 2019 (former Sustainability Report)* (Vizcaya, Spain: 2019), p. 3, <https://www.siemensgamesa.com/-/media/siemensgamesa/downloads/en/sustainability/siemens-gamesa-consolidated-non-financial-statement-2019-en.pdf>. See also D. Snieckus, "Siemens Gamesa tackles wind supply chain emissions in net-zero strategy step-up", Recharge, 23 April 2020, <https://www.rechargenews.com/transition/siemens-gamesa-tackles-wind-supply-chain-emissions-in-net-zero-strategy-step-up/2-1-796565>.
- 259 RE100, "Vestas", <http://there100.org/vestas>, viewed 13 May 2020; A. Lee, "Wind power giant Vestas sets 2030 carbon-neutral goal", Recharge, 6 January 2020, <https://www.rechargenews.com/wind/wind-power-giant-vestas-sets-2030-carbon-neutral-goal/2-1-732261>; WindEurope, "Circular economy: Blade recycling is a top priority for the wind industry" 12 February 2020, <https://windeurope.org/newsroom/news/blade-recycling-a-top-priority-for-the-wind-industry>; C. Richard, "Vestas plans 'zero-waste turbines' by 2040", 20 January 2020, <https://www.windpowermonthly.com/article/1671285/vestas-plans-zero-waste-turbines-2040>.
- 260 Note that longer wind turbine blades have helped to reduce wind energy costs, from M. Bolinger, Lawrence Berkeley National Laboratory, cited in Iaconangelo, op. cit. note 207. **Box 1** from the following sources: uses of small-scale turbines from WWEA, *2017 Small Wind World Report Summary* (Bonn: June 2017), p. 5, <https://wwindea.org/blog/2017/06/02/wwea-released-latest-global-small-wind-statistics/>, from A. Orrell et al., *2016 Distributed Wind Market Report* (Richland, WA: Pacific Northwest National Laboratory, August 2017), p. i, <https://energy.gov/sites/prod/files/2017/08/f35/2016-Distributed-Wind-Market-Report.pdf>, and from SWIP Project, "SWIP objectives and summary", http://swipproject.eu/?page_id=12146, viewed 11 March 2018. Small-scale wind power and capacity limits in footnote from

WWEA, op. cit. this note, and from US DOE, EERE, op. cit. note 213, p. 1. Market shrinkage from US DOE, EERE, *2018 Distributed Wind Market Report* (Washington, DC: 2019), pp. iv, v, 10, <https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Distributed%20Wind%20Market%20Report.pdf>; 47 MW from idem., p. iv. The 114 MW in 2017 was installed in a documented 10 countries, from US DOE, EERE, *2017 Distributed Wind Market Report* (Washington, DC: 2018), p. 9, <https://www.energy.gov/sites/prod/files/2018/09/f55/2017-DWMMR-091918-final.pdf>; China from CWEA, cited in US DOE, EERE, *2018 Distributed Wind Market Report*, op. cit. this note, p. 13. United States from idem, p. iv. Installations in 2018 were down from 1.7 MW (3,269 units) in 2017, 2.4 MW in 2016, and 4.3 MW in 2015, from idem, pp. iv, 8. However, per unit sales of units <1 kW again increased during the year. The states of New York, which has a small-scale turbine incentive programme, and Alaska were the leaders for newly installed capacity in 2018, while Iowa, Nevada and Alaska were the top three for cumulative capacity, from idem, pp. v, 4, 5. United Kingdom, Japan and Denmark from idem, pp. 11, 12. Japan also from Japan Small Wind Turbines Association, cited in idem, pp. 12, 13. Total global small-scale wind power capacity was estimated to be at least 1.7 GW at end-2018, from idem, p. 12; approximately 1 million turbines and more than 1 GW in operation based on data as of end-2016, from WWEA, personal communications with REN21, April-May 2018. CWEA, "The development of Chinese small wind generators", *WWEA Wind Bulletin*, no. 2 (September 2016), pp. 6-7, <http://www.wwindea.org/wwea-bulletin-issue-2-2016-small-wind-special>; Orrell et al., *2016 Distributed Wind Market Report*, op. cit. this note, p. i; Navigant Research, "Market data: Small and medium wind turbines: demand drivers, market trends and challenges, and global market forecasts", 2017, <http://www.navigantresearch.com/research/market-data-small-and-medium-wind-turbines>, viewed 25 May 2017; US DOE, EERE, *2017 Distributed Wind Market Report*, op. cit. this note, p. v. The number of producers in China reporting sales shrank to 15 in 2017, down from 28 in 2014 and 17 in 2016, from idem, p. v. In the United States, 31 companies reported sales in 2012, 16 companies in 2013, 11 in 2014 and 10 (8 domestic manufacturers and 2 importers) in 2015; in addition, foreign manufacturers have lost interest in the United States due to the expiration of important federal incentives, all from A. C. Orrell et al., *2015 Distributed Wind Market Report* (Richland, WA: Pacific Northwest National Laboratory, August 2016), p. ii, https://energy.gov/sites/prod/files/2016/08/f33/2015-Distributed-Wind-Market-Report-08162016_0.pdf. Exports from US-based manufacturers declined from a peak of 21.5 MW (USD 122 million invested) in 2015 to 10.3 MW (USD 62 million) in 2016, to 5.5 MW (USD 42 million) in 2017, from US DOE, EERE, *2017 Distributed Wind Market Report*, op. cit. this note, p. v; US exports and manufacturers from US DOE, EERE, *2018 Distributed Wind Market Report*, op. cit. this note, pp. v, 8, 9; role of tax credit, and US R&D efforts, from J. Gerdes, "Struggling distributed wind sector eyes role in microgrids market", *GTM*, 28 April 2020, <https://www.greentechmedia.com/articles/read/distributed-wind>, and from US DOE, EERE, "Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad", February 2020, <https://www.energy.gov/sites/prod/files/2020/03/f72/miracl-fact-sheet-v2.pdf>. "First vertical axis wind turbine awarded certification", *Wind Systems*, 5 August 2019, <http://www.windsystemsmag.com/news/first-vertical-axis-wind-turbine-awarded-certification>. **Sidebar 5** and **Figure 40** based on IRENA, *Renewable Power Generation Costs in 2019* (Abu Dhabi: 2020), <https://www.irena.org/costs>.

DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

- 1 International Energy Agency (IEA), *Africa Energy Outlook 2019* (Paris: 2019), <https://www.iea.org/reports/africa-energy-outlook-2019#energy-access>.
- 2 IEA et al., "Chapter 1: Access to electricity", in *Tracking SDG 7: The Energy Progress Report 2019* (Washington, DC: 2019), p. 24, https://trackingsdg7.esmap.org/data/files/download-documents/2019-tracking_sdg7-complete-rev030320.pdf;
- International Finance Corporation (IFC), *Off-Grid Solar Market Trends Report 2020* (Washington, DC: Lighting Global Program, March 2020), p. 182, https://www.lightingglobal.org/wp-content/uploads/2020/02/14005VIV_OFF-GRID-SOLAR-REPORT-V13-Exec-Sum-AW4vis.pdf.
- 3 IEA et al., op. cit. note 2, p. 24. **Figure 41** from idem.
- 4 Off Grid Energy Independence, "60% of Papua New Guinea using off-grid solar", 6 September 2019, <https://www.offgridenergyindependence.com/articles/18097/60-of-papua-new-guinea-using-off-grid-solar>; IEA et al., op. cit. note 2, p. 24.
- 5 Sustainable Energy for All (SEforALL), *Integrated Electrification Pathways for Universal Access to Electricity: A Primer* (Vienna: 2019), p.5, https://www.seforall.org/sites/default/files/2019-06/SEforALL_IEP_2019.pdf.
- 6 O. Coldrey, "Lack of clean cooking access: the 'other' public health crisis we cannot ignore", SEforALL, 16 April 2020, <https://www.seforall.org/news/lack-of-clean-cooking-access-the-other-public-health-crisis-we-cannot-ignore>.
- 7 United Nations Development Programme, *Nationally Appropriate Mitigation Action on Access to Clean Energy in Rural Kenya Through Innovative Market Based Solutions* (New York: 2016), p. 25, <http://www.undp.org/content/undp/en/home/librarypage/environment-energy/mdg-carbon/NAMAs/nama-on-access-to-clean-energy-in-rural-kenya-through-innovative.html>; Global Alliance for Clean Cookstoves, *Assessing the Climate and Health Co-benefits of Clean Cooking*, Workshop Report, Washington, DC, 16-17 July 2015, <https://www.cleancookingalliance.org/binary-data/RESOURCE/file/000/000/481-1.pdf>.
- 8 GOGLA, *Powering Opportunity in South Asia* (Utrecht, Netherlands: February 2020), p. 9, https://www.gogla.org/sites/default/files/resource_docs/gogla_powering_opportunity_in_south_asia_0.pdf.
- 9 GOGLA, *Powering Opportunity in East Africa* (Utrecht, Netherlands: February 2020), p. 12, https://www.gogla.org/sites/default/files/resource_docs/powering_opportunity_in_east_africa.pdf.
- 10 Ibid., p. 12.
- 11 Power for All, *Powering Jobs Census 2019: The Energy Access Workforce* (July 2019), p. 16, <https://www.powerforall.org/resources/reports/powering-jobs-census-2019-energy-access-workforce>.
- 12 GOGLA, *Off-Grid Solar. A Growth Engine for Jobs* (Utrecht, Netherlands: 7 June 2019), p. 4, https://www.gogla.org/sites/default/files/resource_docs/gogla_off_grid_solar_a_growth_engine_for_jobs_web_opt.pdf.
- 13 IEA, "Sustainable Development Goal 7: Access to electricity", November 2019, <https://www.iea.org/sdg/electricity>.
- 14 IEA, "Sustainable Development Goal 7: Access to clean cooking", November 2019, <https://www.iea.org/sdg/cooking>. **Figure 42** from IEA, "SDG7: Data and projections – access to electricity," <https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity>, viewed 8 January 2020; IEA, "SDG7: Data and projections – access to clean cooking," <https://www.iea.org/reports/sdg7-data-and-projections/access-to-clean-cooking>, viewed 8 January 2020.
- 15 IEA et al., op. cit. note 2, p. 19.
- 16 IEA, op. cit. note 13.
- 17 Ibid.
- 18 Ibid.
- 19 Ibid.
- 20 Ibid.
- 21 Ibid.
- 22 Ibid.
- 23 Ibid.
- 24 Ibid.
- 25 Ibid.
- 26 Ibid.
- 27 Ibid.
- 28 IEA, "Sustainable Development Goal 7: Access to clean cooking", op. cit. note 14.
- 29 Ibid.
- 30 Ibid.
- 31 Ibid.
- 32 Ibid.
- 33 Ibid.
- 34 Ibid.
- 35 Ibid.
- 36 Ibid.
- 37 Ibid.
- 38 Ibid.
- 39 International Renewable Energy Agency (IRENA), *10 Years: Progress to Action* (Abu Dhabi: 2020), p. 14, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jan/IRENA_10_years_2020.pdf.
- 40 IEA et al., op. cit. note 2, p. 23.
- 41 Ibid., p. 25.
- 42 IFC, op. cit. note 2, p. 6.
- 43 IEA et al., op. cit. note 2, p. 23.
- 44 **Figure 43** from the following sources: estimated annual global sales for 2015-2016 from Dahlberg Advisors and Lighting Global, *Off-Grid Solar Market Trends Report 2018* (Washington, DC: January 2018), p. 77, https://www.gogla.org/sites/default/files/resource_docs/2018_mtr_full_report_low-res-2018.01.15_final.pdf; estimated sales for 2017-2019 from IFC, op. cit. note 2, p. 42; annual sales of affiliated off-grid solar products for 2015-2016 from Dahlberg Advisors and Lighting Global, op. cit. this note, p. 57; sales for 2017-2018 from IFC, op. cit. note 2, p. 42, and for 2019 from GOGLA in partnership with Lighting Global and Efficiency for Access Coalition, *Global Off-Grid Solar Market Report Database 2020* (Washington, DC: March 2020), https://www.lightingglobal.org/wp-content/uploads/2020/03/VIVID%20OCA_2020_Off_Grid_Solar_Market_Trends_Report_Full_High.pdf. Estimated global sales of off-grid solar systems from 2015 to 2019 are based on data from IFC, op. cit. note 2. Total estimated global sales of off-grid solar products for 2019 were extrapolated from sales of affiliated products sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members, companies selling products that meet Lighting Global Quality Standards, and appliance companies that participated in the Global LEAP Awards or are engaging with the Low Energy Inclusive Appliances programme. Non-affiliated products account for around 72%, on average, of the total sales volumes of off-grid solar products. Note that not all products produced by affiliate companies meet Lighting Global Quality Standards, but stakeholders assume that all products of affiliate companies are of reasonably good quality.
- 45 IFC, op. cit. note 2, p. 65.
- 46 Ibid., p. 79.
- 47 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019* (Utrecht, Netherlands: October 2019), p. 20, https://www.gogla.org/sites/default/files/resource_docs/global_off-grid_solar_market_report_h1_2019.pdf; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019* (Utrecht, Netherlands: April 2020), p. 20, https://www.gogla.org/sites/default/files/resource_docs/global_off_grid_solar_market_report_h22019.pdf.
- 48 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 20.
- 49 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 18. **Box 1** from the following sources: growth from Efficiency for Access Coalition, *The State of the Off-grid Appliance Market*, October 2019, p. 13, <https://storage.googleapis.com/clasp-siteattachments/SOGAM-Report-Full>.

- pdf; total sales from GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47; 80% from Efficiency for Access Coalition, *The State of the Off-grid Appliance Market*, op. cit. this note; CLASP, "The Global LEAP Awards launches competition for electric pressure cookers", <https://clasp.ngo/updates/2020/the-global-leap-awards-launches-competition-for-electric-pressure-cookers>, viewed 13 March 2020; productive end-uses from SELCO Foundation, *Sustainable Energy Livelihoods: A Collection of 65 Livelihood Applications* (Bengaluru, India: 2019), <http://www.selcofoundation.org/wp-content/uploads/2019/05/SELCO-Foundation-Sustainable-Energy-Livelihoods-65-Appliances.pdf>; markets in infancy from World Bank, *Off-grid Solar Market Trends Report 2020: Report Summary* (Washington, DC: 2020), <https://www.lightingglobal.org/resource/2020markettrendsreport>, and from Efficiency for Access Coalition, *Solar Milling: Exploring Market Requirements to Close the Commercial Viability*, 2020, <https://clasp.ngo/publications/solar-milling-exploring-market-requirements-to-close-the-commercial-viability>; need for high-risk funding from NextBillion, "Waiting game: Where is all the investment in solar-powered productive use appliances?", <https://nextbillion.net/waiting-for-investment-in-solar-appliances>, viewed 13 March 2020; Efficiency for Access Coalition, "2019 Global Leap Awards winners and finalists", <https://efficiencyforaccess.org/updates/2019-global-leap-awards-winners-and-finalists>, viewed 13 March 2020; Energy for Access Coalition, "Research and Development Fund", <https://efficiencyforaccess.org/grants>, viewed 13 March 2020; CEEW and Villgro, "About", <https://poweringlivelihoods.org/about-powering-livelihoods>, viewed 13 March 2020; unlocking the market from Efficiency for Access Coalition, *The State of the Off-grid Appliance Market*, op. cit. this note; service-based models from NextBillion, op. cit. this note.
- 50 Ibid., p. 18.
- 51 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 20.
- 52 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 20.
- 53 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 20.
- 54 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December*, op. cit. note 47, p. 20.
- 55 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 20. **Figure 44** from idem.
- 56 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 27.
- 57 Ibid., p. 27.
- 58 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 20.
- 59 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 25; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 34.
- 60 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2019*, op. cit. note 47, p. 20; GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 20.
- 61 GOGLA and Lighting Global, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2019*, op. cit. note 47, p. 22.
- 62 Ibid., p. 22.
- 63 Ibid., p. 22.
- 64 World Bank Energy Sector Management Assistance Program (ESMAP), *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers* (Washington, DC: 2019), <https://openknowledge.worldbank.org/bitstream/handle/10986/31926/Mini-Grids-for-Half-a-Billion-People-Market-Outlook-and-Handbook-for-Decision-Makers-Executive-Summary.pdf>.
- 65 Ibid., p. 47.
- 66 IRENA, *Off-grid Renewable Energy Statistics 2019* (Abu Dhabi: 2019), <https://www.irena.org/publications/2019/Dec/Off-grid-renewable-energy-statistics-2019>; A. Whiteman and N. Elhassan, IRENA, Abu Dhabi, personal communication with Renewable Energy Policy Network for the 21st Century (REN21) for the IRENA-REN21 Distributed Renewable Energy Review 2020, 22 February 2020.
- 67 IRENA, op. cit. note 66; Whiteman and Elhassan, op. cit. note 66. **Figure 45** from idem.
- 68 M. Galante, "Mini grids can give millions power, but bureaucracy and technical issues still stand in the way", *Solar Magazine*, 19 February 2019, <https://solarmagazine.com/solar-mini-grids-rural-power-bureaucracy-technical-issues-stand-in-the-way>; ESMAP, op. cit. note 64.
- 69 I. Tsagas, "World Bank: Nigeria's mini-grid sector set to boom", *pv magazine*, 7 October 2019, <https://www.pv-magazine.com/2019/10/07/world-bank-nigeria-mini-grid-sector-set-to-boom>; C. Ezeobi, "Electrifying rural communities", *THISDAY*, 14 November 2019, <https://www.thisdaylive.com/index.php/2019/11/14/electrifying-rural-communities>.
- 70 I. Tsagas, "Nigeria taps mini-grids to power universities", *pv magazine*, 28 June 2019, <https://www.pv-magazine.com/2019/06/28/nigeria-taps-mini-grids-to-power-universities>; Climatescope, "3Q 2019 Off-grid and Mini-grid Market Outlook", 1 October 2019, <https://medium.com/climatescope/3q-2019-off-grid-and-mini-grid-market-outlook-1d2b3c0d877f>; A. Colthorpe, "Africa's 'largest off-grid solar hybrid' goes online at Nigerian University BUK", *Energy Storage News*, 6 September 2019, <https://www.energy-storage.news/news/africas-largest-off-grid-solar-hybrid-goes-online-at-nigerian-university-bu>.
- 71 Climatescope, "2Q 2019 Off-grid and Mini-grid Market Outlook", 28 June 2019, <https://medium.com/climatescope/2q-2019-off-grid-and-mini-grid-market-outlook-aabe027e9e9>.
- 72 "EU, JUMEME install new solar-powered mini-grid on Lake Victoria's Mulumo Island", *EABW News*, 26 June 2019, <https://www.busiweek.com/eu-jumeme-install-new-solar-powered-mini-grid-on-lake-victorias-mulumo-island>.
- 73 J. Takouleu, "Mali: Africa Green Tec installs containerised solar mini grid in Dalakana", *Afriq21*, 16 December 2019, <https://www.afriq21.africa/en/mali-africa-green-tec-installs-containerised-solar-mini-grid-in-dalakana>.
- 74 B. Publicover, "Engie finishes minigrid, expands PV home system business in Zambia", *pv magazine*, 4 April 2019, <https://www.pv-magazine.com/2019/04/04/engie-finishes-minigrid-expands-pv-home-system-business-in-zambia>; Z. Yupeng, "Zambian government lauds Huawei for promoting access to electricity", *Xinhua*, 22 December 2019, http://www.xinhuanet.com/english/2019-12/22/c_138650206.htm.
- 75 Climatescope, "4Q 2019 Off-grid and Mini-grid Market Outlook", 7 January 2020, <https://medium.com/@Climatescope/4q-2019-off-grid-and-mini-grid-market-outlook-ed6349889d1>; S. Akoda, "Togo: A total of 317 communities will have access to light using solar mini-grids", *Togo First*, 15 October 2019, <https://www.togofirst.com/en/energy/1510-4152-togo-a-total-of-317-communities-will-have-access-to-light-using-solar-mini-grids>.
- 76 J. Knuckles, "State of the mini grid market globally", presentation at the 5th Africa Mini-grid Action Learning Event and Summit, 26 June 2019, p. 8, https://atainsights.com/wp-content/uploads/2019/06/2.B.James_.Knuckles.World-Bank-notes.pdf.

- 77 R. Harrison and S. Posner, "Myanmar mini-grids near 100; market at growth cross-roads", Power for All, 11 December 2019, <https://www.powerforall.org/insights/myanmar-mini-grids-near-100-market-growth-cross-roads>.
- 78 J. Liu, "Country's largest mini-grid unveiled in Magway", *Myanmar Times*, 5 December 2019, <https://www.mmtimes.com/news/countrys-largest-mini-grid-unveiled-magway.html>.
- 79 WEnergy Global, "Sabang Renewable Energy Corporation Inauguration Day", press release (Palawan, the Philippines: 7 November 2019), <https://www.wenergyglobal.com/sabang-renewable-energy-corporation-inauguration-day>; WEnergy Global, "Ground breaking ceremony of solar hybrid power plant in Panlaitan Island Busuanga, Palawan", press release (Palawan, the Philippines: 18 December 2019), <https://www.wenergyglobal.com/ground-breaking-ceremony-of-solar-hybrid-power-plant-in-panlaitan-island-busuanga-palawan>.
- 80 D. Lecoque and M. Wiemann, *The Productive Use of Renewable Energy in Africa* (Eschborn, Germany: European Union Energy Initiative Partnership Dialogue Facility, September 2015), p. 3, <https://europa.eu/capacity4dev/public-energy/documents/productive-use-energy-africa>.
- 81 US National Renewable Energy Laboratory, *Productive Use of Energy in African Micro-Grids: Technical and Business Considerations* (Golden, CO: August 2018), p. 2, <https://www.nrel.gov/docs/fy18osti/71663.pdf>.
- 82 EEP Africa, *Powering Productivity: Lessons in Green Growth from the EEP Africa Portfolio* (Pretoria, South Africa: 2019), p. 2, https://eepafrica.org/wp-content/uploads/2019/12/EEP_PUE_Digital-new.pdf.
- 83 SELCO Foundation, op. cit. note 49.
- 84 Power for All, "Factsheet: Mini-grids have strong socioeconomic impact beyond electricity connection and consumption", October 2019, https://www.powerforall.org/application/files/2815/7355/7333/FS_Mini-grids_have_strong_socioeconomic_impact_beyond_electricity_connection_and_consumption4.pdf.
- 85 Ibid.
- 86 EEP Africa, op. cit. note 82.
- 87 IFC, op. cit. note 2, p. 59.
- 88 IFC et al., *The Market Opportunity for Productive Use Leveraging Solar Energy (PULSE) in Sub-Saharan Africa* (Washington, DC: July 2019), <https://www.lightingglobal.org/wp-content/uploads/2019/09/PULSE-Full-Study.pdf>.
- 89 IFC, op. cit. note 2, p. 59.
- 90 Danish Energy Management, *Best Practices for Promoting Improved Cook Stoves in the ACP Region* (Brussels: ACP EU Energy Facility, August 2019), p. 8, https://www.dem.dk/wp-content/uploads/2019/11/Discussion-paper-07_Cooking-stoves.pdf.
- 91 Ibid., p. 10.
- 92 IRENA, op. cit. note 66.
- 93 Ibid.
- 94 Ibid. **Figure 46** from idem and from Whiteman and Elhassan, op. cit. note 66.
- 95 ENERGIA, "Clean Cooking Forum 2019", 5 November 2019, <https://www.energia.org/clean-cooking-forum-2019>.
- 96 IRENA, op. cit. note 66.
- 97 ENERGIA, op. cit. note 95.
- 98 Solar Cookers International, "Distribution of solar cookers", <https://www.solarcookers.org/work/capacity/distribution-solar-cookers>, viewed 9 May 2020.
- 99 T. Couture and D. Jacobs, *Beyond Fire: How to Achieve Electric Cooking* (The Hague: Hivos and World Future Council, 2019), https://greeninclusiveenergy.org/assets/2019/05/Beyond-fire_How-to-achieve-electric-cooking-1.pdf.
- 100 D. Danley "Haiti pilot project with EarthSpark International", Sunspot, 29 October 2019, <https://sunspotpv.com/haiti-pilot-project-with-earthspark-international>.
- 101 GOGLA, "Global Off-Grid Solar Market Report Database 2020", in partnership with Lighting Global and Efficiency for Access Coalition.
- 102 Ibid.
- 103 Ibid.
- 104 IFC, op. cit. note 2, p. 71.
- 105 Ibid., p. 71.
- 106 Ibid., p. 71.
- 107 Angaza, "Angaza Partners to launch JUA Energy TV1G pay-as-you-go television", 29 August 2019, <https://www.angaza.com/2019/08/29/jua-energy-tv1g-pay-as-you-go-television>; Angaza, "Angaza and Endless Solutions join forces to launch first PAYG laptop", 12 February 2019, <https://www.angaza.com/2019/02/12/endless-solutions-os-payg-laptop>.
- 108 Azuri Technologies, "Azuri Technologies launches PayGo solar satellite TV in Zambia", press release (Lusaka, Zambia: 26 June 2019), <https://www.azuri-group.com/azuri-technologies-launches-paygo-solar-satellite-tv-in-zambia>.
- 109 Azuri Technologies, "Azuri GrowFast solar irrigation system named winner of UN Uganda renewable energy fund", press release (Lusaka, Zambia: 1 March 2019), <https://www.azuri-group.com/growfast-solar-irrigation-winner-un-fund>.
- 110 C. Emmott, "Lighting the way: How the PAYGo solar industry is expanding to other life-changing products", Fenix International, 21 January 2020, <https://www.fenixintl.com/blog/lighting-the-way-how-the-paygo-solar-industry-is-expanding-to-other-life-changing-products>; J. Winiecki, "The power of flexibility: How innovative payment models can expand access to energy services", BFA Global, 19 November 2019, <https://bfa-global.com/insight-type/blogs/the-power-of-flexibility-how-innovative-payment-models-can-expand-access-to-energy-services>.
- 111 D. Waldron, A. Sotiriou and J. Winiecki, *A Tale of Two Sisters. Microfinance Institutions and PAYGo Solar*, (Washington, DC: Consultative Group to Assist the Poor, November 2019), p. 9, https://www.cgap.org/sites/default/files/publications/2019_11_Focus_Note_Paygo_Two_Sisters_2.pdf.
- 112 Lighting Global, "Lighting Asia launches PAYGO in Afghanistan", 20 January 2020, <https://www.lightingglobal.org/news/lighting-asia-launches-paygo-in-afghanistan>.
- 113 Techloy, "PAYG solar market leader, Greenlight Planet, partners with leading telecom operators in Africa", 9 November 2019, <https://medium.com/techloy/payg-solar-market-leader-greenlight-planet-partners-with-leading-telecom-operators-in-africa-8e3813d4f7cb>.
- 114 T. Bessarabova, "Solar, expanded: Building the future of utilities in Bangladesh", NextBillion, 16 August 2019, <https://nextbillion.net/solar-future-of-utilities-in-bangladesh>.
- 115 Ibid.
- 116 ATEC Biodigesters, "ATEC Biodigesters raises US\$1,600,000 in Series B equity round", 27 November 2019, <https://atecbio.com/2019/11/27/atec-biodigesters-raises-us1600000-in-series-b-equity-round>.
- 117 Ibid.
- 118 B. Ngounou, "RWANDA: Bboxx becomes diversified with the launch of biogas and LPG cooking", Afrik21, 5 August 2019, <https://www.afrik21.africa/en/rwanda-bboxx-becomes-diversified-with-the-launch-of-biogas-and-lpg-cooking>.
- 119 IFC et al., op. cit. note 88, p. 18.
- 120 Ibid.
- 121 L. Concessao, "The next big thing for energy access in India? Service-based models for productive-use appliances in agriculture", NextBillion, 24 September 2019, <https://nextbillion.net/energy-access-india-appliances-agriculture>.
- 122 J. Wanzala, "Kenya: Danish firm m-payg supports small-scale fishermen access cold storage facilities to curb losses", 25 November 2019, <https://www.business-humanrights.org/en/kenya-danish-firm-m-payg-supports-small-scale-fishermen-access-cold-storage-facilities-to-curb-losses>.
- 123 O. Anudu, "Ikegwuonu: Reducing post-harvest losses with solar-powered storage facilities", Business Day, 30 March 2020, <https://businessday.ng/uncategorized/article/ikegwuonu-reducing-post-harvest-losses-with-solar-powered-storage-facilities>.
- 124 SEforALL, *Energizing Finance: Understanding the Landscape*, Executive Summary (Washington, DC: 2019), p. 8, <https://www.seforall.org/sites/default/files/2019-10/EF-2019-UL-ES-SEforALL.pdf>.
- 125 Wood Mackenzie Power and Renewables, "Foresight 20/20: Off-grid Renewables – Decentralisation Takes Center Stage", March 2019, p. 4, <https://www.woodmac.com/our-expertise/focus/>

- Power--Renewables/off-grid-renewables-2020s.
- 126 Ibid., p. 3. **Figure 47** from idem, p. 3, and from Climatescope, op. cit. note 75.
- 127 Wood Mackenzie Power and Renewables, op. cit. note 125, p. 3.
- 128 Climatescope, op. cit. note 75.
- 129 Ibid.
- 130 IFC, op. cit. note 2, p. 126.
- 131 Ibid., p. 126.
- 132 Ibid., p. 126.
- 133 Ibid., p. 127.
- 134 Ibid., p. 127.
- 135 Ibid., p. 127.
- 136 Mitsubishi Corporation, "Mitsubishi Corporation to invest in next generation utility BBOX Limited", press release (Tokyo: 28 August 2019), <https://www.mitsubishicorp.com/jp/en/pr/archive/2019/html/0000038211.html>; Marubeni Corporation, "Marubeni to enter into the solar home systems business for off-grid areas in Africa by investing in Azuri", press release (Tokyo: 3 June 2019), <https://www.marubeni.com/en/news/2019/release/20190603E.pdf>.
- 137 Climatescope, op. cit. note 71; d.Light, "d.light secures USD 18M of funding to accelerate growth across Africa", press release (Nairobi: 1 July 2019), <https://www.dlight.com/wp-content/uploads/2019/07/d.light-Debt-Financing-Press-Release-Final-July-1-2019-1.pdf>.
- 138 T. Jackson, "Cameroonian PAYG solar startup upOwa raises \$2.7m funding", Disrupt Africa, 13 December 2019, <https://disrupt-africa.com/2019/12/cameroonian-payg-solar-startup-upowa-raises-2-7m-funding>; Sunfunder, "SunFunder closes \$2m multi-currency debt facility in Mozambique with MFX Solutions for SolarWorks!" 17 January 2019, <https://www.sunfunder.com/post/sunfunder-closes-2m-multi-currency-debt-facility-in-mozambique-with-mfx-solutions-for-solarworks>; Electrifi, "Solar Work!" <https://www.electrifi.eu/project/solarworks>, viewed May 2020.
- 139 IFC, op. cit. note 2.
- 140 S. Dutta, "Off-grid solar solutions provider SolarHome raises \$1 million equity funding from Trirec", Mercom India, 29 April 2019, <https://mercomindia.com/solarhome-raises-1-million-equity-funding>.
- 141 Orb Energy, "Orb Energy secures Shell investment in latest funding round", press release (Bangalore, India: 3 October 2019), <https://mailchi.mp/501ef52ba16e/orb-energy-secures-shell-investment-in-latest-funding-round>.
- 142 Climatescope, op. cit. note 75.
- 143 J. Liu, "Yoma Strategic partners with Ayala in renewables", Myanmar Times, 16 October 2019, <https://www.mmtimes.com/news/yoma-strategic-partners-ayala-renewables.html>.
- 144 M. Willuhn, "CBEA lets loose first \$5.5 million for 60 minigrids in Tanzania", pv magazine, 18 July 2019, <https://www.pv-magazine.com/2019/07/18/cbea-lets-loose-first-5-5-million-for-60-minigrids-in-tanzania>; Inspiratia, "Project Finance model emerges for African mini-grids", 28 August 2019, <https://www.crossboundary.com/wp-content/uploads/2019/08/20190828-Inspiratia-Article-Project-finance-model-emerges-for-African-mini-grids.pdf>.
- 145 Infraco Africa, "Transforming energy access in rural Sierra Leone", <http://www.infracofrica.com/transforming-energy-access-in-rural-sierra-leone>, viewed 6 January 2020.
- 146 R. Wuts, "Kouros invests In Powerhive Inc Series B round", Powerhive, 5 July 2019, <https://powerhive.com/kouros-invests-in-powerhive-inc-series-b-round>.
- 147 IFC, op. cit. note 2, p. 130. **Figure 48** from IFC, op. cit. note 2, pp. 121-150.
- 148 Ibid., p. 130.
- 149 ENGIE, "ENGIE acquires Mobisol and becomes market leader in the off-grid solar in Africa", press release (Paris: 3 September 2019), <https://www.engie.com/sites/default/files/assets/documents/2020-01/engie-mobisol-v4-en.pdf>.
- 150 IFC, op. cit. note 2, p. 132; BBOX, "BBOX receives largest crowd-funded debt raise", press release (London: 4 March 2019), <https://www.bbox.co.uk/bbox-receives-largest-crowd-funded-debt-raise-history-solar-africa>.
- 151 "Trine and Greenlight Planet join forces in bringing solar energy to half a million people", Hype, 5 March 2019, <https://hype.news/trine/trine-and-greenlight-planet-join-forces-in-bringing-solar-energy-to-half-a-million-people-r3rvpxdb>.
- 152 SEforALL, op. cit. note 124, p. 8.
- 153 Endeavor, "Sistema.Bio secures \$12 million in financing with participation from Endeavor Catalyst", 27 June 2019, <https://endeavor.org/blog/catalyst/sistema-bio-secures-12-million-financing-participation-endeavor-catalyst>.
- 154 Impact Investment Exchange (IIX), "ATEC Biodigesters secures US\$1.6M Series B with support from the Clean Cooking Alliance and Impact Investment Exchange (IIX) to scale clean energy access in Asia", press release (Singapore and Australia, 27 November 2019), <https://iixglobal.com/atec-biodigesters-secures-us1-6m-series-b-with-support-from-the-clean-cooking-alliance-and-impact-investment-exchange-iix-to-scale-clean-energy-access-in-asia>.
- 155 World Bank, *Policy Matters: Regulatory Indicators for Sustainable Energy (RISE)* (Washington, DC: 2018), p. 35, <http://documents.worldbank.org/curated/en/553071544206394642/pdf/132782-replacement-PUBLIC-RiseReport-HighRes.pdf>.
- 156 Ibid., p. 38.
- 157 Ibid., p. 38. **Table 4** is intended to be only indicative of the overall landscape of DREA policy activity and is not a definitive reference. Generally, listed policies are those that have been enacted by legislative bodies. Some of the listed policies may not yet be implemented, or are awaiting detailed implementing regulations. It is difficult to capture every policy change, so some policies may be unintentionally omitted or incorrectly listed. This report does not cover policies and activities related to technology transfer, capacity building, carbon finance and Clean Development Mechanism projects, nor does it attempt to provide a comprehensive list of broader framework and strategic policies – all of which are still important to DREA progress. For the most part, this report also does not cover policies that are still under discussion or formulation. Information on electricity access policies comes from a wide variety of sources, including the World Bank Regulatory Indicators for Sustainable Energy (RISE), IRENA, the Global Renewable Energy Policies and Measures Database, press reports and announcements from ministries, rural electrification agencies and energy regulators, and submissions from REN21 regional- and country-specific contributors. **Table 5** based on Clean Cooking Alliance Policy Database and A. Towfiq, Clean Cooking Alliance (CCA), Washington, DC, personal communication with REN21, 24 April 2020.
- 158 Government of India, Ministry of New and Renewable Energy, "Schemes – solar off-grid", <https://mnre.gov.in/solar/schemes>.
- 159 Rural Electrification Agency Nigeria, "New analysis finds \$9.2b off-grid electrification opportunity in Nigeria presented at Africa action learning event on scaling minigrids", press release, 11 December 2017, <https://rmi.org/press-release/press-release-off-grid-electrification-opportunity-in-nigeria-on-minigrids>; Rwanda Development Board, "Investment opportunities – energy", <https://rdb.rw/investment-opportunities/energy>, viewed 6 January 2020; Ministry of Infrastructure, Republic of Rwanda, *Energy Sector Strategic Plan 2018/19-2023/24* (Kigali: September 2018), https://www.mininfra.gov.rw/fileadmin/user_upload/infos/Final_ESSP.pdf.
- 160 J. M. Takouleu, "Angola: Government wants to produce 600 MW from solar off grid", Afrik21, 17 September 2019, <https://www.afrik21.africa/en/angola-government-wants-to-produce-600-mw-from-solar-off-grid>.
- 161 World Bank, op. cit. note 155, p. 45; Climatescope, op. cit. note 75.
- 162 E. Bellini, "Guatemala announces new rural electrification policy", pv magazine, 16 January 2019, <https://www.pv-magazine-latam.com/2019/01/16/guatemala-anuncia-nueva-politica-de-electrificacion-rural>.
- 163 SEforALL, op. cit. note 5; Innovation Energie Développement (IED), "Studies rural electrification. Information systems. Least Cost Geospatial Electrification Plan. Namibia", <https://www.ied-sa.fr/en/projects-and-references/references/details/10/401>; IED, "Studies rural electrification. Information systems. Least Cost Geospatial Electrification Options Analysis for Grid and

- Off-Grid Rollout. Congo-Brazzaville", <https://www.ied-sa.fr/en/projects-and-references/references/details/10/397>.
- 164 "Kenya seeks to achieve target of clean cooking for all by 2028", *Xinhua*, 11 November 2019, http://www.xinhuanet.com/english/2019-11/11/c_138546943.htm.
- 165 Agence Togolaise d'Electrification Rurale et des Energies Renouvelables (AT2ER), "L'AT2ER sélectionne des opérateurs pour les kits solaires!" <https://at2er.tg/lat2er-selectionne-des-operateurs-pour-les-kits-solaires>, viewed 29 October 2019; G. Akinocho, "Togo: le gouvernement subventionne le recours aux systèmes solaires domestiques par ses populations", Agence Ecofin, 4 March 2019, <https://www.agenceecofin.com/solaire/0403-64403-togo-le-gouvernement-subventionne-le-recours-aux-systemes-solaires-domestiques-par-ses-populations>.
- 166 E. Bellini, "Mali launches tender for solar-plus-storage", *pv magazine*, 19 August 2019, <https://www.pv-magazine.com/2019/08/19/mali-launches-tender-for-solar-plus-storage>.
- 167 E. Bellini, "Ethiopia's plans for solar mini grids move forward", *pv magazine*, 25 September 2019, <https://www.pv-magazine.com/2019/09/25/ethiopias-plans-for-solar-mini-grids-move-forward>.
- 168 Rural Electrification Agency Nigeria, "Off grid sector advances as federal government signs grant agreements for performance based grant (PBG) & output based fund (OBF) with private sector renewable energy investors", 18 October 2019, <https://rea.gov.ng/30040-2>.
- 169 E. Bellini, "Jordan suspends renewables auctions, new licenses for projects over 1 MW", *pv magazine*, 28 January 2019, <https://www.pv-magazine.com/2019/01/28/jordan-suspends-renewables-auctions-new-licenses-for-projects-over-1-mw>; E. Bellini, "Algerian government approves 200 MW of PV tenders", *pv magazine*, 11 June 2018, <https://www.pv-magazine.com/2018/06/11/algerian-government-approves-200-mw-of-pv-tenders>.
- 170 Rural Electrification Agency, "Mini-grid tender", <https://rea.gov.ng/mini-grid-tender>, viewed 6 January 2020; Rural Electrification Agency, "Mini-grid performance-based grant", <http://rea.gov.ng/mini-grid-pbg>, viewed 6 January 2020; Rural Electrification Agency, "Call for proposals for mini-grid acceleration scheme", 11 February 2019, <https://rea.gov.ng/call-proposal-mini-grid-acceleration-scheme>.
- 171 A. Parikh, "MNRE issues guidelines for DISCOMs procuring power from decentralized solar projects", *Mercom India*, 17 December 2019, <https://mercomindia.com/mnre-guidelines-discoms-power-decentralized-solar>.
- 172 Vikaspedia, "PM KUSUM Scheme", <http://vikaspedia.in/energy/policy-support/renewable-energy-1/solar-energy/scheme-for-farmers-for-solar-pumps-and-power-plant>, viewed 6 January 2020.
- 173 IFC, op. cit. note 2, p. 158.
- 174 Lighting Global, "Quality assurance: Ethiopia streamlines importation for high-quality solar products", 29 May 2019, <https://www.lightingglobal.org/news/quality-assurance-ethiopia-streamlines-importation-for-high-quality-solar-products>.
- 175 S. Sarfraz, "Imports of solar panels, equipment: FBR to ensure implementation on AEDB quality standards", *Business Recorder*, 27 August 2019, <https://fp.brecorder.com/2019/08/20190827512332>.
- 176 Standards Organisation of Nigeria, "SON, World Bank collaborate on standardising the solar industry in Nigeria", 26 June 2019, <https://son.gov.ng/son-and-world-bank-collaborate-on-modalities-for-standardising-the-solar-industry-in-nigeria>; IEC, "First IEC doc to be published in Chinese at IEC GM", 16 October 2019, <https://blog.iec.ch/2019/10/first-iec-doc-to-be-published-in-chinese-at-iec-gm>.
- 177 SNV, "National Standardisation Council endorsed clean cooking solution standard", April 2019, <https://snv.org/update/national-standardisation-council-endorsed-clean-cooking-solution-standard>.
- 178 Climatescope, op. cit. note 75.
- 179 ESMAP, "Off-grid solutions to expand electricity access across West Africa and the Sahel", 7 May 2019, <https://esmap.org/node/181494>.
- 180 World Bank, "Nepal: Private sector-led mini-grid energy access project", 30 January 2019, <https://www.worldbank.org/en/news/loans-credits/2019/01/31/nepa-private-sector-led-mini-grid-energy-access-project>.
- 181 African Development Bank (AfDB), "African Development Bank approves new financing program for energy providers, 4.5 mln people in sub-Saharan Africa to benefit from off-grid power by 2025", 12 July 2019, <https://www.afdb.org/fr/news-and-events/african-development-bank-approves-new-financing-program-energy-providers-45-mln-people-sub-saharan-africa-benefit-grid-power-2025-25545>.
- 182 AfDB, *Nigeria Energy Access Fund (NEAF) – Project Summary Note* (Abidjan: September 2019), <https://www.afdb.org/fr/documents/nigeria-nigeria-energy-access-fund-neaf-project-summary-note>.
- 183 Green Climate Fund, "Mini-grid/Off-grid Solution for Ger Area – Project Preparation Funding Application", 16 April 2019, <https://www.greenclimate.fund/sites/default/files/document/ppf-application-mini-grid-grid-solution-ger-area.pdf>.
- 184 Netherlands Enterprise Agency, "SDG results: Access to renewable energy – SDG 7", <https://english.rvo.nl/subsidies-programmes/sdg-results-access-renewable-energy-sdg-7>, viewed 6 January 2020.
- 185 Shell Foundation, "SF and DFID launch new £30m partnership to increase energy access for smallholder farmers", 30 September 2019, <https://shellfoundation.org/news/sf-and-dfid-launch-new-30m-partnership-to-increase-energy-access-for-smallholder-farmers>.
- 186 UK Department for International Development, "UK aid to give clean energy boost to Africa", 7 March 2019, <https://www.gov.uk/government/news/uk-aid-to-give-clean-energy-boost-to-africa>.
- 187 "US government invests to power 70% of PNG homes", *Post-Courier*, 7 October 2019, <https://postcourier.com.pg/us-government-invests-to-power-70-of-png-homes>.
- 188 "USAID launches solar home systems program in Malawi", *Green Business News Africa*, 21 February 2019, <http://www.greenbusinessnewsafrika.com/usaids-launches-solar-home-systems-program-in-malawi>.
- 189 SIDA, "Sida support to off-grid energy access for millions of people across Africa", 22 February 2019, <https://www.sida.se/English/press/current-topics-archive/2019/sida-invests-usd-50-million-to-increase-off-grid-energy-access-in-africa>.
- 190 IFC, "IFC expands energy access partnership with Italian government", press release (Washington, DC: 26 March 2019), <https://www.lightingglobal.org/news/imels>.
- 191 Rockefeller Foundation, "Tata Power and the Rockefeller Foundation announce breakthrough enterprise to empower millions of Indians with renewable microgrid electricity", press release (New Delhi: 4 November 2019), <https://www.rockefellerfoundation.org/about-us/news-media/tata-power-rockefeller-foundation-announce-breakthrough-enterprise-empower-millions-indians-renewable-microgrid-electricity>.
- 192 I. Anyaogu, "All On, Rockefeller Foundation launch \$3.5m grant for Nigerian Off-Grid entrepreneurs", *Business Day*, 4 December 2019, <https://businessday.ng/energy/article/all-on-rockefeller-foundation-launch-3-5m-grant-for-nigerian-off-grid-entrepreneurs>.
- 193 Schneider Electric Global, "Schneider Electric announces the creation of its third impact fund 'Schneider Energy Access Asia'", press release (Barcelona: 2 October 2019), <https://www.se.com/ww/en/about-us/press/news/corporate-2019/schneider-energy-access-asia.jsp>.
- 194 Triple Jump, "Announcing the launch of the US\$120 million Energy Entrepreneurs Growth Fund to provide affordable access to energy for homes and businesses", press release (Amsterdam: 5 December 2019), <https://triplejump.eu/2019/12/05/launch-us120-million-energy-entrepreneurs-growth-fund>.
- 195 GET.invest, "From RECP to GET.invest", <https://www.get-invest.eu/2019/01/31/from-recp-to-get-invest>, viewed 6 January 2020.
- 196 Global Electrification Platform, "About", <https://electrifynow.energydata.info/about>, viewed 6 January 2020.
- 197 ARE, "Consumer protection principles for clean energy mini-grids", October 2019, <https://www.ruralelec.org/consumer-protection-principles-clean-energy-mini-grids-0>.
- 198 Rockefeller Foundation, "Global leaders launch groundbreaking commission to eliminate energy poverty among 840 million people worldwide", press release (Bellagio, Italy: 12 September 2019), <https://www.rockefellerfoundation.org/about-us/>

- news-media/global-leaders-launch-groundbreaking-commission-eliminate-energy-poverty-among-840-million-people-worldwide.
- 199 UNHCR, "UNHCR launches sustainable energy strategy, strengthens climate action", 24 October 2019, <https://www.unhcr.org/news/press/2019/10/5db156d64/unhcr-launches-sustainable-energy-strategy-strengthens-climate-action.html>.
- 200 UNHCR, "Renewable Energy 4 Refugees", <https://www.unhcr.org/renewableenergy4refugees>, viewed 25 April 2020.
- 201 H. Kuteesa, "BBOX and Practical Action partner to electrify 1500 households across 3 refugee camps", *The New Times*, 21 November 2019, <https://www.newtimes.co.rw/news/featured-bbox-and-practical-action-partner-electrify-1500-households-across-3-refugee-camps>.
- 202 United Nations, *Report of the Secretary-General on the 2019 Climate Action Summit and the Way Forward in 2020* (New York: 11 December 2019), p. 23, https://www.un.org/en/climatechange/assets/pdf/cas_report_11_dec.pdf.
- 203 J. Cook, "Cooking up a storm at the Modern Energy Cooking Services programme launch", Modern Energy Cooking Services, 5 April 2019, <https://www.mecs.org.uk/uncategorized/cooking-up-a-storm-at-the-modern-energy-cooking-services-programme-launch>.
- 204 World Health Organization, "Launch of Health and Energy Platform of Action", *Public Health, Environmental and Social Determinants of Health (PHE) e-News*, no. 108 (June 2019), <https://www.who.int/phe/news/june-2019/en/#5>.
- 205 Clean Cooking Alliance, "Clean Cooking Forum 2019 Recap", press release (Washington, DC: 20 November 2019), <https://www.cleancookingalliance.org/about/news/11-20-2019-clean-cooking-forum-2019-recap.html>.
- 206 Clean Cooking Alliance, "Champions, partners launch global advocacy campaign 'Clean Cooking Is...'", press release (Nairobi: 5 November 2019), <https://markets.businessinsider.com/news/stocks/champions-partners-launch-global-advocacy-campaign-clean-cooking-is-1028657757>.

INVESTMENT FLOWS

- 1 The BloombergNEF estimate for investment in large-scale hydropower (>50 MW) is based on new capacity that secured financing during 2019. Some projects have a disclosed capital cost, but many do not; BloombergNEF's estimates are based on projects reaching final investment decision in 2019 and do not reflect ongoing spending on projects financed in prior years.
- 2 **Box 1** based on the following sources: Clean Technology Fund, *CTF Results Report* (Nairobi: 2020), https://www.climateinvestmentfunds.org/sites/cif_enc/files/ctf_24_4_results_report_final.pdf; Climate Bonds Initiative, *2019 Green Bond Market Summary* (London: 2020), https://www.climatebonds.net/files/reports/2019_annual_highlights-final.pdf; Climate Bonds Initiative, *Climate Bonds Taxonomy* (London: 2019), https://www.climatebonds.net/files/files/CBI_Taxonomy_Tables-Nov19.pdf; Climate Bonds Initiative, *Comparing China's Green Bond Endorsed Project Catalogue and the Green Industry Guiding Catalogue with the EU Sustainable Finance Taxonomy* (London: 2019), https://www.climatebonds.net/files/reports/comparing_chinas_green_definitions_with_the_eu_sustainable_finance_taxonomy_part_1_en_final.pdf; EU Technical Expert Group on Sustainable Finance, *Taxonomy: Final Report of the Technical Expert Group on Sustainable Finance* (Brussels: March 2020), https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy_en.pdf; Green Climate Fund, *Status of the GCF Portfolio: Approved Projects and Fulfilment of Conditions* (Geneva: 2020), <https://www.greenclimate.fund/sites/default/files/document/gcf-b25-inf06.pdf>; Global Environment Facility, "Energy efficiency", <https://www.thegef.org/topics/energy-efficiency>, viewed 25 April 2020; B. Buchner et al., *Global Landscape of Climate Finance 2019* (London: Climate Policy Initiative, 2019), <https://climatepolicyinitiative.org/wp-content/uploads/2019/11/2019-Global-Landscape-of-Climate-Finance.pdf>; S. Brand and J. Steinbrecher, "Green bonds – a sustainable alternative for municipal infrastructure finance?" *KfW Research Focus on Economics*, no. 245 (2019), <https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-Fokus-Volkswirtschaft/Fokus-englische-Dateien/Fokus-2019-EN/Fokus-No.-245-March-2019-Green-Bonds.pdf>; C. Watson and L. Schalatek, *The Global Climate Finance Architecture. Climate Funds Update* (London and Washington, DC: Overseas Development Institute and Heinrich Böll Stiftung North America, 2019), <https://climatefundsupdate.org/wp-content/uploads/2019/03/CF2-2018-ENG.pdf>.
- 3 **Box 2** based on the following sources: Y. Cadan, A. Mokgopo and C. Vondrich, *\$11 Trillion and Counting* (350.org and DivestInvest, 2019), https://631nj1ki9k11gbkx39b3qz-wpengine.netdna-ssl.com/divestment/wp-content/uploads/sites/52/2019/09/FF_11Trillion-WEB.pdf; Unfriend Coal, "What will 2020 bring for coal insurance?" 15 January 2020, <https://unfriendcoal.com/what-will-2020-bring-for-coal-insurance>; Unfriend Coal, *Insuring Coal No More. The 2019 Scorecard on Insurance, Coal and Climate Change*, 2019, <https://unfriendcoal.com/wp-content/uploads/2019/12/2019-Coal-Insurance-Scorecard-soft-version-2.pdf>. The major insurance companies mentioned include Aegon, AG2R La Mondiale, Allianz, Aviva, AXA, California State Compensation Insurance Fund, CNP, Generali, Groupama, Hannover Re, Lloyd's, the Markel Corporation, Munich Re, Natixis, Oslo Pension & Insurance, SCOR, Storebrand, Swiss Re and Zurich. Chubb will no longer underwrite the construction and operation of new coal-fired plants or new risks for companies that generate more than 30% of their revenues from coal mining or energy production from coal, and was the first US insurer to adopt a coal policy, later accompanied by AXIS Capital, Liberty Mutual and the Hartford, from Chubb Ltd., "Chubb announces new policy on coal underwriting and investment", press release (Zurich: 1 July 2019), <https://news.chubb.com/2019-07-01-Chubb-Announces-New-Policy-on-Coal-Underwriting-and-Investment>. (Note that although Chubb and AXIS Capital are registered in Switzerland and Bermuda, respectively, their senior management and most of their business operations are located in the United States, so they are considered US insurers for the purposes of this report.) DivestInvest, <https://www.divestinvest.org>, viewed 4 March 2020; T. Solsvik, "Norway sovereign wealth fund to divest oil explorers, keep refiners", *Reuters*, 1 October 2019, <https://www.reuters.com/article/us-norway-swf-oil/norway-sovereign-wealth-fund-to-divest-oil-explorers-keep-refiners-idUSKBN1WG4R9>; C40 Cities, "C40 Cities to accelerate urban fossil fuel divestment with

first-of-its kind City Partnership Network", press release (London and New York: 2018), https://www.c40.org/press_releases/fossil-fuel-divestment-city-partnership-network. The Financing the Future Summit was held in South Africa with delegates from more than 44 countries, from Financing the Future, *Final Summit Report* (Cape Town, South Africa: 2019), <https://financingthefuture.global/final-summit-report>.

ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

- 1 International Renewable Energy Agency (IRENA), *Power System Organisational Structures for the Renewable Energy Era* (Abu Dhabi: 2020), p. 6, <https://www.irena.org/publications/2020/Jan/IRENA-Power-system-structures>; S. Fields, "Economic benefits of renewable energy", EnergySage, 13 May 2019, <https://news.energysage.com/economic-benefits-of-renewable-energy/>; US Environmental Protection Agency, "Energy resources for state and local governments: Local renewable energy benefits and resources", 13 August 2019, <https://www.epa.gov/statelocalenergy/local-renewable-energy-benefits-and-resources>.
- 2 See the Policy Landscape chapter for examples of how governments are working to advance renewables. See also IRENA, *Solutions to Integrate High Shares of Variable Renewable Energy (Report to the G20 Energy Transitions Working Group (ETWG))* (Abu Dhabi: 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_grid_integration_2019.pdf.
- 3 G. Feller, "Renewable energy's impact on power systems", T&DWorld, 26 November 2019, <https://www.tdworld.com/renewables/article/20973433/renewable-energys-impact-on-power-systems>; A. M. Oosthuizen, "The transition from fossils to renewables and its impact on consumer prices", The Conversation, 9 November 2019, <https://theconversation.com/the-transition-from-fossils-to-renewables-and-its-impact-on-consumer-prices-125242>.
- 4 International Energy Agency (IEA), *Status of Power System Transformation 2018* (Paris: 2019), <https://www.iea.org/reports/status-of-power-system-transformation-2019>.
- 5 Ibid.
- 6 See Figure 10 in Global Overview chapter and related endnote.
- 7 Whereas renewables met around 26% of global electricity demand in 2017, they supplied only some 10.1% and 3.3% of thermal and transport energy, respectively. See Global Overview chapter.
- 8 Both the IEA and IRENA note the role and importance of renewable hydrogen, electrification of energy end-uses, and seasonal or long-term storage in the context of high renewables or low-carbon scenarios. See IRENA, *Electricity Storage and Renewables: Costs and Markets to 2030* (Abu Dhabi: 2017), <https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets>, and IEA, "Will system integration of renewables be a major challenge by 2023?" 7 January 2020, <https://www.iea.org/articles/will-system-integration-of-renewables-be-a-major-challenge-by-2023>.
- 9 **Figure 53** from the following sources: **Denmark** share of net generation based on preliminary net generation data of 16,150 GWh from wind power, 963 GWh from solar PV and total net production of 28,457 GWh, from Danish Energy Agency, "Månedlig elstatistik. Oversigtstabeller", in Electricity Supply, <https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics>, viewed 15 April 2020; **Uruguay** share of total generation based on data from Uruguay Ministry of Industry, Energy and Mining (MIEM), "Generación de electricidad por fuente (GWh), 2019", provided by MIEM, personal communication with REN21, 2 April 2020; **Ireland** from EirGrid, "Annual fuel mix", <http://www.eirgridgroup.com/site-files/library/EirGrid/Fuel20Mix.jpg>, viewed 15 April 2020; **Germany** from Bundesministerium für Wirtschaft und Energie (BMWi), Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland - Stand: Februar 2020* (Dessau-Roßlau: 2020), https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html. **Portugal** share of net generation based on net generation data of 13,423 GWh from wind power, 1,052 GWh from solar PV and total net production of 48,771 GWh, from REN, "Dados Tecnicos 19", p. 8, [https://www.ren.pt/files/2020-03/2020-03-18181207_f7664ca7-3a1a-4b25-9f46-2056eef44c33\\$72f445d4-8e31-416a-bd01-d7b980134d0f\\$ebbb69f10-6bdf-42e0-bcc4-a449cddf60ca\\$\\$storage_image\\$\\$pt\\$1.pdf](https://www.ren.pt/files/2020-03/2020-03-18181207_f7664ca7-3a1a-4b25-9f46-2056eef44c33$72f445d4-8e31-416a-bd01-d7b980134d0f$ebbb69f10-6bdf-42e0-bcc4-a449cddf60ca$$storage_image$$pt$1.pdf); **Spain** share of consumption/production based on provisional data from Red Eléctrica de España (REE), *The Spanish Electricity System - Preliminary Report 2019* (Madrid: January 2020), with estimated data as of 10 January 2020, p. 16, https://www.ree.es/sites/default/files/11_PUBLICACIONES/Documentos/InformesSistemaElectrico/2020/avance_ISE_2019_EN.pdf; **Greece** from the following sources: for interconnected systems, data from Greek Operator of Electricity Market, "DAS Monthly Reports", <http://www.lagie.gr/en/market/market-analysis/das-monthly-reports/>; for non-interconnected islands, data from Hellenic Energy Exchange S.A. (EnEx), <http://www.enxgroup.gr/en/market/market-analysis/das-yearly-report/> and from www.enxgroup.gr/en/market/marketanalysis/das-monthly-reports, viewed April 2020 (in Greek and provided by I. Tsipouridis, R.E.D. Pro Consultants, Athens, personal communication with REN21, 17 April 2020); **United Kingdom** share of generation (9.9% onshore wind, 9.9% offshore wind, 3.9% solar PV) from UK Department for Business, Energy & Industrial Strategy, "Energy Trends: Renewables", Table 6.1, <https://www.gov.uk/government/statistics/energy-trends-section-6-renewables>, updated 26 March 2020; **Honduras** from T. Vindel, Secretary of State in the Energy Office of Honduras, provided by G. Bravo, Fundación Bariloche, personal communication with REN21, 27 April 2020; **Nicaragua** share of net generation from Nicaraguan Institute of Energy, Regulatory Entity, "Generación neta sistema eléctrico nacional año 2019", https://www.ine.gob.ni/DGE/estadisticas/2019/generacion_neta_dic19_actmar20.pdf, viewed 17 April 2020.
- 10 IEA, *Status of Power System Transformation 2019: System Flexibility* (Paris: 2019), p. 3, https://webstore.iea.org/download/direct/2782?fileName=Status_of_Power_System_Transformation_2019.pdf.
- 11 IEA, "System integration of renewables: Decarbonising while meeting growing demand", <https://www.iea.org/topics/system-integration-of-renewables>, viewed 23 March 2020.
- 12 IEA, op. cit. note 10, p. 3; 21st Century Power Partnership, "Flexibility in 21st Century Power Systems" (Golden, CO: Clean Energy Ministerial, May 2014), <https://www.nrel.gov/docs/fy14osti/61721.pdf>.
- 13 IRENA, *Innovation Landscape for a Renewable-powered Future: Solutions to Integrate Variable Renewables* (Abu Dhabi: 2019), <https://www.irena.org/publications/2019/Feb/Innovation-landscape-for-a-renewable-powered-future>.
- 14 R. Walton, "CAISO to develop regional day-ahead market for renewables after participant push", Utility Dive, 23 September 2019, <https://www.utilitydive.com/news/caiso-to-develop-regional-day-ahead-market-for-renewables-after-participant/563480>.
- 15 G. Baratti, "Terna proposes Italian intraday power market reform amid renewable increase", S&P Global, 17 April 2019, <https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/041719-terna-proposes-italian-intraday-power-market-reform-amid-renewable-increase>.
- 16 IEA, op. cit. note 10, p. 3.
- 17 IRENA, op. cit. note 2.
- 18 See examples in the text, as well as the following: E. Howland, "Report sees major potential for flexible demand response", American Public Power Association, 2 July 2019, <https://www.publicpower.org/periodical/article/report-sees-major-potential-flexible-demand-response>; A. Nikoobakht et al., "Assessing increased flexibility of energy storage and demand response to accommodate a high penetration of renewable energy sources", *IEEE Transactions on Sustainable Energy*, vol. 10, no. 2 (2019), <https://ieeexplore.ieee.org/document/8370663>; R. Hledik et al., The Brattle Group, "The national potential for load flexibility: Value and market potential through 2030", presentation, June 2019, https://brattlefiles.blob.core.windows.net/files/16639_national_potential_for_load_flexibility_-_final.pdf.
- 19 I. Chernyakhovskiy et al., *Grid-friendly Renewable Energy* (Washington, DC: US National Renewable Energy Laboratory (NREL), June 2019), <https://www.nrel.gov/docs/fy19osti/73866.pdf>.
- 20 Energy.gov, "Demand response", <https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/demand-response>, viewed 1 May 2020.

- 21 Enel X, "Enel X reaffirmed market leader for demand response in Ontario following tender win", press release (Boston, MA: 8 January 2019), <https://www.globenewswire.com/news-release/2019/01/08/1682216/0/en/Enel-X-Reaffirmed-Market-Leader-for-Demand-Response-in-Ontario-Following-Tender-Win.html>.
- 22 B. Coyne, "UK Power Networks spends £450k on 18MW of flex", *theenergyst*, 15 May 2019, <https://theenergyst.com/ukpn-spends-450k-18mw-flex>; A. Grundy, "WPD expands flexibility services with new 184MW tender", *CURRENT*, 2 July 2019, <https://www.current-news.co.uk/news/wpd-expands-flexibility-services-with-new-184mw-tender>; M. Lempriere, "Northern Powergrid announce 'UK-first' e-auction for domestic flexibility", *CURRENT*, 22 November 2019, <https://www.current-news.co.uk/news/northern-powergrid-announce-uk-first-e-auction>.
- 23 J. Spector, "Southern California Edison picks 195MW battery portfolio in place of Puente Gas Plant", *GTM*, 25 April 2019, <https://www.greentechmedia.com/amp/article/sce-picks-major-battery-portfolio-in-place-of-puente-gas-plant>.
- 24 J. S. Hill, "AEMO to trial using virtual power plants for frequency control", *RenewEconomy*, 5 April 2019, <https://reneweconomy.com.au/aemo-to-trial-using-virtual-power-plants-for-frequency-control-92695>; M. Brown, "Tesla's virtual solar plant is already saving the grid mid-construction", *Inverse*, 11 December 2019, <https://www.inverse.com/article/61592-tesla-s-virtual-solar-plant-is-already-saving-the-grid>; Government of South Australia, "South Australia's virtual power plant", <https://virtualpowerplant.sa.gov.au>, viewed 22 February 2020.
- 25 P. Shrestha, "Siemens pilots virtual power plant project in Finland", *Energy Live News*, 17 May 2019, <https://www.energylivenews.com/2019/05/17/siemens-pilots-virtual-power-plant-project-in-finland>.
- 26 C. Y. Ting, "Singapore to develop first virtual power plant to link and coordinate energy resources", *The Straits Times*, 8 October 2019, <https://www.straitstimes.com/singapore/singapore-to-develop-first-virtual-power-plant-to-link-and-coordinate-energy-resources>.
- 27 M. Lempriere, "Surging wind and plunging prices as flexibility helps to balance record-breaking generation", *CURRENT*, 9 December 2019, <https://www.current-news.co.uk/news/surging-wind-and-plunging-prices-as-flexibility-helps-to-balance-record-breaking-generation-2>.
- 28 Ibid.
- 29 Ibid.
- 30 A. Woods, "GE to digitize Tata Power's thermal and renewable fleet in India", *Energy Digital*, 25 January 2019, <https://www.energydigital.com/renewable-energy/ge-digitise-tata-powers-thermal-and-renewable-fleet-india>.
- 31 NREL, "Forecasting Wind and Solar Generation: Improving System Operations", *Greening the Grid*, January 2016, <https://www.nrel.gov/docs/fy16osti/65728.pdf>.
- 32 Ibid.
- 33 E. Bellini, "Neural networks improving solar power forecasting", *pv magazine*, 11 December 2019, <https://www.pv-magazine.com/2019/12/11/neural-networks-improving-solar-power-forecasting>.
- 34 A. Grundy, "Solar forecasting accuracy improves by 33% through AI machine learning", *Solar Power Portal*, 25 June 2019, https://www.solarpowerportal.co.uk/news/solar_forecasting_accuracy_improves_by_33_through_ai_machine_learning.
- 35 A. Frangoul, "A firm on an island in the Indian Ocean is developing cutting-edge solar tech", *Sustainable Energy*, 10 May 2019, <https://www.cnbc.com/2019/05/10/a-business-in-the-indian-ocean-is-developing-solar-forecasting-tech.html>.
- 36 Vestas, "Vestas and Utopus Insights to pilot energy forecasting solutions for renewable power plants in Australia, improving energy system stability and increasing potential revenue generation for customers", press release (Melbourne: 18 March 2019), <https://www.globenewswire.com/news-release/2019/03/18/1756078/0/en/Vestas-and-Utopus-Insights-to-pilot-energy-forecasting-solutions-for-renewable-power-plants-in-Australia-improving-energy-system-stability-and-increasing-potential-revenue-generati.html>.
- 37 N. Statt, "Google and DeepMind are using AI to predict the energy output of wind farms", *The Verge*, 26 February 2019, [google-deepmind-wind-farm-ai-machine-learning-green-energy-efficiency](https://www.theverge.com/2019/2/26/18241632/google-deepmind-wind-farm-ai-machine-learning-green-energy-efficiency); M. Brown and R. Mahendra, "How will the energy landscape change in 2019?" *Power Engineering International*, 1 January 2019, <https://www.powerengineeringint.com/2019/01/09/how-will-the-energy-landscape-change-in-2019>.
- 38 IEA, op. cit. note 4.
- 39 See, for example: European Commission, "Overcoming grid constraints for renewable energy provision", 28 May 2018, https://ec.europa.eu/research/infocentre/article_en.cfm?artid=48778; E. Bellini, "Netherlands grid constraints becoming serious threat to solar", *pv magazine*, 27 November 2019, <https://www.pv-magazine.com/2019/11/27/netherlands-grid-constraints-becoming-serious-threat-to-solar>; J. Thornhill, "A creaking grid jams up Australia's switch to green energy", *Bloomberg*, 1 August 2019, <https://www.bloomberg.com/news/articles/2019-08-01/creaking-grid-is-jamming-up-australia-s-switch-to-green-energy>.
- 40 Greenlink, "Project benefits", <https://www.greenlink.ie/project-benefits>, viewed 6 January 2019; Greenlink, "Greenlink welcomes award of €3.6m in EU funding", 18 February 2019, <https://www.greenlink.ie/post/greenlink-welcomes-award-of-3-6m-in-eu-funding>; Greenlink, "Greenlink interconnector brings in new private capital", 12 March 2019, <https://www.greenlink.ie/post/greenlink-interconnector-brings-in-new-private-capital>; Greenlink, "First planning applications submitted in Ireland and Wales for Greenlink electricity interconnector", 12 November 2019, <https://www.greenlink.ie/post/first-planning-applications-submitted-in-ireland-wales-for-greenlink-electricity-interconnector>.
- 41 The US states included Missouri, New Mexico, New York and Wisconsin. M. Froese, "TransWest Express Transmission Project passes major development approval", *Windpower Engineering & Development*, 22 April 2019, <https://www.windpowerengineering.com/transwest-express-transmission-project-passes-major-development-hurdle>; Transwest Express LLC, "Critical grid infrastructure to connect the West", <http://www.transwestexpress.net>, viewed 6 January 2019; "Western Spirit Transmission Project acquisition receives regulatory approval", *T&DWorld*, 10 October 2019, <https://www.tdworld.com/overhead-transmission/article/20973230/western-spirit-transmission-project-acquisition-receives-regulatory-approvals>; M. Froese, "Grain Belt Express transmission line passes major regulatory hurdle", *Windpower Engineering & Development*, 22 March 2019, <https://www.windpowerengineering.com/grain-belt-express-transmission-line-passes-major-regulatory-hurdle>; J. Weaver, "Powerline for \$4 billion of wind+solar approved", *pv magazine*, 21 August 2019, <https://pv-magazine-usa.com/2019/08/21/powerline-for-4-billion-of-windsolar-approved>; C. Howe and M. Farmer, "Transmission project approvals help unlock NY's clean future", *NRDC*, 15 April 2019, <https://www.nrdc.org/experts/miles-farmer/ransmission-project-approvals-help-unlock-nys-clean-future>.
- 42 L. Hobday, "Australia's old powerlines are holding back the renewable energy boom", *ABC*, 2 September 2019, <https://www.abc.net.au/news/2019-09-02/powerline-infrastructure-holding-back-renewable-energy-boom/11457694>; Thornhill, op. cit. note 39.
- 43 The initiative is part of a broader plan to build new grid infrastructure to unlock the energy potential of 50 GW of solar PV and 16.5 GW of wind power across the country. Smiti, "India plans \$1.8 billion transmission projects for renewable energy projects", *CleanTechnica*, 27 March 2019, <https://cleantechnica.com/2019/05/27/india-plans-1-8-billion-transmission-projects-for-renewable-energy-projects>.
- 44 M. Lempriere, "China's mega transmission lines", *Power Technology*, 6 March 2019, <https://www.power-technology.com/features/chinas-mega-transmission-lines>; C. Richard, "Curtailed reduction 'could double Chinese wind fleet'", *Wind Power Monthly*, 23 August 2019, <https://www.windpowermonthly.com/article/1594722/curtailment-reduction-could-double-chinese-wind-fleet>; P. Fairley, "China's ambitious plan to build the world's biggest supergrid", *IEEE Spectrum*, 21 February 2019, <https://spectrum.ieee.org/energy/the-smarter-grid/chinas-ambitious-plan-to-build-the-worlds-biggest-supergrid>; P. Fairley, "China's State Grid Corp crushes power transmission records", *IEEE Spectrum*, 10 January 2019, <https://spectrum.ieee.org/energywise/energy/the-smarter-grid/chinas-state-grid-corp-crushes-power-transmission-records>; J. Temple, "China's giant transmission grid could be the key to cutting climate emissions",

- MIT Technology Review, 8 November 2018, <https://www.technologyreview.com/s/612390/chinas-giant-transmission-grid-could-be-the-key-to-cutting-climate-emissions>.
- 45 Eskom, "NDB and Eskom sign loan agreement for renewable energy integration and transmission augmentation project", 1 April 2019, <http://www.eskom.co.za/news/Pages/2019Apr1.aspx>; Eskom, "Agence Française de Développement signs a R 1,5 billion loan agreement to support Eskom's investments in power grid", 13 December 2018, <http://www.eskom.co.za/news/Pages/2018Dec13.aspx>.
- 46 "Mozambique secures \$420m grants for transmission upgrades", ESI Africa, 23 June 2019, <https://www.esi-africa.com/industry-sectors/transmission-and-distribution/mozambique-secures-420-million-world-bank-grants-for-energy-transmission>.
- 47 L. Morais, "BNDES okays loan for 6.4-GW wind power transmission project", Renewables Now, 10 October 2019, <https://renewablesnow.com/news/bndes-okays-loan-for-64-gw-wind-power-transmission-project-672133>.
- 48 Mainstream Renewable Power, "New transmission line for solar projects", 18 June 2019, <https://www.mainstreamrp.com/insights/new-transmission-line-for-solar-projects-chile/>. In Latin America, the Colombian Ministry of Mines and Energy advanced plans to strengthen transmission and distribution and reduce bottlenecks for connecting solar projects, from A. Critchley, "Colombia takes another step towards solar growth", Solarplaza, 9 May 2018, <https://www.solarplaza.com/channels/markets/11822/colombia-takes-another-step-towards-solar-growth>.
- 49 M. Holland, "Fossil vehicle sales in global freefall – down 4.7% in 2019! Electric vehicle sales continue to grow – CleanTechnica report", CleanTechnica, 18 January 2020, <https://cleantechnica.com/2020/01/18/fossil-vehicle-sales-in-global-freefall-down-4-7-in-2019-electric-vehicle-sales-continue-to-grow>. For heat pump applications and types, see Energy.gov, "Heat pump systems", <https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems>, viewed 1 May 2020.
- 50 A. Arteconi and F. Polonara, "Assessing the demand side management potential and the energy flexibility of heat pumps in buildings", *Energies*, vol. 11, no. 7 (2018), p. 1846, <https://www.mdpi.com/1996-1073/11/7/1846>; P. Patel, "Heat pumps could shrink the carbon footprint of buildings", IEEE Spectrum, 19 September 2019, <https://spectrum.ieee.org/energywise/energy/environment/heat-pumps-could-shrink-the-carbon-footprint-of-buildings>.
- 51 IEA, "Tracking buildings: Heat pumps", <https://www.iea.org/reports/tracking-buildings/heat-pumps>, updated May 2019.
- 52 Ibid.
- 53 J. Skeen, SOLA Group, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 1 May 2020.
- 54 IEA, *Renewables 2019* (Paris: 2019), <https://www.iea.org/reports/renewables-2019>.
- 55 IEA, op. cit. note 51.
- 56 Ibid.
- 57 Ibid.
- 58 Ibid.
- 59 Ibid.
- 60 C. Zhao, China Heat Pump Association, personal communication with REN21, 22 April 2020.
- 61 Japan Refrigeration and Air Conditioning Industry Association, "Number of household heat pump water heaters shipped", <https://www.jraia.or.jp/english/index.html>, viewed 4 May 2020 (using Google Translate).
- 62 T. Nowak, European Heat Pump Association (EHPA), personal communication with REN21, 4 May 2020.
- 63 Zhao, op. cit. note 60.
- 64 Air-Conditioning, Heating, and Refrigeration Institute, "Central air conditioners and air-source heat pumps", <http://www.ahrinet.org/Resources/Statistics/Historical-Data/Central-Air-Conditioners-and-Air-Source-Heat-Pumps>, viewed 1 May 2020.
- 65 Nowak, op. cit. note 62.
- 66 Ibid.
- 67 See, for example: C. McLaughlin, "5 MW ammonia heat pump to warm Copenhagen", Ammonia21, 4 April 2019, https://www.ammonia21.com/articles/8947/5_mw_ammonia_heat_pump_to_warm_copenhagen; European Commission, "New heating network in Amiens, France uses renewable energy sources", 27 September 2019, https://ec.europa.eu/regional_policy/en/projects/france/new-heating-network-in-amiens-france-uses-renewable-energy-sources; CNIM, "CNIM to optimize renewable heat production for Nantes district heating", press release (Paris: 20 May 2019), <https://www.businesswire.com/news/home/20190520005678/en/CNIM-Optimize-Renewable-Heat-Production-Nantes-District>; "Scottish Green co-convenor Patrick Harvie visits Star's manufacturing facility in Glasgow", Yahoo Finance, 15 May 2019, <https://finance.yahoo.com/news/star-renewable-energy-provides-scotlands-133000851.html>.
- 68 IRENA, *Demand-side Flexibility for Power Sector Transformation* (Abu Dhabi: 2019), <https://www.irena.org/publications/2019/Dec/Demand-side-flexibility-for-power-sector-transformation>; A. Provaggi, Euroheat and Power, personal communication with REN21, 19 March 2020.
- 69 V. Spasić, "Decarbonisation is next step in development of district heating, cooling systems", Balkan Green Energy News, 6 December 2019, <https://balkangreenenergynews.com/decarbonization-is-next-in-development-of-district-heating-cooling-systems>.
- 70 Mitsubishi Heavy Industries, "Agreement concluded to form joint venture with major local partner firm in Turkey – MHI Thermal Systems to strengthen sales network for air-conditioning and refrigeration business in Turkey", 31 January 2019, <https://www.mhi.com/news/story/19013103.html>; "Panasonic to acquire Finnish business", Cooling Post, 2 December 2020, <https://www.coolingpost.com/world-news/panasonic-to-acquire-finnish-business>.
- 71 Bravida, "Bravida acquires cooling company in Denmark", 28 October 2019, <https://news.cision.com/bravida-holding-ab/r/bravida-acquires-cooling-company-in-denmark.c2943232>; Swegon, "Swegon acquires Klimax AS, a leading distributor of chillers and heat pumps", 13 August 2019, <https://blog.swegon.com/en/news/swegon-acquires-klimax-as>.
- 72 A. Dimitrova, "Dalrada takes over low-carbon heat pump maker Likido", Renewables Now, 13 December 2019, <https://renewablesnow.com/news/dalrada-takes-over-low-carbon-heat-pump-maker-likido-680213>.
- 73 T. Nowak, EHPA, personal communication with REN21, 22 January 2020.
- 74 Ibid.; EHPA, "Market data: The European heat pump market has achieved double-digit growth for the fourth year in a row", 2 May 2019, <https://www.ehpa.org/market-data>.
- 75 ReportLinker, "The global heat pump market size is expected to reach \$102.5 billion by 2025, rising at a market growth of 8.6% CAGR during the forecast period", press release (New York: 6 November 2019), <https://www.globenewswire.com/news-release/2019/11/06/1942088/0/en/The-Global-Heat-Pump-Market-size-is-expected-to-reach-102-5-billion-by-2025-rising-at-a-market-growth-of-8-6-CAGR-during-the-forecast-period.html>; Bosch, "Inverter ducted packaged unit", <https://www.bosch-thermotechnology.us/en/ocs/residential/inverter-ducted-packaged-unit-1100955-p>, viewed 27 March 2019; Trane, "Ingersoll Rand launches Oxbox™, a durable line of residential HVAC equipment for budget-conscious customers", 12 February 2019, <https://www.trane.com/residential/en/news/ingersoll-rand-launches-oxbox.html>.
- 76 T. Stausholm, "Danish Technological Institute developing air-to-water heat pumps with R290", Hydrocarbons21, 6 January 2020, http://hydrocarbons21.com/articles/9317/danish_technological_institute_developing_air_to_water_heat_pumps_with_r290.
- 77 J. Murray, "What EDF's acquisition of Pivot Power means for the UK storage market", NS ENERGY, 6 November 2019, <https://www.nsenerybusiness.com/features/edf-pivot-power-uk>; Oxford Energy, "Energy Superhub Oxford (ESO)", <https://www.energy.ox.ac.uk/wordpress/events/event/energy-superhub-oxford-eso>, viewed 3 March 2020.
- 78 B. Publicover, "Moixa to build virtual power plant as first phase of UK smart energy project", pv magazine, 18 April 2019, <https://www.pv-magazine.com/2019/04/18/moixa-to-build-virtual-power-plant-as-first-phase-of-uk-smart-energy-project>.
- 79 "Germany backs smart energy neighbourhoods", reNEWS, 16 December 2019, <https://renews.biz/56995/germany-backs-smart-energy-neighbourhoods>.

- 80 L. Cattaneo, "Plug-in electric vehicle policy", Center for American Progress, 7 June 2018, <https://www.americanprogress.org/issues/green/reports/2018/06/07/451722/plug-electric-vehicle-policy>.
- 81 See examples provided in the markets and industry sub-sections of the EV section in this chapter.
- 82 D. Sukharenko, "All-electric, hybrid ships not ready for long haul", Journal of Commerce, 30 July 2019, https://www.joc.com/maritime-news/container-lines/all-electric-hybrid-ships-not-ready-long-haul_20190730.html; "World's first fully electric commercial aircraft takes flight in Canada", *The Guardian* (UK), 11 December 2019, <https://www.theguardian.com/world/2019/dec/11/worlds-first-fully-electric-commercial-aircraft-takes-flight-in-canada>.
- 83 IEA, *Global EV Outlook 2020* (Paris: 2020), <https://www.iea.org/reports/global-ev-outlook-2020>.
- 84 International Transport Forum, "Covid-19 Transport Brief" (Paris: 27 April 2020), <https://www.itf-oecd.org/sites/default/files/electric-vehicles-covid-19.pdf>; IEA, op. cit. note 83.
- 85 **Figure 54** from IEA, op. cit. note 83.
- 86 Ibid.
- 87 N. Anwar, "Electric cars may be powering ahead, but it will be a long way before they go mainstream", CNBC, 4 November 2019, <https://www.cnbc.com/2019/11/04/long-way-before-electric-cars-evs-become-mainstream-transportation.html>; IEA, op. cit. note 83.
- 88 IEA, op. cit. note 83.
- 89 Ibid.
- 90 Ibid.
- 91 Ibid.
- 92 Ibid.; C. Riley, "The recession in global car sales shows no sign of ending", CNN Business, 20 January 2020, <https://edition.cnn.com/2020/01/20/business/global-auto-recession/index.html>.
- 93 Z. Shahan, "EV market share growing fast In top electrifying countries", CleanTechnica, 27 March 2020, <https://cleantechnica.com/2020/03/27/ev-market-share-growing-fast-in-hot-ev-markets>.
- 94 IEA, op. cit. note 83.
- 95 Ibid.
- 96 Ibid.
- 97 Ibid.
- 98 Ibid.
- 99 Ibid.
- 100 **Figure 55** from IEA, op. cit. note 83. A. Bhattacharjee, "Best of 2019: Electric buses a golden opportunity for India", India Climate Dialogue, 1 January 2020, <https://indiadialogue.net/2020/01/01/electric-buses-a-golden-opportunity-2>.
- 101 S. Prateek, "Delhi Cabinet approves procurement of 1,000 electric buses", Mercom India, 6 March 2019, <https://mercomindia.com/delhi-cabinet-procurement-1000-electric-buses>.
- 102 IEA, op. cit. note 83.
- 103 Ibid.
- 104 Ibid.
- 105 Ibid.
- 106 IEA, *The Future of Rail* (Paris: January 2019), <https://www.iea.org/reports/the-future-of-rail>.
- 107 Ibid.
- 108 Ibid.
- 109 V. Saraogi, "Riding Sunbeams launch pilot scheme for UK's first solar powered railways", Railway Technology, 18 July 2019, <https://www.railway-technology.com/features/uks-first-solar-powered-railways>.
- 110 A. Berti, "Solar-powered trains: The future of rail?" Railway Technology, 12 September 2019, <https://www.railway-technology.com/features/solar-powered-trains>.
- 111 M. Kane, "Global EV sales for 2019 now in: Tesla Model 3 totally dominated", InsideEVs, 2 February 2020 <https://insideevs.com/news/396177/global-ev-sales-december-2019>.
- 112 Ibid.
- 113 PR Newswire, op. cit. note 83; J. Jolly, "2020 set to be year of the electric car, say industry analysts", *The Guardian* (UK), 25 December 2019, <https://www.theguardian.com/environment/2019/dec/25/2020-set-to-be-year-of-the-electric-car-say-industry-analysts>.
- 114 R. Baldwin, "Toyota's hydrogen fuel-cell Mirai gets a new, luxurious look", Engadget, 10 October 2019, <https://www.engadget.com/2019/10/10/2021-toyota-mirai-unveil>; S. Pham, "Toyota is pushing ahead with hydrogen-powered cars", CNN, 11 October 2019, <https://edition.cnn.com/2019/10/11/business/toyota-mirai-hydrogen-fuel-cell-car/index.html>; Green Car Congress, "Hyundai Motor Group to invest \$87B over next 5 years; 44 electrified vehicles; new EV development system; Hydrogen plans", 2 January 2020, <https://www.greencarcongress.com/2020/01/20200102-hmg.html>.
- 115 B. Prior, "Volvo to launch new electric vehicles every year until 2025", MyBroadband, 17 October 2019, <https://mybroadband.co.za/news/motoring/323632-volvo-to-launch-new-electric-vehicles-every-year-until-2025.html>; "VW vows to build 22-million electric cars over next decade", Wheels24, 12 March 2019, https://www.wheels24.co.za/News/Industry_News/vw-vows-to-build-22-million-electric-cars-over-next-decade-20190312.
- 116 Jolly, op. cit. note 113.
- 117 Y. Li, "Hydrogen as a clean fuel for transportation", ASEAN Post, 7 October 2019, <https://theaseanpost.com/article/hydrogen-clean-fuel-transportation>.
- 118 Baldwin, op. cit. note 114; Y. Shimibun, "Widespread use of hydrogen energy essential for decarbonized society", Japan News, 5 June 2019, <https://the-japan-news.com/news/article/0005790305>.
- 119 Green Car Congress, op. cit. note 114.
- 120 SolarEdge, "SolarEdge to enter e-mobility market with acquisition of S.M.R.E. Spa", press release (Fremont, CA and Umbertide, Italy: 7 January 2019), <https://www.businesswire.com/news/home/20190106005154/en/SolarEdge-Enter-E-Mobility-Market-Acquisition-S.M.R.E.-Spa>.
- 121 M. Kolakowski, "Why Tesla is rebounding as China's electric car market faces shakeout", Investopedia, 10 December 2019, <https://www.investopedia.com/why-tesla-is-rebounding-as-china-s-electric-car-market-faces-shakeout-4778556>; P. Campbell, "Nio forced to raise \$200m from chief and shareholder Tencnet", *Financial Times*, 24 September 2019, <https://www.ft.com/content/bb9704f0-deb6-11e9-9743-d5a370481bc>; J. Zhu, "Alibaba-backed EV startup XPeng says raises \$400 million for growth", *Reuters*, 12 November 2019, <https://www.reuters.com/article/us-xpeng-fundraising/alibaba-backed-ev-startup-xpeng-raises-nearly-400-million-for-growth-sources-idUSKBN1XM23S>; J. Shen, "Baidu invests further in WM Motor to raise stakes in smart mobility", TechNode, 8 March 2019, <https://technode.com/2019/03/08/baidu-invests-wm-motor-2>.
- 122 M. Froese, "EVgo goes 100% renewable to power nation's largest EV fast-charging network", Windpower Engineering & Development, 8 May 2019, <https://www.windpowerengineering.com/evgo-goes-100-renewables-to-power-nations-largest-ev-fast-charging-network>.
- 123 Austin Energy, "Plug-in Austin electric vehicles", 11 January 2019, <https://austinenergy.com/ae/green-power/plug-in-austin>.
- 124 "BMW I and grid operator TenneT pilot new type of charging strategy for EVs using the BMW i3", TAAS Magazine, 7 November 2019, https://taas.news/article/109383/BMW_I_And_Grid_Operator_TenneT_Pilot_New_Type_Of_Charging_Strategy_For_EVs_Using_The_BMW_I3.
- 125 P. Largue, "Global vehicle-to-grid trials go full throttle", Power Engineering International, 3 December 2019, <https://www.powerengineeringint.com/2019/12/03/global-vehicle-to-grid-trials-go-full-throttle>; V2GHub, "Insights", <https://www.v2g-hub.com/insights>, viewed 7 March 2020; Everose & EVConsult, "V2G global roadtrip: Around the world in 50 projects", October 2018, <https://www.v2g-hub.com/Final-Report-UKPN001-S-01-I-V2G-global-review.pdf>.
- 126 V2GHub, op. cit. note 125 Everose & EVConsult, op. cit. note 125.
- 127 Navigant, *Long Duration Energy Storage*, Q4 2018 (Boulder, CO: 2019), <https://www.navigantresearch.com/reports/long-duration-energy-storage>.
- 128 Clean Energy Institute, "Lithium ion battery", <https://www.cei.washington.edu/education/science-of-solar/battery-technology>, viewed 7 March 2020.

- 129 A. Colthorpe, "China deployed 855MWh of electromechanical storage in 2019 despite slowdown", Energy Storage News, 3 March 2020, <https://www.energy-storage.news/news/china-deployed-855mwh-of-electrochemical-storage-in-2019-despite-slowdown>.
- 130 Global total and additions based on International Hydropower Association, *2020 Hydropower Status Report* (London: 2020), https://www.hydropower.org/sites/default/files/publications-docs/2020_hydropower_status_report_-_28_may_2020.pdf.
- 131 I. Tsipouridis, "Naeras: a pumped storage clean energy plant on the island of Ikaria, Greece", E=mc², 6 June 2019, <https://www.e-mc2.gr/el/news/naeras-pumped-storage-clean-energy-plant-island-ikaria-greece>; D. Proctor, "Group will build 'first of its kind' pumped-storage project in Dubai", POWER, 19 August 2019, <https://www.powermag.com/group-will-build-first-of-its-kind-pumped-storage-project-in-dubai>; Institute for Energy Economics and Financial Analysis, "Major pumped hydro storage project moves forward in Montana", 15 July 2019, <https://ieefa.org/major-pumped-hydro-storage-project-moves-forward-in-montana>; B. Bungane, "Pumped storage hydro proposed for Zimbabwe", ESI Africa, 18 November 2019, <https://www.esi-africa.com/industry-sectors/generation/pumped-storage-hydro-proposed-for-zimbabwe>.
- 132 M. Mazengarb, "Hydro Tasmania pushes 'battery of the nation' plan, will unlock wind and solar", RenewEconomy, 31 October 2019, <https://reneweconomy.com.au/hydro-tasmania-pushes-battery-of-the-nation-plan-will-unlock-wind-and-solar-55299>; L. Middleton, Hydro Tasmania, personal communication with REN21, 16 March 2020.
- 133 Developments based on several sources including IEA, "Combined utility-scale and behind-the-meter deployment in selected countries, 2013-2018", <https://www.iea.org/data-and-statistics/charts/combined-utility-scale-and-behind-the-meter-deployment-in-selected-countries-2013-2018>, updated 25 November 2019; "COVID-19: Storage braced for deployment dip", reNEWS, 1 April 2020, <https://renews.biz/59450/covid-19-virus-could-cut-storage-projections-19>; Energie Consulting, Team Consult, BVES, "BVES Branchenanalyse 2020 – Entwicklung und Perspektiven der Energiespeicherbranche in Deutschland", 12 March 2020, https://www.bves.de/wp-content/uploads/2020/03/Branchenanalyse_BVES_2020.pdf; IEA, *Tracking Energy Integration* (Paris: 2020), <https://www.iea.org/reports/tracking-energy-integration/energy-storage>. China Energy Storage Alliance, "CNESA Global Energy Storage Market Analysis – 2019.Q4 (Summary)", 29 February 2020, <http://en.cnesa.org/latest-news/2020/2/29/cnesa-global-energy-storage-market-analysis-2019q4-summary>; Wood Mackenzie, "U.S. energy storage monitor: 2019 year in review executive summary", March 2020, <https://www.woodmac.com/research/products/power-and-renewables/us-energy-storage-monitor>; Energy by IHS Markit, LinkedIn post, 2020, https://www.linkedin.com/posts/energy-by-ihm-markit_battery-energy-activity-6641644764871696384-Tk3h; See also "Report offers forecasts for utility-scale energy storage systems", T&DWorld, 5 September 2019, <https://www.tdworld.com/distributed-energy-resources/energy-storage/article/20973053/report-offers-forecasts-for-utilityscale-energy-storage-systems>.
- 134 Wood Mackenzie, op. cit. note 133; IHS Markit, op. cit. note 133.
- 135 **Figure 56** from sources in note 133.
- 136 S. Vorrath, "Australia's big battery market set to add 'at least' 500MWh in 2020", RenewEconomy, 17 April 2020, <https://reneweconomy.com.au/australias-big-battery-market-set-to-add-at-least-500mwh-in-2020-2020>.
- 137 S. Vorrath, "Australians installed 22,661 home battery systems in 2019", RenewEconomy, 16 April 2020, <https://reneweconomy.com.au/australians-installed-22661-home-battery-systems-in-2019>.
- 138 "COVID-19: Storage braced for deployment dip", op. cit. note 133.
- 139 European Association for the Storage of Energy (EASE) and Delta Energy & Environment (Delta-ee), *European Market Monitor on Energy Storage – Latest Status and Trends in Europe Edition 4.0* (Brussels: 2020), <https://ease-storage.eu/category/publications/emmes>.
- 140 Ibid.
- 141 BloombergNEF, "Energy storage investments boom as battery costs halve in the next decade", press release (London and New York: 31 July 2019), <https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade>; BloombergNEF, "Battery power's latest plunge in costs threatens coal, gas", press release (London and New York: 26 March 2019), <https://about.bnef.com/blog/battery-powers-latest-plunge-costs-threatens-coal-gas>.
- 142 A. Larson, "PV peaker plant a model for solar-plus-storage projects", POWER, 9 March 2019, <https://www.powermag.com/pv-peaker-plant-a-model-for-solar-plus-storage-projects>; L. Stoker, "UK developer completes 'pioneering' solar-plus-storage suite boasting trackers and bifacial modules", PV-Tech, 19 December 2019, <https://www.pv-tech.org/news/uk-developer-completes-pioneering-solar-plus-storage-site-boasting-trackers>; M. Willuhn, "Gridserve to deploy 60 MW of bifacial-plus-tracking projects in the UK", pv magazine, 1 March 2019, <https://www.pv-magazine.com/2019/03/01/gridservice-to-deploy-60-mw-of-bifacial-plus-tracking-projects-in-the-uk>; S. Hanley, "Largest community solar & storage installation in Massachusetts is now open for business", CleanTechnica, 11 March 2019, <https://cleantechnica.com/2019/03/11/largest-community-solar-storage-installation-in-massachusetts-is-now-open-for-business>; T. Kenning, "Ørsted starts building solar-plus-storage project in Texas", Energy Storage, 13 November 2019, <https://www.energy-storage.news/news/orsted-starts-building-solar-plus-storage-project-in-texas>. Other projects are in Arizona, California, Florida, Hawaii, Massachusetts, Oklahoma and Texas. See, for example: T. Gibson, "Lithium-ion battery prices are declining, powering growth and opportunity in the U.S. energy market", Smart Electric Power Alliance, 15 August 2019, <https://sepapower.org/knowledge/lithium-ion-battery-prices-are-declining-powering-growth-and-opportunity-in-the-u-s-energy-storage-market>; Hawaiian Electric, "Six low-priced solar-plus-storage projects approved for Oahu, Maui and Hawaii islands", 27 March 2019, <https://www.hawaiianelectric.com/six-low-priced-solar-plus-storage-projects-approved-for-oahu-maui-and-hawaii-islands>; C. Keating, "NV Energy's 1,190MW / 590MW solar-plus-storage triple threat of projects waved through approvals", Energy Storage News, 9 December 2019, <https://www.energy-storage.news/news/nv-energy-1190mw-590mw-solar-plus-storage-triple-threat-of-projects-waved>; M. Froese, "Western Farmers Electric signs PPA for wind, solar & storage with NextEra", Windpower Engineering & Development, 26 July 2019, <https://www.windpowerengineering.com/western-farmers-electric-signs-ppa-for-wind-solar-storage-with-nextera>; I. Shumkov, "8minute to build massive solar-plus-storage plant to serve LA utility", Renewables Now, 7 November 2019, <https://renewablesnow.com/news/8minute-to-build-massive-solar-plus-storage-plant-to-serve-la-utility-675428>; C. Keating, "Engie buys 25MW/22MWh solar-plus-storage portfolio in Massachusetts", Energy Storage News, 24 September 2019, <https://www.energy-storage.news/news/engie-buys-25mw-22mwh-solar-plus-storage-portfolio-in-massachusetts>; Florida Power & Light Company, "FPL announces plan to build the world's largest solar-powered battery and drive accelerated retirement of fossil fuel generation", press release (Juno Beach, FL: 28 March 2019), <http://newsroom.fpl.com/2019-03-28-FPL-announces-plan-to-build-the-worlds-largest-solar-powered-battery-and-drive-accelerated-retirement-of-fossil-fuel-generation>; J. Spector, "What a year! 10 stories that propelled energy storage in 2019", GTM, 17 December 2019, <https://www.greentechmedia.com/articles/read/10-stories-that-propelled-energy-storage-in-2019>; J. Parnell, "Energy storage developer buy Texas windfarms with major battery retrofit planned", *Forbes*, 24 August 2019, <https://www.forbes.com/sites/johnparnell/2019/08/24/energy-storage-developer-buy-texas-windfarms-with-major-battery-retrofit-planned>; J. St. John, "Hawaiian Electric seeks bids for 900MW of 'dispatchable renewables' and storage", GTM, 23 August 2019, <https://www.greentechmedia.com/articles/read/hawaiian-electric-seeks-bids-for-900mw-of-dispatchable-renewables-storage-a>.
- 143 A. Grundy, "RES' major wind-plus-storage project given go ahead in South Australia", Energy Storage News, 30 October 2019, <https://www.energy-storage.news/news/major-solar-plus-storage-project-given-go-ahead-in-south-australia>; E. Bellini, "Solar-plus-storage to cover 25% of electricity demand of Saint Kitts and Nevis", pv magazine, 8 August 2019, <https://www.pv-magazine.com/2019/08/08/solar-plus-storage-to-cover-25-of-electricity-demand-of-saint-kitts-and-nevis>; E. Bellini, "South Sudan to get 20 MW/35 MWh solar-plus-storage plant", pv magazine, 5 December 2019, <https://www.pv-magazine.com/2019/12/05/20mw-35mwh-solarstorage-plant-to-be-built-in-sudan>; R. Suba, "Tesla Big Battery deal will help South Australia push for 100 percent green energy by 2030s", TESLARATI, 22 January 2020, <https://www.teslarati.com/tesla-powerpack-south-australia-wind-farm-100-percent-renewable-energy>; N. Harmsen, "South Australia's giant Tesla battery output and storage set to increase by 50 percent", ABC News,

- 20 November 2019, <https://www.abc.net.au/news/2019-11-19/sa-big-battery-set-to-get-even-bigger/11716784>; B. Match, "Massive hybrid renewable energy plant + storage set for South Australia", pv magazine, 12 September 2019, <https://www.pv-magazine-australia.com/2019/09/12/massive-hybrid-renewable-energy-plant-storage-set-for-south-australia>; M. Maisch, "China's largest renewables hybrid project adds 100 MWh battery", pv magazine, 7 February 2019, <https://www.pv-magazine.com/2019/02/07/chinas-largest-renewables-hybrid-project-adds-100-mwh-battery>.
- 144 A. Colthorpe, "New York City's biggest: Enel X connects grid-scale battery storage in Brooklyn", Energy Storage News, 9 December 2019, <https://www.energy-storage.news/news/new-york-citys-biggest-enel-x-connects-grid-scale-battery-storage-in-brookl>; C. Roselund, "Inside GlidePath's merchant battery in Texas", pv magazine, 21 June 2019, <https://pv-magazine-usa.com/2019/06/21/inside-glidepaths-merchant-battery-in-texas>; R. Randazzo, "Historic shift: APS says batteries are cheapest energy option, plans big investment", azcentral, 21 February 2019, <https://amp.azcentral.com/amp/2911299002>.
- 145 Colthorpe, op. cit. note 144; Roselund, op. cit. note 144; Randazzo, op. cit. note 144.
- 146 Australian Renewable Energy Agency, *Large Scale Battery Storage Knowledge Sharing Report* (Canberra: November 2019), <https://arena.gov.au/assets/2019/11/large-scale-battery-storage-knowledge-sharing-report.pdf>; R. Drekeni, "Tonga uses big batteries to reach ambitious renewable energy goal", Pacific Tourism Organisation, 18 December 2019, <https://corporate.southpacificislands.travel/tonga-uses-big-batteries-to-reach-ambitious-renewable-nergy-goal>; Pacific Centre for Renewable Energy and Energy Efficiency, "Tonga's first large batteries will store renewable energy", 18 July 2019, <https://www.pcreee.org/article/tonga-s-first-large-batteries-will-store-renewable-energy>; A. Bhambhani, "Asian Development Bank, Green Climate Fund & Government of Australia pool in \$44.6 million grant to support renewable energy project in Tonga for battery energy storage, grid-connected & RE hybrid systems & mini-grids", TaiyangNews, 14 March 2019, <http://taiyangnews.info/business/44-6mn-grant-for-renewable-energy-in-tonga>.
- 147 Germany from EASE and Delta-ee, op. cit. note 139; "Latest U.S. solar installer survey finds that solar-plus-storage doubled between 2017 and 2019", pvbuzz, 4 March 2020, <https://pvbuzz.com/us-solar-installer-survey-solar-plus-storage-doubled>. For the United States, see, for example: J. Weaver, "Residential solar plus storage is taking over Hawaii's grid", pv magazine, 4 September 2019, <https://pv-magazine-usa.com/2019/09/04/hawaiian-homes-becoming-even-more-important-to-the-power-grid>; I. Ivanova, "After PG&E blackout, California homeowners shift to solar and batteries", CBS News, 21 October 2019, <https://www.cbsnews.com/news/after-pg-e-blackouts-california-homeowners-move-to-solar-and-batteries>; L. Milford, "California power shut-offs drive customers to solar and storage", *RenewableEnergyWorld.com*, 11 August 2019, <https://www.renewableenergyworld.com/2019/11/08/california-power-shut-offs-drive-customers-to-solar-and-storage>; L. Collins, "Residential solar-plus-storage systems close to grid parity in Europe", Recharge, 6 August 2019, <https://www.rechargenews.com/transition/residential-solar-plus-storage-systems-close-to-grid-parity-in-europe/2-1-649602>; P. Hockenos, "In Germany, solar-powered homes are really catching on", *Wired*, 25 March 2019, <https://www.wired.com/story/in-germany-solar-powered-homes-are-catching-on>.
- 148 G. Hering, "At 'tipping point', battery-backed solar homes gain foothold on New England grid", S&P Global, 8 February 2019, <https://www.spglobal.com/marketintelligence/en/news-insights/trending/PXvDLhX2Wx9-Xht6lw4Bg2>.
- 149 M. Mazengarb, "South Australia home battery scheme now half the size of Tesla big battery", RenewEconomy, 14 January 2020, <https://reneweconomy.com.au/south-australia-home-battery-scheme-now-half-the-size-of-tesla-big-battery-58667>.
- 150 See endnote 1 of the CSP section in the Market and Industry chapter.
- 151 United Nations Environment Programme, *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy* (Paris: 2015), https://wedocs.unep.org/bitstream/handle/20.500.11822/9317/-District_energy_in_cities_unlocking_the_potential_of_energy_efficiency_and_renewable_ene.pdf.
- 152 IRENA, *Power System Flexibility for the Energy Transition, Part 1: Overview for Policy Makers* (Abu Dhabi: 2018), p. 8, https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Nov/IRENA_Power_system_flexibility_1_2018.pdf.
- 153 IRENA, *Hydrogen from Renewable Power: Technology Outlook for the Energy Transition* (Abu Dhabi: 2018), p. 15, <https://irena.org/publications/2018/Sep/Hydrogen-from-renewable-power>.
- 154 IHS Markit, *IHS Markit's 10 Cleantech Trends in 2020* (London: 2020), <https://cdn.ihsmarkit.com/www/prot/pdf/0320/IHS-Market-Top-10-Cleantech-Trends-2020.pdf>.
- 155 R. Harding, "Japan's hydrogen dream: Game-changer or a lot of hot air?" *Financial Times*, 17 June 2019, <https://www.ft.com/content/c586475e-7260-11e9-bf5c-6eeb837566c5>.
- 156 Commonwealth of Australia, "Australia's National Hydrogen Strategy", 22 November 2019, <https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy>.
- 157 J. Deign, "10 countries moving toward a green hydrogen economy", GTM, 14 October 2019, <https://www.greentechmedia.com/articles/read/10-countries-moving-towards-a-green-hydrogen-economy>; J. Thornhill, "Siemens backs mega green power hydrogen project in Australia", *Bloomberg*, 8 October 2019, <https://www.bloomberg.com/news/articles/2019-10-08/siemens-backs-mega-green-power-hydrogen-project-in-australia>.
- 158 Deign, op. cit. note 157.
- 159 T. Gibson, "Lithium-ion battery prices are declining, powering growth and opportunity in the U.S. energy market", Smart Electric Power Alliance, 15 August 2019, <https://sepapower.org/knowledge/lithium-ion-battery-prices-are-declining-powering-growth-and-opportunity-in-the-u-s-energy-storage-market>.
- 160 Hydrostor, "Hydrostor and NRStor announce completion of world's first commercial advanced-CAES facility", press release (Toronto: 25 November 2019), <https://www.globenewswire.com/news-release/2019/11/25/1952039/0/en/Hydrostor-and-NRStor-Announce-Completion-of-World-s-First-Commercial-Advanced-CAES-Facility.html>.
- 161 Ibid.; J. Spector, "Hydrostor will build compressed air storage for the Australian grid", GTM, 18 February 2019, <https://www.greentechmedia.com/articles/read/hydrostor-will-build-compressed-air-storage-for-the-australian-grid>.
- 162 R. McCarthy, "What technology is winning the energy storage race?" Wood Mackenzie, 26 November 2019, <https://www.woodmac.com/news/opinion/what-is-winning-the-global-energy-storage-race>; L. Goldie-Scot, "A behind the scenes take on lithium-ion battery prices", BloombergNEF, 5 March 2019, <https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices>.
- 163 BloombergNEF, "Scale-up of solar and wind puts existing coal, gas at risk", press release (London and New York: 28 April 2020), <https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk>.
- 164 E. Niiler, "Cheap at last, batteries are making a solar dream come true", *Wired*, 2 December 2019, <https://www.wired.com/story/cheap-at-last-batteries-are-making-a-solar-dream-come-true>.
- 165 P. LeBleu, "Tesla's competitors play catch-up on electric batteries", CNBC, 10 February 2020, <https://www.cnb.com/2020/02/10/teslas-competitors-play-catch-up-on-electric-batteries.html>.
- 166 IHS Markit, op. cit. note 154; D. Gielen, E. Taibi and R. Miranda, *Hydrogen: A Renewable Energy Perspective* (Abu Dhabi: IRENA, September 2019), <https://www.irena.org/publications/2019/Sep/Hydrogen-A-renewable-energy-perspective>.
- 167 K. Silverstein, "The hydrogen economy is within grasp and progressive energy companies know it", *Forbes*, 8 October 2019, <https://www.forbes.com/sites/kensilverstein/2019/10/08/the-hydrogen-economy-is-within-grasp-and-progressive-energy-companies-know-it>.
- 168 The hydrogen will only be available in 2022 from a gasification plant supplied with hydroelectricity and waste wood from the forestry, paper and construction industries, from L. Collins, "'Green hydrogen' on sale in open market at 80% higher price than grey H2", Recharge, 23 January 2020, <https://www.rechargenews.com/transition/green-hydrogen-on-sale-in-open-market-at-80-higher-price-than-grey-h2/2-1-743348>.
- 169 McCarthy, op. cit. note 162; IHS Markit, op. cit. note 154; R. Rapier, "Why China is dominating lithium-ion battery production", *Forbes*, 4 August 2019, <https://www.forbes.com/sites/rrapier/2019/08/04/why-china-is-dominating-lithium-ion-battery-production>.

- 170 M. Maisch, "Australia's Townsville battery giga factory reaches new milestone", pv magazine, 3 October 2019, <https://www.pv-magazine.com/2019/10/03/australias-townsville-battery-gigafactory-reaches-new-milestone>; U. Gupta, "AEPPL signs \$689.7m deal for li-ion battery plant in western India", pv magazine, 15 October 2019, <https://www.pv-magazine.com/2019/10/15/aeppl-signs-689-7m-deal-for-li-ion-battery-plant-in-western-india>; U. Gupta, "Indian state of Telangana pitches for 5 GW lithium-ion battery plant", pv magazine, 10 June 2019, <https://www.pv-magazine.com/2019/06/10/indian-state-of-telangana-pitches-for-5-gw-lithium-ion-battery-plant>; R. J. Kuhudzai, "Hopes to put Southern Africa on path to battery manufacturing self sufficiency", CleanTechnica, 9 February 2020, <https://cleantechnica.com/2020/02/09/new-south-african-lithium-ion-cell-mega-factory-plans-for-32-gwh-year-by-2028>; K. Pickerel, "KORE Power will start a 10-GWh lithium-ion battery manufacturing plant in the United States", Solar Power World, 22 October 2019, <https://www.solarpowerworldonline.com/2019/10/kore-power-will-start-a-10-gwh-lithium-ion-battery-manufacturing-plant-in-the-united-states>.
- 171 M. Bohlsen, "A look at the top 5 lithium-ion battery manufacturers in 2019", Seeking Alpha, 4 September 2019, <https://seekingalpha.com/article/4289626-look-top-5-lithium-ion-battery-manufacturers-in-2019>.
- 172 L. Collins, "World's largest green-hydrogen plant begins operation in Austria", Recharge, 18 November 2019, <https://www.rechargenews.com/transition/worlds-largest-green-hydrogen-plant-begins-operation-in-austria/2-1-708381>.
- 173 Wind Power Monthly, "New 100MW power-to-gas project planned", 12 February 2019, <https://www.windpowermonthly.com/article/1525509/new-100mw-power-to-gas-project-planned>. Also in Germany, construction began on a 10 MW electrolyser from A. Bergenson, "Construction starts on hydrogen electrolysis plant in Germany", Hydrogen Fuel News, 27 June 2019, <http://www.hydrogenfuelnews.com/construction-starts-on-hydrogen-electrolysis-plant-in-germany/8537764>.
- 174 T. Hood, "Hydrogenics to build world's largest hydrogen electrolysis plant in Canada", Hydrogen Fuel News, 5 March 2019, <http://www.hydrogenfuelnews.com/hydrogenics-to-build-worlds-largest-hydrogen-electrolysis-plant-in-canada/8537033>; M. Maisch, "Construction begins at Hydrogen Park South Australia", pv magazine, 3 December 2019, <https://www.pv-magazine.com/2019/12/03/construction-begins-at-hydrogen-park-south-australia>.
- 175 Power Engineering, "Lithium-ion startups attract lion's share of energy storage venture capital in 2019", 22 January 2020, <https://www.power-eng.com/2020/01/22/lithium-ion-startups-attract-lions-share-of-energy-storage-venture-capital-in-2019>; M. Tyson and C. Bloch, *Breakthrough Batteries: Powering the Era of Clean Electrification* (Basalt, CO: Rocky Mountain Institute, 2019), <http://www.rmi.org/breakthrough-batteries>; J. McMahon, "Huge battery investments drop energy-storage costs faster than expected, threatening natural gas", *Forbes*, 29 October 2019, <https://www.forbes.com/sites/jeffmcmahon/2019/10/29/huge-battery-investments-drop-energy-storage-costs-threaten-natural-gas-industry>.
- 176 Spector, op. cit. note 142.
- 177 H. Finzel, "Shell tightens grip on storage with Sonnen takeover", Energy Storage Publishing, 25 February 2019, <https://www.bestmag.co.uk/content/shell-tightens-grip-storage-sonnen-takeover>; Spector, op. cit. note 142.
- 178 V. Zhou, "Wesfarmers takes control on Kidman Resources", Australian Mining, 24 September 2019, <https://www.australianmining.com.au/news/wesfarmers-takes-control-of-kidman-resources>.
- 179 World Bank, "New international partnership established to increase the use of energy storage in developing countries", press release (Vancouver: 28 May 2019), <https://www.worldbank.org/en/news/press-release/2019/05/28/new-international-partnership-established-to-increase-the-use-of-energy-storage-in-developing-countries>.
- 180 Bhambhani, op. cit. note 146.
- 181 J. Spector, "5 tangible advances for long-duration energy storage in 2019", GTM, 30 December 2019, <https://www.greentechmedia.com/articles/read/5-tangible-advances-for-long-duration-energy-storage-in-2019>; IRENA, op. cit. note 8; IEA, op. cit. note 8.
- 182 A. Hayes, "Why Amazon invested in Plug Power (AMZN, PLUG)", Investopedia, 25 June 2019, <https://www.investopedia.com/news/why-amazon-invested-plug-power-amzn-plug>; Loop Energy, "Loop Energy announces investment by Cummins", press release (Vancouver: 18 September 2019), <https://www.newswire.ca/news-releases/loop-energy-announces-investment-by-cummins-834545911.html>; FreightWaves, "Startup Loop Energy gets cash infusion from engine-maker Cummins", 19 September 2019, <https://www.benzinga.com/news/19/09/14455436/startup-loop-energy-gets-cash-infusion-from-engine-maker-cummins>.
- 183 M. Burgess, "Cummins closes on Hydrogenics acquisition", Gasworld, 9 September 2019, <https://www.gasworld.com/cummins-completes-hydrogenics-acquisition/2017755.article>; Cummins, "Cummins unveils new environmental sustainability strategy to address climate change, conserve natural resources", press release (Columbus, IN: 15 November 2019), <https://investor.cummins.com/news-releases/news-release-details/cummins-unveils-new-environmental-sustainability-strategy>.
- 184 Vattenfall, "Vattenfall and Preem are designing a fossil-free hydrogen gas plant", <https://group.vattenfall.com/what-we-do/roadmap-to-fossil-freedom/industry-decarbonisation/preem>, viewed 4 January 2019; Vattenfall, "Vattenfall's initiatives in Green Hydrogen", https://group.vattenfall.com/contentassets/311e64472a0f41eaac286629f3a39696/_vattenfall_greenhydrogen_illustration_extended-ext.png, viewed 4 January 2019.
- 185 Spector, op. cit. note 181.
- 186 Ibid.; A. Colthorpe, "Softbank's SB Energy among investors in US\$30m Series C for 'all-iron' flow battery", Energy Storage News, 29 October 2019, <https://www.energy-storage.news/news/softbanks-sb-energy-among-investors-in-us30m-series-c-for-all-iron-flow-bat>.
- 187 M. Froese, "What's new in energy storage", Wind Power Engineering, 13 May 2019, <https://www.windpowerengineering.com/whats-new-in-energy-storage>; Green Car Congress, "IBM Research announces heavy-metal-free battery design; partnering with Mercedes-Benz R&D to advance the discovery", 16 December 2019, <https://www.greencarcongress.com/2019/12/20191218-ibm.html>; F. Lambert, "Tesla battery research partner unveils path to more energy-dense Li-ion cells that could beat solid-state", Electrek, 6 August 2019, <https://electrek.co/2019/08/06/tesla-battery-research-energy-dense-lii-cells-beat-solid-state>.
- 188 C. Delbert, "Future lithium-ion batteries could one day 'heal' themselves", *Popular Mechanics*, 31 December 2019, <https://www.popularmechanics.com/science/energy/a30363787/lithium-ion-battery-heal>; Spector, op. cit. note 181. Preliminary reports indicate that the battery fires in the Republic of Korea may have been largely due to poor management of the batteries, and not due to product defects, from A. Colthorpe, "Korea's ESS fires: Batteries not to blame but industry takes hit anyway", Energy Storage News, 19 June 2019, <https://www.energy-storage.news/news/koreas-ess-fires-batteries-not-to-blame-but-industry-takes-hit-anyway>.
- 189 "US Navy testing battery energy storage systems in two new transportable microgrids", Renewable Energy World, 17 December 2019, <https://www.renewableenergyworld.com/2019/12/17/us-navy-testing-battery-energy-storage-systems-in-two-new-transportable-microgrids>.
- 190 B. Deboysier, "Siemens Gamesa stores wind energy in volcanic rocks", Révolution Énergétique, 28 November 2019, <https://www.revolution-energetique.com/siemens-gamesa-stocke-lenergie-eolienne-dans-des-roches-volcaniques>.
- 191 C. Roselund, "Ice Energy brings the deep freeze to U.S. energy storage", pv magazine, 13 February 2019, <https://pv-magazine-usa.com/2019/02/13/ice-energy-brings-the-deep-freeze-to-u-s-energy-storage>.

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- 1 See, for example, the following: United Nations Environment Programme (UNEP), "Renewable energy and energy efficiency in developing countries can support Paris Agreement, and benefit people", press release (Nairobi: 31 October 2017), <https://www.unenvironment.org/news-and-stories/press-release/renewable-energy-and-energy-efficiency-developing-countries-can>; C. Lins and H. E. Murdock, "The impact of renewable energy technologies on global energy efficiency", *UN Chronicle*, <https://www.un.org/en/chronicle/article/impact-renewable-energy-technologies-global-energy-efficiency>, viewed 9 February 2020; International Renewable Energy Agency (IRENA), *Global Energy Transformation: A Roadmap to 2050* (Abu Dhabi: 2019), <https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition>.
- 2 US Environmental Protection Agency, *Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments*, Part 1 (Washington, DC: 2018), https://www.epa.gov/sites/production/files/2018-07/documents/mbg_1_multiplebenefits.pdf; UNEP, op. cit. note 1.
- 3 United Nations Sustainable Development Goals Knowledge Platform, "Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all", <https://sustainabledevelopment.un.org/sdg7>, viewed 20 November 2019.
- 4 UNEP, "Why does energy matter?" <https://www.unenvironment.org/explore-topics/energy/why-does-energy-matter>, viewed 2 February 2020.
- 5 See, for example, the following: UNEP, *Renewable Energy and Energy Efficiency in Developing Countries: Contributions to Reducing Global Emissions* (Nairobi: 2017), https://wedocs.unep.org/bitstream/handle/20.500.11822/22149/1_Gigaton_Third%20Report_EN.pdf; International Energy Agency (IEA), *Perspectives for the Clean Energy Transition: The Critical Role of Buildings* (Paris: 2019), <https://www.iea.org/publications/reports/PerspectivesfortheCleanEnergyTransition>; IRENA, *Synergies Between Renewable Energy and Energy Efficiency: A Working Paper Based on REmap* (Abu Dhabi: 2017), <https://www.irena.org/publications/2017/Aug/Synergies-between-renewable-energy-and-energy-efficiency>.
- 6 IRENA, op. cit. note 5.
- 7 See, for example, the following: IEA, "IEA welcomes commitment by leading countries to drive global progress on energy efficiency", press release (Paris: 23 September 2019), <https://www.iea.org/news/iea-welcomes-commitment-by-leading-countries-to-drive-global-progress-on-energy-efficiency>; Energy Efficiency Global Alliance, "About", <https://eeglobalalliance.org/about>, viewed 4 February 2020; IEA, "IEA unveils global high-level commission for urgent action on energy efficiency", 9 July 2019, <https://www.iea.org/news/iea-unveils-global-high-level-commission-for-urgent-action-on-energy-efficiency>.
- 8 Of the NDC data analysed, 105 of the commitments were accessed from the United Nations Framework Convention on Climate Change, "NDC Registry", <https://www4.unfccc.int/sites/NDCStaging/Pages/Search.aspx?k=>, viewed February 2020. The remaining data were retrieved from IRENA, "Renewable energy in the NDCs", <https://www.irena.org/Statistics/View-Data-by-Topic/Climate-Change/Renewable-Energy-in-the-NDCs>, viewed February 2020.
- 9 IEA, "Global CO2 emissions in 2019", 11 February 2020, <https://www.iea.org/articles/global-co2-emissions-in-2019>. **Box 1** from the following sources: IRENA, *Renewable Power Generation Costs in 2019* (Abu Dhabi: 2020), <https://irena.org/costs>; Lazard, "Levelized cost of energy and levelized cost of storage 2018", 8 November 2018, <https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018>. Higher renewable electricity prices than conventional electricity prices for end-consumers likely reflect the following: the costs associated with the transmission and distribution of renewable power (since generation often occurs far from population centres), the costs associated with the variability of renewables, and the fact that current retail prices paid by consumers take into account the historically higher-cost renewable technologies rather than newer and lower-cost technologies, which have not yet impacted prices. M. Greenstone and I. Nath, *Do Renewable Portfolio Standards Deliver?* (Chicago, IL: University of Chicago, 2019), <https://bf.uchicago.edu/working-paper/do-renewable-portfolio-standards-deliver>; B. Murray, "The paradox of declining renewable costs and rising electricity prices", *Forbes*, 17 June 2019, <https://www.forbes.com/sites/brianmurray1/2019/06/17/the-paradox-of-declining-renewable-costs-and-rising-electricity-prices>; IEA, "Energy efficient prosperity: Low-hanging fruits", 12 October 2016, <https://www.iea.org/news/energy-efficient-prosperity-low-hanging-fruits>. When comparing the levelised cost of energy efficiency programmes versus renewable energy generation, efficiency improvements often remain the initial lowest-cost resource. In the United States, investments in energy savings cost 2-5 US cents (an average of 3 cents) per kilowatt-hour, whereas generating the same amount of electricity from wind or solar PV can cost the same or three times more. American Council for an Energy-Efficient Economy, "New data, same results – saving energy is still cheaper than making energy", 1 December 2017, <https://www.aceee.org/blog/2017/12/new-data-same-results-saving-energy>; B. Bungane, "Seychelles to launch energy efficiency programme", *ESI Africa*, 11 October 2017, <https://www.esi-africa.com/industry-sectors/energy-efficiency/seychelles-to-launch-energy-efficiency-programme>; N. Nhede, "Seychelles targets energy efficiency in state buildings", *Smart Energy International*, 11 October 2017, <https://www.smart-energy.com/regional-news/africa-middle-east/seychelles-energy-efficiency>; Ministry of Energy, Mines and Environment, Kingdom of Morocco, "Energetic Efficiency: Jiha Tinou Program", <https://www.mem.gov.ma/en/Pages/secteur.aspx?e=3&prj=23>, viewed 10 February 2020.
- 10 For a definition of carbon intensity, see "Carbon intensity (energy supply)" at US Energy Information Administration (EIA), "U.S. energy-related carbon dioxide emissions, 2018", <https://www.eia.gov/environment/emissions/carbon/#CI>, viewed 21 February 2020.
- 11 **Box 2** from the following sources: Energy Sufficiency and European Council for an Energy Efficient Economy, *Energy Sufficiency and Rebound Effects* (Stockholm: 2018), https://www.energysufficiency.org/static/media/uploads/site-8/library/papers/sufficiency-rebound-final_formatted_181118.pdf; EE-Rebound, "Rebound effect and renewable energy", <https://www.ee-rebound.de/ee-rebound>, viewed 20 November 2019; E. Delzendeh et al., "The impact of occupants' behaviours on building energy analysis: A research review", *Renewable and Sustainable Energy Reviews*, vol. 80 (September 2016), pp. 1061-71, <http://dx.doi.org/10.1016/j.rser.2017.05.264>.
- 12 Renewable Energy Network for the 21st Century (REN21), *Renewables 2019 Global Status Report* (Paris: 2019), p. 325, <https://www.ren21.net/reports/global-status-report>. See also A. Langenheld and C. Noll, "Von wegen Rebound-Effekt", *Tagesspiegel* Background, <https://background.tagesspiegel.de/von-wegen-rebound-effekt>, updated 15 November 2018. Note that the GSR applies the physical energy content method to establish the primary energy equivalent of the primary energy form of non-combustible energy sources. Where the primary energy form is electricity (hydropower, wind power, solar PV, tidal/wave energy), the primary energy equivalent is the gross electricity generated. Where the primary energy form is heat (nuclear, geothermal and CSP), the primary energy equivalent is the estimated heat generated in the production of usable energy. Each technology has an assumed universal conversion efficiency: 50% for geothermal heat, 33% for nuclear and CSP generation, and 10% for geothermal power. See IEA, *World Energy Balances: Database Documentation*, 2018 edition (Paris: 2018), pp. 198-99, http://wds.iea.org/wds/pdf/WORLDBAL_Documentation.pdf.
- 13 International Institute for Applied Systems Analysis, *Global Energy Assessment* (Laxenburg, Austria: 2012), pp. 768-69, https://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter11_renewables_lowres.pdf.
- 14 IRENA, op. cit. note 5.
- 15 IRENA, *Electrification with Renewables: Driving the Transformation of Energy Services* (Abu Dhabi: 2019), p. 5, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_RE-Electrification_SGCC_2019_preview.pdf.
- 16 IEA, *Energy Efficiency 2019* (Paris: 2019), p. 13, <https://www.iea.org/reports/energy-efficiency-2019>.
- 17 IEA, *World Energy Statistics and Balances, 2019 edition* (Paris: 2019), <https://webstore.iea.org/world-energy-statistics-and-balances-2019>. **Figure 57** from Enerdata, energy statistics database (data extracted 12 March 2020), personal communication with REN21, March 2020.

- 18 Ibid.
- 19 Ibid.
- 20 Based on IEA, op. cit. note 17.
- 21 Based on Ibid.
- 22 Based on Ibid.
- 23 Based on Ibid.
- 24 IEA, *Electricity Information*, 2018 edition (Paris: 2018), <https://webstore.iea.org/electricity-information-2018>.
- 25 Eurostat, *Calculation Methodologies for the Share of Renewables in Energy Consumption* (Luxembourg: 2018), <https://ec.europa.eu/eurostat/web/energy/methodology>.
- 26 Calculation is an estimation of required additional primary energy input in the absence of the additional renewable electricity uptake since 2012, all else being equal. Therefore, the estimation accounts for the difference in transformation losses between conventional and renewable electricity generation, but does not account for potential resultant feedback loops on the energy demand itself, such as due to energy prices, effects of structural changes in economic activity or any similar effect. The figure is not intended to provide results of a comprehensive energy model. Based on IEA, op. cit. note 17; GDP from World Bank, "GDP, PPP (current international \$)", World Development Indicators, <https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD>, viewed 20 November 2019.
- 27 **Figure 58** shows the actual primary energy demand (PED) intensity calculated based on the actual World PED and the World GDP versus an "adjusted PED intensity". This "adjusted PED intensity" is calculated in a similar manner taking into account the estimated PED had renewable electricity remained constant at the 2012 level. This is done by taking the additional renewable electricity uptake since 2012 (considering modern renewables only, which includes the following IEA categories: renewable municipal waste, solid biofuels, liquid biofuels, hydropower, geothermal, solar PV, solar thermal, tide, wave and ocean, and wind) multiplied by the difference in the transformation losses in renewable electricity and CHP plants versus the transformation losses in conventional plants (%). The "adjusted PED" is then estimated by adding the difference in transformation losses between conventional and renewable power to the actual PED. This "adjusted PED" represents the PED that would have had the additional renewable electricity uptake since 2012 generated by conventional power. Energy data based on IEA, op. cit. note 17; GDP from World Bank, op. cit. note 26.
- 28 Based on IEA, op. cit. note 17.
- 29 Based on Ibid. and on Enerdata, op. cit. note 17.
- 30 Based on IEA, op. cit. note 17, World Bank, op. cit. note 26 and Enerdata, op. cit. note 17. Without these improvements in final energy intensity, the estimated share of modern renewables in TFEC in 2017 could have been 9.2%, as opposed to the actual share of 10.2%. These calculations are an imperfect approximation and assume that the remaining demand in a case of stagnant energy intensity would be supplied by non-renewable resources.
- 31 Based on IEA, op. cit. note 17, and on Enerdata, op. cit. note 17.
- 32 **Figure 59** based on IEA, op. cit. note 17.
- 33 Based on Ibid.
- 34 Based on Ibid.
- 35 Based on Ibid.
- 36 Based on Ibid.
- 37 Global Alliance for Buildings and Construction (GlobalABC), IEA and UNEP, *2019 Global Status Report for Buildings and Construction* (Paris: 2019), <https://www.worldgbc.org/sites/default/files/2019%20Global%20Status%20Report%20for%20Buildings%20and%20Construction.pdf>.
- 38 Based on IEA, op. cit. note 17.
- 39 Based on Ibid.
- 40 GlobalABC, IEA and UNEP, op. cit. note 37.
- 41 IEA, op. cit. note 16; energy demand of buildings based on IEA, op. cit. note 17.
- 42 Based on IEA, op. cit. note 17.
- 43 Factors include a growing population, increased GDP, increase in building floor area per household, increasing urbanisation and access to modern energy services in emerging and developing countries. See IEA, op. cit. note 16, p. 33.
- 44 Based on IEA, "Energy Efficiency Indicators database (2019 edition) – extended version" (Paris: 2019), <http://data.iea.org/payment/products/120-energy-efficiency-indicators-2017-edition.aspx>.
- 45 Based on Ibid.
- 46 Based on Ibid.
- 47 Based on Ibid.
- 48 Enerdata, op. cit. note 17.
- 49 GlobalABC, IEA and UNEP, *2018 Global Status Report: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector* (Paris: 2018), p. 12, <https://www.worldgbc.org/sites/default/files/2018%20GlobalABC%20Global%20Status%20Report.pdf>; United Nations Sustainable Development Goals, *Analysis of the Voluntary National Reviews Relating to Sustainable Development Goal 7* (New York: 2018), https://sustainabledevelopment.un.org/content/documents/258321159DESASDG7_VNR_Analysis2018_final.pdf.
- 50 World Green Building Council, *Advancing Net Zero: Status Report May 2019* (London: 2019), <https://www.worldgbc.org/advancing-net-zero-status-report-2019>.
- 51 International Partnership for Energy Efficiency Cooperation (IPEEC), *Zero Energy Building Definitions and Policy Activity: An International Review* (Paris: 2018), pp. 24-25, https://ipeec.org/upload/publication_related_language/pdf/766.pdf.
- 52 Team Zero, *To Zero and Beyond. Zero Energy Residential Buildings Study. 2018 Inventory of Residential Projects on the Path to Zero in the U.S. and Canada* (Richmond, CA: 2018), <https://teamzero.org/resources/zero-energy-inventory>.
- 53 IPEEC, op. cit. note 51, pp. 24-25.
- 54 ZEBRA2020, "About us", <https://zebra2020.eu/about>, viewed 22 November 2019. The project gathered eight partners from academia, research and private consultancy and included the following countries: Austria, Belgium, the Czech Republic, Denmark, France, Germany, Italy, the Netherlands, Norway, Poland, Lithuania, Luxembourg, Romania, the Slovak Republic, Spain, Sweden and the United Kingdom.
- 55 GlobalABC, IEA and UNEP, op. cit. note 49, p. 12; IEA, "Tracking buildings", <https://www.iea.org/tcep/buildings>, viewed 23 November 2019.
- 56 Enerdata, op. cit. note 17.
- 57 Ibid.
- 58 IEA et al., *Tracking SDG7: The Energy Progress Report 2019* (Washington, DC: 2019), p. 4, <https://www.worldbank.org/en/topic/energy/publication/tracking-sdg7-the-energy-progress-report-2019>.
- 59 IEA, op. cit. note 16, pp. 33-34.
- 60 Ibid., p. 47; IEA, op. cit. note 5, pp. 6, 34.
- 61 Sustainable Energy for All, *2019 Chilling Prospects: Tracking Sustainable Cooling for All* (Vienna: 2019), <https://www.seforall.org/publications/chilling-prospects-2019>.
- 62 Ibid.; Lebanese Center for Energy Conservation, "The COOL_ME project: Scaling-Up Sustainable Cooling in the Middle East", 30 October 2019, <http://lcec.org.lb/en/LCEC/NewsAndMedia#page=4>; IEA, "Green and High-Efficiency Cooling Action Plan", <https://www.iea.org/policies/8512-green-and-high-efficiency-cooling-action-plan>, updated 19 November 2019.
- 63 IEA, "SDG7: Data and Projections. Access to Electricity", <https://www.iea.org/sdg/electricity>, viewed 23 November 2019.
- 64 IEA et al., *Tracking SDG7. The Energy Progress Report, Executive Summary* (Washington, DC: 2019), https://www.seforall.org/sites/default/files/2019-05/TrackingSDG7_execsum-2019.pdf.
- 65 IRENA, *Off-grid Renewable Energy Solutions: Global and Regional Status and Trends* (Abu Dhabi: 2018), <https://www.irena.org/publications/2018/Jul/Off-grid-Renewable-Energy-Solutions>.
- 66 Industrial energy use includes agriculture and based on IEA, op. cit. note 17; Enerdata, op. cit. note 17.
- 67 IEA, "Industry", <https://www.iea.org/tcep/industry>, viewed 13 November 2019; IEA, op. cit. note 16, p. 28.
- 68 IEA, op. cit. note 16, p. 28.
- 69 IEA, op. cit. note 67; IEA, op. cit. note 16, p. 28.
- 70 Based on IEA, op. cit. note 17.
- 71 Based on Ibid.
- 72 Based on Ibid.

- 73 Beyond Zero Emissions, *Zero Carbon Industry Plan: Electrifying Industry* (Melbourne: 2018), <https://bze.org.au/wp-content/uploads/electrifying-industry-bze-report-2018.pdf>; European Commission, *In-Depth Analysis in Support of the Commission Communication (2018) A Clean Planet for All. A European Long-term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy* (Brussels: 2018), p. 142, https://ec.europa.eu/knowledge4policy/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en.
- 74 Based on IEA, op. cit. note 17.
- 75 IEA, *Energy Efficiency 2018: Analysis and Outlook to 2040* (Paris: 2018), <https://www.iea.org/efficiency2018/>.
- 76 Based on IEA, op. cit. note 17.
- 77 L. Cozzi, "Growing preference for SUVs challenges emissions reductions in passenger car market", IEA, 15 October 2019, <https://www.iea.org/commentaries/growing-preference-for-suvs-challenges-emissions-reductions-in-passenger-car-market>.
- 78 Based on IEA, op. cit. note 44.
- 79 Based on Ibid.
- 80 Based on Ibid.
- 81 IEA, op. cit. note 16, pp. 30-31.
- 82 IEA, op. cit. note 75; IEA, *Renewables 2018: Analysis and Forecasts to 2023* (Paris: 2018), <https://webstore.iea.org/market-report-series-renewables-2018>.
- 83 Based on IEA, op. cit. note 17; IEA, *Renewables 2017* (Paris: 2017), <https://www.iea.org/renewables>.
- 84 M. Vieweg et al., *Towards Decarbonising Transport 2018: A Stocktake on Sectoral Ambition in the G20* (Berlin: Agora, 2018), p. 37, <https://www.agora-verkehrswende.de/en/publications/towards-decarbonising-transport-2018>.
- 85 Despite the necessary role that renewable energy would play in decarbonising the transport sector, many adaptations of the ASI framework have failed to include renewable energy or mention the source of energy under the improve section and focus only on energy efficiency. IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition* (Abu Dhabi and Paris: 2018), p. 23, <https://www.irena.org/publications/2018/Apr/Renewable-energy-policies-in-a-time-of-transition>; SLOCAT Partnership on Sustainable, Low Carbon Transit, *Transport and Climate Change Global Status Report 2018* (Shanghai: 2018), p. 3, <https://slocat.net/tcc-gsr>. In developing countries and rural areas, equitable access to transport is also a major concern, from Sustainable Mobility for All, "Mobility for the Future", presentation, 2019, https://www.unece.org/fileadmin/DAM/trans/events/2019/ITC/presentations_81st/4_d__i__SuM4All.pdf. **Figure 60** adapted from SLOCAT, op. cit. this note, p. 3, and from Transformative Urban Mobility Initiative et al., "Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I)" (Eshborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2019), p. 2, https://www.transformative-mobility.org/assets/publications/ASI_TUMI_SUTP_iNUA_No-9_April-2019.pdf.
- 86 Vieweg et al., op. cit. note 84.
- 87 See Policy Landscape chapter and Reference Tables R5 and R10.
- 88 International Council on Clean Transportation (ICCT), *Electric Vehicle Capitals: Showing the Path to a Mainstream Market* (Washington, DC: 2019), <https://theicct.org/publications/ev-capitals-of-the-world-2019>; IEA, *Global EV Outlook 2020* (Paris: 2020), <https://www.iea.org/reports/global-ev-outlook-2020>.
- 89 ICCT, op. cit. note 88; IEA, op. cit. note 88.

FEATURE: PUBLIC SUPPORT FOR RENEWABLES

- 1 **Figure 61** adapted from R. Wüstenhagen, M. Wolsink and M. J. Bürer, "Social acceptance of renewable energy innovation: An introduction to the concept", *Energy Policy*, vol. 35, no. 5 (2007), pp. 2683-91, <https://www.sciencedirect.com/science/article/abs/pii/S0301421506004824>.
- 2 **Box 1** from the following sources: M. Wolsink, "Undesired reinforcement of harmful 'self-evident truths' concerning the implementation of wind power," *Energy Policy*, vol. 48 (September 2012), pp. 83-87, <https://www.sciencedirect.com/science/article/abs/pii/S0301421512005174>; G. Ellis, J. Barry and C. Robinson, "Many ways to say 'no', different ways to say 'yes': Applying Q-methodology to understand public acceptance of wind farm proposals", *Journal of Environmental Planning and Management*, vol. 50, no. 4 (2007), pp. 517-51, <https://www.tandfonline.com/doi/abs/10.1080/09640560701402075>; M. Wolsink, "Wind power and the NIMBY-myth: Institutional capacity and the limited significance of public support", *Renewable Energy*, vol. 21, no. 1 (2000), pp. 49-64, <https://www.sciencedirect.com/science/article/abs/pii/S0960148199001305>; P. Devine-Wright, "Rethinking NIMBYism: The role of place attachment and place identity in explaining place-protective action", *Journal of Community & Applied Social Psychology*, vol. 19, no. 6 (2009), pp. 426-41, <https://onlinelibrary.wiley.com/doi/abs/10.1002/casp.1004>.
- 3 C. De Laurentis and P. J. Pearson, "Understanding the material dimensions of the uneven deployment of renewable energy in two Italian regions", *Energy Research & Social Science*, vol. 36 (February 2018), pp. 106-19, <https://www.sciencedirect.com/science/article/abs/pii/S2214629617303985>; O. Bayulgen and J. W. Ladewig, "Vetoing the future: Political constraints and renewable energy", *Environmental Politics*, vol. 26, no. 1 (2017), pp. 49-70, <https://www.tandfonline.com/doi/full/10.1080/09644016.2016.1223189>; R. Cowell et al., "Rescaling the governance of renewable energy: Lessons from the UK devolution experience", *Journal of Environmental Policy & Planning*, vol. 19, no. 5 (2017), pp. 480-502, <https://www.tandfonline.com/doi/full/10.1080/1523908X.2015.1008437>; D. Newbery et al., "Market design for a high-renewables European electricity system", *Renewable and Sustainable Energy Reviews*, vol. 91 (August 2018), pp. 695-707, <https://www.sciencedirect.com/science/article/abs/pii/S1364032118302454>.
- 4 For example, support for renewables is highest among those in the 55-plus age bracket, among those who would classify themselves as "liberal" and among those with some university education, from Edelman Intelligence, *Green Energy Barometer* (Fredericia, Denmark: Ørsted, 2017), https://orstedcdn.azureedge.net/-/media/WWW/Docs/Corp/COM/Campaigns/Barometer-campaign/Green-Energy-Barometer-2017_with-appendix.ashx. A survey of a random sample of residents of the US state of Maine showed that both concern for the environment and everyday "green" behaviour (e.g., recycling, buying eco-labelled products, etc.) was an important predictor of acceptance of wind energy, and that both everyday "green" behaviour and the acceptance of wind power were rooted in environmental concern, from J. Thøgersen and C. Noblet, "Does green consumerism increase the acceptance of wind power?" *Energy Policy*, vol. 51 (December 2012), pp. 854-62, <https://www.sciencedirect.com/science/article/abs/pii/S0301421512008191>.
- 5 US Environmental Protection Agency, *Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy – Full Report* (Washington, DC: 2018), <https://www.epa.gov/statelocalenergy/quantifying-multiple-benefits-energy-efficiency-and-renewable-energy-guide-state>.
- 6 See, for example: J. Moyo, "Solar cures energy ills at Zimbabwe's power-short clinics", *Reuters*, 21 December 2018, <https://www.reuters.com/article/us-zimbabwe-health-energy-solar/solar-cures-energy-ills-at-zimbabwes-power-short-clinics-idUSKCN1OK0QV>; J. J. Buonocore et al., "Health and climate benefits of different energy-efficiency and renewable energy choices", *Nature Climate Change*, vol. 6, no. 1 (2016), pp. 100-05, <https://www.nature.com/articles/nclimate2771>; S. V. Valentine, "Emerging symbiosis: Renewable energy and energy security", *Renewable and Sustainable Energy Reviews*, vol. 15, no. 9 (2011), pp. 4572-78, <https://www.sciencedirect.com/science/article/abs/pii/S1364032111003406>; Intergovernmental Panel on Climate Change, *Special Report: Renewable Energy Sources and Climate Change Mitigation Summary for Policy Makers and Technical Summary* (New York and Geneva: Cambridge University Press, 2011), https://www.ipcc.ch/site/assets/uploads/2018/03/SRREN_FD_SPM_final-1.pdf; S. Szabó et al., "Sustainable energy planning: Leapfrogging the energy poverty gap in Africa", *Renewable and Sustainable Energy Reviews*, vol. 28 (December 2013), pp. 500-09, <https://www.sciencedirect.com/science/article/abs/pii/S1364032113005844>.
- 7 A. L. Berka and E. Creamer, "Taking stock of the local impacts of community owned renewable energy: A review and research agenda", *Renewable and Sustainable Energy Reviews*, vol. 82, pt. 3 (February 2018), pp. 3400-19, <https://www.sciencedirect.com/science/article/abs/pii/S1364032117314247>.
- 8 European Commission, *Europeans' Attitudes on EU Energy Policy* (Brussels: September 2019), <https://op.europa.eu/en/publication-detail/-/publication/b891cfb7-d50f-11e9-b4bf-01aa75ed71a1>. In total, 80% of Europeans were in favour of the use of solar energy, 71% for wind energy, 65% for hydroelectric and 60% for marine energy, with only a small number of respondents opposing these energy sources. In contrast, only 27% and 26% favoured the use of oil and coal, respectfully.
- 9 E3G, "Polling finds citizens in six belt and road countries want clean energy, not coal", press release (London/Brussels/Berlin/Washington: 24 April 2019), <https://www.e3g.org/news/media-room/polling-citizens-six-belt-and-road-countries-want-clean-energy-not-coal>.
- 10 Greenpeace, "Poll: Australians want renewable energy", 6 August 2018, <https://www.greenpeace.org.au/research/polling-australians-want-renewable-energy>; Lowy Institute, "Climate change and energy", 2019, <https://lowyinstitutepoll.lowyinstitute.org/themes/climate-change-and-energy>; A. Boutillier, "Canadians back shift to renewable energy: Poll", *The Star*, 22 January 2018, <https://www.thestar.com/news/canada/2018/01/22/canadians-back-shift-to-renewable-energy-poll.html>; ADEME, "#Barometre: Les Français et l'environnement", press release (Montrouge, France: 11 February 2020), <https://presse.ademe.fr/2020/02/barometre-les-francais-et-lenvironnement.html>; J. Cousse, M. Kubli and R. Wüstenhagen, *10th Consumer Barometer of Renewable Energy* (St. Gallen, Switzerland: University of St. Gallen, April 2020), https://kuba.iwoe.unisg.ch/wp-content/uploads/Technical-report_Consumer-Barometer_2020.pdf; C. Roselund, "2/3 of U.S. voters say 100% renewable electricity by 2030 is important", *pv magazine*, 19 April 2019, <https://pv-magazine-usa.com/2019/04/19/2-3-of-u-s-voters-say-100-renewable-electricity-by-2030-is-important/>; T. Cama, "Greens' poll shows support for renewable energy transition in swing states", *The Hill*, 19 March 2018, <https://thehill.com/policy/energy-environment/379097-greens-poll-shows-support-for-renewable-energy-transition-in-swing>.
- 11 Ørsted, "The largest-ever survey of attitudes towards green energy", <https://orsted.com/en/Barometer>, viewed 27 March 2020.
- 12 D. Bell, T. Gray and C. Haggett, "The 'social gap' in wind farm siting decisions: Explanations and policy responses", *Environmental Politics*, vol. 14, no. 4 (2005), pp. 460-77, <https://rsa.tandfonline.com/doi/abs/10.1080/09644010500175833>.
- 13 C. Von Borgstede, M. Andersson and F. Johnsson, "Public attitudes to climate change and carbon mitigation – Implications for energy-associated behaviours", *Energy Policy*, vol. 57 (June 2013), pp. 182-93, <https://www.sciencedirect.com/science/article/abs/pii/S0301421513000785>.
- 14 M. Taylor, J. Watts and J. Bartlett, "Climate crisis: 6 million people join latest wave of protests", *The Guardian* (UK), 27 September 2019, <https://www.theguardian.com/environment/2019/sep/27/climate-crisis-6-million-people-join-latest-wave-of-worldwide-protests>. Similar social movements have emerged in recent years that push for government action against climate change; see, for example: "Extinction Rebellion", *The Guardian* (UK), <https://www.theguardian.com/environment/extinction-rebellion>, viewed 27 March 2020.
- 15 London School of Economics, Global institute on Climate Change and the Environment, *Global Trends in Climate Change Litigation: 2019 Snapshot* (London: 4 July 2019), <http://www.ise.ac.uk/GranthamInstitute/publication/global-trends-in-climate-change-litigation-2019-snapshot>. For example, in the Netherlands a 2018 lawsuit obliged the government to increase its carbon emissions reduction goal to 25% in 2020 instead of an initial 17%, from J. Cossardeaux, "Climat: Les Pays-Bas épinglés par la justice pour leur manque d'ambition",

- Les Échos, 9 October 2018, <https://www.lesechos.fr/monde/enjeux-internationaux/climat-les-pays-bas-epingles-par-la-justice-pour-leur-manque-dambition-141333>. In France, four non-governmental organisations filed a lawsuit against the state for neglecting its duties against global warming and doing too little to fight climate change. The lawsuit, nicknamed "L'Affaire du siècle" (The case of the century), was supported by a petition signed by more than 2 million people and received considerable media attention. The complainants ask for a moral and ecological prejudice to be recognised and intend for the action to push towards a recognition of the duties of the state in the fight against climate change. See Cimatecasechart.org, "Database of climate change caselaw: Notre Affaire à Tous and Others v. France", 2018, <http://climatecasechart.com/non-us-case/notre-affaire-a-tous-and-others-v-france>.
- 16 For example, in late 2019, a legal commission in the Philippines concluded that 47 corporations including BP, Total, Shell and ExxonMobil were found to have played a clear role in anthropogenic climate change and could be held legally and morally liable for human rights violations to Filipinos as a result of climate change impacts. While the Commission's findings have no legal weight, they could lead to stricter regulations, increased pressure on companies and even encourage countries to establish legal liability in their courts and hold these companies civilly and/or criminally accountable. I. Kaminski, "Carbon majors can be held liable for human rights violations, Philippines commission rules", Climate Liability News, 9 December 2019, <https://www.climateabilitynews.org/2019/12/09/philippines-human-rights-climate-change-2>. In the United Kingdom, Friends of the Earth brought a case against the proposed expansion of Heathrow Airport, from T. Espiner, "Climate campaigners win Heathrow expansion case", BBC, 27 February 2020, <https://www.bbc.co.uk/news/business-51658693>.
- 17 B. Quinn and J. Henley, "Yellow vests: protesters fight for ideological ownership", *The Guardian* (UK), 13 January 2019, <https://www.theguardian.com/world/2019/jan/13/yellow-vests-protesters-fight-for-ideological-ownership>; A. Abu Omar, "Protests erupt across Iran after gasoline-price increase", *Bloomberg*, 16 November 2019, <https://www.bloomberg.com/news/articles/2019-11-16/protests-erupt-in-iranian-cities-after-fuel-price-hike-irna>; J. Gambrell, "AP explains: Iran gas price protests quickly turn violent", ABC News, 18 November 2019, <https://abcnews.go.com/Politics/wireStory/ap-explains-iran-gas-price-protests-quickly-turn-67101344>.
- 18 Although ultimately growing to encompass more than one singular issue, the protests in France arose from the implementation of a fuel tax as part of France's "ecological transition" to move away from fossil fuels by making them more expensive, and to encourage the use of renewable sources; see A. Gopnik, "The yellow vests and why there are so many street protests in France", *New Yorker*, 6 December 2018, <https://www.newyorker.com/news/daily-comment/the-yellow-vests-and-why-there-are-so-many-street-protests-in-france>.
- 19 "Ontario government cancels 758 renewable energy contracts, says it will save millions", CBC, 13 July 2018, <https://www.cbc.ca/news/canada/toronto/758-renewable-energy-cancelled-1.4746293>; "Doug Ford's vow to fight federal carbon tax part of concerted effort, prof says", CBC Radio, 20 June 2018, <http://www.cbc.ca/radio/thecurrent/the-current-for-june-20-2018-1.4713749/doug-ford-s-vow-to-fight-federal-carbon-tax-part-of-concerted-effort-prof-says-1.4713865>; B. Labby, "Industry worries new Alberta government will cancel solar-power rebates", CBC, 13 May 2019, <https://www.cbc.ca/news/canada/calgary/alberta-solar-energy-rebates-uncertainty-1.5131001>.
- 20 S. Nazalya and O. Dobson, "Human rights challenges flying below radar for renewables", GTM, 16 October 2019, <https://www.greentechmedia.com/articles/read/human-rights-challenges-flying-under-radar-for-renewables-industry>.
- 21 According to a 2019 industry report, less than half of 109 surveyed renewable energy companies had enacted human rights policies, from Columbia Center on Sustainable Investment, "Renewable energy poses a serious threat to human rights — but it doesn't have to", 5 September 2019, <https://blogs.ei.columbia.edu/2019/09/05/renewable-energy-human-rights>.
- 22 Transition Network, "Transition near me", <https://transitionnetwork.org/transition-near-me>, viewed 29 April 2020. The Transition Town movement began in 2005 in Kinsale (Ireland) when permaculture students decided to design an Energy Descent Action Plan to reduce their dependency on fossil fuels and overall consumption of energy. Kinsale's Energy Action Plan, designed in 2005, included elements such as: increased self-reliance for food production; carbon neutrality with energy use reduction and total reliance on renewable energy sources and especially wind; sustainable and energy-efficient housing; and eco-friendly transport systems, from Transition Town Kinsale, "Summary of the Kinsale Energy Descent Action Plan" (Kinsale, Ireland: 2012), <http://www.transitiontownkinsale.org/wp-content/uploads/2012/07/TTK-booklet-for-website-2012.pdf>.
- 23 On Samsø, 5 of 10 offshore turbines are owned by the municipality, 3 by private investors and 2 by several small shareholders, while 9 of the onshore wind turbines are owned by local farmers and 2 by local co-operatives. The island has been "energy positive" since 2000, and in 2019 its inhabitants had a negative carbon footprint. Rapid Transition Alliance, "Stories: The world's first renewable island – when a community embraces wind power", 4 February 2019, <https://www.rapidtransition.org/stories/the-worlds-first-renewable-island-when-a-community-embraces-wind-power>.
- 24 Devine-Wright, op. cit. note 2.
- 25 S. Batel et al., "Developing a critical agenda to understand pro-environmental actions: Contributions from social representations and social practices theories", *Climate Change*, vol. 7, no. (2016), pp. 727-45, <http://eprints.lse.ac.uk/67289>.
- 26 S. Derya, "Jeotermalin etkileri uluslararası raporlarla aydınlanacak", *Jesder*, 7 July 2019, <https://jesder.org/jeotermalin-etkileri-uluslararasi-raporlarla-aydinlanacak>; "Jeotermal Enerji Santralleri İçin 'Etik Kurul' ile Üst Denetim Yapılanması", *Enerji Gazetesi*, 20 October 2019, <https://www.enerjigazetesi.ist/jeotermal-enerji-santralleri-icin-etik-kurul-ile-ust-denetim-yapilanmasi>; S. Avila, "Environmental justice and the expanding geography of wind power conflicts", *Sustainability Science*, vol. 13 (2018), pp. 599-616, <http://link.springer.com/article/10.1007/s11625-018-0547-4>; D. J. Hess, "Industrial fields and countervailing power: The transformation of distributed solar energy in the United States", *Global Environmental Change*, vol. 23, no. 5 (2013), pp. 847-55, <https://www.sciencedirect.com/science/article/abs/pii/S0959378013000198>; B. K. Sovacool et al., "Halting hydro: A review of the socio-technical barriers to hydroelectric power plants in Nepal", *Energy*, vol. 36, no. 5 (2011), pp. 3468-76, <https://www.sciencedirect.com/science/article/abs/pii/S0360544211002192>; N. Muzi, "Seven in 10 Europeans are against burning palm oil in their cars – poll", *Transport & Environment*, 21 November 2018, <https://www.transportenvironment.org/press/seven-10-europeans-are-against-burning-palm-oil-their-cars-poll>.
- 27 Interest is emerging in an overall concept of energy justice; see K. Jenkins et al., "Energy justice: A conceptual review", *Energy Research & Social Science*, vol. 11 (January 2016), pp. 174-82, <https://www.sciencedirect.com/science/article/abs/pii/S2214629615300669>.
- 28 For example, there is a strong association between individuals' attitudes to renewable energy and their concerns around climate change. Renewable Energy Policy Network for the 21st Century (REN21), *Renewables in Cities 2019 Global Status Report* (Paris: 2019), https://www.ren21.net/wp-content/uploads/2019/05/REC-2019-GSR_Full_Report_web.pdf.
- 29 Government of Mauritius, "National awareness campaign on renewable energy launched", press release (Port Louis, Mauritius: 30 January 2020), <http://www.govmu.org/English/News/Pages/National-Awareness-Campaign-on-Renewable-Energy-launched.aspx>; Government of the Netherlands, "Central government promotes energy savings", <https://www.government.nl/topics/renewable-energy/central-government-promotes-energy-savings>, viewed 29 April 2020.
- 30 Global Bioenergy Partnership, "Working together for sustainable development since 2006", <http://www.globalbioenergy.org/>, viewed 29 April 2020.
- 31 European Parliament, "The European Parliament declares climate emergency", press release (Brussels: 29 November 2019), <https://www.europarl.europa.eu/news/en/press-room/20191121PR67110/the-european-parliament-declares-climate-emergency>.
- 32 Climate Emergency Declaration, "Climate emergency declarations in 1,488 jurisdictions and local governments cover 820 million citizens", 5 May 2020, <https://climateemergencydeclaration.org/climate-emergency-declarations-cover-15-million-citizens>.
- 33 People and Planet, "Join the Fossil Free Campaign", <https://peopleandplanet.org/fossil-free>, viewed 29 April 2020.

- 34 Greenpeace, "Reenergise", <https://act.greenpeace.org.au/reenergise>, viewed 29 April 2020.
- 35 FIT schemes have been introduced from the 1990s onwards in many countries and regions, including the following: Europe, from RES Legal, "Legal Sources on Renewable Energy", <http://www.res-legal.eu>, viewed 29 April 2020; US states, from US Energy Information Administration, "Feed-in tariff: A policy tool encouraging deployment of renewable electricity technologies", 30 May 2013, <https://www.eia.gov/todayinenergy/detail.php?id=11471>; and Latin America, from REN21, *Renewable Energy Tenders and Community [Empowerment]: Latin America and the Caribbean* (Paris: 2017), <https://www.ren21.net/2017-renewable-energy-tenders-and-community-empowerment-lac>.
- 36 M. J. Burke and J. C. Stephens, "Energy democracy: Goals and policy instruments for sociotechnical transitions", *Energy Research & Social Science*, vol. 33 (November 2017), pp. 35-48, <https://www.sciencedirect.com/science/article/pii/S2214629617303031>; M. D. Leiren and I. Reimer, "Historical institutionalist perspective on the shift from feed-in tariffs towards auctioning in German renewable energy policy", *Energy Research & Social Science*, vol. 43 (September 2018), pp. 33-40, <https://www.sciencedirect.com/science/article/pii/S2214629618305152>.
- 37 International Renewable Energy Agency (IRENA), *Renewable Energy Auctions: A Guide to Design* (Abu Dhabi: 2015), <https://www.irena.org/publications/2015/Jun/Renewable-Energy-Auctions-A-Guide-to-Design>.
- 38 K. Grashof, "Are auctions likely to deter community wind projects? And would this be problematic?" *Energy Policy*, vol. 125 (February 2019), pp. 20-32, <https://www.sciencedirect.com/science/article/abs/pii/S0301421518306633>; H. J. Fell, *The Shift from Feed-in-Tariffs to Tenders Is Hindering the Transformation of the Global Energy Supply to Renewable Energies* (Berlin: Energy Watch Group, 2017), http://energywatchgroup.org/wp-content/uploads/2018/01/2017-07-15-Policy_Paper_Feed-in-Tariff-Tenders.pdf; IRENA, *Renewable Energy Auctions: Analysing 2016* (Abu Dhabi: 2017), <https://www.irena.org/publications/2017/Jun/Renewable-Energy-Auctions-Analysing-2016>.
- 39 Government of Ireland, Department of Communications, Climate Action and Environment (DCCAE), "Renewable Electricity Support Scheme (RESS)", <https://www.dccae.gov.ie/en-ie/energy/topics/Renewable-Energy/electricity/renewable-electricity-supports/ress/Pages/default.aspx>, viewed 29 April 2020; C. Klessmann and S. Tiedemann, "Germany's first renewables auctions are a success, but new rules are upsetting the market", *Energy Post*, 27 July 2017, <https://energypost.eu/germanys-first-renewables-auctions-are-a-success-but-new-rules-are-upsetting-the-market>.
- 40 Y. Parag and B. K. Sovacool, "Electricity market design for the prosumer era", *Nature Energy*, vol. 1, no. 4 (2016), pp. 1-6, <https://www.nature.com/articles/nenergy201632>.
- 41 S. MacDonald and N. Eyre, "An international review of markets for voluntary green electricity tariffs", vol. 91 (August 2018), pp. 180-92, <https://doi.org/10.1016/j.rser.2018.03.028>; Modra Energija, <http://www.modra-energija.si/si>, viewed 29 April 2020; EKOenergy Network, *Energy in Action Annual Report 2015* (Helsinki: 2015), <https://www.ekoenergy.org/fr/annual-report-2015-ekoenergy-in-action>; Green-e, <https://www.green-e.org>, viewed 29 April 2020; Nano Energies, <https://www.nanoenergies.cz/?lang=en>, viewed 29 April 2020.
- 42 International Labour Organization, "Guidelines for a just transition towards environmentally sustainable economies and societies for all" (Geneva: 2 February 2016), https://www.ilo.org/global/topics/green-jobs/publications/WCMS_432859/lang--en/index.htm; N. Healy and J. Barry, "Politicizing energy justice and energy system transitions: Fossil fuel divestment and a 'just transition'", *Energy Policy*, vol. 108 (September 2017), pp. 451-59, <https://www.sciencedirect.com/science/article/abs/pii/S0301421517303683>.
- 43 European Commission (EC), "Communication from the Commission: The European Green Deal" (Brussels: 11 December 2019), https://ec.europa.eu/info/files/communication-european-green-deal_en; EC, "Financing the green transition: The European Green Deal Investment Plan and Just Transition Mechanism", press release (Brussels: 14 January 2020), https://ec.europa.eu/commission/presscorner/detail/en/ip_20_17; European Parliament, "Just Transition Fund" (Brussels: 2020), [https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/646180/EPRS_BRI\(2020\)646180_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/646180/EPRS_BRI(2020)646180_EN.pdf); Industrial Global Union, "Spanish coal unions win landmark Just Transition deal", 1 November 2018, <http://www.industrial-union.org/spanish-coal-unions-win-landmark-just-transition-deal>; DCCAE, "Accelerated exit from peat will be accompanied by just transition for workers and the Midlands – Minister Bruton", 8 November 2019, <https://dccae.gov.ie/en-ie/news-and-media/press-releases/Pages/-Accelerated-Exit-from-Peat-will-be-accompanied-by-Just-Transition-for-Workers-and-the-Midlands-%E2%80%93-Minister-Bruton-Accelerat.aspx>; Just Transition Fund, <https://www.justtransitionfund.org>, viewed 29 April 2020.
- 44 R. Cowell and P. Devine-Wright, "A 'delivery-democracy dilemma'? Mapping and explaining policy change for public engagement with energy infrastructure", *Journal of Environmental Policy & Planning*, vol. 20, no. 4 (2018), pp. 499-517, <https://www.tandfonline.com/doi/full/10.1080/1523908X.2018.1443005>.
- 45 G. Bristow, R. Cowell and M. Munday, "Windfalls for whom? The evolving notion of 'community' in community benefit provisions from wind farms", *Geoforum*, vol. 43, no. 6 (2012), pp. 1108-20, <https://www.sciencedirect.com/science/article/abs/pii/S0016718512001455>.
- 46 Scottish Government, "Scottish Crown Estate - Devolution delivering for coastal communities.", 29 September 2019, <https://www.gov.scot/news/scottish-crown-estate-3> and Local Energy Scotland, "Review the Community Benefit Register", <https://www.localenergy.scot/projects-and-case-studies/searchable-register-of-community-benefits>, viewed 29 April 2020; M. L. Jørgensen et al., "Distributive fairness and local acceptance of wind turbines: The role of compensation schemes", *Energy Policy*, vol. 138 (March 2020), p. 111294, <https://www.sciencedirect.com/science/article/abs/pii/S0301421520300525>.
- 47 See, for example: J. Stephens, "Energy democracy: Redistributing power to the people through renewable transformation", *Environment: Science and Policy for Sustainable Development*, vol. 61, no. 2 (2019), pp. 4-13, <https://www.tandfonline.com/doi/full/10.1080/00139157.2019.1564212>.
- 48 Citizens' Assembly Ireland, "How the state can make Ireland a leader in tackling climate change", <https://www.citizensassembly.ie/en/how-the-state-can-make-ireland-a-leader-in-tackling-climate-change>, viewed 29 April 2020; D. Rainer, "In Mauritius, the fight for clean energy is a battle against inequality", *Open Democracy*, 23 April 2018, <https://www.opendemocracy.net/en/tc-port-louis-energy-transition>; K. Szulecki, "Conceptualizing energy democracy", *Environmental Politics*, vol. 27, no. 1 (2018), pp. 21-41, <https://www.tandfonline.com/doi/full/10.1080/09644016.2017.1387294>.
- 49 T. von Wirth, L. Gislason and R. Seidl, "Distributed energy systems on a neighborhood scale: Reviewing drivers of and barriers to social acceptance", *Renewable and Sustainable Energy Reviews*, vol. 82, pt. 3 (February 2018), pp. 2,618-28, <https://www.sciencedirect.com/science/article/abs/pii/S1364032117313412>.
- 50 Burke and Stephens, op. cit. note 36.
- 51 Transnational Institute (TNI), *Towards Energy Democracy: Discussions and Outcomes from an International Workshop, Amsterdam, 11-12 February 2016* (Amsterdam: May 2016), https://www.tni.org/files/publication-downloads/energy_democracy_workshop_report_for_web-2.pdf.
- 52 Asian Development Bank, *Baikonyr Solar Power Project: Stakeholder Engagement Plan* (Manila: 2017), <https://www.adb.org/projects/documents/kaz-51250-001-dpta>; Pamir Energy, *Rural Electrification Project Stakeholder Engagement Plan* (Washington, DC: World Bank, May 2019), <http://documents.worldbank.org/curated/en/817421569768404590/pdf/STakeholder-Engagement-Plan-SEP-Support-for-Preparation-of-the-Rural-Electrification-Sebzor-HPP-and-Khorog-Qozideh-Power-Transmission-Line-Projects-P171248.pdf>; Asia-Plus, "Sebzor hydropower plant expected to be introduced into operation in 2022", 26 December 2019, <https://asiaplustj.info/en/news/tajikistan/economic/20191226/sebzor-hydropower-plant-expected-to-be-introduced-into-operation-in-2022>.
- 53 DCCAE, op. cit. note 39; IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), Box 4.4, <https://www.irena.org/publications/2019/Dec/Renewable-energy-auctions-Status-and-trends-beyond-price>.
- 54 A. Cumbers, "Remunicipalization, the low-carbon transition, and energy democracy", in Worldwatch Institute, *State of the World 2016: Can a City Be Sustainable?* (Washington, DC: Island Press, 2016), pp. 275-89, <https://link.springer>.

- com/chapter/10.5822/978-1-61091-756-8_23; A. Rüdinger, "Local energy ownership in Europe", *Energy Cities* (Brussels: 2017), <https://energy-cities.eu/publication/local-energy-ownership-in-europe>. By 2019 there had been 374 examples of re-municipalisation, 90% of which were in Germany and other examples from the US, UK and Japan, from TNI, *The Future Is Public: Towards Democratic Ownership of Public Services* (Amsterdam: December 2019), https://www.tni.org/files/publication-downloads/tni_the-future-is-public_online.pdf.
- 55 S. Becker, "Chapter 8 – Our city, our grid: The energy remunicipalisation trend in Germany", in TNI, *Reclaiming Public Services: How Cities and Citizens Are Turning Back Privatisation* (Amsterdam: 23 June 2017), pp. 118-30, https://www.tni.org/files/publication-downloads/reclaiming_public_services.pdf; T. Moss, "Historicising accountability: Berlin's energy transitions", in S. Sareen, ed., *Enabling Sustainable Energy Transitions* (12 October 2019), https://link.springer.com/chapter/10.1007/978-3-030-26891-6_4; World Future Council, "Energy remunicipalisation: How Hamburg is buying back energy grids", 19 October 2016, <https://www.worldfuturecouncil.org/energy-remunicipalisation-hamburg-buys-back-energy-grids>.
- 56 Resilience, "El Cuá, Nicaragua: Community-owned hydropower transforms rural economy", *Transformative Cities*, 22 January 2019, <https://www.resilience.org/stories/2019-01-22/el-cua-nicaragua-community-owned-hydropower-transforms-rural-economy>; Aran Islands Energy Co-op, "Welcome to the Aran Islands Energy Co-op", <http://www.aranislandsenergycoop.ie/contact-us/welcome>, viewed 29 April 2020.
- 57 N. Yamashita, Institute for Sustainable Energy Policies, "Experiences and lessons from the community-based renewable energy development in Japan", presentation at Asia Clean Energy Forum 2018, Manila, 8 May 2018, <https://pronto-core-cdn.prantomarketing.com/449/wp-content/uploads/sites/2/2018/06/Noriaki-Yamashita-Experiences-and-Lessons-from-the-Community-based-Renewable-Energy-Development-in-Japan.pdf>.
- 58 D. Chavez, "COOPELESCA, Costa Rica", *Energy Democracy*, 12 December 2016, <https://www.energy-democracy.net/?p=367>.

REFERENCE TABLES

- 1 **Table R1** from the following sources: **Bio-power** based on the following: US Federal Energy Regulatory Commission, "Office of Energy Projects Energy Infrastructure Update for December 2019" (Washington, DC: 2019), <https://www.ferc.gov/legal/staff-reports/2018/dec-energy-infrastructure.pdf>; Federal Ministry for Economic Affairs and Energy (BMWi), "Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, 1990-2019", Table 5, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html, updated March 2020; UK Department for Business, Energy and Industrial Strategy (BEIS), "Energy Trends: Renewables", Table 6.1, <https://www.gov.uk/government/statistics/energy-trends-section-6-renewables>, updated 26 March 2020; Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements) for 2018 and 2019", <https://mnre.gov.in/physical-progress-achievements>, viewed 23 February 2020; data for other countries based on forecast 2019 capacity figures from International Energy Agency (IEA), *Renewables 2019* (Paris: 2019), <https://www.iea.org/reports/renewables-2019>, datafiles. **Geothermal power** from sources in endnote 1 of Geothermal section in Market and Industry chapter, and from country-specific sources noted elsewhere in that section. **Hydropower** from sources in endnotes 1 and 2 of Hydropower section in Market and Industry chapter. **Ocean power** from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2020* (Abu Dhabi: March 2020), <https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020>. **Solar PV** from sources in endnote 16 of this section. **CSP** from sources in endnote 17 of this section. **Wind power** from sources in endnote 19 of this section. **Modern bio-heat** consumption based on the following: Estimate for modern bio-heat in 2018 of 13.2 EJ direct heat and 0.7 EJ from district heating and an anticipated annual growth rate of 1.8% and 4.0% respectively from IEA, op. cit. this note, making it 14.1 EJ total in 2018. **Geothermal heat** from estimates of annual growth is based on a survey report published in early 2020. The annual growth estimate for 2019 is based the annualised growth rate in the five-year period since 2014. See endnote 64 in Geothermal section of Market and Industry chapter. **Solar collectors for water heating** from sources in endnote 18 of this section. **Ethanol** from US Energy Information Administration (EIA), *Monthly Energy Review*, March 2020, Table 10.3, <https://www.eia.gov/totalenergy/data/monthly/#renewable>, and from Brazil Agencia Nacional do Petroleo, Gas Natural e Biocombustiveis (ANP), "Dados estatísticos", <http://www.anp.gov.br/dados-estatisticos>, viewed 24 February 2019. Biodiesel from EIA, op. cit. this note, Table 10.4, from ANP, op. cit. this note and from Argentine Ministry of Energy and Mines, "Energy Market Statistics", resumen biodiesel, <http://datos.minem.gob.ar/dataset/estadisticas-de-biodiesel-y-bioetanol>. Other ethanol and biodiesel data based on biofuels data in IEA, *Oil 2020* (Paris: 2020), <https://www.iea.org/reports/oil-2020>. HVO production is estimated based on a review of the production of the major producers.
- 2 **Table R2** from the following sources: For all **global data**, see endnote 1 for this section and other relevant reference tables. For more-specific data and sources, see Global Overview and Market and Industry chapters and related endnotes. For sources for **BRICS, EU and individual countries**, see endnote 5 in Global Overview chapter. **Per capita data** are based on capacity data provided in Reference Table R2 and on 2018 country population data from World Bank, "Population, total", World Development Indicators, <http://data.worldbank.org/indicator/SP.POP.TOTL>, updated 19 May 2020.
- 3 **Table R3** from sources in REN21 GSR 2020 data pack, available online at www.ren21.net/GSR.
- 4 **Table R4** from Ibid.
- 5 **Table R5** from Ibid.
- 6 **Table R6** from Ibid.
- 7 **Table R7** from Ibid.
- 8 **Table R8** from Ibid.
- 9 **Table R9** from Ibid.
- 10 **Table R10** from Ibid.
- 11 **Table R11** from Ibid.
- 12 **Table R12** from Ibid.
- 13 **Table R13** from sources in endnote 1 of this section.
- 14 **Table R14** from sources in endnote 1 of this section.
- 15 **Table R15** from sources in endnote 1 of this section.
- 16 **Table R16** from the following sources: Unless noted otherwise, data for end-2018 from the following: IEA Photovoltaic Power Systems Programme (PVPS), *Trends 2019 in Photovoltaic Applications: Survey Report of Selected IEA Countries Between 1992 and 2018* (Paris: 2019), pp. 96, 97, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/5319_iea-pvps_report_2019_08_lr.pdf; Becquerel Institute, Brussels, personal communication with REN21, February-May 2020; SolarPower Europe, *EU Market Outlook for Solar Power, 2019-2023* (Brussels: December 2019), https://www.solarpowereurope.org/wp-content/uploads/2019/12/SolarPower-Europe_EU-Market-Outlook-for-Solar-Power-2019-2023_.pdf; SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023* (Brussels: 2019), p. 22, <https://www.solarpowereurope.org/global-market-outlook-2019-2023>. Data for 2019 from the following: IEA PVPS, *Snapshot of Global PV Markets 2020* (Paris: April 2020), https://iea-pvps.org/wp-content/uploads/2020/04/IEA_PVPS_Snapshot_2020.pdf; Becquerel Institute, op. cit. this note; SolarPower Europe, *EU Market Outlook for Solar Power, 2019-2023*, op. cit. this note; and sources provided below. This report aims to provide all solar PV data in direct current (DC) units. Note that some countries (for example, Canada, Chile, India, Japan, Malaysia, Sweden and the United States) report data officially in alternating current (AC); for consistency across countries, AC data were converted to DC by the relevant sources listed. Additional country sources are as follows: **China**: Total end-2018 from the following: Becquerel Institute, op. cit. this note; China's National Energy Administration (NEA), "2018 added solar PV capacities," *Finance World*, 28 January 2019, <https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&for=pc> (using Google Translate); NEA, "Photovoltaic power generation statistics for 2018," 19 March 2019, http://www.nea.gov.cn/2019-03/19/c_137907428.htm (using Google Translate); China Electricity Council (CEC), cited in China Energy Portal, "2018 electricity & other energy statistics," 25 January 2019, <https://chinaenergyportal.org/en/2018-electricity-other-energy-statistics>. Additions and total in 2018 from NEA, "PV grid-connected operation in 2019," 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827923.htm (using Google Translate), and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 10. **United States**: Solar Energy Industries Association and Wood Mackenzie, *U.S. Solar Market Insight, 2019 Year in Review – Executive Summary* (Washington, DC: March 2020), p. 5, <https://www.woodmac.com/research/products/power-and-renewables/us-solar-market-insight>; US EIA, *Electric Power Monthly with Data for December 2019* (Washington, DC: February 2020), Table 6.1, <https://www.eia.gov/electricity/monthly/archive/february2020.pdf>. **India**: IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 10; Government of India, MNRE, "Physical progress (achievements)", <http://mnre.gov.in/mission-and-vision-2/achievements>, viewed 30 January 2019; MNRE, "Physical progress (achievements)", <https://mnre.gov.in/the-ministry/physical-progress>, viewed 9 January 2020. **Japan**: IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; RTS Corp, cited in T. Ohigashi and I. Kaizuka, "The beginnings of a post FIT-market", *pv magazine*, 25 February 2020, <https://www.pv-magazine.com/2020/02/25/the-beginnings-of-a-post-fit-market/>; data in AC, based on grid-connected capacity of utilities, provided by H. Matsubara, Institute for Sustainable Energy Policies, Tokyo, personal communication with REN21, 14 April 2020. **Vietnam**: IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; Becquerel Institute, provided by A. Detollenaere, Becquerel Institute, personal communication with REN21, 10 April 2020. **Spain**: Carlos De Sande, Unión Española Fotovoltaica (UNEF), Madrid, personal communication with REN21, 28 May 2020. UNEF numbers are based on data from the Spanish system operator RED Eléctrica de España, which are in DC and for utility-scale plants only, plus UNEF's estimates of solar PV capacity for self-consumption. See also RED Eléctrica de España, "Potencia instalada nacional (MW) – nacional", data as of April 2020, <https://www.ree.es/datos/publicaciones/series-estadisticas-nacionales>. **Germany**: German Federal Ministry for Economic Affairs and Energy and Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Time Series for the Development of Renewable Energy Sources in Germany, Based on Statistical Data from the Working Group on Renewable Energy Statistics (AGEE-Stat)*(Status: February 2020) (Dessau-Roßlau: February 2020), p. 7, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html.

- Australia:** IEA PVPS, *Trends 2019 in Photovoltaic Applications*, op. cit. this note, p. 25; Australian Photovoltaic Institute, personal communication with REN21, 12 May 2020; IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), pp. 4, 6, 18, 69, 72, 76, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf>. **Ukraine:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, pp. 6, 12, Becquerel Institute, provided by Detollenaere, op. cit. this note; Ukrainian Wind Energy Association, *Wind Power Sector of Ukraine 2019* (Kyiv: February 2020), p. 18. **Republic of Korea:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; Becquerel Institute, provided by Detollenaere, op. cit. this note. **Italy:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, pp. 8, 10; Becquerel Institute, provided by Detollenaere, op. cit. this note; Italian renewables association Anie Rinnovabili and grid operator Terna, cited in E. Bellini, "Italy deployed 737 MW of solar in 2019", pv magazine, 21 April 2020, <https://www.pv-magazine.com/2020/04/21/italy-deployed-737-mw-of-solar-in-2019>. **United Kingdom:** UK BEIS, "Solar photovoltaics deployment in the UK", <https://www.gov.uk/government/statistics/solar-photovoltaics-deployment>, updated 27 February 2020. See Solar PV section in Market and Industry chapter and related endnotes for additional statistics and details.
- 17 **Table R17** from the following sources: New Energy Update, "CSP Today global tracker", <http://tracker.newenergyupdate.com/tracker/projects>, viewed on numerous dates leading up to 27 April 2020; US National Renewable Energy Laboratory, "Concentrating solar power projects", <https://solarpaces.nrel.gov>, with the page and its subpages viewed on numerous dates leading up to 27 April 2020 (some subpages are referenced individually throughout the CSP section) and references cited in the CSP section of Renewable Energy Policy Network for the 21st Century (REN21), *Renewables 2019 Global Status Report* (Paris: 2019), pp. 107-09, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf. In some cases, information from the above sources was verified against additional country specific sources, as cited in the endnotes for the CSP section. Global CSP data are based on commercial facilities only; demonstration and pilot facilities are excluded, with the exception of certain plants in China that are described as "demonstration" plants by the government but are nonetheless large- (utility-) scale, grid-connected plants that are operating or will operate commercially. Data discrepancies between REN21 and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals.
- 18 **Table R18** from the following sources: cumulative solar thermal capacity in operation nationally and globally at end-2018 from M. Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communications with REN21, March-May 2020; W. Weiss and M. Spörk-Dür, *Solar Heat Worldwide. Global Market Development and Trends in 2019, Detailed Market Figures 2018* (Gleisdorf, Austria: IEA Solar Heating and Cooling Programme, 2020), <https://www.iea-shc.org/solar-heat-worldwide>. Gross additions on a national level from the following associations and experts: David Ferrari, Sustainability Victoria, Melbourne, Australia; Werner Weiss, AEE INTEC, Vienna, Austria; Danielle Johann, Brazilian Solar Thermal Energy Association (ABRASOL), São Paulo, Brazil; Hongzhi Cheng, Shandong SunVision Management Consulting, Dezhou, China; Panayiotis Kastanias, Cyprus Union of Solar Thermal Industrialists (EBHEK), Nicosia, Cyprus; Daniel Trier and Jan Erik Nielson, PlanEnergi, Skørping, Denmark; Andrea Liesen, BSW Solar, Berlin, Germany; Costas Travasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; Jaideep Malaviya, Solar Thermal Federation of India (STFI), Pune, India; Eli Shilton, Elsol, Kohar-yair, Israel; Federico Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milan, Italy; Daniel Garcia, Solar Thermal Manufacturers Organisation (FAMERAC), Mexico City, Mexico; Janusz Staroscik, Association of Manufacturers and Importers of Heating Appliances (SPIUG), Warsaw, Poland; Karin Kritzinger, Centre for Renewable and Sustainable Energy Studies, University of Stellenbosch, Stellenbosch, South Africa; Pascual Polo, Spanish Solar Thermal Association (ASIT), Madrid, Spain; Abdullh Azzam, Palestinian Central Bureau of Statistics, Ramallah, State of Palestine; David Stickelberger, Swissolar, Zurich, Switzerland; Abdelkader Baccouche, ANME, Tunis, Tunisia; Kutay Ülke, Rural Heating, Kayseri, Turkey; Les Nelson, Solar Heating & Cooling Programs at the International Association of Plumbing and Mechanical Officials (IAPMO), Ontario, California, United States, all personal communications with REN21, February-April 2020. Data for China and World Total assume that systems in China have a 10-year operational lifetime; national data for all other countries reflect a 25-year lifetime, with the exceptions of Turkey (14 years prior to 2018, and 15 years starting with 2018) and Germany (20 years). Total gross additions worldwide for 2018 are based on estimates from Spörk-Dür, op. cit. this note.
- 19 **Table R19** from the following sources: Unless noted otherwise, data are from the following: Global Wind Energy Council (GWEC), *Global Wind Report 2019* (Brussels: March 2020), pp. 13, 42, 43, <https://gwec.net/global-wind-report-2019>; GWEC, "Global Wind Statistics 2019: Status as End of 2019" (Brussels: March 2020); WindEurope, *Wind Energy in Europe in 2019: Trends and Statistics* (Brussels: 2020), pp. 8, 10, 13, 15, 16, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf>; World Wind Energy Association (WWEA), "Global wind installations", <https://library.windeurope.org/global-statistics>, viewed 16 April 2020. **China:** Official total for end-2018 from NEA, "2018 wind power grid operation", 28 January 2019, http://www.nea.gov.cn/2019-01/28/c_137780779.htm (using Google Translate), and from NEA and CEC, cited in China Energy Portal, "2018 wind power installations and production by province", 28 January 2019, <https://chinaenergyportal.org/en/2018-wind-power-installations-and-production-by-province>, viewed 30 April 2020; official data for 2019 additions and total from NEA, cited in National Energy Board, "2019 wind power grid operation", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827910.htm (using Google Translate), and from NEA and CEC, cited in China Energy Portal, "2019 wind power installations and production by province", 28 February 2020, <https://chinaenergyportal.org/en/2019-wind-power-installations-and-production-by-province>. Unofficial data from H. Yu, Chinese Wind Energy Association, personal communication with REN21, 18 May 2020, and from GWEC, "Global Wind Statistics 2019", op. cit. this note; unofficial data for 2019 additions and total from GWEC, idem. **United States:** American Wind Energy Association (AWEA), *U.S. Wind Industry Quarterly Market Report, Fourth Quarter 2019* (Washington, DC: January 2020), p. 3, <https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/4q2019-marketreport>; AWEA, "Wind Powers America Annual Report", press release (Washington, DC: 16 April 2020), <https://www.awea.org/resources/news/2020/wind-is-now-america%E2%80%99s-largest-renewable-energy-pro>. **United Kingdom:** WindEurope, op. cit. this note, pp. 8, 16. Also based on data from UK BEIS, op. cit. note 1, viewed 29 April 2020. **India:** Government of India, MNRE, cited in Ministry of Power, Central Electricity Authority (CEA), "All India installed capacity (in MW) of power stations (as on 31.01.2019) (utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2020/installed_capacity-01.pdf; Government of India, MNRE, cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2018) (utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2018/installed_capacity-12.pdf; GWEC, *Global Wind Report 2019*, op. cit. this note. **Spain:** WindEurope, op. cit. this note, pp. 8, 10; Red Eléctrica de España, "Potencia instalada nacional (MW)", as of 31 December 2019, <https://www.ree.es/es/datos/publicaciones/series-estadisticas-nacionales>. **Germany:** WindEurope, op. cit. this note, pp. 10, 16; Federal Ministry for Economic Affairs and AGEE-Stat, op. cit. note 16, p. 7; Deutsche Windguard, *Status of Offshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, <https://www.windguard.com/year-2019.html>; Deutsche Windguard, *Status of Offshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, <https://www.windguard.com/year-2019.html>. **Sweden:** WindEurope, op. cit. this note, pp. 10, 11, 13. **France:** WindEurope, idem, p. 10. Also based on data from Réseau de transport d'électricité (RTE), *Bilan Électrique 2019* (Paris: 2020), p. 27, https://www.rte-france.com/sites/default/files/bilan-electrique-2019_1.pdf. **Mexico:** GWEC, "Global Wind Statistics 2019", op. cit. this note; Mexican Association of Wind Energy, cited in "Las energías renovables batan su récord en México pese a las tensiones con el Gobierno", *El País*, 26 February 2020, https://elpais.com/economia/2020/02/26/actualidad/1582694040_481642.html (using Google Translate). **Argentina:** GWEC, "Global Wind Statistics 2019", op. cit. this note. **Brazil:** GWEC, idem. Also based on data from Associação Brasileira de Energia Eólica (ABEEólica), *Infowind Brazil*, no. 14

- (13 December 2019), http://abeeolica.org.br/wp-content/uploads/2020/02/Infovento-14_ENG.pdf; Operador Nacional do Sistema Eléctrico (ONS), "Geração de energia – composição", for period 1 January 2019 to 31 December 2019, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx; ONS, "Geração de energia – composição", for period 1 January 2018 to 31 December 2018, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx. **Canada:** End-2018 from CanWEA, "Installed capacity", December 2018, <https://canwea.ca/wind-energy/installed-capacity>, viewed 11 March 2019; additions and total in 2019 from CanWEA, "Installed capacity", December 2019, <https://canwea.ca/wind-energy/installed-capacity>, viewed 5 March 2020. **Italy:** WindEurope, op. cit. this note, p. 10. Also based on data from D. A. Garcia, Italian Wind Energy Association, presentation for WWEA, "Webinar: Wind power markets around the world", 8 April 2020, <https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world>. See Wind Power section in Market and Industry chapter and related endnotes for additional statistics and details.
- 20 **Table R20** from the following sources: share of population with access derived from IEA, *World Energy Outlook 2019 Access to Electricity Database*, <https://iea.blob.core.windows.net/assets/ecaa2844-dce8-4710-80fb-4085a58f292f/WEO2019-Electricity-database.xlsx>, viewed 25 April 2020; population without access derived from idem and from A. Contejean, IEA, Paris, personal communication with REN21, 20 May 2020; targets derived from World Bank, Access to Electricity Database, <https://data.worldbank.org/indicator/eg.elc.accs.zs>, viewed 25 April 2020, and from J. Rafalowicz, "Power for All Fact Sheet: Energy Access Target Tracker" (Power for All, 4 April 2017), https://www.powerforall.org/application/files/4715/2385/7938/Energy_Access_Target_Tracker_Fact_Sheet_April_2017.pdf.
- 21 **Table R21** from the following sources: IEA, *World Energy Outlook 2019 Access to Clean Cooking Database*, <https://iea.blob.core.windows.net/assets/b6baec29-6a12-40d6-8333-b89519660299/WEO2019-Clean-Cooking-database.xlsx>, viewed 25 April 2020; Rafalowicz, op. cit. note 20.
- 22 **Table R22** from Frankfurt School–United Nations Environment Programme Centre for Climate & Sustainable Energy Finance and BloombergNEF, *Global Trends in Renewable Energy Investment 2020* (Frankfurt: May 2020).

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