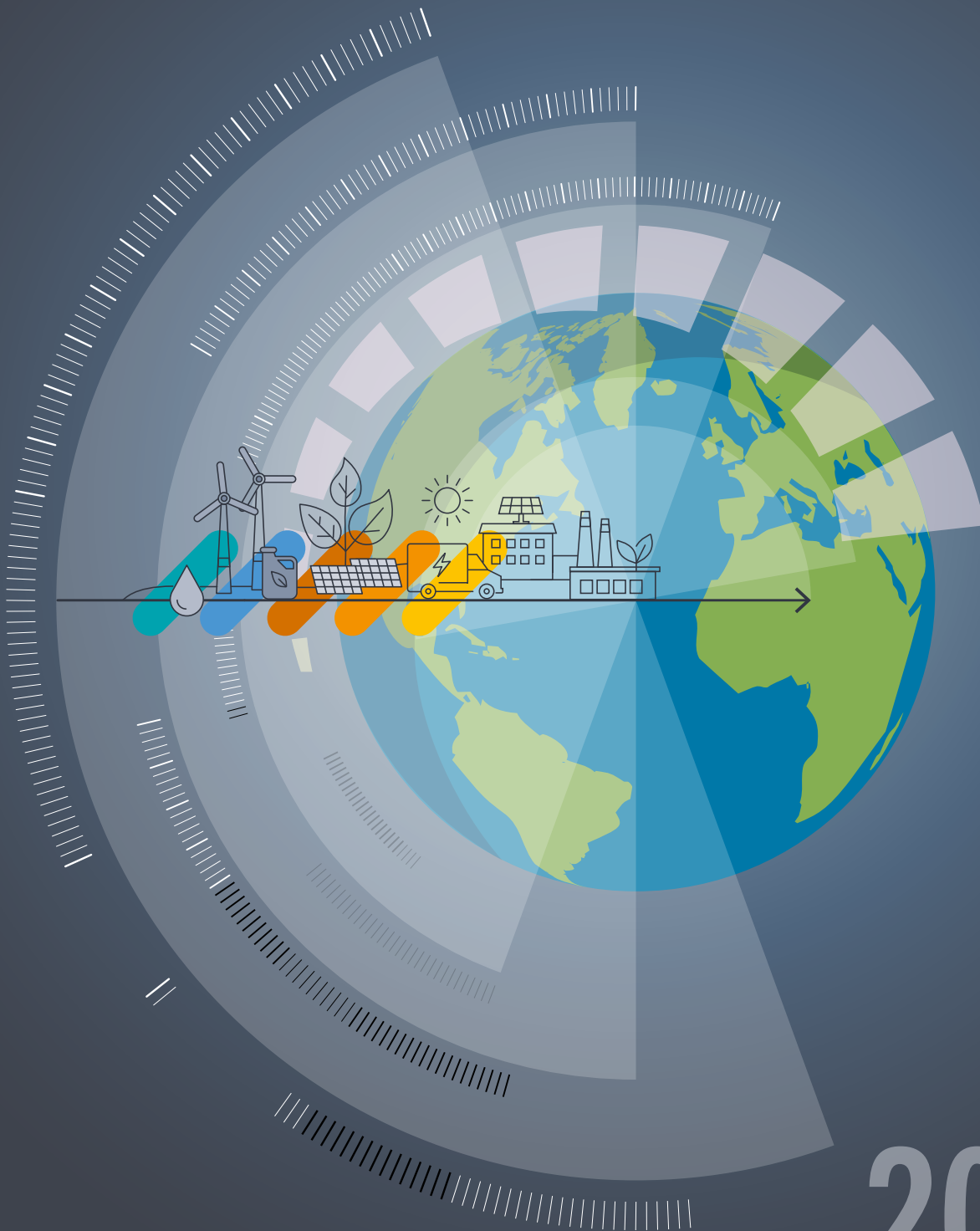


# RENEWABLES 2021

## GLOBAL STATUS REPORT



2021

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REN21 is the only **global renewable energy community** of actors from science, governments, NGOs and industry. We provide up-to-date and peer-reviewed facts, figures and analysis of global developments in technology, policies and markets. Our goal: enable decision-makers 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 publications**, the *Renewables Global Status Report* and the *Renewables in Cities Global Status Report*, are probably the world's most comprehensive crowdsourced reports on renewables. It is a truly collaborative process of co-authoring, data collection and peer reviewing.

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## SUSTAINABLE DEVELOPMENT GOALS

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



Gefördert durch:



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# FOREWORD

2020 was a year of disruption. The pandemic had a tragic impact on our communities but our health benefited from the extreme drop in fossil fuel use. It was also a year of new norms in the renewable energy sector. Ambition increased at an accelerated pace with a dramatic expansion of net zero emission targets. Increasing pressure from citizens and civil society led courts to force countries to strengthen their own climate plans, while the private sector purchased record amounts of renewable energy.


However, the past teaches us that ambition is not enough. It must be translated into action. While this year's *Renewables 2021 Global Status Report (GSR)* shows continuing progress in the power sector, the share of renewables in heating and transport has barely changed from past levels. Despite all the rhetoric, we are nowhere near the necessary paradigm shift towards a clean, healthier and more equitable energy future.

Clearly, we need a structural shift. It's not just about deploying and installing renewables. It's also about conserving energy, integrating energy efficiency AND leaving fossil fuels in the ground. It's time to stop talking only about gigawatts of installed capacity. We must emphasise how renewables can support development, economic development and a cleaner, healthier environment. If we are to achieve the energy transition, we need to integrate renewables across all economic sectors.

This year's report shows that governments need to act more aggressively and press forward with renewables in all sectors. The window of opportunity is closing and efforts must be ramped up significantly. This will not be easy. The share of fossil fuels in overall final energy demand is as high as it was a decade ago. While renewables grew almost 5% per year from 2009 to 2019, fossil fuel shares remained at around 80% over the same period. And with fossil fuel subsidies in 2019 totalling USD 550 billion – almost double the total investment in renewables – the last 10 years of climate policy promises have shown themselves to be mostly empty words.

One way to accelerate development is to define the uptake of renewable energy as a key performance indicator (KPI). To borrow a business adage, "What gets measured gets done." By measuring our performance, we can close the gap between ambition and target. And how better to measure our progress towards a clean energy transition? We must use the share of renewable energy in final energy consumption as a KPI and link it to every economic activity, every budget, every single purchase. This may sound overly ambitious, but we need urgent action. We cannot afford to make any more commitments that do not produce action. This needs to happen now.

I hope that the pages of this report contain the data and information you need to continue your work in making renewable energy the new norm. I would like to thank all those who have contributed to this year's edition. Particular thanks go to the Research Direction Team of Hannah E. Murdock, Duncan Gibb and Thomas André; Special Advisors Janet L. Sawin, Adam Brown and Lea Ranalder; the many authors; our editors, Lisa Mastny and Leah Brumer; our designers, Caren Weeks, Nicole Winter and Sebastian Ross; and all those who provided data and participated in the peer review process. Once again, this report illustrates the power of a collective process.



**Rana Adib**  
Executive Director, REN21

June 2021



**Cascades Inc. diverts three-quarters of the residual materials from its plants away from landfills, using them in biomass boilers or to fertilise farmland, and has committed to achieving 100% renewable electricity by 2030.**



# EXECUTIVE SUMMARY

## 01 GLOBAL OVERVIEW

Despite the impacts of the COVID-19 pandemic, renewable energy set a record in new power capacity in 2020 and was the only source of electricity generation to register a net increase in total capacity. Investment in renewable power capacity rose, although slightly, for the third consecutive year, and corporations continued to break records for sourcing renewable electricity. More countries shifted towards renewables for the electrification of heat. Although production of transport biofuels declined, electric vehicle (EV) sales expanded, as did the linking of EVs and renewable power, although to a lesser extent. China was among the countries that strengthened their commitments to action on the climate crisis, setting a carbon-neutral target. The United States re-joined the Paris Agreement in early 2021.

Meanwhile, previous obstacles to progress in the renewable energy sector persisted during 2020. They include the slow increase in the share of renewables in total final energy consumption (TFEC), inadequate innovation in some sectors, the need for infrastructure development, the lack of affordability in some markets, the absence of sufficient policy and enforcement, and ongoing support for fossil fuels.

For the first time, the number of countries with renewable energy support policies did not increase from the previous year. Despite greater interest in net zero targets during 2020, these targets do not necessarily cover all greenhouse gases or sectors, nor do they necessarily lead to increased attention to renewables or to success in meeting renewable energy targets. While such targets are in place in nearly all countries, many countries were not on track to achieve their 2020 targets in multiple sectors, and

many had not yet set new targets as their 2020 targets expired. In addition, investments in fossil fuels outlined in COVID-19 recovery packages worldwide were six times greater than the level of investments allocated to renewable energy.

As in past years, the highest share of renewable energy use was in the electricity sector (26% renewables); however, electrical end-uses accounted for only 17% of total final energy consumption. The transport sector, meanwhile, accounted for an estimated 32% of TFEC and had the lowest share of renewables (3.3%). The remaining thermal energy uses, which include space and water heating, space cooling, and industrial process heat, represented more than half (51%) of TFEC; of this, renewables supplied some 11%.

As of 2019, modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11.2% of TFEC, up from 8.7% a decade earlier. Despite tremendous growth in some renewable energy sectors, the share of renewables has increased only moderately each year. This is due to rising global energy demand, continuing consumption of and investment in new fossil fuels, and declining traditional use of biomass (which has led to a shift towards fossil fuels).

This slow progress points to the complementary and fundamental roles of energy conservation, energy efficiency and renewables in reducing the contribution of fossil fuels to meeting global energy needs and reducing emissions. With the concentration of carbon dioxide (CO<sub>2</sub>) in the atmosphere still rising to record levels even as emissions have fallen, it has become increasingly clear that a structural shift is needed to reach long-term climate targets.

## BUILDINGS

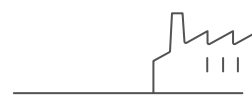


**Renewable energy meets a growing portion of final energy demand in buildings, although its share is still less than 15%.**

Renewables remained the fastest growing source of energy in buildings, increasing 4.1% annually on average between 2009 and 2019. The highest growth was in electricity use, whereas heating with renewable energy rose more slowly. Modern bioenergy (such as the use of wood-based fuel in efficient stoves) still represented the largest source of renewables in the buildings sector, especially in providing heat, although its growth has been roughly stagnant.

The use of renewable electricity for heat (for example, through electric heat pumps) provided the second largest renewable energy contribution to heat demand and showed the greatest growth in recent years. Solar thermal heat, geothermal heat and district energy networks also have grown quickly, albeit starting from a smaller base. Policies to stimulate renewable energy uptake in buildings remain relatively scarce, although many options exist to improve efficiency in new and existing buildings, expand access to electricity and clean cooking, and encourage the use of renewables.

## INDUSTRY



**The share of renewables in industrial energy demand remains small, particularly in sectors that require high temperatures for processing.**

Renewable energy accounts for only around 14.8% of total industrial energy demand and is used mainly in industries with low-temperature requirements for process heat. In heavy industries – iron and steel, cement, and chemicals – renewables accounted for less than 1% of the combined energy demand in 2018.

Bioenergy (mainly biomass) supplies around 90% of renewable heat in the industrial sector, primarily in industries where biomass waste and residues are produced on-site. Renewable electricity accounts for the second largest share (10%) of renewable industrial heat, although it represented only 1% of total industrial heat consumption in 2019. Solar thermal and geothermal technologies accounted for less than 0.05% of total final industrial energy use in 2018.

The COVID-19 pandemic temporarily reduced industrial energy demand, with global bioenergy use in industry falling 4% in 2020. Measures to promote the uptake of renewables in industries received limited attention in COVID-19 stimulus packages, although some countries announced renewable hydrogen strategies or investment plans to support industrial decarbonisation. By the end of 2020, only 32 countries had at least one renewable heating and cooling policy for industry (all of them economic incentives, such as subsidies, grants, tax credits or loan schemes).

Despite tremendous growth in some renewable energy sectors, the share of renewables has **increased only moderately** each year.





## TRANSPORT



**After falling initially, transport energy demand rebounded by the end of the year. Trends show rising demand and a stagnant share of renewable energy.**

The COVID-19 pandemic had significant impacts on the transport sector and its use of renewable energy. Transport activity and energy demand fell sharply in the early months of 2020 but rebounded by year's end. Longer-term trends have shown that growth in energy demand for transport has far outpaced that for other sectors.

Transport remains the sector with the lowest share of renewables, as oil and petroleum products (and 0.8% non-renewable electricity) continue to meet nearly all global transport energy needs (95.8%). Biofuels and renewable electricity met small shares of those needs (3.1% and 0.3%, respectively). Following a decade of steady growth, biofuel production decreased in 2020 due to the overall decline in transport energy demand, while electric car sales increased 41% during the year. The use of or investment in renewable hydrogen and synthetic fuels for transport increased in some regions but remained relatively minimal.

Overall, the transport sector is not on track to meet global climate targets. Many countries still lack a holistic strategy for decarbonising transport. Such a strategy could greatly decrease energy demand in the sector and thus allow for the renewable share in transport to increase.

## POWER



**Driven by solar photovoltaic (PV) and wind power, the renewable power sector surged in the second half of 2020 to overcome the pandemic's impacts.**

Installed renewable power capacity grew by more than 256 gigawatts (GW) during the pandemic, the largest ever increase. Continuing a trend dating back to 2012, net additions of renewable power generation capacity outpaced net installations of both fossil fuel and nuclear power capacity combined. China again led the world in renewable capacity added, accounting for nearly half of all installations in 2020 and leading the global markets for concentrating solar thermal power (CSP), hydropower, solar PV and wind power.

China added nearly 117 GW, bringing online more renewable capacity in 2020 than the entire world did in 2013 and almost doubling its additions from 2019. By the end of 2020, at least 19 countries had more than 10 GW of non-hydropower renewable capacity, up from 5 countries in 2010. Renewable energy reached a record share – an estimated 29% – of the global electricity mix. 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.



### China

added nearly 117 GW of renewable power, bringing online more capacity in 2020 than the entire world did in 2013.

## 02 POLICY LANDSCAPE

**Despite the COVID-19 crisis, policy support for renewables generally remained strong throughout 2020.**

By the end of 2020, nearly all countries had in place renewable energy support policies, although with varying degrees of ambition. Corporate commitments to renewable energy also increased during the year, led by market-based drivers such as action on climate change and the declining costs of renewable electricity.

While the suite of renewable energy policies implemented during the year was affected in part by the COVID-19 pandemic, it also evolved in response to increased action on climate change, falling costs of renewables, evolving network and system integration demands, and the changing needs and realities of different jurisdictions.

### RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

**2020 was an important year for climate change policy commitments.**

Although the COVID-19 crisis was the central political focus of the year, commitments to climate change mitigation stood out. Overall, 2020 was an important milestone for climate change policy, as many countries' greenhouse gas targets for the year expired. Countries set new targets, and many committed to carbon neutrality.

While some jurisdictions enacted climate change policies that indirectly stimulate the uptake of renewable energy, a growing number adopted comprehensive policies directly linking decarbonisation with increased deployment of renewables. Policy mechanisms implemented in 2020 that can indirectly stimulate interest in renewable energy included fossil fuel bans and phase-outs, greenhouse gas emission reduction targets, and carbon pricing and emission trading systems. In addition, at least six regional, national and state/provincial governments adopted comprehensive, cross-sectoral climate policies that include direct support for renewables.



### HEATING AND COOLING IN BUILDINGS

**Despite the enormous potential for renewable energy in heating and cooling, policy developments in heating and cooling for buildings in 2020 remained limited, outstripped by policies aimed at electricity generation and transport.**

Financial incentives were the most common mechanism used to encourage renewable heating and cooling in buildings in 2020. All such policies enacted or revised during the year were in Europe.

Evidence also points to growing interest in electrification of heating and cooling, which can increase the penetration of renewables in the buildings sector if the electricity used is generated from renewable sources. In 2020, policy makers in a number of national and sub-national jurisdictions focused rising attention on policies targeting building heating and cooling electrification. Energy efficiency policies also received international attention.

### INDUSTRY

**Policy developments related to increasing the share of renewables in industry remained scarce in 2020, compared with policies directed at all other end-use sectors.**

Although renewable energy solutions for industrial uses are available, they are not yet competitive with fossil fuels, and policy support remains critical for increasing renewables in this sector. However, such support remained rare in 2020. By year's end, only 32 countries had some form of renewable heating and cooling policy for industry (no change from 2019), with financial incentives being the most common form of policy support.



## TRANSPORT

**Decision makers are focusing increasingly on expanding the use of renewables in the transport sector, with an emphasis on transport electrification.**

Although biofuels continue to be a central component of road transport policy frameworks, the electrification of transport received much of the attention in 2020. Policies aimed at transport electrification are not renewable energy policies in and of themselves, but they offer the potential for greater penetration of renewable electricity in the sector, to the extent that the electricity used for charging vehicles is generated from renewable sources.

As in past years, policy makers focused most of their attention on road transport. EV policies became increasingly popular in 2020, although the vast majority of these continued to lack a direct link to renewable electricity generation. However, the number of countries with EV policies that do have a direct link to renewables increased from two to three during the year.

Rail, aviation and shipping still receive much less policy attention than road transport, even though they are the fastest growing transport sub-sectors and account for a rising share of total final energy use in transport.

### EV policies

became increasingly popular in 2020, although the vast majority of these continued to lack a direct link to renewable electricity generation.

## POWER

**As in previous years, the power (electricity generation) sector continued to receive significant renewable energy policy attention in 2020.**

The power sector continued to receive the bulk of renewable energy policy attention in 2020, as in previous years. Targets were the most popular form of intervention: by the end of 2020, 137 countries had some form of renewable electricity target, compared with 166 in 2019.

Although feed-in policies remain a widely used policy mechanism for supporting renewable power, in 2020 the shift continued from feed-in policies (set administratively) to competitive remuneration through tenders and auctions. Despite the continued popularity of net metering policies, some jurisdictions began transitioning away from net metering or modified their programmes to charge customers fees for participating.

Financial incentives, while always an important policy tool, were especially important for the power sector in 2020 as a result of the COVID-19 pandemic.

## SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY (VRE)

**Many jurisdictions with relatively high shares of renewables are implementing policies designed to ensure the successful integration of VRE into the broader energy system.**

The policy push for systems integration of renewables and enabling technologies, such as energy storage, focuses primarily on increasing power system flexibility and control, as well as grid resilience. Policies to advance the integration of VRE focused on market design, improving electricity transmission and distribution system infrastructure, and supporting the deployment of energy storage.





## 03 MARKET AND INDUSTRY TRENDS

### BIOENERGY

**Modern bioenergy provided 5.1% of total global final energy demand in 2019, accounting for around half of all renewable energy in final energy consumption.**

Modern bioenergy provided 9.5% of the heat required in industry and agriculture in 2019, an increase of around 16% since 2009. Bioenergy also provided 5% of the heat needed for buildings, with this use up 7% over the decade.

Biofuels – mostly ethanol and biodiesel – provide around 3% of transport energy. In 2020, global biofuel production fell 5% due to the impacts of the COVID-19 pandemic on overall transport energy demand. Ethanol production declined around 8%, with an 11% drop in production in the United States, the major producer. Global biodiesel production increased slightly to meet higher blending levels in Indonesia (the world’s largest biodiesel producer) and in Brazil, as well as higher demand in the United States.

In the electricity sector, bioenergy’s contribution rose 6% in 2020, reaching 602 terawatt-hours (TWh). China remained the largest generator of bio-electricity, followed by the United States and Brazil.

The most notable industry trend was rising investment in hydrotreated vegetable oil (HVO), with a 12% increase in production in 2020. Plans were announced for many additional plants, which could more than quadruple current capacity. HVO production would then exceed that of FAME (fatty acid methyl ester) biodiesel.

### GEOTHERMAL POWER AND HEAT

**Geothermal electricity generation totalled around 97 TWh in 2020, while direct use of geothermal heat reached about 128 TWh (462 petajoules).**

An estimated 0.1 GW of new geothermal power generating capacity came online in 2020, bringing the global total to around 14.1 GW. The year saw relatively little growth in capacity compared to recent years (attributed in part to pandemic-related disruption), with almost all new facilities located in Turkey. The United States and Japan added minor amounts of geothermal power capacity in 2020.

Direct use of geothermal energy for thermal (heat) applications is highly concentrated geographically, with only four countries – China, Turkey, Iceland and Japan – accounting for three-quarters of the energy consumed. Direct use has grown at an average rate of nearly 8% in recent years, with space heating being the primary driver. Some of the most active markets lack access to high-temperature resources and often face higher costs and greater technical challenges to accessing geothermal heat. Countries with noteworthy activity in 2020 included France, Germany and the Netherlands.

The geothermal industry was characterised by project delays and by meagre and highly concentrated market growth. The main focus continued to be on technological innovation, such as new resource recovery techniques and seismic risk mitigation, with the aim of improving the economics, lowering the development risk and strengthening prospects for expanded resource development. However, as in past years, the hopes of expanding geothermal development beyond the relatively few and concentrated centres of existing activity remained largely unmet. High costs and project risks have continued to deter investment in most places, especially in the absence of government support (such as feed-in tariffs and risk mitigation funds), although certain pockets of innovation attracted new investment from established entities in the energy industry.



In 2020,  
**global biofuel  
 production**  
 fell 5% due to the impacts  
 of the COVID-19 pandemic  
 on overall transport energy  
 demand.



## HYDROPOWER

**The global hydropower market grew in 2020, but China was responsible for more than half of capacity additions.**

Despite a 24% increase in capacity additions, driven mainly by China, the global hydropower market did not recover in 2020 after several years of deceleration. The effects of the COVID-19 pandemic were notable, with the market slowing as construction was halted temporarily, component supply chains were disrupted, and energy demand fell. New capacity was an estimated 19.4 GW, raising the total global installed capacity to around 1,170 GW. Global hydropower generation increased 1.5% in 2020 to reach an estimated 4,370 TWh, representing around 16.8% of the world's total electricity generation.

China added 12.6 GW of hydropower capacity in 2020, its largest addition of the previous five years, and regained the lead from Brazil in commissioning new hydropower capacity, followed by Turkey, India and Angola. Pumped storage capacity increased slightly (up 1.5 GW, or 0.9%), with projects in China and Israel, bringing total capacity to 160 GW. Several large pumped storage projects were in the pipeline, including in Australia, Greece, India, Portugal, Scotland and Turkey, in part to support growth in solar PV and wind power.

The hydropower industry continued to face challenges as well as opportunities, with both of these affected by the pandemic-induced recession. Challenges included operational and technical factors, environmental and social acceptability, a global decline in wholesale electricity prices, and adverse climate impacts on hydropower production and infrastructure. Opportunities for industry expansion included technology improvements and increased performance, the remaining untapped potential of smaller resources, synergies with VRE, and increased needs for grid flexibility.



## OCEAN POWER

**Ocean power represented the smallest portion of the renewable energy market, yet new targets for ocean power capacity were set during the year.**

Ocean power represents the smallest portion of the renewable energy market, with most projects focused on relatively small-scale demonstration and pilot projects of less than 1 megawatt (MW). Net additions in 2020 totalled around 2 MW, with an estimated 527 MW of operating capacity at year's end. Ocean power technologies are steadily advancing towards commercialisation, and tidal turbines continued to demonstrate their reliability. However, consistent policy and revenue support remain critical.

Development activity is concentrated primarily in Europe, and particularly off the coast of Scotland, but has increased steadily in China, the United States and Canada. The resource potential of ocean energy is enormous, but it remains largely untapped despite decades of development efforts.

The ocean power industry experienced delays of planned deployments due to COVID-19, and developers redirected their focus to device and project development. Operational tidal turbines continued to generate power reliably and to move towards commercialisation. Across the sector, financial and other support from governments, particularly in Europe and North America, continued to boost private investments in ocean power technologies, especially tidal stream and wave power devices.



## SOLAR PHOTOVOLTAICS (PV)

**Solar PV had another record-breaking year, adding as much as an estimated 139 GW, for an estimated total of 760 GW.**

Pending policy changes drove much of the growth in the top three markets – China, the United States and Vietnam – but several other countries saw noteworthy expansion.

Favourable economics have boosted interest in distributed rooftop solar PV systems. In 2020, growth in this market share was due mainly to a rush of installations in Vietnam in advance of the expiry of the country’s feed-in tariff; however, Australia, Germany and the United States also saw significant increases as homeowners invested in home improvements during the pandemic.

South Australia achieved one of the world’s highest levels of solar penetration in 2020. The state’s power system has become the world’s first large-scale system to approach the point at which rooftop solar PV effectively eliminates demand for electricity from the grid.

The solar PV industry rode a roller coaster in 2020, driven largely by pandemic-related disruptions, as well as by accidents at polysilicon facilities in China and a shortage of solar glass. These disruptions, due in large part to heavy reliance on China as the world’s dominant producer, combined with concerns about possible forced labour in polysilicon production, led to calls in many countries for the creation of local supply chains.

Despite the multiple challenges, new actors entered the sector. Competition and price pressures continued to motivate investment to improve efficiencies, reduce costs and improve margins.

The solar PV industry has become the major driver of growth in polysilicon production and accounts for a rising share of demand for other resources and materials, such as glass and silver. In most countries, recycling panels at the end of their useful life – as a means to reclaim these resources and minimise associated environmental impacts – is only starting to gain attention.

## CONCENTRATING SOLAR THERMAL POWER (CSP)

**Despite declining costs, CSP capacity grew in only one country during 2020.**

Global CSP capacity grew a mere 1.6% in 2020 to 6.2 GW, with a single 100 MW parabolic trough project coming online in China. This was the lowest annual market growth in over a decade, the result of increasing cost competition from solar PV, the expiry of CSP incentive programmes and a range of operational issues at existing facilities.

More than 1 GW of CSP projects was under construction in the United Arab Emirates, China, Chile and India during the year. The majority of this capacity is based on parabolic trough technology and is being built in parallel with thermal energy storage (TES). At year’s end, an estimated 21 gigawatt-hours of thermal energy storage was operating in conjunction with CSP plants across five continents. Global TES capacity, installed mainly alongside CSP, is almost double that of utility-scale battery storage.

During the 2010s, CSP costs fell nearly 50%, the largest decline for all renewable energy technologies, with the exception of solar PV. In many cases, CSP plants are being retrofitted with TES or co-located with solar PV capacity to lower costs and increase capacity values.

**Solar PV had another record year, while only a single CSP project came online in 2020.**





## SOLAR THERMAL HEATING

**An estimated 25.2 gigawatts-thermal (GW<sub>th</sub>) of new solar thermal capacity was added in 2020, increasing the global total 5% to around 501 GW<sub>th</sub>.**

China again led in new solar thermal installations, followed by Turkey, India, Brazil and the United States. Most large solar thermal markets were constrained by COVID-19-related challenges, and in some cases commercial clients postponed investment decisions. However, the reduction was smaller than expected due to stabilising factors such as ongoing business in the construction sector and higher demand from residential owners, many of whom spent more time at home and invested in infrastructure improvements.

The year was bright for solar district heating in China and Germany, thanks to policy support for green heating technologies. The global solar district heating market also diversified into new markets in Europe (Croatia, Kosovo and Serbia) and Asia (Mongolia). In addition, central solar hot water systems for large residential and commercial buildings sold well in China, Brazil and Turkey. By year's end, at least 471 solar district heating or central hot water systems (at least 350 kilowatts-thermal) were operating worldwide, totalling 1.8 GW<sub>th</sub> of capacity.

Hybrid, or solar PV-thermal (PV-T), collectors became more popular in several countries. In total, 36 manufacturers worldwide reported PV-T capacity of at least 60.5 megawatts-thermal (MW<sub>th</sub>) (connected to 24 MW-electric), up sharply from 46.6 MW<sub>th</sub> in 2019.

More collector manufacturers and project developers began offering solar industrial heat (SHIP) solutions to factories worldwide. At least 74 SHIP systems, totalling 92 MW<sub>th</sub>, started operation globally in 2020, raising the number of facilities in operation 9% to around 891 SHIP plants. Although many technology suppliers reported delays in installation and construction, some megawatt-scale plants were successfully commissioned during the year, including Europe's largest (10.5 MW<sub>th</sub>), used to heat agricultural greenhouses.



## WIND POWER

**The wind power market achieved a record-breaking 93 GW of new installations, bringing total capacity onshore and offshore to nearly 743 GW.**

China and the United States led the growth in wind power with record years, driven by pending policy changes at the end of 2020 in both countries. Several other countries also reached installation records, while the rest of the world installed about the same amount as in 2019. Wind power accounted for a substantial share of electricity generation in several countries in 2020, including Denmark (over 58%), Uruguay (40.4%), Ireland (38%) and the United Kingdom (24.2%).

Nearly 6.1 GW of capacity was connected offshore for a global total of 35.3 GW. Interest in offshore wind power is increasing – including among corporations looking to sign power purchase agreements (PPAs) – due to the large scale of generation, high capacity factors, fairly uniform generation profiles and falling costs.

The wind industry continued to face perennial challenges that were exacerbated by the pandemic. Despite selling more turbines, even top manufacturers suffered losses for the year, closed factories and laid off workers as the highly competitive market, together with pandemic-related costs and delays, squeezed profit margins further.

In some markets, governments responded by extending policy deadlines, and new policy commitments helped stimulate record investments. For the first time, global capital expenditures committed to offshore wind power during the year surpassed investments in offshore oil and gas.

To diversify in key markets, turbine manufacturers and project developers continued expanding into new sectors, even as new actors – including oil majors – moved further into the wind sector. Manufacturers focused on technology innovation to continuously reduce costs and achieve an ever lower levelised cost of energy. In addition, they expanded their work with other researchers to increase wind turbine sustainability during production and at the end of useful life.



## 04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS (DREA)

**Distributed renewables have continued to enable energy access, reaching electricity generation shares as high as 10% in some countries.**

By the end of 2019, 90% of the global population had gained access to electricity, although one-third (2.6 billion people) still lack access to clean cooking, relying on mostly traditional use of biomass. Renewables-based electric power systems and clean cooking solutions have played an increasingly important role in improving energy access rates, especially in rural and remote areas where such access remains low. Stand-alone solar systems and renewables-based mini-grids are often the most cost-effective way of electrifying off-grid areas in the developing world, providing power for households and productive uses. Options that help reduce the health and environmental impacts of the traditional use of biomass include improved biomass stoves and fuels, biogas, ethanol, solar cookers and, increasingly, renewables-based electric cooking.

After several years of strong growth, the market for renewables-based energy access systems was negatively impacted by the COVID-19 pandemic. Global sales of off-grid solar systems fell 22% in 2020, with the greatest regional decline in South Asia (51%), while sales in East Africa, the largest market, dipped 10%. Despite the drop in sales, financing for off-grid solar companies increased slightly by 1%. While equity funding fell significantly, debt and grant funding increased.

Although many planned renewables-based mini-grid projects were delayed due to the pandemic, new solar mini-grids were commissioned in several countries specifically to power healthcare facilities as an emergency response to the crisis. By late 2020, new financing deals were signed for several larger mini-grid developments across Africa.

The clean cooking sector has seen less funding and private sector involvement than the electricity access sector. However, funding for the 25 largest clean cooking companies increased 68% in 2019, to USD 70 million. In 2020, several new large-scale funding initiatives were announced for clean cooking in Africa, where the clean cooking deficit remains the largest. Policy makers in several countries also have focused on clean cooking, setting new targets and developing financial support packages.



## 05 INVESTMENT FLOWS

**Global investment in renewable energy capacity increased 2% in 2020, resisting the COVID-19-induced economic crisis.**

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) totalled USD 303.5 billion in 2020. Developing and emerging economies surpassed developed countries in renewable energy capacity investment for the sixth year running, reaching USD 153.4 billion (a smaller margin than in previous years). Investments for the year rose 13% in developed countries and fell 7% in developing and emerging countries.

Investment in renewables continued to focus on wind and solar power, with solar representing nearly half of global renewable energy investment in 2020, at USD 148.6 billion (up 12%). Investments fell in all renewable technologies except solar power, with wind power falling 6% to USD 142.7 billion (47% of the total). The remaining technologies continued their downward trend, with investment in small hydropower falling to USD 0.9 billion, geothermal to USD 0.7 billion and biofuels to USD 0.6 billion.

COVID-19 economic recovery packages included significant spending to stimulate further investment in renewables. Around 7% of the USD 732.5 billion total announced by 31 governments to support all types of energy was allocated directly to policies favouring the production or consumption of renewables. However, renewable energy investments outlined in recovery packages were still only around one-sixth the level of investments allocated to fossil fuels.

Energy projects represented nearly 60% of all climate finance in 2017 and 2018, averaging USD 337 billion. Climate finance flows from developed to developing countries reached USD 78.9 billion in 2018, of which USD 12.5 billion was allocated to projects targeting energy generation from renewable sources. Multilateral climate funds and multilateral development banks play an important role in providing direct support to developing countries, while climate finance instruments, such as green bonds, hit record levels for a second consecutive year, up 1.1% in 2020 to USD 269.5 billion.

The divestment movement continued its upward trend in 2020, with more than 1,300 institutional investors and institutions worth nearly USD 15 trillion committing to divesting partially or fully from fossil fuel-related assets. Investors increasingly have aligned their portfolios with the emission reduction goals of the Paris Agreement. However, investment in fossil fuel-related companies also has grown, and it is difficult to establish a direct link between divesting from fossil fuels and investing in renewables.

## 06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

**Wind and solar reached record levels in the electricity mix in 2020, while sales of heat pumps, electric vehicles and energy storage grew strongly despite the COVID-19 pandemic.**

In the power sector, the installed capacity and penetration of variable renewable electricity sources – mainly solar PV and wind power – have grown rapidly in many countries. Several power systems reached record-high shares of instantaneous VRE in 2020 due to lower costs of these renewable technologies and to the effects of COVID-19 containment measures on electricity markets.

The wider digitalisation of transmission and distribution grids continued, as did growth in “behind-the-meter” systems. In addition, electricity markets were adapted during 2020 to allow for the participation of ancillary services from wind, solar and battery storage. Flexibility services were procured increasingly from VRE power plants, flexible sources of demand and virtual power plants.

Grid infrastructure constraints have become a significant bottleneck for the integration of renewables in several locations. Large transmission projects also have faced regulatory hurdles. Despite this, major projects were advanced in 2020, driven by demand for grid capacity from VRE generators.

In contrast to the power sector, shares of renewables in global transport and heating systems remained low in 2020. Integration of renewable energy into road-based transport was advanced mainly through vehicle electrification, while heat pumps offer untapped potential to enable the use of renewables in the heating and cooling sector. Along with energy storage, the enabling technologies of heat pumps and EVs support the integration of renewables and contribute to greater flexibility in power systems. Sales of all three technologies increased in 2020, despite the onset of the COVID-19 pandemic.

In 2020, heat pump uptake slowed in the Asia-Pacific region, while it continued to increase in North America and Europe. The heat pump industry was characterised by company acquisitions, technological developments in refrigerants that have low global warming potential, and the emergence of new solutions integrating heat pumps with other energy devices.

While global car sales decreased in 2020, sales of electric cars (including both battery electric vehicles and plug-in hybrids) resisted the COVID-19-induced downturn with nearly 3 million units sold, up 41% from 2019. The share of electric cars in new car sales worldwide reached 4.6% in 2020, surpassing the 2019 record of 2.7%. Meanwhile, around one-third of the two- and three-wheelers sold were electric, nearly all of them in China. Notable activity in the EV industry during the year included significant reductions in battery costs and automakers’ announcements that they would shift, partially or fully, to electric production.

The global market for energy storage of all types reached 191.1 GW in 2020. Mechanical storage in the form of pumped hydropower accounted for the vast majority of this capacity, followed by roughly 14.2 GW of electro-mechanical and electro-chemical storage, and around 2.9 GW of thermal energy storage. The energy storage industry saw significant cost reductions, innovation in battery technologies and increased collaboration in the production of renewable hydrogen.

At least nine countries  
**generated more than 20%**  
of their electricity from  
solar PV and wind in 2020.





## 07 ENERGY EFFICIENCY, RENEWABLES AND DECARBONISATION

**Integrating renewable energy deployment and energy efficiency measures remains crucial for decarbonising end-use sectors and the energy system as a whole.**

Renewable energy and energy efficiency have long been known to provide multiple benefits to society, such as lowering energy costs, improving air quality and public health, and boosting jobs and economic growth. Increasingly, renewables and efficiency are viewed as crucial to reduce carbon emissions. Energy production and use account for more than two-thirds of global greenhouse gas emissions. Together, renewables and energy efficiency have made significant contributions to limiting the rise in CO<sub>2</sub> emissions.

Trends in carbon intensity – measured as energy-based CO<sub>2</sub> emissions per unit of gross domestic product (GDP) – help to better understand the full impact of both energy efficiency and renewables on the transition to more efficient and cleaner energy production and use. Unlike overall emissions, the carbon intensity of GDP reflects technical or structural improvements in various sectors.

Between 2013 and 2018, global energy-related CO<sub>2</sub> emissions grew 1.9%, to nearly 38 gigatonnes. The increase occurred during a period of economic growth – global GDP grew 23% during the five-year period – but was slowed by improvements in the overall carbon intensity of GDP. These improvements were due in part to increased renewable electricity production and, to a greater extent, to improved energy efficiency; this occurred despite an overall decline in energy efficiency improvements that began in 2015 and that was reinforced by the COVID-19 crisis and low energy prices.

Some measures that apply to end-use sectors – such as building energy codes and the deployment of distributed renewables, heat pumps, and technologies for electrification – impact carbon intensity as they can have both an energy efficiency and a renewable energy component. Other energy efficiency measures can play a role in each sector, including digitalisation in the buildings and industry sectors, and vehicle fuels and emission standards in the transport sector. In 2020, the COVID-19 pandemic impacted the energy efficiency of all end-use sectors.

Together, renewables and energy efficiency have made significant contributions to limiting the rise in CO<sub>2</sub> emissions.



## 08 FEATURE: BUSINESS DEMAND FOR RENEWABLES

**Businesses are increasing their uptake of renewable energy across power, heating and cooling, and transport needs. Company membership in business coalitions promoting renewable energy procurement surged across all sectors.**

Several factors incentivise business demand for renewables. Government policy continues to play a key role, but company-level factors also are becoming prominent. Environmental and ethical considerations encourage companies to adopt renewable energy as part of their broader sustainability or emission reduction goals. Renewables also are increasingly associated with lower costs and a variety of risk mitigation opportunities, thereby driving business demand. Surging membership in coalitions, such as RE100 and EV100, that promote business demand for renewables is also driving corporate uptake.

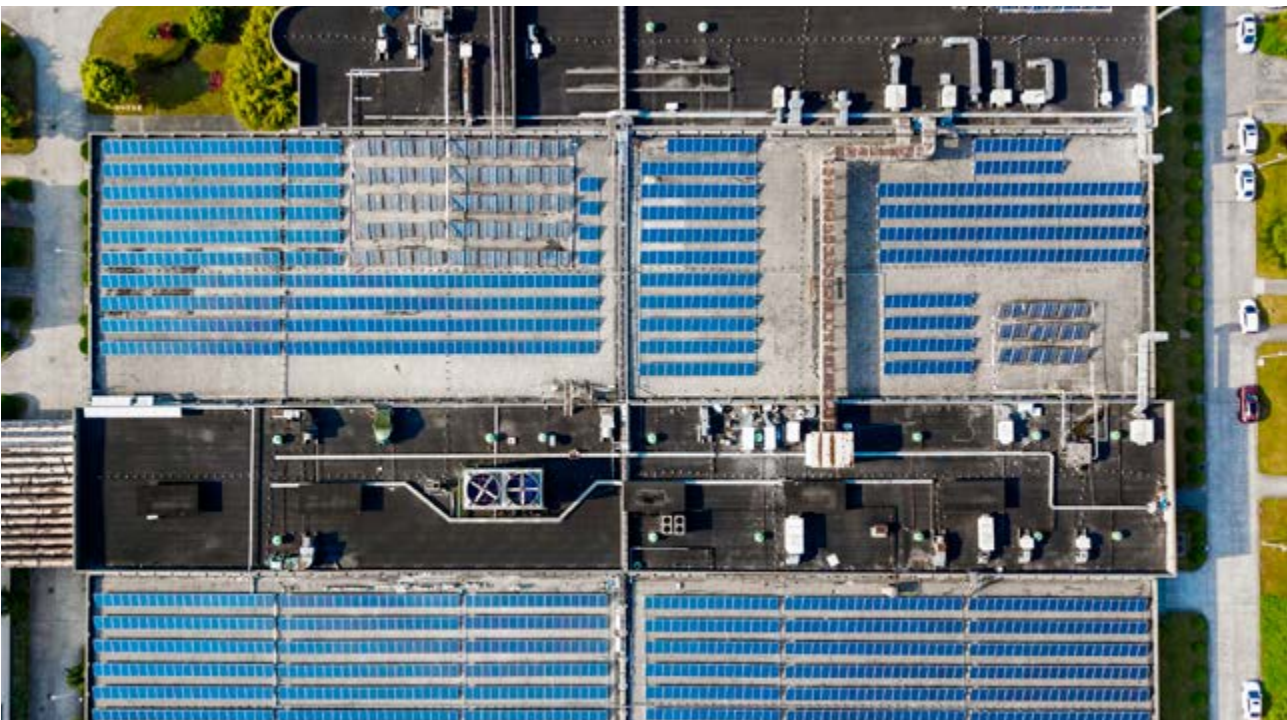
Businesses source their electricity from renewables in multiple ways, including by generating it themselves (either on- or off-site); procuring it from utilities through direct billing; purchasing environmental attribute certificates from energy suppliers; and signing long-term power purchase agreements with producers. Despite a challenging business year, the new renewable energy capacity that businesses sourced through PPAs increased 18% in 2020, across nearly all regions. North America accounted for the majority of the new capacity procured, and Amazon was the leading corporate power purchaser. Policies to enable cross-border PPAs were under development in Europe. In the Asia-Pacific region, ongoing challenges to corporate sourcing included regulatory and market barriers and limited or no availability of corporate sourcing mechanisms.

Corporations meet their needs for low-temperature thermal energy through renewables-based electrification, renewable gases, procurement of renewable district heat, and the direct use of geothermal heat, solar thermal heat and modern bioenergy. By the end of 2020, nearly 900 solar thermal systems were supplying industrial process heat, with new projects concentrated in China, Mexico and Germany. In most cases, corporations produce and consume on-site the energy they need for heating and cooling, rather than sourcing it from elsewhere.

Corporations in energy-intensive industrial sectors – such as iron and steel, cement, and chemicals production – use smaller shares of renewables to meet their energy needs. Still, interest in renewable energy procurement in these sectors has grown, and business coalitions emerged on both the demand and supply sides in 2020.

Businesses source renewable energy for their transport needs mainly from biofuels, renewables-based electricity, and renewable hydrogen across the road, rail, maritime and aviation sectors. Electrification of fleet vehicles has become increasingly popular, especially among companies operating in the more than 300 zero-emission zones in cities worldwide. However, the COVID-19 pandemic contributed to a 20% drop in sales and investment in hydrogen-powered transport in 2020, as the demand for hydrogen fuel cell buses fell.

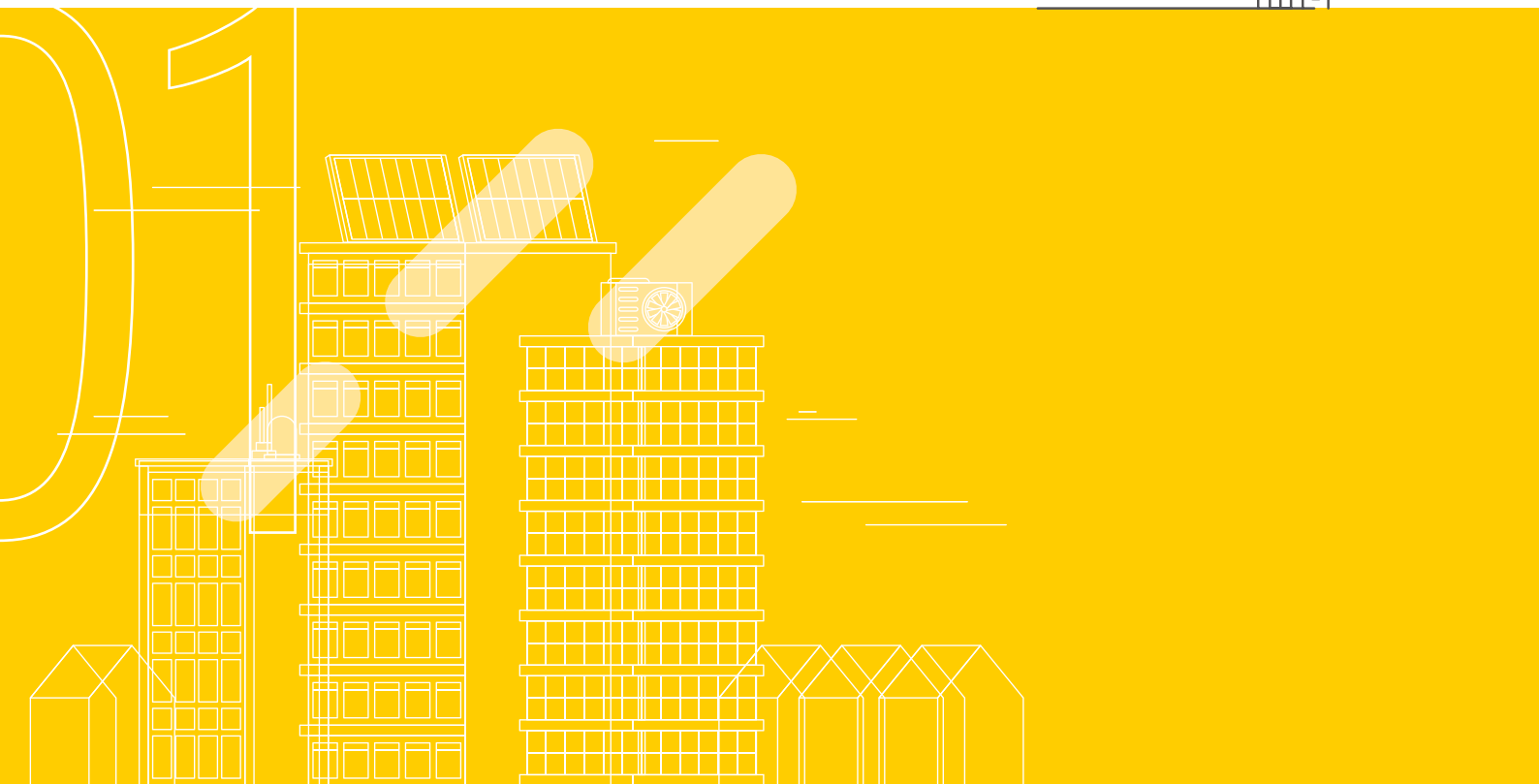
Declining costs have made biofuels an increasingly viable option for corporate procurement in maritime shipping, although their use in this sector is marginal. Interest in renewable hydrogen and ammonia also increased in the maritime transport sector. In 2020, several aviation companies committed to sourcing more-sustainable aviation fuels, while others showed interest in developing electric and hydrogen aircraft.







**City Developments Limited has mapped a pathway to reach its goal of net zero carbon emissions by 2030, including investing heavily in energy efficiency and targeting 100% renewable energy.**





# 01 GLOBAL OVERVIEW

## KEY FACTS

- Despite the impacts of the COVID-19 pandemic, **renewable energy set a record in new power capacity in 2020** and was the only source of electricity generation to register a net increase in total capacity.
- Renewables continued to meet low shares of final energy demand in the buildings, industry and transport sectors, where **policy support remains crucial** to spurring uptake but is insufficient.
- For the first time, the **number of countries with renewable energy support policies did not increase** from the previous year. While renewable energy targets are in place in nearly all countries, **many countries were not on track to achieve their 2020 targets** in multiple sectors, and many had not yet set new targets as their 2020 targets expired.
- With the atmospheric concentration of CO<sub>2</sub> rising to record levels even as emissions have fallen, it has become increasingly clear that **a structural shift is needed to reach long-term climate and development goals.**

**T**he renewable energy story during a crisis year was one of resilience and adaptation, yet significant challenges remain. During the year, restrictions on movement and goods as well as the introduction of COVID-19 recovery packages all had an impact on the production and use of renewable energy.

Despite suffering during the onset of the pandemic, renewable energy saw a record increase of new power capacity in 2020 globally and was the only source of electricity generation to experience a net increase in total capacity. Investment in renewable power capacity increased (albeit slightly) for the third consecutive year, and corporations continued to break records for sourcing renewable electricity. More countries are turning towards electrification of heat with renewables, and although production of transport biofuels decreased, sales of electric vehicles (EVs) expanded as did the linking of EVs to renewable power (to a lesser extent). A wave of commitments to action on the climate crisis included a carbon-neutral<sup>i</sup> target by China, while the United States re-joined the Paris Agreement in early 2021.

At the same time, obstacles that have slowed progress in the renewables sector in past years persisted during 2020. For the first time ever, the number of countries with renewable energy support policies did not increase from the previous year. While renewable energy targets are in place in nearly all countries, many countries were not on track to achieve their 2020 targets in multiple sectors, and many had not yet set new targets as their 2020 targets came to term. Moreover, in COVID-19 recovery packages, investment in fossil fuels was six times greater than for renewable energy.

<sup>i</sup> See Glossary.

## RENEWABLES IN 2020

As governments worldwide instituted lockdowns in 2020 to slow the spread of COVID-19 and to respond to the resulting global health crisis, economies ground to a halt and **energy demand** plummeted. Overall, primary energy demand worldwide fell around 4% during the year, resulting in a 5.8% drop in global energy-related carbon dioxide (CO<sub>2</sub>) **emissions** – the largest percentage decrease since World War II.<sup>1</sup>

Renewable energy reached its highest recorded share in the global electricity mix in 2020 – an estimated 29% – due in large part to low operating costs and preferential access to electricity networks during periods of low electricity demand.<sup>2</sup> Data for countries representing more than one-third of global electricity demand showed that every month of full lockdown during the pandemic reduced electricity demand 20% on average, or more than 1.5% on an annual basis.<sup>3</sup>

In the meantime, more than 256 gigawatts (GW) of **renewable power capacity** was added globally during the year, surpassing the previous record by nearly 30%.<sup>4</sup> (→ See *Table 1*.) While the renewables sector proved to be notably robust during this period, the fossil fuel industry largely struggled – especially the global coal and oil industries – due to decreased demand as well as difficulties for the oil industry in reaching production agreements within the Organization of the Petroleum Exporting Countries (OPEC)+ alliance.<sup>5</sup>

Costs of producing electricity from wind and solar energy have dropped significantly in recent years. In 2020, the global weighted average levelised cost of electricity from utility-scale solar photovoltaics (PV) declined 85% since 2010, while onshore wind power costs fell 56% during the same period. (→ See *Sidebar 6 in Market and Industry chapter*.) These declines mean that for most of the world's population, electricity production from new renewables is more cost effective than from new coal-fired power plants.<sup>6</sup> In a growing number of regions, including parts of China, the European Union (EU), India and the United States, it has already become cheaper to build new wind or solar PV plants than to operate existing coal-fired power plants.<sup>7</sup> 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 major continents.<sup>8</sup>

In contrast to previous years, which had seen some growth, the share of renewables in the transport sector remained constant.<sup>9</sup> Although biofuels have continued to dominate the renewable energy contribution in transport, the global EV stock has grown significantly, increasing opportunities to integrate renewables in road transport.<sup>10</sup> The global market share of EVs remains low overall, however.<sup>11</sup>

The uptake of modern renewables for heating and cooling progressed at a slow pace. Consumption of renewable heat suffered during the pandemic, and electrification of heating

in buildings (and to some extent in industry) attracted policy-maker attention.<sup>12</sup> However, the uptake of renewables in both heating and transport remains constrained by insufficient policy support and enforcement and by slow developments in new technologies (such as advanced biofuels).<sup>13</sup>

Distributed renewables for **energy access** (DREA) systems proved invaluable in many rural and remote communities during the early phases of the pandemic, notably in Africa, powering health facilities and other essential services through solar PV mini-grids.<sup>14</sup> However, measures to contain the virus hindered companies, delayed projects and held back end-customers from purchasing new systems.<sup>15</sup> Sales of solar lanterns, in particular, fell 30% in 2020 compared to 2019 even though they rebounded in the second half of the year.<sup>16</sup>

The global population without access to electricity continued to shrink, although 771 million people (10% of the world's population) still lacked electricity access in 2019 (latest data available), nearly 75% of them in sub-Saharan Africa.<sup>17</sup> However, estimates for 2020 suggest that the pandemic led to reversals in this trend for the first time since 2013: in Africa, 2% fewer people (13 million people) had access to electricity in 2020.<sup>18</sup> Meanwhile, the global population lacking access to clean cooking<sup>i</sup> increased slightly in 2019 to around 2.6 billion people, with few signs of progress.<sup>19</sup> In addition, the pandemic further worsened the inequities of lack of energy access, as populations without access were more heavily affected during the year.<sup>20</sup>



i Established in 2016, OPEC+ includes the 14 OPEC members as well as 10 additional oil and gas producing countries.

ii The REN21 Global Status Report (GSR) refers to clean and/or efficient cook stoves or fuels as per the methodology of the Multi-Tier Framework.

Although analysts widely expected the economic blow in 2020 to decrease **renewable energy investment** as much as 10%, the opposite ended up being true.<sup>21</sup> Due to a combination of factors including policy support, low interest rates, fluctuating oil and gas prices, and longer-term investor perspectives, global investment in new renewable energy capacity (excluding large hydropower projects) increased 2% from the previous year, reaching USD 303.5 billion.<sup>22</sup> In 2020, global investment in new renewable power and fuel capacity was estimated to be more than twice the investment in coal, gas and nuclear power generating plants combined.<sup>23</sup> However, considering all types of energy investment, investment in fossil fuels far outweighed that of renewables.<sup>24</sup>

At least two countries **withdrew support for fossil fuel exploration**. Denmark will cease all new oil and gas exploration as part of a larger plan to stop extracting fossil fuels entirely (overseas and domestic) by 2050.<sup>25</sup> The United Kingdom announced its intentions to end support for oil, gas and coal projects overseas "as soon as possible".<sup>26</sup> Japan also was considering withdrawing support for overseas exploration.<sup>27</sup> Multilateral development banks dedicated more than USD 13 billion to "clean"<sup>iii</sup> energy, but at the same time they committed over USD 3 billion to fossil fuels.<sup>28</sup> By early 2021, numerous private banks, pension funds and insurers also had committed to ending or seriously restricting support for fossil fuels.<sup>29</sup>

**Businesses** continued to purchase more and more renewable electricity. Corporate sourcing of renewable power set a record in 2020, increasing 18% and reaching more than 23 GW of power purchase agreements (PPAs) signed during the year.<sup>30</sup> Most of the installed capacity was solar PV, followed by wind power.<sup>31</sup>

By early 2021, more than 300 leading global corporations had joined the RE100 initiative – committing to using 100% renewable electricity – up from 167 corporations a year before.<sup>32</sup> EV100 and EP100 both saw growth in membership in 2020, while SteelZero was launched in December.<sup>33</sup>

Companies also are meeting their heating, cooling and transport needs with renewable energy, although these activities are at a much smaller scale. (→ See *Feature chapter*.) In some manufacturing industries, such as pulp and paper and food processing, firms supply relatively high shares of their heat demand with renewables (mostly bioenergy), while those in energy-intensive industries, such as steelmaking, are exploring activities to decarbonise their energy use with renewable hydrogen.<sup>34</sup> (→ See *Box 1*.) By early 2021, at least 2,360 companies had committed to net zero targets, a more than four-fold increase since 2019.<sup>35</sup>

The ongoing shift among major **energy companies** to invest in renewable energy highlights both the cost-competitiveness and public appeal of renewables, in addition to political and investor pressure. The world's largest oil and gas companies continued to invest in the renewable energy sector in 2020 (as well as to acquire companies already active in the sector) and to invest in technologies such as electric mobility and energy storage as well as hydrogen production and distribution (although often not renewable hydrogen).<sup>36</sup> 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.<sup>37</sup> (→ See *Sidebar 1*.)

## BOX 1. Renewable Hydrogen in the GSR

In 2020, policy, industry and civil society attention to the use of renewable hydrogen to reduce demand for fossil fuels grew rapidly around the world. REN21's *Renewables Global Status Report (GSR)* treats (renewable) hydrogen as an energy storage technology that is capable of converting primary renewables into useful forms of energy in key sectors, including certain industrial processes, maritime shipping and aviation. As such, readers will find information on renewable hydrogen distributed throughout the report, most prominently in the Policy Landscape chapter (Sidebar 5 and Table 5) and in the Energy Systems Integration and Enabling Technologies chapter (pages 213 and 215).



i Including upstream/downstream oil, gas and coal supply.

ii "Clean" energy in this case includes renewable energy, energy efficiency, active transport (e.g., walking and cycling) and electric vehicles, but also may include hydrogen that is produced from fossil fuels.

Beyond cost competitiveness and public appeal, awareness of the multiple co-benefits of renewables increased during the year, including improved public health through reduced pollution, increased reliability and resilience, access to modern energy services and job creation.<sup>38</sup> (→ See Sidebar 2.)

Awareness also increased surrounding equality and inclusiveness in the energy sector, and the strong business case was reaffirmed for increasing gender equality and cultural and ethnic diversity in companies.<sup>39</sup> An increasing number of companies joined the Equal by 30 campaign, aiming for more gender equality in the “clean energy” sector, specifically through equal opportunities, pay and leadership.<sup>40</sup> By early 2021, the campaign counted at least six countries among its signatories (Canada, Finland, Japan, the Netherlands, Sweden and the United Kingdom).<sup>41</sup>

Overall, **commitments towards climate action** greatly increased during 2020. At least 21 countries and the EU committed to greenhouse gas emission reduction targets during the year – covering around 48% of global emissions – including at least 9 countries committing to net zero emission targets and 9 committing to carbon-neutral targets in numerous significant markets, such as China, the EU, the Republic of Korea and Japan.<sup>42</sup> (→ See Table 4 in Policy Landscape chapter.) By the end of 2020, around 800 cities had committed to net zero emissions – up sharply from the 100 cities with such commitments by the end of 2019.<sup>43</sup> (→ See Box 2.)

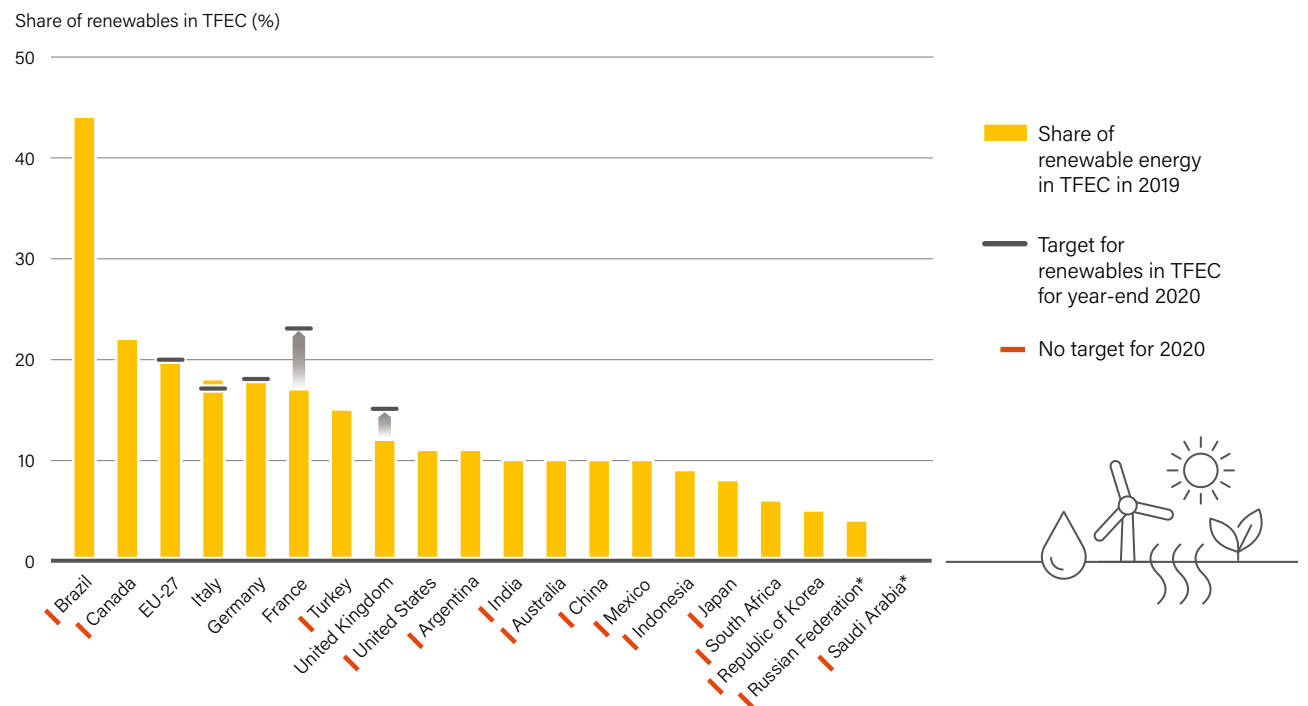
## STRUCTURAL SHIFT NECESSARY TO REACH CLIMATE AND DEVELOPMENT GOALS

Even as global emissions decreased in 2020, the concentration of CO<sub>2</sub> in the atmosphere continued to rise to record levels, highlighting that a **structural shift** is necessary to reach long-term climate targets.<sup>44</sup> This was vividly demonstrated at year’s end when it became clear that, despite the lockdowns and drop in economic activity, particularly early in 2020, there was no real lasting dent in global emissions as some estimates had anticipated.<sup>45</sup> Already by year’s end, while most countries continued to grapple with the pandemic, CO<sub>2</sub> emissions had strongly rebounded from their earlier lows, rising in December to levels that were 2% higher than a year prior.<sup>46</sup>

Despite more interest in net zero targets in 2020, these targets do not necessarily cover all greenhouse gases or all sectors, nor do they necessarily lead to greater attention to renewables or to success in meeting renewable energy targets. Only five of the world’s largest member economies in the Group of Twenty (G20) – the EU-27, France, Germany, Italy and the United Kingdom – had set 2020 targets to achieve a certain share of renewables in final energy use.<sup>47</sup> Of them, several were clearly not on track to achieve these targets by year’s end.<sup>48</sup> (→ See Figure 1.)

i In 2019, 77 countries joined the Climate Ambition Alliance with an aspirational commitment to net zero carbon emissions by 2050; by early 2021, the country total reached 121, although not all commitments have been backed by domestic action. The increased ambition and awareness among governments and companies alike also is being reflected by international organisations, notably the International Energy Agency, which in early 2021 recommended under its new net zero scenario no further investment in new fossil fuel supply projects and no further final investment decisions for new “unabated coal plants”. See endnote 42 for this chapter.

**FIGURE 1.** Renewable Energy Shares and Targets, G20 Countries, 2019 and 2020



Note: TFEC = Total final energy consumption. Data for Russian Federation and Saudi Arabia are for 2018 and 2017 respectively. Source: See endnote 48 for this chapter.

## ONGOING CHALLENGES TOWARDS A RENEWABLES-BASED WORLD

The developments during 2020 highlighted some of the key ongoing challenges impeding the widespread adoption of renewable energy. They include the slow increase of renewables in total final energy consumption (TFEC), the need for more innovation in some sectors, the need for infrastructure development and increased affordability in some markets, the lack of sufficient policy support and enforcement, and persistent support for fossil fuels.

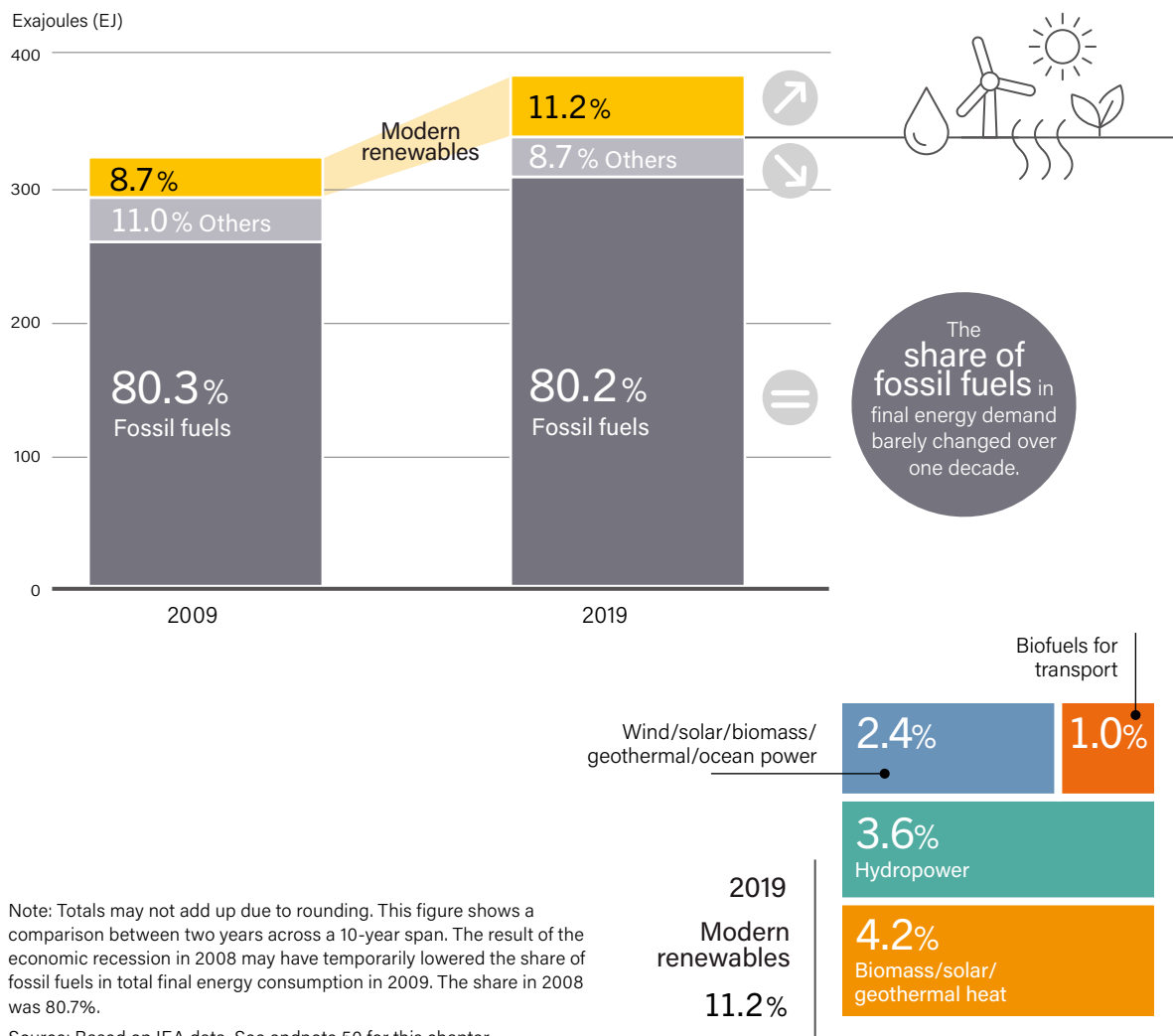
The share of renewables in TFEC has increased only moderately due to:

- rising global energy demand;
- continuing consumption of and investment in new fossil fuels, resulting in fossil fuels meeting most of the increasing demand, and
- declining traditional use of biomass, which although a positive development due to sustainability and health concerns (→ see Box 3) has meant that as people shift towards modern sources of energy, much of this is via fossil fuels.<sup>49</sup>

As of 2019<sup>i</sup>, modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11.2% of TFEC, up from 8.7% a decade earlier.<sup>50</sup> (→ See Figure 2.) The largest portion was renewable electricity (6.0% of TFEC), followed by renewable heat (4.2%) and transport biofuels (1.0%).<sup>51</sup>

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 2018; values for 2019 are estimates.

**FIGURE 2.**  
Estimated Renewable Share of Total Final Energy Consumption, 2009 and 2019





## BOX 2. Renewable Energy in Cities

REN21's *Renewables in Cities Global Status Report* is an annual stock-taking of the global transition to renewable energy at the city level. City governments around the world have taken action to accelerate the global uptake of renewables, driven by air pollution concerns, public pressure and the need to create clean, liveable, climate-resilient and equitable communities.

Cities are home to 55% of the global population and growing, and they account (directly or indirectly) for more than 80% of global GDP. Urban energy use also has grown significantly in recent decades due to global population growth, urbanisation and urban economic activity. By 2018, cities accounted for around three-quarters of global final energy use, and cities release a similar share of global energy-related CO<sub>2</sub> emissions. This makes cities high-impact areas for climate action, including for decarbonising the energy system and accelerating renewable energy investments, which help cities achieve their own objectives as well as global goals.

Urban commitments to directly support renewables are increasing. By the end of 2020, more than 1 billion people – 25% of the world's urban population – lived in a city that had a renewable energy target and/or policy (for a total of over 1,300 cities), and during the year around 260 cities set new targets or passed new policies. This includes more than 830 cities in 72 countries that had adopted targets for renewables, with more than 600 cities setting targets for 100% renewable energy (with varying target dates).

Commitments to decrease greenhouse gas emissions also can result indirectly in greater use of renewables citywide. By 2020, more than 10,500 cities had adopted targets to reduce their greenhouse gas emissions, and around 800 cities had committed to net zero emissions, with the number of such net zero targets increasing roughly eight-fold from 2019. To achieve these targets, city governments have been leading by example, scaling up on-site renewable energy generation (mostly solar PV) and/or procurement for public buildings and municipal fleets.

Achieving urban renewable energy targets depends not only on political commitment and municipal investment in renewables, but also on the city's ability to enable the uptake of renewables city-wide, by other actors. Contrary to the slow pace at the national level, momentum has been growing for city-level policies that move beyond the power sector to support renewables in heating and cooling, the transport sector, and integrated policy approaches. These include both direct and indirect support policies, municipal codes and mandates for new buildings, incentives for retrofitting existing buildings, and bans and restrictions on fossil fuel use for both the buildings and transport sectors.

→ See *Renewables in Cities 2021 Global Status Report*, along with the report's city case studies and cities data pack at <https://www.ren21.net/cities>.

Source: See endnote 43 for this chapter.



### BOX 3. Sustainability in the GSR

Much of the support for renewables to-date has focused on the social and economic acceptance of the energy transition, including the roles of political leadership, financial measures and market confidence. Accelerating the scale-up of renewables also means fostering public acceptance of renewable energy systems and investigating the key challenges to acceptance that they are facing. The sustainability of renewable energy technologies, infrastructure and supply chains is a key emerging issue. While there is no one definition of sustainability within the renewable energy context, this concept is usually determined by environmental, social and economic dimensions.

Even though the development of renewable energy is understood as essential for tackling climate change, the recent and planned expansion of renewables has raised notable sustainability concerns. Some of these issues have a longer history, such as considerations around the impacts that hydropower reservoirs and dams have on ecosystems and host communities and, in recent years, the debate on the role of bioenergy, especially in the context of the unsustainable use of biomass. More recently, as solar and wind power projects have become more numerous, issues around their long-term sustainability have come into the spotlight<sup>1</sup>. In addition, the resource requirements and lifecycle emissions of renewable energy technologies have received increasing attention.

Critically examining the environmental, social and economic impacts of renewables along the value chain, using a comprehensive approach and having an informed and transparent debate is necessary to address perceived tensions and challenges in shifting to a renewable-based energy system. Future editions of the GSR will address the topic more holistically, as will additional projects from REN21.

i See, for example, L. Bennun et al., *Mitigating Biodiversity Impacts Associated with Solar and Wind Energy Development* (Gland, Switzerland: IUCN, 2021), <https://portals.iucn.org/library/sites/library/files/documents/2021-004-En.pdf>.

Source: See endnote 49 for this chapter.



Renewable energy accounted for **only one-quarter** of the total increase in energy demand between 2009 and 2019.

The share of renewable energy has increased only moderately each year despite tremendous growth in some renewable energy sectors. Total demand for modern renewables grew strongly (15.1 exajoules, EJ) during the 10-year period 2009–2019, rising around 4.4% annually.<sup>52</sup> Total final

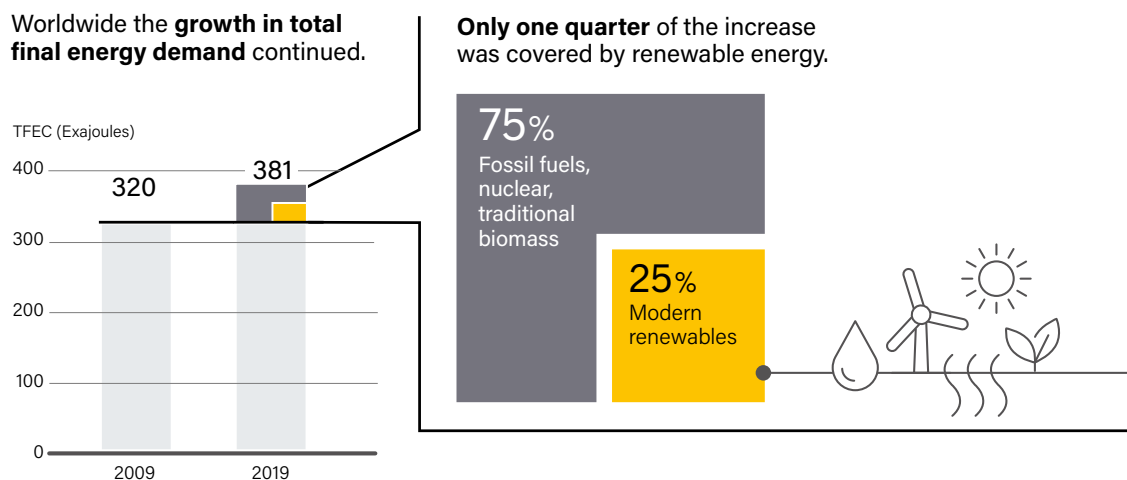
energy consumption grew 60.9 EJ, or around 1.8% annually.<sup>53</sup> Thus, renewable energy increased at more than twice the rate of TFEC, accounting for 25% of the total increase in energy demand.<sup>54</sup>

However, this means that other energy sources (mainly fossil fuels, which grew 1.7% annually) accounted for 75% of the total increase in energy demand during this period, highlighting

the challenge that renewables faced in gaining greater TFEC shares.<sup>55</sup> (→ See Figure 3.) This slow progress points to the complementary and fundamental roles of energy conservation, energy efficiency and renewables in reducing the contributions of fossil fuels in meeting global energy needs and reducing emissions.

Efficiency and conservation reduce overall demand for (additional) energy to achieve the same energy services, making it easier for renewables to attain a larger share of the total. However, energy efficiency also faced challenges in 2020. The rate of energy intensity improvements had been declining since 2015, and in 2020 the global crisis coupled with low energy prices resulted in only an estimated 0.8% improvement in energy intensity – half the rate of the previous two years.<sup>56</sup>

**FIGURE 3.** Estimated Growth in Modern Renewables as Share of Total Final Energy Consumption Between 2009 and 2019



Source: Based on IEA data. See endnote 55 for this chapter.

As in past years, the highest share of renewable energy is in electrical applications (excluding electricity for heating, cooling and transport), such as lighting and appliances.<sup>57</sup> However, these end-uses account for only 17% of TFEC.<sup>58</sup> Energy use for transport represents some 32% of TFEC, and has the lowest share of renewables (3.4%).<sup>59</sup> The remaining thermal<sup>ii</sup> 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 10.2% was supplied by renewables.<sup>60</sup> Increasing the renewable share in transport and thermal end-uses is necessary to reach a higher share of renewable energy in overall TFEC.<sup>61</sup> (→ See Figure 4.)

Although costs for most renewable energy technologies have fallen (some precipitously, such as for solar PV and onshore wind power), **innovation** is still needed to enable the widespread adoption of renewables in harder-to-decarbonise sectors, such as energy-intensive industrial processes and long-haul transport.<sup>62</sup> The integration of variable renewable energy sources (such as solar and wind) into existing power systems could be further enabled by expanded and modernised grid **infrastructure**, further cost declines in energy storage, and advances in new business models and market design that allow electricity supply to flexibly meet demand.<sup>63</sup> In addition, **affordability** in some markets can be hampered by various elements, such as higher labour costs, permitting costs, land constraints, availability of renewable resources, lack of favourable policy frameworks and infrastructure issues.<sup>64</sup>

Another key reason for the low penetration of renewables is the persistent lack of **supporting policies and policy enforcement**, particularly in the transport and heating and cooling sectors.

Targets for renewables are not only more numerous but also more ambitious for the power sector. While renewable energy targets are in place in nearly all countries, many countries were not on track to achieve their 2020 **targets** in multiple sectors, and many had not yet set new targets as their 2020 targets were coming to term.

Targets also were more often achieved and set for the power sector than for heating and cooling or transport. (→ See Figure 11 in Policy Landscape chapter.) However, many jurisdictions announced emission reduction targets during the year, which could support increasing the renewable share in these sectors where the targets are economy-wide.<sup>65</sup> Also, many countries have submitted more ambitious climate pledges across sectors for 2030 through their updated Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.<sup>66</sup>

In contrast to previous years, the number of countries with renewable energy **support policies** did not increase in 2020.<sup>iii, 67</sup> The number of countries with mandates for renewable heat also did not grow, and policy examples for renewable energy support in industry remained scarce. No new countries added regulatory incentives or mandates for renewables in transport, although some countries that already had mandates added new ones or strengthened existing ones. Only three countries had a policy directly linking renewables and EVs by year's end, with Japan newly joining Austria with a similar incentive for charging EVs with renewable electricity, alongside Germany with its policy supporting renewable-based charging infrastructure.<sup>68</sup> Policies supporting renewable hydrogen also remained rare. (→ See Table 5 in Policy Landscape chapter.)

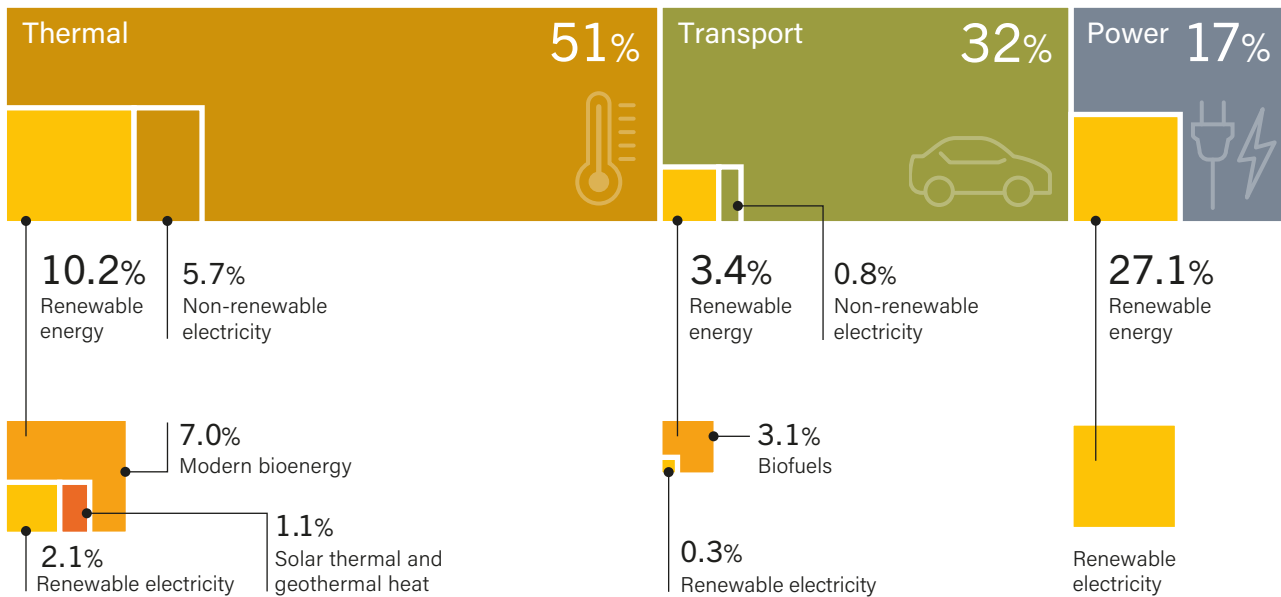
i Electrical applications account for a higher portion of *primary* energy consumption. See Glossary for definitions.

ii 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.

iii However, policy support increased at the local level, where city governments have continued to take action to accelerate the global uptake of renewable energy to create clean, livable and equitable cities and have had a particular impact in the uptake of renewables in buildings and transport. Overall, more than 1 billion people lived in a city with a renewable energy target and/or policy in 2020. (→ See Box 2.)



**FIGURE 4.**  
Renewable Energy in Total Final Energy Consumption, by Final Energy Use, 2018



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 61 for this chapter.

In addition, **fossil fuel subsidies** remain a persistent challenge for renewable energy. Despite calls by world leaders, leading economists, international organisations and non-governmental organisations for governments to use COVID-19 recovery efforts to advance the phase-out of fossil fuel subsidies, this support remained in the hundreds of billions of dollars (nearly USD 500 billion as of 2019), far above the support for renewables.<sup>69</sup> In many countries, **investment in new fossil fuel production** and related infrastructure continued. Although some countries were phasing out coal, others invested in new coal-fired power plants, both domestically and abroad. Similar to the previous year, in 2020 many coal-fired plants announced closures in Europe and the United States, where almost no new plants had been planned for a few years and decommissioning has been accelerating, although some new plants began operating during the year.<sup>70</sup> Most of the still-operating, new and planned coal plants were located in developing and emerging Asia.<sup>71</sup>

During the first half of 2020, global net coal power capacity fell for the first time in history, as decommissioning outpaced new installations.<sup>72</sup> However, by year's end a steep increase in **new coal capacity** in China offset global retirements, resulting in the first annual increase in global coal capacity since 2015.<sup>73</sup> In line with past years, 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.<sup>74</sup> 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.<sup>75</sup>

Despite international calls to "build back better"<sup>ii</sup> from the COVID-19 crisis, the majority of energy-related **recovery** funds were either directly or indirectly in support of fossil fuels.<sup>76</sup> (→ See Figure 49 in Investment chapter.) Governments around the world announced at least USD 732.5 billion in energy-related stimulus during 2020, and some stimulus packages included incentives for renewables; however, as of April 2021 only around USD 264 billion (36%) of the total amount provided by governments globally was for renewables, whereas more than USD 309 billion was allocated to fossil fuels, although the shares of funds for "clean" energy versus fossil fuels varied by region and country.<sup>77</sup> In some cases, coal was explicitly supported in recovery packages, such as in Poland, which seeks to maintain coal operations until 2049.<sup>78</sup>

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

i For example, in the Czech Republic and in Germany.

ii "Build back better" was a term adopted by the international community in the Sendai Framework for Disaster Risk Reduction 2015-2030.

## SIDEBAR 1. Oil and Gas Suppliers and the Renewable Energy Transition

The year 2020 was challenging for the oil and gas industry. Demand disruption due to the COVID-19 crisis and an oil price war between OPEC and the Russian Federation combined to create oversupply and plunging prices. Conventional oil and gas suppliers increasingly are feeling the impetus to participate in the renewable energy transition in order to remain competitive, and due to pressure from energy users and investors.

In many parts of the world, public sentiment is rapidly turning against fossil fuels. Public and private investors alike are pulling money out of fossil fuel companies, with institutional investors worth nearly USD 15 trillion committed to divestment as of early 2021. (→ See *Investment chapter*.) While the transition away from fossil fuels is most visible in the power sector, it has been much slower in harder-to-decarbonise sectors such as industrial heat and heavy-duty transport, where oil and gas are more heavily embedded.

Major oil and gas companies have used a variety of strategies to try to position themselves as key players in the energy transition. Many have sought to signal a shift in priorities through their communications and public relations activities, including rebranding efforts. BP spearheaded the trend when it rebranded itself as “Beyond Petroleum” from “British Petroleum” in 2001. A host of other companies followed suit: GDF (Gaz de France) Suez became ENGIE in 2015, Danish Oil and Natural Gas (DONG Energy) became Ørsted in 2017, Statoil became Equinor in 2018, Gas Natural Fenosa became Naturgy in 2018, and Total became TotalEnergies in 2021. In a similar vein, the chief executive officer of Royal Dutch Shell communicated to investors in 2018 that the company is no longer an oil and gas company, but rather an “energy transition company”.

While Ørsted has gone further than name change, transitioning from an oil and gas company to a large player in renewable power (predominantly offshore wind), others are still at early stages in their transitions. By the end of 2020, European majors BP, Eni, Equinor, Repsol, Shell and Total had all announced net zero emission targets for 2050, albeit with vast differences in coverage and ambition. While BP, Eni and Equinor have committed to absolute reductions in emissions, Repsol, Shell and Total aim to cut their emission intensities instead, making it possible for them to meet their targets without having to actually cut fossil fuel production. Reflecting these differences, BP announced in 2020 that it aims to slash oil and gas production 40%<sup>1</sup> by 2030 from 2019 levels, while Shell revealed in early 2021 that it had committed far more to oil and gas exploration and production than to renewables. However, in May 2021, Shell was ordered by a Dutch court to reduce carbon dioxide emissions (including emissions arising from the use of its products) 45% by 2030, relative to 2019 levels.

Each of these companies also has intermediate targets to invest in renewables or to expand their own renewable energy (mostly power) capacities. BP aims for 50 GW by 2030, Total plans to install 35 GW of renewable power capacity by 2025,

Eni and Repsol are both targeting 15 GW by 2030, Equinor is targeting 12-16 GW by 2035 and Shell has an annual investment target of USD 2-3 billion in renewable energy and hydrogen (although not necessarily produced from renewables). Some companies – such as Repsol, Shell and Total – also link executive remuneration to emission reduction measures. On the other hand, US-based oil and gas giants Chevron and ExxonMobil do not have any renewable energy targets, and the emissions intensity reduction targets they do have are short-term and less ambitious<sup>2</sup>. The difference in their approaches reflects the divergent policy priorities and shareholder interests in the United States and Europe so far, although these trends may be changing. In May 2021, 61% of Chevron shareholders voted to cut Scope 3 emissions – emissions arising from the use of the company's products – and ExxonMobil lost two board seats to a climate activist hedge fund.

Oil and gas companies can help advance the energy transition by reallocating their significant capital to address the investment gap facing the renewable energy sector. However, some companies still hesitate to diversify much into renewable energy and remain more inclined to protect their core businesses. Chevron, ExxonMobil and Shell, for example, have started sourcing renewable electricity to power their oil and gas operations by signing long-term PPAs with renewable energy companies, a move that lowers their emission intensities but may not greatly impact their absolute emissions. Chevron and ExxonMobil also are mostly allocating their energy transition funds (roughly 3-4% of their total capital expenditures) to research and development of technologies like carbon capture and storage, nuclear fusion reactors, EV charging infrastructure, battery storage and advanced biofuels.

At the same time, other oil and gas majors have invested in renewables either by acquiring stakes in renewable energy companies or by diversifying their core businesses towards renewables. For example, in 2011 Total purchased a 60%



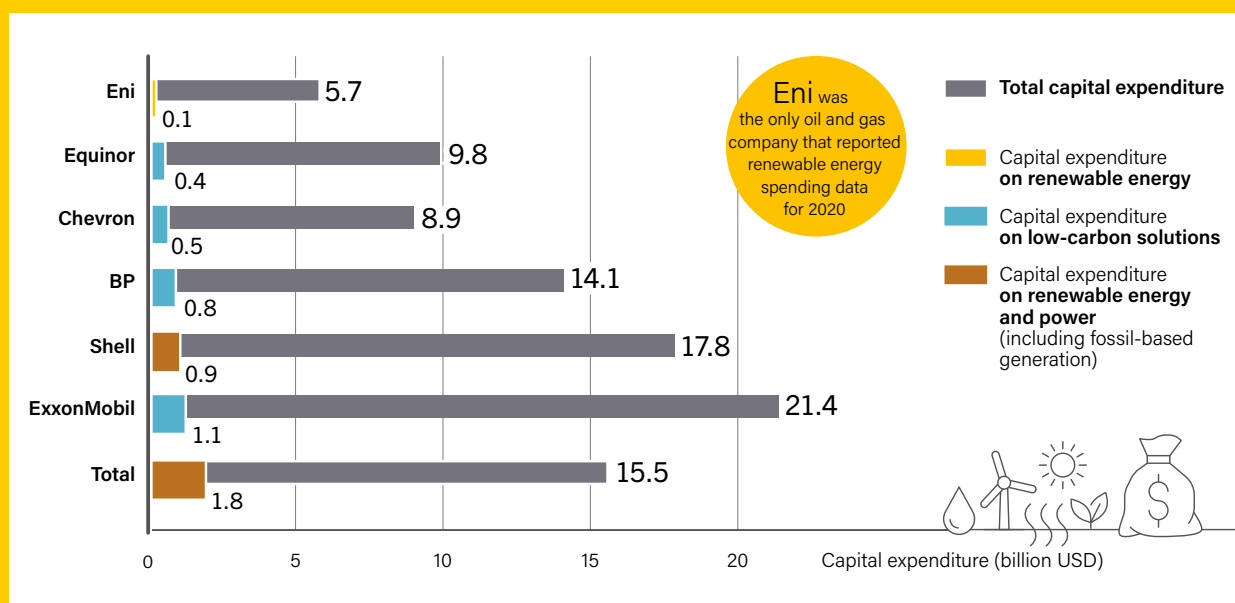
majority stake in US solar company SunPower in a USD 1.4 billion deal. In 2017, BP acquired a 43% stake in European solar developer Lightsource BP, and later increased its stake to 50% in 2019. In 2018, Shell acquired 44% of US solar power firm Silicon Ranch and made an equity investment of USD 20 million in India's distributed renewable utility company Husk Power Systems.

In terms of installed renewable energy capacity, Total and BP led in 2020 with 3 GW and 2 GW respectively, followed by Repsol at 1.3 GW, Shell at 0.9 GW, Equinor at 0.5 GW and Eni at 0.2 GW. Companies such as BP, Chevron, Equinor, Total and Unocal have begun making forays into the geothermal energy and offshore wind power sectors, which are readily accessible by oil and gas majors and present organic growth opportunities.

Despite changing headwinds, many forces motivate oil and gas companies to continue with business as usual. As of 2019, these companies had collectively invested less than 1% of their total capital expenditure in activities outside their core business areas<sup>iii</sup>, with the leading companies spending on average around 5% on projects outside core oil and gas supply. (→ See Figure 5.) Companies like BP and Shell maintain membership in industry associations that lobby against climate action. Moreover, provisions of international trade pacts like the Energy Charter Treaty<sup>iv</sup> protect the fossil fuel industry at the expense of the renewable energy sector, and global post-COVID recovery packages have tended to favour fossil fuel industries over renewables. (→ See Sidebar 3 in Policy Landscape chapter.)

- i BP's commitment does not, however, include production from Rosneft, the Russian oil and gas company of which it holds a major share. This means that nearly 30% of BP's carbon emissions (Rosneft's share of emissions in 2019) would remain unaffected by its net zero ambition. See endnote 37 for this chapter.
- ii Chevron has a 40% emissions intensity reduction target in oil production and 26% in gas production by 2028 (relative to the 2016 baseline), while ExxonMobil has a 15-20% upstream emissions intensity reduction target by 2025.
- iii Activities outside core business areas may include any ventures outside exploration and production for oil and gas companies, with the exact definition differing across companies. Renewable energy projects are likely to form a small proportion of such activities, however the exact proportion is unknown due to lack of disaggregated reporting by oil and gas majors.
- iv The Energy Charter Treaty is a multilateral agreement for energy co-operation, enforced under international law since 1998. One of its provisions protects foreign investments from policy changes in host countries, and effectively allows fossil fuel companies to sue national governments for climate action and seek compensation when their interests are threatened. Talks on reforming the treaty are ongoing. For details, see sources in endnote 37 for this chapter.














**FIGURE 5.** Spending on Renewable Energy versus Total Capital Expenditure, Selected Oil and Gas Companies, 2020



Note: Oil and gas companies do not explicitly report on renewable energy spending in their financial statements. Eni was the only company that provided this number for 2020. Equinor, Chevron, BP and ExxonMobil conflate renewable spending with environmental or low-carbon spending in general. Total and Shell conflate renewable spending with spending on power generation, including fossil-based generation.

Source: See endnote 37 for this chapter.

**TABLE 1.**  
Renewable Energy Indicators 2020

		2019	2020
<b>INVESTMENT</b>			
New investment (annual) in renewable power and fuels <sup>1</sup>	billion USD	298.4	<b>303.5</b>
<b>POWER</b>			
Renewable power capacity (including hydropower)	GW	2,581	<b>2,838</b>
Renewable power capacity (not including hydropower)	GW	1,430	<b>1,668</b>
 Hydropower capacity <sup>2</sup>	GW	1,150	<b>1,170</b>
 Solar PV capacity <sup>3</sup>	GW	621	<b>760</b>
 Wind power capacity	GW	650	<b>743</b>
 Bio-power capacity	GW	137	<b>145</b>
 Geothermal power capacity	GW	14.0	<b>14.1</b>
 Concentrating solar thermal power (CSP) capacity	GW	6.1	<b>6.2</b>
 Ocean power capacity	GW	0.5	<b>0.5</b>
<b>HEAT</b>			
 Modern bio-heat demand (estimated) <sup>4</sup>	EJ	13.7	<b>13.9</b>
 Solar hot water demand (estimated) <sup>5</sup>	EJ	1.5	<b>1.5</b>
 Geothermal direct-use heat demand (estimated) <sup>6</sup>	PJ	421	<b>462</b>
<b>TRANSPORT</b>			
 Ethanol production (annual)	billion litres	115	<b>105</b>
 FAME biodiesel production (annual)	billion litres	41	<b>39</b>
 HVO biodiesel production (annual)	billion litres	6.5	<b>7.5</b>
<b>POLICIES<sup>7</sup></b>			
Countries with renewable energy targets	#	172	<b>165</b>
Countries with renewable energy policies	#	161	<b>161</b>
Countries with renewable heating and cooling targets	#	49	<b>19</b>
Countries with renewable transport targets	#	46	<b>35</b>
Countries with renewable electricity targets	#	166	<b>137</b>
Countries with heat regulatory policies	#	22	<b>22</b>
Countries with biofuel blend mandates <sup>8</sup>	#	65	<b>65</b>
Countries with feed-in policies (existing)	#	83	<b>83</b>
Countries with feed-in policies (cumulative) <sup>9</sup>	#	113	<b>113</b>
Countries with tendering (held during the year)	#	41	<b>33</b>
Countries with tendering (cumulative) <sup>9</sup>	#	111	<b>116</b>

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 in the GSR 2021 Data Pack and related endnote for more information.

5 Includes glazed (flat-plate and vacuum tube) and unglazed collectors only. The number for 2020 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 2020 is based on the annualised growth rate in the five-year period since 2014. See 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 6 and Reference Tables R3-R11 in the GSR 2021 Data Pack.

8 Biofuel policies include policies listed both under the biofuel obligation/mandate column in Table 6 and in Reference Table R8 in the GSR 2021 Data Pack.

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 R10 and R11 in the GSR 2021 Data Pack.









Note: All values are rounded to whole numbers except for numbers <15, biofuels and investment, which are rounded to one decimal point. FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil.



**TABLE 2.**  
Top Five Countries 2020

### Annual Investment / Net Capacity Additions / Production in 2020

Technologies ordered based on total capacity additions in 2020.

	1	2	3	4	5
 Solar PV capacity	China	United States	Vietnam	Japan	Germany
 Wind power capacity	China	United States	Brazil	Netherlands	Spain or Germany
 Hydropower capacity	China	Turkey	Mexico	India	Angola
 Geothermal power capacity	Turkey	United States	Japan	–	–
 Concentrating solar thermal power (CSP) capacity	China	–	–	–	–
 Solar water heating capacity	China	Turkey	India	Brazil	United States
 Ethanol production	United States	Brazil	China	Canada	India
 Biodiesel production	Indonesia	Brazil	United States	Germany	France

### Total Power Capacity or Demand / Output as of End-2020

	1	2	3	4	5
<b>POWER</b>					
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) <sup>1</sup>	Iceland	Denmark	Sweden	Germany	Australia
 Bio-power capacity	China	Brazil	United States	Germany	India
 Geothermal power capacity	United States	Indonesia	Philippines	Turkey	New Zealand
 Hydropower capacity <sup>2</sup>	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	China	Morocco	South Africa
 Wind power capacity	China	United States	Germany	India	Spain
<b>HEAT</b>					
 Modern bio-heat demand in buildings	United States	Germany	France	Italy	Sweden
 Modern bio-heat demand in industry	Brazil	India	United States	Finland	Sweden
 Solar water heating collector capacity <sup>2</sup>	China	Turkey	India	Brazil	United States
 Geothermal heat output <sup>3</sup>	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 2019 population data from the World Bank.

2 Solar water heating collector ranking for total capacity is for year-end 2020 and is based on capacity of water (glazed and unglazed) collectors only. Data from International Energy Agency Solar Heating and Cooling Programme.

3 Not including heat pumps.

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



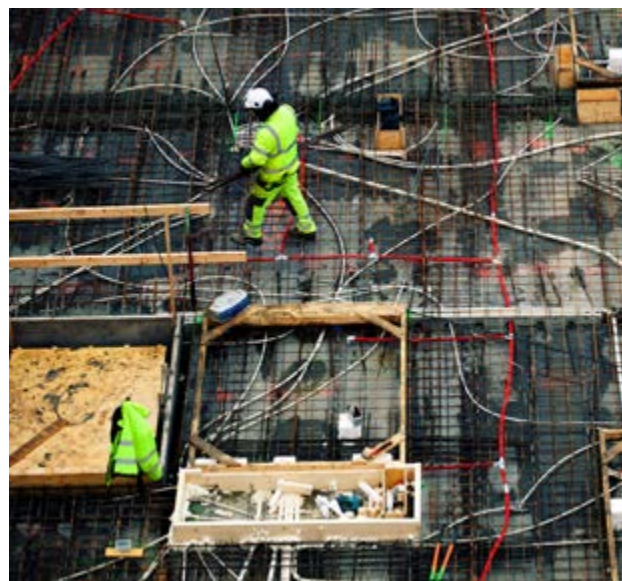
Buildings historically have accounted for around 33% of final energy use, a share that was relatively stable in the decade leading up to 2020.<sup>79</sup> Renewable energy meets a growing share of final energy demand in buildings, although it remains less than 15% and has risen slowly overall.<sup>80</sup> Increases in renewable energy consumption are most noticeable in electricity use, whereas heating with renewables is rising more slowly.<sup>81</sup> Bioenergy remains the global front-runner in supplying renewable heat to buildings, while the use of renewable electricity to meet heating loads (i.e., electrification) is rising rapidly and already covers the full renewable contribution to cooling demand.<sup>82</sup>

The COVID-19 pandemic impacted energy use in the buildings' sector – at their peak in April 2020, partial or full stay-at-home orders were active in countries responsible for around 55% of global primary energy demand.<sup>83</sup> As a result of these restrictions, millions of people began working from home. This shifted energy use, particularly electricity demand, away from industrial activity, transport and commercial buildings and towards residential buildings.<sup>84</sup> The global impact on energy demand in 2020 was not known at the time of publication; however, first estimates suggest that remote work could have contributed to a net reduction in building energy consumption in 2020.<sup>85</sup>

The sector is a significant contributor to global energy-related CO<sub>2</sub> emissions.<sup>86</sup> Prior to the pandemic, this share was 28%, with significant regional variations, and was increasing steadily, driven mainly by growth in indirect emissions from electricity generation and from production of heat consumed in buildings.<sup>87</sup>

Population and building floor area are typical indicators that have propelled past trends in global building energy use.<sup>88</sup> In the decade leading to 2020, growth in both indicators exceeded any reductions in demand resulting from energy efficiency measures, leading to around a 1% annual increase in building energy consumption.<sup>89</sup> However, growth in both energy demand and CO<sub>2</sub> emissions was lower than the rise in population and building floor area, underlining a gradual decoupling and overall improvement in the energy and carbon intensity of building operations.<sup>90</sup> Increased use of renewables was responsible for an estimated 15% of this improvement across all sectors.<sup>91</sup>

Renewables are the fastest growing energy source for buildings, rising 4.1% annually on average between 2009 and 2019.<sup>92</sup> Despite this growth, renewables met only an estimated 14.3% of total energy demand in buildings in 2019, up from 10.5% in 2009.<sup>93</sup> Energy use in buildings can be split into two basic needs. Thermal energy<sup>iii</sup> needs – including space heating and



cooling, water heating and cooking – account for around 77% of global final energy demand in buildings.<sup>94</sup> The remaining 23% is electrical end-uses, which comprise lighting, appliances and other uses unrelated to heating or cooling.<sup>95</sup>

Already, most of the world's cooling demand is supplied by electricity.<sup>96</sup> Meanwhile, the demand for cooling has continued to grow rapidly in emerging countries, notably in Sub-Saharan Africa and in Southeast Asia.<sup>97</sup> However, the world's average cooling load is met mainly by less-efficient models of air conditioner compared to the most efficient technology available.<sup>98</sup>

Electricity also meets a rising proportion of the world's heat demand in buildings, having increased from around 9.6% in 2009 to 11.7% in 2019.<sup>99</sup> As the share of renewable electricity in the global power system continues to grow, electrification has increasingly emerged as the preferred route to decarbonise heating systems in buildings.<sup>100</sup>

Total energy demand for **heating and cooling** grew at around the same rate as building energy use (1% per year) between 2009 and 2019.<sup>101</sup> It was outpaced by the growth of renewable heating and cooling in buildings over the same period (around 6%).<sup>102</sup> Chief among the factors for this increase was the use of renewable electricity for heating (and cooling), while modern bioenergy<sup>iv</sup> use has stayed relatively stable.<sup>103</sup> However, the renewable energy share of heating demand grew from only around 8% to nearly 11% over the same decade, underscoring the importance of energy efficiency in enabling higher shares of renewables.<sup>104</sup> (→ See Figure 6.)

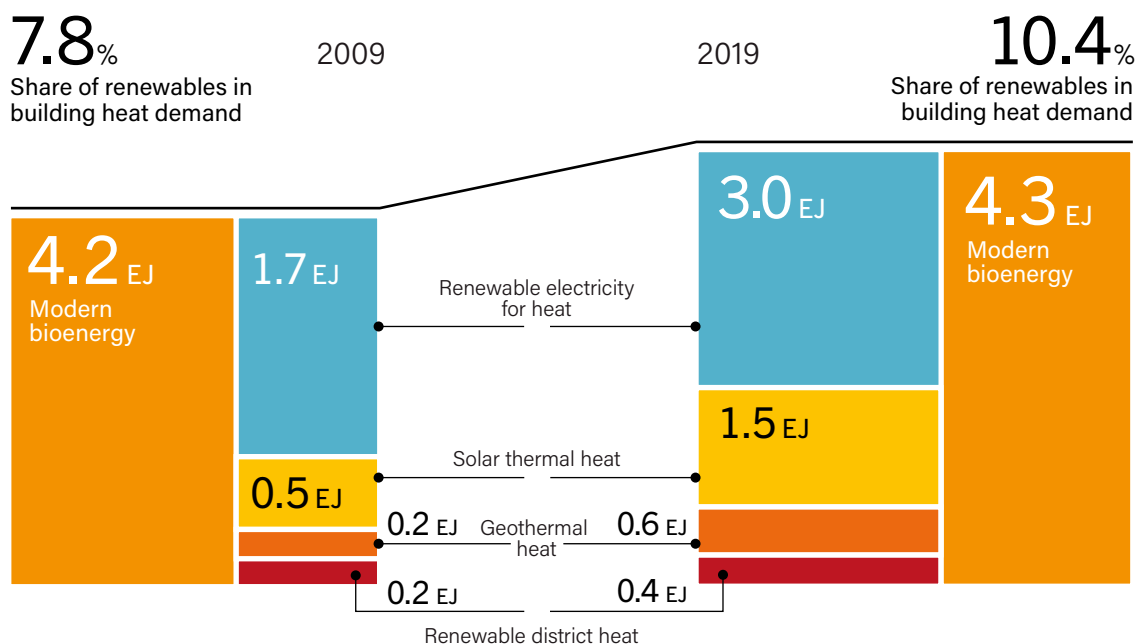
i "Buildings" in the GSR refers to the activities and energy used in building operation and maintenance, and does not include manufacturing, transport or use of building materials, or energy use in construction activities.

ii Due to data availability and publication dates for comprehensive datasets, the most recent data available for energy consumption are in the year 2018. Throughout this section, estimates are made for the year 2019.

iii 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 Note.

iv The traditional use of biomass for heat involves burning woody biomass or charcoal, as well as dung and other agricultural residues, in simple and inefficient devices to provide energy for residential cooking and heating in developing and emerging economies. Modern bioenergy is any production and use of bioenergy that is not classified as "traditional use of biomass".

**FIGURE 6.**  
Renewable Energy Contribution to Heating in Buildings, by Technology, 2009 and 2019



Note: Energy demand is reported in exajoules (EJ). Includes space heating, space cooling, water heating and cooking. Renewable district heat is virtually all supplied by bioenergy. Totals may not add up due to rounding.

Source: Based on IEA data. See endnote 104 for this chapter.

Although the global renewable heating and cooling share in buildings remains low, some countries and regions have achieved relatively higher shares. In the EU, a global leader in this area, renewable energy accounted for more than 21% of total heating and cooling needs (including industrial process heat) in 2018 (latest data available).<sup>105</sup> Certain Baltic and Nordic countries' supply more than 50% of their building heat demand with renewables.<sup>106</sup>

Demand for cooling is the most rapidly growing energy end-use in buildings.<sup>107</sup> Sales of cooling devices are growing fastest in developing and emerging countries.<sup>108</sup> As most cooling is supplied by electric devices, the contribution of renewables to meeting this demand depends largely on the prevailing electricity fuel mix; however, significant regional variations exist.<sup>109</sup>

The global mix of renewable energy technologies supplying heat to buildings is gradually shifting. **Modern bioenergy** has long delivered the largest amount of renewable heat to buildings, responsible for around half of all renewable heat consumption.<sup>110</sup> Bioheat typically is produced in wood-burning furnaces or combusted and delivered via district energy networks.<sup>111</sup> In 2019, bioheat met around 4.6% of total heat demand in buildings.<sup>ii,112</sup> Its role is shrinking, however, as solar thermal heat, geothermal heat and renewable electricity for heat are expanding and gaining shares.<sup>113</sup>

**Solar thermal** and **geothermal energy** together contributed some 2.2% of heat demand in buildings in 2019, up from 0.8% in 2009.<sup>114</sup> Globally, demand for new solar thermal systems contracted slightly in 2020, and the impact of existing policy had a greater effect than the general impact of the pandemic, notably in China (the global leader).<sup>115</sup> China was similarly the world's largest and fastest-growing market for direct consumption of geothermal heat in buildings, growing 21% annually during 2015-2020, while the runners-up (Turkey, Iceland and Japan) grew 3-5%.<sup>116</sup> Overall, consumption of solar and geothermal heat sources has grown more rapidly (each up around 11% per year) than bioenergy use in recent years, although starting from a small base.<sup>117</sup>

After bioenergy, the use of **renewable electricity for heat** provided the second largest renewable energy contribution to building heat demand at around 3.2% in 2019, up from 2.0% in 2009.<sup>118</sup> 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.<sup>119</sup> However, most of the increase was due to the growing share of renewables in the global electricity supply, rather than to rising electrification of heating in buildings.<sup>120</sup> In total, the global share of all electricity use in final energy consumption of buildings grew from 28% in 2009 to an estimated 32% in 2019, an increase in global share even as final energy consumption rose.<sup>121</sup>

i As of 2019, these included Iceland, Sweden, Latvia, Finland and Estonia. See endnote 106.

ii When accounting for bioenergy delivered by district heating networks, the share rises to around 5%.

Renewable electricity supplies heat to buildings in various ways, notably through electric radiators or highly efficient electric heat pumps. Major global markets for electric heat pumps in China, Japan, Europe and the United States grew in 2020, continuing a multi-year acceleration.<sup>122</sup> Government policy related to heat pumps also is expanding, with several countries setting targets for installations of the technology while also pledging to increase their renewable power capacities.<sup>123</sup>

Total electrification of heating is garnering increasing policy attention as well. In 2020, **electrification of heat** was prominently pursued in the United States, continuing a trend from 2019.<sup>124</sup> US states such as Colorado, Maine, Michigan, Nevada and New Jersey released plans to address climate change that targeted “all-electric” buildings, mandated heat pump installations and/or cited electric heating as a way to achieve their climate goals.<sup>125</sup> In Australia, the Australian Capital Territory committed to supporting numerous all-electric residential and business developments, some of which included the choice to participate in community solar projects.<sup>126</sup>

During the year, attention grew on the use of **hydrogen for heating buildings**. Communities in Canada and the United Kingdom announced pilot projects to blend hydrogen with fossil gas in gas distribution networks to provide heat to buildings.<sup>127</sup> As part of its Hydrogen Strategy, the EU is conducting pilot projects to analyse the potential to replace fossil gas boilers with hydrogen boilers.<sup>128</sup> At the same time, numerous studies from research organisations and think tanks found that using hydrogen for home heating could be less energy efficient and more cost intensive than electrification, most notably with electric heat pumps.<sup>129</sup> Moreover, in early 2021 a coalition spanning businesses and civil society organisations sent a letter to the European Commission asking it to prioritise renewables and energy efficiency over hydrogen for building heat.<sup>130</sup>

**District energy networks** can efficiently meet urban heating and cooling needs; however, these systems currently account for just 6.7% of heat demand in buildings.<sup>131</sup> Moreover, the low global share of renewable energy in these networks (5.6%) means that only 0.4% of the world’s heat demand in buildings was met by renewables in district networks in 2018.<sup>132</sup> Nevertheless, some European countries have achieved relatively high shares of renewables in the district heat supply (more than 50%<sup>i</sup> in at least six countries in recent years<sup>ii</sup>).<sup>133</sup> In 2020, solar thermal systems for district heating were brought online in China, Denmark and Germany, and these markets have continued to grow.<sup>134</sup>

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.<sup>135</sup> In these countries, the use of gaseous fuels<sup>iii</sup> reached 37% of the population in 2019 (compared to 35% for the traditional use of biomass).<sup>136</sup> At the same time, the share of electricity for cooking rose to 10% in 2019; due to its use mostly in urban areas, the use of renewable electricity for cooking is dependent on the

overall renewable share in national power grids.<sup>137</sup> Use of solar energy for cooking is also rising: by early 2021, more than 14 million people had benefited from the 4 million solar cookers that had been distributed around the world.<sup>138</sup>

**Electricity** is the fastest growing energy source in buildings, with demand up 2.2% annually between 2009 and 2019.<sup>139</sup> Renewable electricity is delivered to buildings both from centralised plants by the electricity grid, and by distributed systems, depending on the location.<sup>140</sup> Although the penetration of distributed systems is growing, the global contribution of renewables to electricity demand in buildings is largely dependent on the prevailing local electricity mix in the grid.<sup>141</sup> In 2020, the renewable share of electricity production was around 29%, up from 20% in 2010.<sup>142</sup> (→ See *Power section in this chapter*.)

Distributed renewables also provide **electricity access** to growing shares of the population in developing and emerging economies.<sup>143</sup> As of mid-2020, more than 100 million people had gained access to basic residential electricity services through the use of solar lighting and solar home systems alone.<sup>144</sup> In addition, as of March 2020, 87% of operational mini-grids were providing renewables-based electricity access, with solar PV as the fastest growing technology for mini-grids.<sup>145</sup>

**Policy attention** to stimulate renewable energy uptake in buildings is lacking on a global scale, particularly related to heating end-uses.<sup>146</sup> New or updated financial incentives in 2020 were introduced only in Europe, and included the Netherlands’ incentive scheme that was expanded to include renewable heat and the United Kingdom’s extension of its funding programme to retrofit buildings with renewables-based heating systems.<sup>147</sup> At the city level, policy trends for buildings include energy codes that mandate the use of renewables for heating (or electricity).<sup>148</sup> Such codes typically apply to new buildings, while renewables for existing buildings often are encouraged through financial and fiscal incentives.<sup>149</sup>

An enabling policy measure becoming increasingly prevalent is bans and restrictions on some types of fossil fuels in new and existing buildings. Examples of this trend are present in more than 50 cities in 10 countries (and at least 7 national governments).<sup>150</sup> Numerous cities in Asia, North America (especially the US state of California), Europe and Oceania have introduced policies to phase out the use of fossil fuels for space and water heating in new and/or existing buildings.<sup>151</sup> Policies subsidising the use of fossil fuels for heating continue to exist and clash with those that encourage the uptake of renewables.<sup>152</sup>

**Policies subsidising the use of fossil fuels for heating continue to clash with those that encourage the uptake of renewables.**

i These statistics often include waste heat as a “renewable” source of district heat.

ii The six countries are, in descending order, Iceland, Norway, Sweden, Lithuania, Denmark and France.

iii Gaseous fuels refer to liquefied petroleum gas (LPG), natural gas and biogas, with LPG comprising the majority. Although not all renewable, these fuels – in addition to electricity and improved biomass – combined with their related stoves are considered “clean cooking” facilities as per the guidelines of the World Health Organization (WHO) for indoor air quality linked to household fuel combustion. See WHO, *WHO Guidelines for Indoor Air Quality: Household Fuel Combustion* (Geneva: 2014), <https://www.who.int/airpollution/guidelines/household-fuel-combustion/en>.

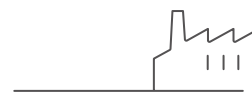


Efforts to restrict use of fossil fuels (mostly fossil gas) for heating have met heavy resistance from the incumbent industry in many regions, notably in the United Kingdom, the EU and the United States.<sup>153</sup> In the United States, fossil gas companies and industry associations launched public relations campaigns and spent millions of dollars in 2020 attempting to sway public opinion against electrification.<sup>154</sup> In the state of California, a consumer protection agency recommended that the largest US fossil gas utility pay USD 255 million in fines after misusing public funds to oppose local fossil gas bans.<sup>155</sup>

The emergence of targets towards achieving net zero emissions, as well as rising interest in **net and nearly zero energy buildings**<sup>i</sup>, also are spurring increased use of renewables in buildings.<sup>156</sup> In late 2020, 18 new signatories signed the Net Zero Carbon Buildings Commitment to bring the total to 6 states and regions, 28 cities, and 98 businesses and organisations that had agreed to achieve net zero emissions in their operations by 2030.<sup>157</sup> Beginning in 2021, the EU's Energy Performance in Buildings Directive mandated that all new public buildings in the region be "nearly zero energy buildings".

In addition to improving the performance of new buildings, addressing the **existing building stock** is expected to be an important step towards meeting climate targets. The EU's Renovation Wave strategy, announced in 2020, aims to support the decarbonisation of heating and cooling by strengthening regulations, providing incentives for private financing and introducing minimum energy performance standards, among other objectives.<sup>158</sup> Mandatory building performance standards were introduced and strengthened in the United States in 2020 and early 2021.<sup>159</sup> By the end of 2020, 67 countries had mandatory or voluntary building energy codes at the national level, although no new requirements for renewables in building energy codes were introduced during the year.<sup>160</sup>

## INDUSTRY



Industrial energy use accounts for around 34% of total final energy consumption, growing at an annual rate of around 1%.<sup>161</sup> In certain energy-intensive sub-sectors such as chemicals and non-ferrous metals processing, the annual growth in energy demand nears 4%.<sup>162</sup> Around three-quarters of the energy used in industry is for direct thermal or mechanical end-uses that involve combustion, as well as the use of electricity to meet thermal energy needs.<sup>163</sup> Overall, these processes include the generation of industrial process steam as well as drying and refrigeration by use of thermally driven chillers. The remaining share is for electrical end-uses, including the operation of machinery and lighting.<sup>164</sup> Direct energy-related industrial CO<sub>2</sub> emissions (excluding agriculture and land use) comprise around 24% of the global total.<sup>165</sup>

The COVID-19 pandemic and related economic slowdown led to curtailed demand for industrial output worldwide and to a temporary reduction in industrial energy demand in 2020.<sup>166</sup> As a result, global industrial bioenergy consumption fell 4% for the year.<sup>167</sup> Measures to promote the uptake of renewables in industries received limited attention in stimulus packages implemented in response to the pandemic. Some countries – notably Australia, Chile, Germany, the Netherlands, Norway and the United Kingdom – announced renewable hydrogen strategies or investment plans to support efforts in harder-to-decarbonise sectors including heavy industry. (→ See *Sidebar 5 and Table 5 in Policy Landscape chapter*). By the end of 2020, only 32 countries had at least one renewable heating and cooling policy for industry, all of them in the form of economic incentives such as subsidies, grants, tax credits and loan schemes. (→ See *Reference Table R9 in GSR 2021 Data Pack*.)



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 endnote 156 for this chapter.

The industrial sector relies heavily on fossil fuels, with renewables accounting for only around 14.8% of total industrial energy demand.<sup>168</sup> Around 90% of the renewable heat in the sector is supplied by bioenergy (mainly biomass), and mostly in industries where biomass waste and residues are produced on-site, such as pulp and paper, food, forestry and wood products.<sup>169</sup> Uptake of bioenergy also is rising in the cement industry due to increasing use of municipal waste in China and the EU.<sup>170</sup> Bioenergy use for industrial heating is concentrated in countries with large bio-based industries, such as Brazil, China, India and the United States.<sup>171</sup> In 2019, Brazil was the world's largest user of bioenergy for industrial heat, with an estimated 1.6 EJ, followed by India (1.4 EJ) and the United States (1.3 EJ).<sup>172</sup>

Renewable electricity accounts for the second largest share (10%) of renewable industrial heat, although it represented only 1% of the total industrial heat consumption in 2019.<sup>173</sup> It is used mainly for processes such as drying, refrigeration, and packaging and hardening for metal production.<sup>174</sup> Solar thermal and geothermal technologies also increasingly supply direct renewable heat for low-temperature industrial applications (20 degrees Celsius (°C) to 300°C), although they still accounted for less than 0.05% of total final industrial energy use in 2018.<sup>175</sup>

As of 2020, 98% of the geothermal industrial process heat was used in China, New Zealand, Iceland, the Russian Federation and Hungary.<sup>176</sup> Geothermal heat is used mainly in the food and beverages, pulp and paper processing, and chemical extraction industries.<sup>177</sup> For solar thermal industrial heat, as of early 2020, the leading countries in total installed capacity were Oman (300 megawatts-thermal (MW<sub>th</sub>), Chile (25 MW<sub>th</sub>) and China (24 MW<sub>th</sub>), while Mexico and India led in the number of installations with 77 and 44 systems respectively.<sup>178</sup> The mining sector had the largest share of installed solar thermal capacity (75%), followed by food and beverages (10%) and textiles (5.6%).<sup>179</sup>

Three key industrial sectors that have low-temperature process heat requirements, and where renewable energy is used, are pulp and paper, food and beverages, and mining. The **pulp and paper** industry uses the highest share of renewables in industrial process heat, with bioenergy and other renewable

fuels accounting for 30% of the sector's total energy use.<sup>180</sup> This industry is located mainly in North America, Europe, East Asia and Brazil.<sup>181</sup> In particular, renewable energy provides low-temperature heat for chemical pulping, the predominant mode of paper production.<sup>182</sup> In 2020, Navigator Company (Portugal) invested EUR 55 million (USD 68 million) in a new biomass boiler plant at its pulp and paper complex in the city of Figueira da Foz.<sup>183</sup> Renewables also provide electricity for producing paper through mechanical pulping.<sup>184</sup> In Eastern Croatia, a paper mill operated by sustainable packaging company DS Smith announced in 2020 that it was shifting to renewable electricity to power its paper-making process.<sup>185</sup>

The **food and tobacco** industry ranks second, with renewables supplying more than a quarter of the energy supply for industrial process heat.<sup>186</sup> Here, the renewable heat is supplied by heat pumps, solar thermal heat and electric heating.<sup>187</sup> In Cyprus, a solar thermal system designed for continuous operation was installed at a Kean Juices facility as part of a demonstration project in mid-2020.<sup>188</sup> Renewable electrification also was a popular option during the year. McCain Foods (Australia) began building an 8.2 MW renewable energy system at its food processing facility in Ballarat using a combination of ground-mounted solar PV and a co-generation anaerobic digester that uses food waste to generate energy.<sup>189</sup> In India, SunAlpha Energy installed 12 MW of solar PV capacity for the food processing sector and announced plans to exceed 30 MW at facilities across the country by 2030.<sup>190</sup>

The **mining** industry accounts for around 6.2% of the world's energy consumption and 22% of global industrial CO<sub>2</sub> emissions.<sup>191</sup> Electricity represents 32% of the energy consumed by mines, presenting an opportunity for direct use of renewable power.<sup>192</sup> However, renewables comprise less than 10% of energy consumption in the sector, a share that has been constant for some five decades.<sup>193</sup> This share is higher in Australia, a leading region in the use of renewables in mining.<sup>194</sup>

Progress towards renewable electrification in mining also continued in some regions in 2020, with several major mining companies building on-site renewable power plants in Australia, Chile, Saudi Arabia and South Africa.<sup>195</sup> Additionally,

Around 90% of the renewable heat in the industry sector is supplied by bioenergy, most of which comes from biomass produced on-site.



Australia-based iron ore mining giant Fortescue Metals announced plans to build over 235 GW of renewable capacity to become a supplier of renewable power and hydrogen while also decarbonising its own energy consumption.<sup>196</sup>

In more energy-intensive industries, renewables face limitations in meeting the requirements for high-temperature process heat (> 400°C). Three heavy industries in particular – chemicals, iron and steel, and cement – require vast quantities of energy, together accounting for 60% of industrial energy use and 70% of industrial emissions.<sup>197</sup> The penetration of renewables in these heavy industries remains low, comprising less than 1% of their combined energy demand in 2018.<sup>198</sup> In the face of reduced demand due to the COVID-19 crisis, both energy use and emissions in heavy industries declined around 5% in 2020.<sup>199</sup>

Renewable hydrogen<sup>i</sup> can potentially play a key role in decarbonising heavy industries.<sup>200</sup> In 2020, the world's largest developers<sup>ii</sup> of **renewable hydrogen** came together to form the Green Hydrogen Catapult initiative, aiming to greatly reduce costs to stimulate a more rapid energy transition in the most carbon-intensive industries.<sup>201</sup> Government support for renewable hydrogen increased during the year, and by year's end at least 10 countries globally had adopted some kind of renewable hydrogen support policy. (→ See *Sidebar 5 and Table 5 in Policy Landscape chapter*.)

The **chemicals and petrochemicals** industry is the largest industrial energy user worldwide, consuming 46.8 EJ in 2017 and producing 5% of total global energy- and process-related CO<sub>2</sub> emissions.<sup>202</sup> Only 3% of the industry's energy demand comes from renewables.<sup>203</sup> Energy in this industry is used as feedstock (primarily oil, natural gas, and coal) and for providing high-temperature process heat (close to 1,000°C).<sup>204</sup> Renewables could meet this energy demand in two main ways: using biomass to replace fossil fuels as a feedstock, and using renewable hydrogen for process heat or as a feedstock.<sup>205</sup>

Some companies already have begun using renewable hydrogen for these purposes. In late 2020, in Western Australia, YARA and Engine formed a partnership to develop a renewable hydrogen project to provide feedstock for ammonia<sup>iii</sup> production.<sup>206</sup> Also during the year, BioMCM and four partners won an EUR 11 million (USD 13.5 million) European grant for a renewable hydrogen project based in the Netherlands to produce renewable methanol.<sup>207</sup> Additionally, BioBTX, an innovative technology that converts biomass into chemicals, secured financing to operationalise its first commercial plant by 2023.<sup>208</sup>

The **iron and steel** industry consumed 32 EJ of energy in 2017 and contributed 8% of total global energy- and process-related CO<sub>2</sub> emissions, making it the largest emitter among heavy industries.<sup>209</sup> Renewables accounted for only 4% of the industry's energy consumption in 2017.<sup>210</sup> Nearly three-quarters (almost 72%) of global steel is produced via the blast furnace/basic oxygen

furnace (BF-BOF) route, using metallurgical coal as the chemical reducing agent, where the potential for renewables use is limited.<sup>211</sup>

However, the remaining production occurs mostly through direct reduction of iron ore or scrap steel using electric arc furnaces, where renewable penetration is possible if renewable hydrogen is used as the reducing agent and renewables are used to power the furnaces.<sup>212</sup>

The “green steel” concept received considerable attention from industry players in 2020, mainly in Europe.<sup>213</sup> Sweden's HYBRIT green steel venture, which aims to replace coking coal with fossil-free electricity and hydrogen, began operations at its pilot plant.<sup>214</sup> LKAB, one of the partners in the HYBRIT initiative, also became the world's first producer of fossil-free iron ore pellets during the year.<sup>215</sup> Another Swedish start-up, H2 Green Steel, drew significant investments to build the world's largest hydrogen electrolyser to produce green steel starting in 2024.<sup>216</sup> Germany's largest steelmaker, Thyssenkrupp, announced plans to build a direct reduced iron plant running on renewable hydrogen by 2025.<sup>217</sup>

The **cement and lime** industry consumed 15.6 EJ of energy in 2017 and accounted for 6.7% of total global energy- and process-related CO<sub>2</sub> emissions.<sup>218</sup> However, the bulk of the CO<sub>2</sub> emissions in this industry are not energy-related but are a by-product of the chemical process used to produce clinker, the main constituent of cement.<sup>219</sup> Remaining emissions come mainly from the combustion of fossil fuels to supply process heat for this reaction. The only feasible entry point for renewables in this industry is through fuel switching for process energy from coal to biomass, waste fuels, renewable hydrogen or direct electrification.<sup>220</sup> By 2017, renewables accounted for around 6% of energy use in the cement and lime sector, the largest share of renewables among heavy industries.<sup>221</sup>

Regional and global cement industry associations around the world announced carbon neutrality targets and roadmaps in 2020, outlining the role of renewable heat, electricity and renewable hydrogen, notably in the Dominican Republic, Europe and the United Kingdom.<sup>222</sup> Additionally, the Mineral Products Association secured a GBP 6 million (USD 8.2 million) grant from the UK government to conduct fuel switching trials into hydrogen, biomass and plasma technology to decarbonise cement and lime production.<sup>223</sup> In February 2021, Hanson UK installed a renewable hydrogen demo unit at its cement facility in Wales to partially replace natural gas in the kiln combustion system.<sup>224</sup>

By the end of 2020, at least 10 countries had adopted a **renewable hydrogen** support policies.

i Renewable hydrogen is electrolytic hydrogen produced with renewable electricity.

ii Founding partners of the initiative include ACWA Power (Saudi Arabia), CWP Renewables (Australia), Envision (China), Iberdrola (Spain), Ørsted (Denmark), Snam (Italy) and Yara (Norway).

iii Ammonia is predominantly used to produce fertilisers. It also is used as a refrigerant gas and for purification of water supplies, as well as in the manufacture of household and industrial-strength cleaning products, plastics, explosives, textiles, pesticides, dyes and other chemicals. There has been growing interest in ammonia as a transport fuel.



## TRANSPORT



For the transport sector, the year 2020 was marked by impacts from COVID-19, which also had an impact on the use of renewable energy in the sector. Transport activity and energy demand fell sharply early in the year as lockdowns were put in place, while sales and use of both standard and electric bikes rose dramatically in many places as hundreds of emergency measures were implemented to support cycling and walking infrastructure.<sup>225</sup> Aviation saw a 60% drop in traffic during the year, rail demand fell by up to an estimated 30%, and maritime trade declined an estimated 4.1%.<sup>226</sup> Public transport demand dropped in 2020 and remained low in many countries as of early 2021 due to fears of COVID-19 contagion from being on crowded buses or trains, while people turned to private vehicles and non-motorised or “active” transport (e.g., walking and cycling) in some areas.<sup>227</sup>

While EV sales increased around 41% during 2020, global passenger vehicle sales plummeted 14%.<sup>228</sup> The number of electric and plug-in hybrid passenger cars on the road surpassed 10 million in 2020, while the number of e-buses increased to 600,000, and electric two-/three-wheelers totalled around 290 million.<sup>229</sup> Although sport utility vehicle (SUV) sales decreased, SUVs were the only area globally across all sectors – even beyond transport – to see their emissions increase in 2020 due to their much higher average fuel consumption, their continued growth in popularity and the fact that in most cases they are not electric.<sup>230</sup>

The transport sector accounts for around 60% of global oil demand, which dropped sharply in 2020.<sup>231</sup> While oil demand in transport fell an estimated 8.8% during the year, it had nearly rebounded to pre-pandemic levels by mid-2021, and longer-term trends have shown that the growth in energy demand for transport has far outpaced other sectors.<sup>232</sup> Energy use for transport accounted for around one-third (32%) of total final energy consumption globally in 2018.<sup>233</sup> Road transport represented the bulk of the sector’s energy demand (74%), followed by aviation (12%), maritime transport (9.6%) and rail (2%).<sup>234</sup> Transport remains the sector with the lowest share of renewable energy: in 2018, the vast majority (95.8%) of global transport energy needs were met by oil and petroleum products (including 0.8% non-renewable electricity), with small shares met by biofuels (3.1%) and renewable electricity (0.3%).<sup>235</sup>

Despite continued gains in energy efficiency, particularly in road transport, global energy demand<sup>i</sup> in the transport sector increased 2.2% annually on average between 2008 and 2018.<sup>236</sup> 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), to a reduction in average passenger-kilometres travelled per person for buses, and to a lesser extent to rising air transport.<sup>237</sup> Passenger transport activity increased 74% between 2000 and 2015, almost entirely in developing and emerging countries, while surface freight (road and rail) activity increased 40% during this period.<sup>238</sup> However, while passenger transport energy intensity fell 27%, road freight transport energy intensity declined only 5% during these years.<sup>239</sup>

Because nearly all of the increases in energy demand in transport have been met by fossil fuels, the result has been a general trend of rising<sup>ii</sup> greenhouse gas emissions from the transport sector across all modes except rail, which remains the most highly electrified sub-sector.<sup>240</sup> Nearly three-quarters (74%) of all transport emissions are from road vehicles, 12% from aviation, 11% from maritime shipping and 1% from rail.<sup>241</sup>

Renewables can meet energy needs in the transport sector through the use of biofuels in pure (100%) form or blended with conventional fuels in internal combustion engine vehicles; biomethane in natural gas vehicles; and renewable electricity in battery electric<sup>iii</sup> and plug-in hybrid vehicles, and converted to renewable hydrogen through electrolysis for use in fuel cell vehicles, or used to produce synthetic fuels and electro-fuels.<sup>242</sup>

Following a decade of steady growth, **biofuels** production<sup>iv</sup> fell 5% in 2020 due to the overall decline in transport energy demand during the year.<sup>243</sup> Nevertheless, they remained by far the largest contributor of renewable energy to the transport sector. Ethanol volumes fell significantly during the year (down 8%), while biodiesel production and use was much less affected.<sup>244</sup> At the same time, production of HVO and HEFA fuels<sup>v</sup> grew sharply.<sup>245</sup> (→ See *Bioenergy section in Market and Industry chapter.*)

In contrast, the share of **renewable electricity** in the transport sector remained stable compared to 2019.<sup>246</sup> Greater electrification of transport can help to dramatically reduce CO<sub>2</sub> emissions in the sector, particularly in countries that are reaching high renewable shares in their electricity mix.<sup>247</sup> EVs also offer the potential for significant final energy savings, as they are inherently more efficient than comparable internal combustion engine vehicles.<sup>248</sup> Investments in charging infrastructure can further enable the electrification of transport, with some infrastructure relying on 100% renewable electricity.<sup>249</sup> (→ See *Systems Integration chapter.*)

Some regions, particularly China, Japan and the Republic of Korea, also saw increases in the fuel cell electric vehicle market, and in

i At the same time, the carbon intensity of transport (i.e., the CO<sub>2</sub> emitted per vehicle-kilometre) has improved in many countries due mainly to the implementation of fuel economy or emission standards for light-duty vehicles. (→ See *Transport section in Energy Efficiency chapter.*)

ii Transport CO<sub>2</sub> emissions increased 19% between 2008 and 2018, at an average annual rate of 1.8%. Emissions from SUVs alone tripled between 2010 and 2020 due to the increasing number and larger sizes relative to other passenger vehicles. The sector as a whole accounted for nearly one-quarter of global energy-related greenhouse gas emissions in 2018 (latest available data). While emissions from transport decreased an estimated 15% in 2020 due to the pandemic, they are expected to rebound. See endnote 240 for this chapter.

iii See Glossary.

iv This section concentrates on biofuel production, rather than use, because available production data 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 do exist, particularly for biodiesel.

v HVO is hydrotreated vegetable oil and HEFA is hydrogenated esters of fatty acids. These fuels often are described as renewable diesel, especially in North America. See *Bioenergy section in Market and Industry chapter.*



the use of or investment in **renewable hydrogen<sup>i</sup> and synthetic fuels for transport**, but these remained relatively minimal.<sup>250</sup> (→ See Box 1 and Table 5 in Policy Landscape chapter.)

Overall, the transport sector is not on track to meet global climate targets for 2030 and 2050.<sup>251</sup> The majority of countries worldwide have acknowledged the transport sector's role in mitigating emissions by including transport in their NDCs under the Paris Agreement.<sup>252</sup> However, just 10% of the NDCs as of 2020 included measures for renewables-based transport.<sup>253</sup>

Many countries still lack a **holistic strategy** for decarbonising transport, although cities often are well placed to take more comprehensive action – and many are already doing so.<sup>254</sup> Such strategies include reducing the overall demand for transport; transitioning to more efficient transport modes, such as (renewables-based) public transport and rail or non-motorised/active transport (e.g., walking and cycling); and improving vehicle technology and fuels, such as through higher fuel efficiencies and emission standards along with greater incorporation of renewables. Together, these strategies – commonly referred to as Avoid-Shift-Improve<sup>ii</sup> – can greatly decrease energy demand and associated greenhouse gas emissions in the sector and thus allow for the renewable share in transport to increase.<sup>255</sup>

Overall, the  
**transport  
sector is not  
on track**  
to meet global climate  
targets for 2030 and 2050.

## TRENDS BY TRANSPORT MODE

**Road transport** accounted for around 75% of global transport energy use in 2019, with passenger transport representing about two-thirds of this.<sup>256</sup> Biofuels continue to comprise nearly all (91%) of the renewable energy share in road transport energy use.<sup>257</sup> By the end of 2020, at least 65 countries had blending mandates for conventional biofuels (a number unchanged since 2017), and several countries with existing mandates strengthened them or added new targets; at least 17 countries had mandates or incentive programmes for advanced biofuels.<sup>258</sup>

Although rarely linked directly to renewable sources, the use of **electric vehicles** continued to expand during the year. EVs became more commonplace in more countries, often as a result of policies and targets adopted in prior years.<sup>259</sup> Global electric car sales remained strong despite the COVID-19 crisis, due in part to support policies and falling costs; however, the overall share of electricity in the transport sector remains low and has increased little in recent years.<sup>260</sup>

Only limited examples exist of direct policy linkages between EVs and renewable electricity. During 2020, one additional country adopted an e-mobility policy directly linked to renewables, bringing the total to three countries globally with such policies (Austria, Germany and Japan).<sup>261</sup> Nevertheless, at least 9 states/provinces, 33 countries, and the EU had independent targets both for EVs and for renewable power generation, which could facilitate greater use of renewables in transport.<sup>262</sup>

Policies restricting the use of fossil fuels can help increase renewable energy shares in the sector. By early 2021, at least 19 jurisdictions (national and state/provincial) 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 17 jurisdictions a year before.<sup>263</sup> At least 6 cities had adopted such bans, while at least 225 cities had already partially restricted the circulation of fossil fuel vehicles through the use of low-emission zones.<sup>264</sup>



i Almost all hydrogen production globally is from fossil fuels.

ii These actions 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.

Partly in response to these and other policy developments, an increasing number of private companies have begun increasing the use of renewables in their fleets'. (→ See *Transport section in Feature chapter and Box 2 in GSR 2020 Policy Landscape chapter*.) An increasing number of auto manufacturers also committed to moving away from fossil fuel-powered vehicles during the year, including General Motors, Nissan and Ford, while Volvo and Daimler announced a new joint venture aimed at developing, producing and commercialising hydrogen fuel cells for the heavy-duty vehicle industry.<sup>265</sup>

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 and flexibility services to the grid<sup>ii</sup>.<sup>266</sup> Vehicle-to-grid (V2G)<sup>iii</sup> is still relatively in its infancy, but during 2020 more companies invested in the technology and numerous new projects continued to be launched.<sup>267</sup> For example, ENGIE and Fiat-Chrysler began construction on the world's largest V2G project in Turin, Italy to provide 25 MW of renewable energy storage using batteries from 700 EVs.<sup>268</sup>

**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.<sup>269</sup> Fuel economy standards push manufacturers to seek to improve fuel efficiency and facilitate the adoption of alternative drivetrains based on low-carbon solutions, including renewable energy.<sup>270</sup> 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.<sup>271</sup> Moreover, no new countries have adopted such standards since 2017<sup>iv</sup>. In 2019, the EU adopted the first-ever CO<sub>2</sub> emission standards for heavy-duty vehicles.<sup>272</sup>

The larger the vehicles and the longer the range, the more challenging it is to find cost-effective alternatives to diesel.<sup>273</sup> However, both public and private entities have supported renewable alternatives. In 2020, the US state of California became the first jurisdiction worldwide to require truck manufacturers to transition from diesel trucks and vans to "near-zero-emission vehicles", such as electric or biomethane<sup>v</sup> vehicles.<sup>274</sup> Finnish state-owned gas company Gasum expanded its liquefied biogas (LBG)<sup>vi</sup> filling station network in Finland, Sweden and Norway.<sup>275</sup> In the private sector, Volvo Trucks (Sweden) reported seeing increased interest in LBG during the year, while Finnish freight firm Posti increased investment in LBG trucks.<sup>276</sup>

A few local governments and companies are using renewable energy in their **bus fleets**. While many cities have been using biofuels in buses for some time, an increasing number are linking renewable electricity to e-bus charging (such as charging the buses with solar power), notably in Europe, the United States and China.<sup>277</sup> Many more cities are running public urban **rail systems** on electricity, sometimes directly linked to renewable electricity and in other cases using biofuels.<sup>278</sup> By the end of 2020, just two countries (France and India) had enacted new policies and targets to advance the use of renewables in the rail sector.<sup>279</sup>

The overall share of electricity in the transport sector remains low and has increased little in recent years.

As the most highly electrified transport sector, rail transport accounts for around 2% of the total energy used in transport.<sup>280</sup> Renewables contribute an estimated 11% of global rail-related energy consumption.<sup>281</sup> Some jurisdictions have increased the share of renewable energy in rail transport to well above its share in their power sectors.<sup>282</sup> In 2020, at least two railway companies set net zero targets: Indian Railways for 2030 and UK-based Network Rail for 2050.<sup>283</sup>

**Maritime transport**<sup>vii</sup> consumes around 10% of the global energy used in transport – with around 0.1% estimated to be renewable – and is responsible for around 2.9% of global greenhouse gas emissions.<sup>284</sup> Although renewables do not feature significantly in the maritime fuel mix, some advances occurred during 2020. The Netherlands was the only country to advance the use of renewable energy in shipping, announcing plans obliging suppliers of heavy fuel oil and diesel for inland shipping to take part in its renewable fuel scheme.<sup>285</sup>

At the international level, the International Chamber of Shipping (the global shipping trade association) announced plans to invest USD 5 billion in research and development related to alternative fuels, with a goal of reducing the sector's greenhouse gas emissions 50% by 2050 (from 2008 levels).<sup>286</sup> Also, stricter energy efficiency targets and new fuel and emission standards adopted by the International Maritime Organization in 2019 began being implemented in 2020, and the organisation set goals with the Global Industry Alliance to reduce emissions in the ship-port interface.<sup>287</sup>

i This trend also continued in some new mobility service companies, including micro-mobility services such as electric sidewalk/"kick" scooters and dockless bicycles (both electric and traditional), as well as electric moped-style scooters and ridehailing and car-sharing services. (→ See *Box 2 in GSR 2020 Global Overview chapter*.)  
 ii EVs could ease the integration of variable renewable energy 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.  
 iii 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.  
 iv Heavy-duty vehicles are the fastest growing source of oil demand worldwide and the fastest growing emitter of CO<sub>2</sub> emissions. Even though they account for less than a quarter of total freight activity, they account for three-quarters of the energy demand and CO<sub>2</sub> emissions from freight. See endnote 240 for this chapter.  
 v Also called renewable natural gas or RNG.  
 vi Also called liquefied biomethane or bio-LNG.  
 vii The transport of goods or people via sea routes, including inland and coastal shipping.



In addition to the use of biofuels and other renewable-based fuels for propulsion, maritime transport has the possibility to directly incorporate wind power (via sails) and solar energy.<sup>288</sup> Some fleets already have moved to 100% renewable fuels, while others have moved to hybrid systems with energy storage (although not always operating on renewable energy).<sup>289</sup> In 2020, Finnish firms began testing LBG as a shipping fuel.<sup>290</sup> By early 2020, trials also had begun on the use of ammonia as a shipping fuel, with the potential to produce it using renewable electricity.<sup>291</sup> By year's end, discussions had begun on using green hydrogen in ferries and short-distance shipping.<sup>292</sup> At a smaller scale, electric outboard engines increasingly are being used in many markets and can be charged directly with renewable energy; some governments, such as Sweden, have offered incentives for electric models.<sup>293</sup>

By early 2021, at least one new **port** (Valenciaport, Spain) had joined the World Ports Climate Action Program, bringing the membership to 12 ports committed to advancing reductions in maritime transport emissions in support of the Paris Agreement.<sup>294</sup> In 2020, Valenciaport committed to building 8.5 MW of solar PV at two of its ports on Spain's coast for its own operations.<sup>295</sup> Also during the year, Portugal and the Netherlands signed a memorandum of understanding to connect Portugal's renewable hydrogen project with the Dutch Port of Rotterdam.<sup>296</sup>

**Aviation** accounts for around 12% of the total energy used in transport – less than 0.1% of which is renewable – and for around 2% of global greenhouse gas emissions.<sup>297</sup> 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 increased significantly leading up

to 2020, with emissions growing more rapidly than expected.<sup>298</sup> However, air travel plummeted with the onset of the pandemic.<sup>299</sup>

Support for and use of renewable fuels in the aviation sector made slight progress during 2020. Belarus, Ethiopia and Qatar submitted voluntary State Action Plans to the International Civil Aviation Organization, bringing to 120 the total number of member states<sup>i</sup> supporting the production and use of "sustainable alternative"<sup>ii</sup> aviation fuels, specifically drop-in fuels<sup>iii</sup>.<sup>300</sup> Meanwhile, as of early 2021, more than 315,000 commercial flights had flown on blends of alternative fuels, up from 200,000 a year before.<sup>301</sup> However, this is still a negligible share of the tens of millions of flights performed each year.<sup>302</sup> At least 9 airports had regular distribution of blended alternative fuel, up from 8 the year before, while at least 13 airports had batch deliveries of such fuels.<sup>303</sup> During 2020, as in the previous year, some companies announced targets for their own aircraft to run on biofuels and were developing planes made specifically to do this.<sup>304</sup>

Although interest in the electrification of aviation is increasing, as of May 2021 only electric drones or small planes had been developed. Some companies were planning fully electric airlines to carry more than 120 passengers, while others have aimed for hydrogen-powered electric planes.<sup>305</sup> A few "solar at gate"<sup>iv</sup> pilot projects have been developed in recent years in Cameroon, Jamaica and Kenya, although none were added in 2020.<sup>306</sup> Several airports announced during the year that their operations would be partly powered by solar power, including at all airports in Ghana, three French airports and major airports in the cities of Edmonton (Canada), Melbourne (Australia) and New York (US).<sup>307</sup>

i Representing 97.4% of global air traffic, up from 94.3% a year earlier.

ii The International Civil Aviation Organization (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/environmentalprotection/Pages/AltFuel-SustainableAltFuels.aspx>, viewed 14 April 2021.

iii Drop-in biofuels are produced from biomass, including different types of organic waste, and have properties enabling them to replace fossil fuels directly in transport systems, or to be blended at high levels with fossil fuels.

iv Using solar power for air conditioning and other services while a plane is at the airport gate.

# POWER

The renewable power sector experienced a turbulent first half of 2020 during the onset of the COVID-19 pandemic. Supply chain disruptions, restrictions on the movement of labour and goods, postponed or cancelled auctions, and other factors led to levels of new additions and investment that were markedly lower than in the same period in 2019.<sup>308</sup> Pandemic-related restrictions led to project developers facing significant labour shortages and delays in the supply chain as they rushed to complete projects on time.<sup>309</sup>

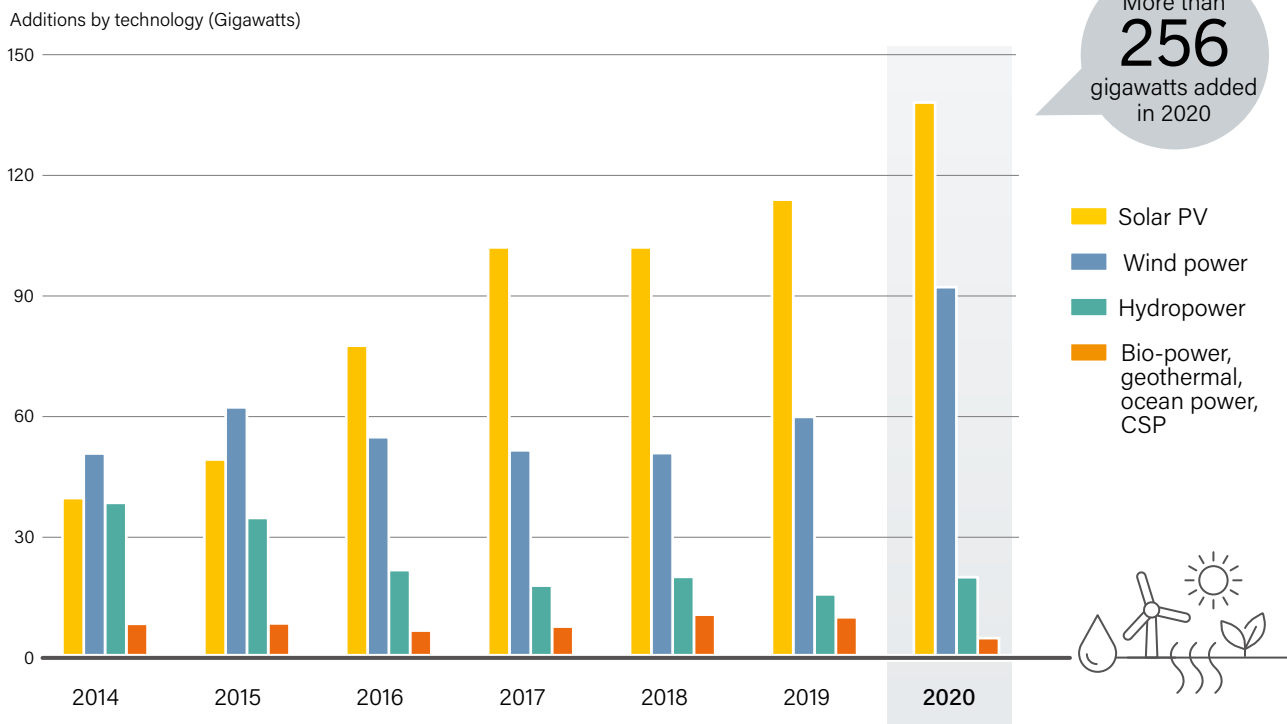
However, the solar PV and wind power sectors rebounded in the second half of 2020, and by year's end these two technologies each had installed a record amount of new capacity, steering the renewable power sector to an all-time high of more than 256 GW of added capacity.<sup>310</sup> Worldwide, total installed renewable power capacity grew almost 10% to reach 2,839 GW.<sup>311</sup> (→ See *Figure 7 and Reference Table R1* in *GSR 2021 Data Pack*.)

Continuing a trend going back to 2012, most of the newly installed power capacity in 2020 was renewable. Even as the fossil fuel and nuclear power sectors struggled, renewables reached 83% of net power capacity additions.<sup>312</sup> (→ See *Figure 8*.) As in recent years, solar PV and wind power made up the bulk of new renewable power additions. Around 139 GW of solar PV<sup>i</sup> was added, comprising more than half of the renewable additions, while 93 GW of installed wind power capacity made up some 36%.<sup>313</sup> Almost 20 GW of hydropower capacity was brought online, and the remaining additions were from bio-power, with ocean, geothermal and concentrating solar thermal power (CSP) adding only marginal net capacity.<sup>314</sup>

Once again, China led in capacity added during the year, accounting for almost half of new installations and leading global markets for bio-power, CSP, hydropower, solar PV and wind power.<sup>315</sup> With more than 116 GW added, China brought online more capacity in 2020 than the entire world did in 2013, and it nearly doubled its own additions of the previous year.<sup>316</sup> Countries

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

**FIGURE 7.** Annual Additions of Renewable Power Capacity, by Technology and Total, 2014-2020



Note: Solar PV capacity data are provided in direct current (DC). Data are not comparable against technology contributions to electricity generation. Source: See endnote 311 for this chapter.



outside of China added around 140 GW of capacity, up around 5% from 2019 and led by the United States (36 GW) and Vietnam (11 GW).<sup>317</sup> China also remained the global leader in cumulative renewable energy capacity (908 GW) at year's end, followed by the United States (313 GW), Brazil (150 GW), India (142 GW) and Germany (132 GW).<sup>318</sup> (→ See Table 2.)

By the end of 2020, at least 34 countries had more than 10 GW of renewable power capacity in operation, up from 20 countries in 2010.<sup>319</sup> 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 19 countries had more than 10 GW of non-hydropower renewable capacity at the end of 2020, up from 5 countries<sup>i</sup> in 2010.<sup>320</sup>

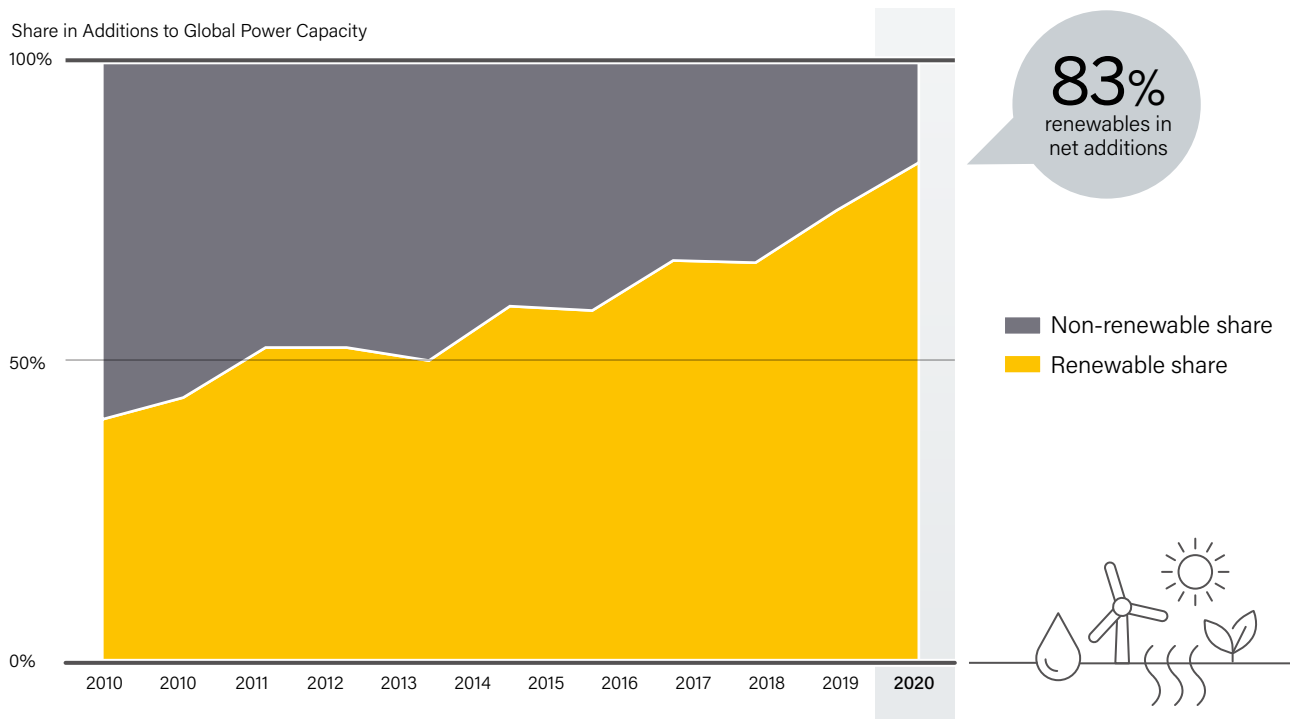
The top countries for non-hydro renewable power capacity per person were unchanged from previous years: Iceland, Denmark, Sweden, Germany and Australia.<sup>321</sup> (→ See **Reference Table R2** in *GSR 2021 Data Pack*.)

Driven by government policy and low costs, **major markets for leading renewable energy technologies** withstood the worst effects of the economic shocks in 2020. During the second half of the year, activity accelerated dramatically as developers sought to make up for delays and to take advantage of expiring incentives in Vietnam and the United States as well as expiring subsidies in China, which led to an installation rush (particularly for solar PV and wind power but also for hydropower).<sup>322</sup> In solar PV markets, rapid growth in rooftop solar projects compensated for a smaller increase in the utility-scale market, while growth in the wind power sector rose sharply in the second half of the year, driven mainly by onshore wind installations in China.<sup>323</sup> The global offshore market was stagnant compared to 2019.<sup>324</sup>

The global market for hydropower, still the leading technology in renewable electricity generation, grew significantly (24%) in 2020 due to the commissioning of several large projects in China.<sup>325</sup> CSP and geothermal power markets both declined during the year, with only a handful of countries accounting for most of the

i In 2010, China, India, Germany, Spain and the United States exceeded 10 GW of non-hydro renewable power capacity. As of 2020, Australia, Brazil, Canada, Italy, France, Japan, the Republic of Korea, Mexico, the Netherlands, Poland, Sweden, Turkey, the United Kingdom and Vietnam also joined this list.

**FIGURE 8.**  
Shares of Net Annual Additions in Power Generating Capacity, 2010-2020



Source: See endnote 312 for this chapter.

new installations.<sup>326</sup> Ocean power was still disadvantaged by a lack of policy support and of sufficient technological innovation to reduce costs significantly; however, the EU passed a new target for 1 GW of ocean power by 2030 and 40 GW by 2050.<sup>327</sup>

**Auctions and tenders** for renewable power have become one of the most common market support mechanisms for new projects.<sup>328</sup> In the first half of 2020, 13 countries awarded nearly 50 GW in new capacity, breaking a record for auctioned capacity.<sup>329</sup> The total number of countries that held renewable power auctions decreased during the year (from 41 to at least 33), but several new countries held auctions for the first time.<sup>330</sup> In some markets, the shift to auctions also has reduced the diversity of participants, notably the involvement of community energy groups.<sup>331</sup>

Alongside significant and ongoing cost reductions in solar PV and wind power, the growth of auctions has created a highly competitive bidding environment that has placed strong downward pressure on price levels for renewable power projects. In 2020, developers around the world continued to submit bids for tenders at record-low prices for utility-scale solar PV and wind power.<sup>332</sup> However, low bid prices in tendering processes do not necessarily reflect overall costs, as prices depend on resource availability, local labour and land prices and costs of financing, while tendering conditions might include the provision of grid connection to developers, among other incentives.<sup>333</sup>

The amount of renewable electricity from **power purchase agreements** has grown substantially in recent years, with a record 23.7 GW sourced from corporate PPAs in 2020.<sup>334</sup> The United States remained the world's leading market for corporate PPAs

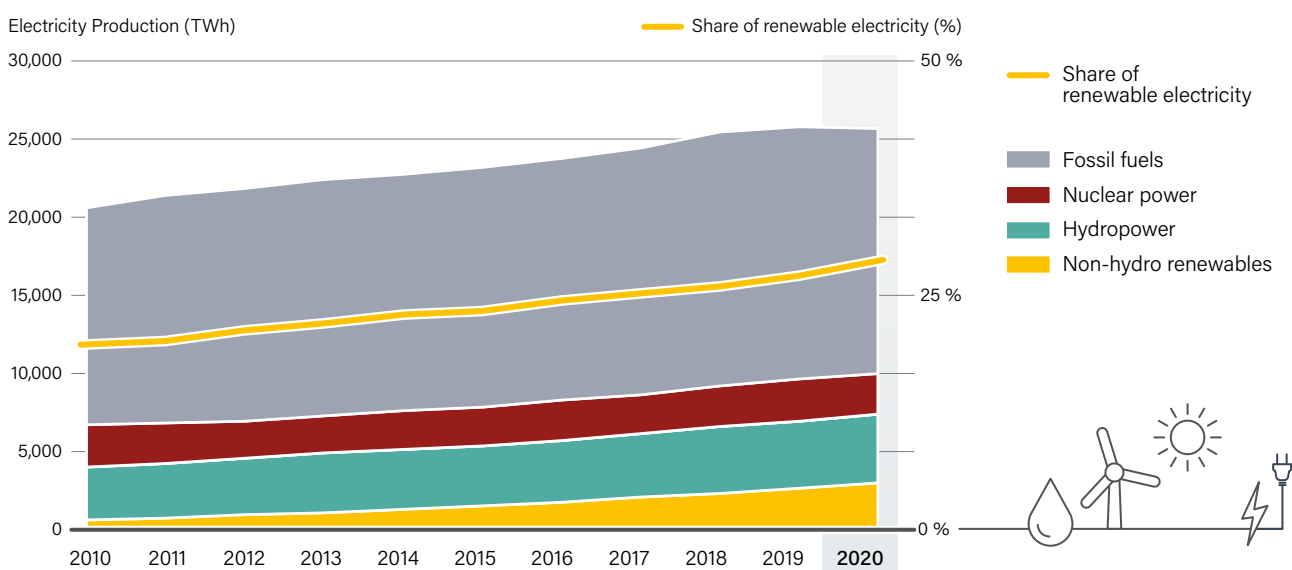
Renewables generated an estimated **29% of global electricity** in 2020.

despite declining 16%, while the record additions were driven by a combined tripling in Europe, the Middle East and Africa.<sup>335</sup> US companies that successfully closed PPAs in the United States have shown growing interest in expanding their efforts to Europe.<sup>336</sup>

In early 2020, **global electricity demand** dropped sharply in the wake of the COVID-19 pandemic.<sup>337</sup> However, demand rebounded by year's end, resulting overall in a slight decline of around 2%, the first annual decline since the global economic crisis of 2008/2009.<sup>338</sup> Production of electricity from renewables was favoured under these low-demand circumstances due to its inherent low operating costs, as well as the dispatch rules in many countries that prioritise renewable electricity.<sup>339</sup>

Each year for the past decade, renewables have met a higher share of global electricity demand than in the previous year.<sup>340</sup> This trend accelerated in 2020 amid the lower demand and favourable conditions for renewable power. For the second consecutive year, electricity production from fossil fuels was estimated to decline, driven mainly by a 2% decrease in coal power generation.<sup>341</sup> Overall, renewables generated an estimated 29.0% of global electricity in 2020, up from 27.3% in 2019.<sup>342</sup> (→ See Figure 9.)

**FIGURE 9.** Global Electricity Production by Source, and Share of Renewables, 2010-2020



Source: Ember. See endnote 342 for this chapter.

The progress in renewable energy, and the decline in fossil fuels (especially coal), has been especially pronounced in certain countries and regions. Wind power, hydropower, solar power and bioenergy became the EU-27's main source of electricity in 2020, growing from 30% of generation in 2015 to 38%.<sup>343</sup> Electricity generation from these renewable sources grew 23% as production from coal power fell by half over this period.<sup>344</sup> Similarly, in the United Kingdom, renewables grew to a 42% share of generation to become the main source of electricity in 2020, beating out fossil gas and coal at a combined 41%.<sup>345</sup>

In the United States, renewable energy reached nearly 20% of net electricity generation by year's end, with solar and wind energy accounting for more than half of this; meanwhile, coal's share fell from around 24% in 2019 to less than 20% in 2020.<sup>346</sup> More than 19% of Australia's electricity came from wind and solar energy in 2020, and, overall, renewable energy represented nearly 28% of the country's generation, up from 24% in 2019.<sup>347</sup> In China, electricity from hydropower, solar energy and wind energy provided more than 27% of production, up from around 26% in 2019.<sup>348</sup>

The share of electricity generated by **variable renewable electricity** (wind power and solar PV) continued to rise in several countries around the world. While variable renewables contributed more than 9% of global electricity in 2020, in some countries they met much higher shares of production, including in Denmark (63%), Uruguay (43%), Ireland (38%), Germany

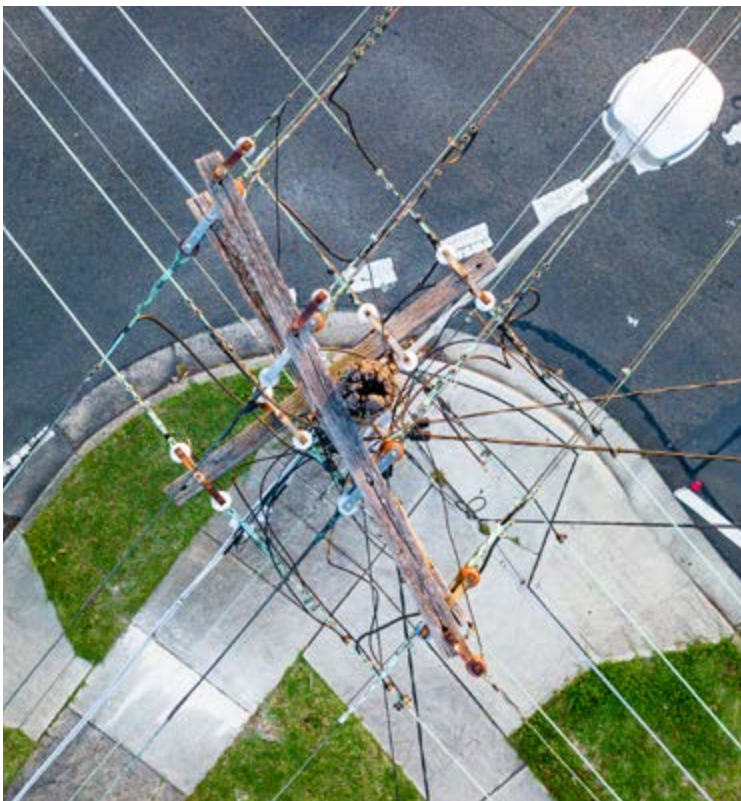
(33%), Greece (32%), Spain (28%), the United Kingdom (28%), Portugal (27%) and Australia (20%).<sup>349</sup>

The cost-effective **integration** of variable renewable electricity has spurred industry players and governments to make efforts to increase the flexibility of their energy technologies and systems. Some countries expanded or modernised transmission infrastructure specifically to adapt their systems to rising shares of variable renewables.<sup>350</sup> Manufacturers of wind turbines and solar PV modules are working to make their technologies more flexible so that they provide services<sup>i</sup> to the grid, as well as better facilitate their own integration into the energy system.<sup>351</sup> Governments have introduced policies to support demand flexibility measures such as time-of-use pricing, incentive payments and penalties to influence the electricity use of consumers.<sup>352</sup>

**Hybrid systems**, consisting of at least two renewable energy technologies and/or energy storage, are able to provide flexibility to the grid as well as to decrease costs and deliver technical benefits (including higher capacity factors) due to co-localisation.<sup>353</sup> In 2020 and early 2021, hybrid projects combining solar PV, wind and/or energy storage were announced or commissioned in many countries, including India where a massive 30 GW solar-wind project began construction in Gujarat.<sup>354</sup> Markets for hybrid solar thermal collectors<sup>ii</sup> grew in China, France, Germany, Ghana and the Netherlands during 2020.<sup>355</sup>

i Grid services include the ability to provide operating reserve, voltage support and black start capabilities. (→ See Systems Integration chapter.)

ii Also known as PV-T, or photovoltaic-thermal collectors, these systems convert solar radiation into both electrical and thermal energy.



In 2020,  
wind power  
and solar PV  
generated more than  
20% of electricity in  
nine countries.



## SIDEBAR 2. Impacts of COVID-19 on Renewable Energy-Related Jobs in 2020

A variety of factors shape employment trends in the renewable energy sector. They include costs and investments as well as labour, industry and trade policies. The intensity of labour changes as technologies mature, as the scale and complexity of operations grow and as automation takes hold. Gender disparities also persist in the sector, with women accounting for less than one-third of the overall renewable energy workforce in 2018. In addition to these factors, the COVID 19 pandemic had unprecedented impacts on renewable energy-related employment in 2020.

Although renewables fared better than expected compared with conventional energy sources (in terms of new capacity additions), the sector faced uncertainties and disruptions during the year. Lockdowns and other restrictions on movement put pressure on supply chains and constrained economic activity. In many countries, project delays early in 2020 were followed by surges of activity by year’s end, reflecting cycles of rising and falling COVID-19 infections. The year-end surge was driven in part by developers rushing to meet permitting deadlines (some of which were extended in response to pandemic delays) or reacting to impending changes in policies, such as expiring tax credits,

subsidy phase-outs or cuts in feed-in tariff rates. In a sense, the pandemic amplified the business cycle fluctuations typically seen in the sector.

As a result, employment in renewables fluctuated considerably over the year. Depending on labour market policies and industry practices in different countries, workers were furloughed, had their work hours reduced or were laid off (and, in some cases, rehired later). The ability of governments, companies and industries to cope with disruptions by switching to remote working arrangements or to comply with social distancing requirements in the workplace differed enormously.

COVID-19’s impacts on employment also varied by renewable energy technology, end-use sector and value chain segment. (→ See Table 3.) Disruptions in the supply of inputs and raw materials were common. For example, the supply of balsa, a key component of wind turbine blades, was affected by the lockdown in Ecuador, which supplies 95% of the wood globally. As a result, production was shifted to other countries (including Papua New Guinea), and other materials (such as PET plastic) were substituted – resulting in job losses in Ecuador.

**TABLE 3.** COVID-19’s Impacts on Employment in Segments of the Renewable Energy Supply Chain

Value chain segment	Magnitude of impact	Comments
Distributed renewables for energy access	Very high	Demand affected by reduced incomes and by social distancing requirements.
Transport and logistics	High (medium term)	Greatly affected by temporary parts shortages, social distancing measures, quarantines and border controls.
Construction and installation	High	Strongly affected by lockdowns and delays, limits on the numbers of workers allowed on-site and social distancing requirements. Less impact in the second half of 2020.
Biofuels	High	Drop in demand due to the decline in transport volumes and to cheaper fossil-based diesel, but this was moderated in some countries by increases in blending mandates.
Manufacturing and procurement	High (short term)	Heavy effects on factory workers, technicians and engineers due to temporary factory closures.
Operations and maintenance	Low to medium	Travel to some project sites affected by border closures and quarantine rules; however, energy generation is an essential service and the physical space available at wind and solar farms often allows for social distancing.
Project planning	Low	Many jobs can be performed remotely.

Source: IRENA. See endnote 38 for this chapter.



Experience also diverged widely across countries, affecting local employment trends. Some countries (such as China) witnessed substantial growth in new renewable power capacity additions in 2020, while in other countries (such as India), renewables stagnated. However, new installations did not always translate into job growth. For example, the United States added record amounts of solar energy in 2020, but one survey found that US employment in the sector dropped 6.7% during the year, to around 231,500 workers. This could be due to a decline in labour intensity, given that large utility-scale projects accounted for three-quarters of new installations, as well as to fewer in-person sales, which shifted to online marketing to comply with social distancing requirements. By mid-2020, the US solar industry had lost as many jobs as it had added in the past five years, due primarily to a shift away from door-to-door sales.

Meanwhile, energy use in the transport sector collapsed in early 2020. This affected biofuel demand in two ways: directly through reduced demand for fuels and indirectly due to falling crude oil prices, which made biofuels less competitive. During the year, employment rose in biodiesel while it fell in ethanol. In Brazil, the world's largest biofuels employer, the increase in the blending mandate drove biodiesel production up: jobs in this sector climbed from 294,900 in 2019 to 323,800 in 2020. In contrast, jobs in ethanol have continued to fall as increasing mechanisation reduces the need for manual labour in feedstock operations, declining from an estimated 574,400 in 2018 to an estimated 547,300 in 2019.

In Indonesia, another major biodiesel producer, employment remained virtually unchanged in 2020 at around 475,000 jobs. Although COVID-19 restrictions reduced overall diesel fuel consumption, the government raised the biodiesel blending mandate from 20% to 30%, substantially increasing domestic biodiesel consumption and, thus, supporting employment. However, the country's exports collapsed as a result of unfavourable prices compared to conventional diesel and countervailing duties imposed by the European Union in 2019.

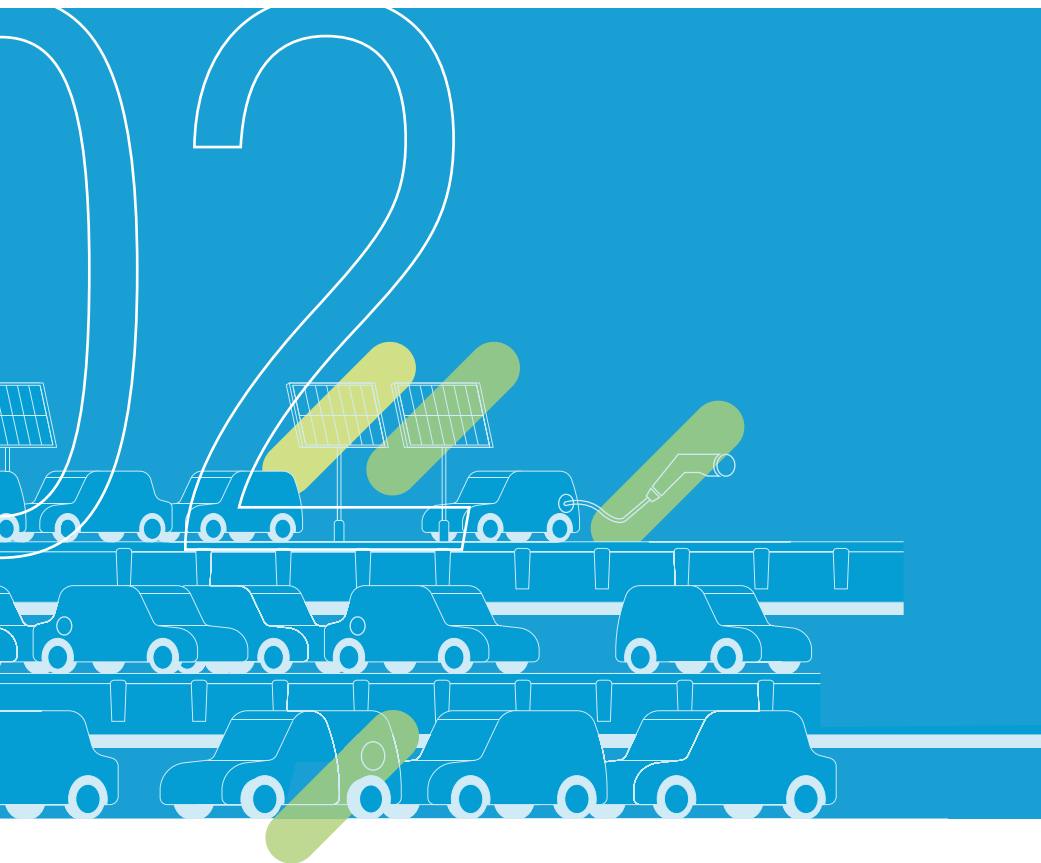
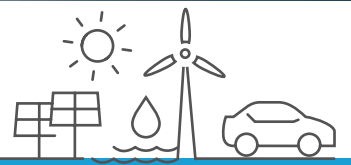
In the off-grid power sector, COVID-19 slowed the pace of new capacity additions and electricity access considerably in many countries in 2020. This was especially true for sales of off-grid solar lighting products. The finances of off-grid solar companies were constrained due to reduced equity funding, while reductions in income restricted households' abilities to afford cash purchases. (→ See *Distributed Renewables chapter*.) Consequently, employment in the sector suffered. Jobs plummeted from an estimated 339,000 in 2019 to just 187,500 in 2020. COVID-19 also heavily impacted women's employment and livelihoods in the off-grid sector, since women are more often employed in small businesses and segments of the informal economy that already faced challenges to energy access.

Source: IRENA. See endnote 38 for this chapter.





Since 2020, the BMW Group has used 100% renewable energy sources for its operations globally. It also aims to increase electric vehicle sales to one-fifth of all sales by 2023.



# 02 POLICY LANDSCAPE

## KEY FACTS

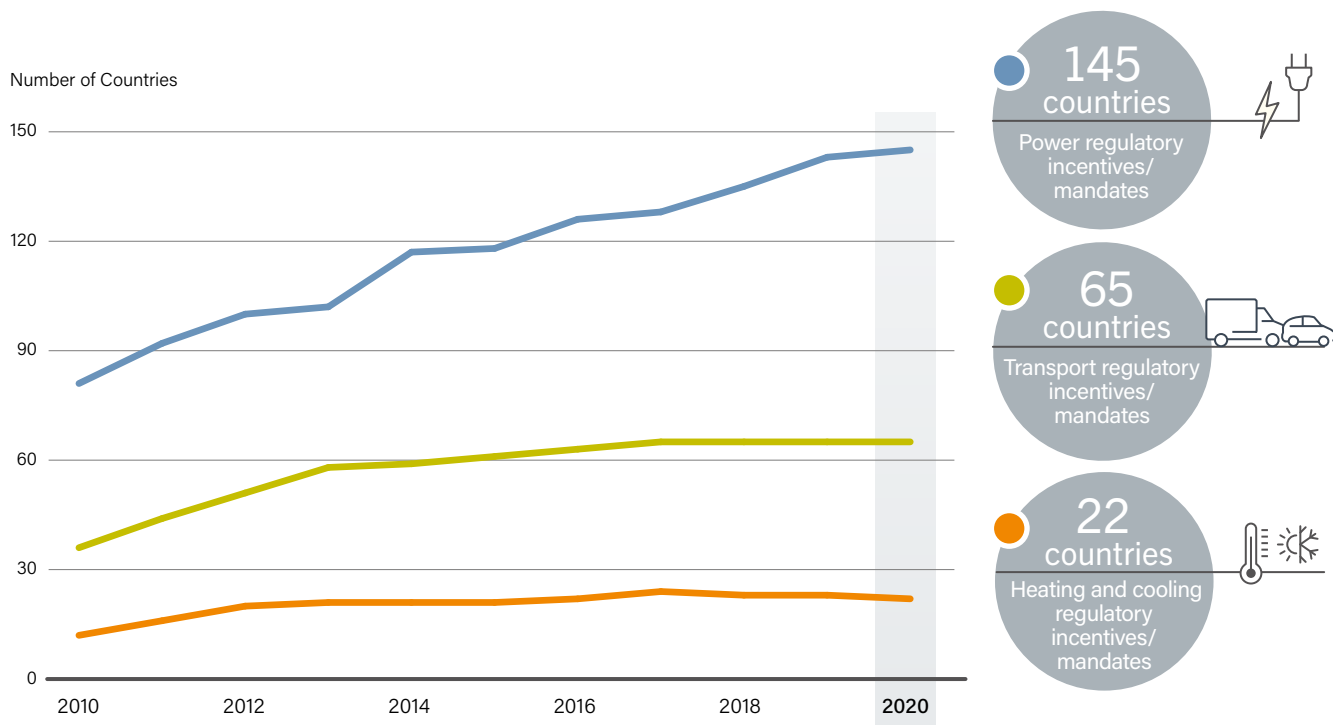
- Despite the COVID-19 crisis, **policy support for renewables remained strong** throughout 2020.
- Many **countries were not on track to achieve their 2020 targets**, and many had not yet set new targets for future years.
- **Policy related to heating and cooling in buildings and industry remained scarcer** than policies directed at electricity generation and transport.
- EV policies became increasingly popular in 2020, but **most continued to lack a direct link to renewable electricity**.
- Many jurisdictions with **high shares of variable renewable electricity** implemented policy to ensure successful integration.
- 2020 saw important **climate change policy commitments** in some major markets.

**G**overnment policies continue to play a crucial role in accelerating the adoption and deployment of renewable energy technologies, particularly in sectors other than power generation. Policies also continue to be critical for achieving renewable energy cost reductions and innovation.<sup>1</sup> By the end of 2020, nearly all countries worldwide had in place renewable energy support policies, although with varying degrees of ambition.<sup>2</sup> (→ See Figure 10 and Table 6.) In addition, renewable energy deployment continued to expand outside of government policies in the form of corporate commitments to renewables and utility-led activities. This was driven by market-based factors such as corporate action on climate change and the declining costs of renewable electricity.<sup>3</sup> (→ See Feature chapter.)





**FIGURE 10.** Number of Countries with Renewable Energy Regulatory Policies, 2010–2020



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 6 in this chapter and Reference Tables R8-R10 in GSR2021 Data Pack. Source: REN21 Policy Database.

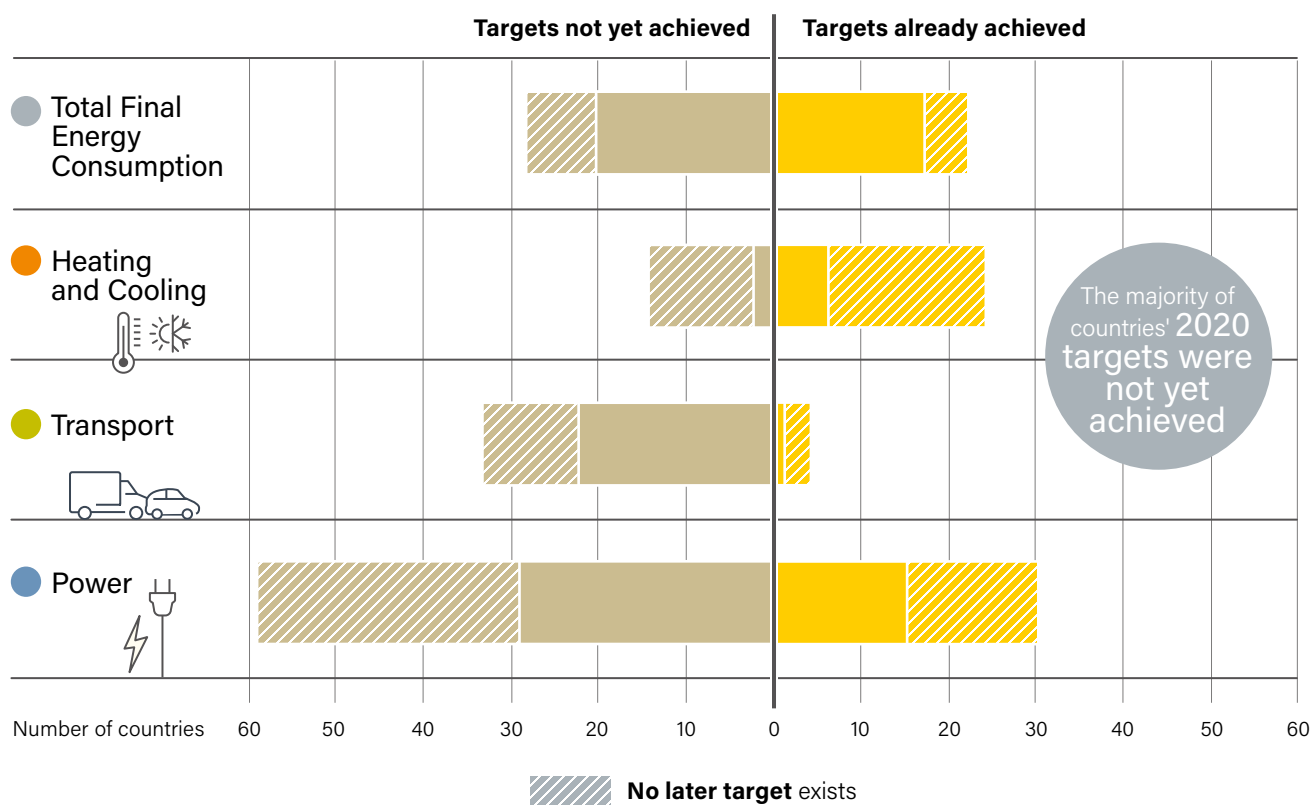
The year 2020 was critical for assessing progress on renewable energy targets. Worldwide, 165 countries had in place targets to increase uptake of renewables in various sectors by year's end.<sup>4</sup> Most of these targets were for the power sector, followed by targets for total final energy consumption, heating and cooling, and transport. However, success in actually being on track to meet the 2020 targets varied widely: overall, some 80 targets were achieved, while the majority (134) were not yet achieved according to the latest data available (ranging from 2017 to 2020). While some countries were close to achieving their targets, others were far from being on track. Moreover, as countries' 2020 targets were coming to term at the end of the year, as many as 30 countries had not yet set new targets for future years (compared to 67 that had). Many of the achieved targets were for power, heating and cooling, and total final energy consumption, while very few were in the transport sector. (→ See Figure 11 and Reference Tables R3-R8 in GSR 2021 Data Pack<sup>i</sup>.)



<sup>i</sup> See [www.ren21.net/gsr-2021](http://www.ren21.net/gsr-2021).



**FIGURE 11.**  
Status of Countries in Meeting Their 2020 Renewable Energy Targets and Setting New Ones



Note: 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.

Source: REN21 Policy Database. See Reference Tables R3-6 in GSR 2021 Data Pack.

Continuing a trend of the past decade – and despite the COVID-19 crisis – policy support for renewables generally remained strong throughout 2020. In some countries, economic recovery policies and funding packages related to the pandemic included explicit support for renewables, although, overall, far more support was allocated to fossil fuels.<sup>5</sup> (→ See *Sidebars 3 and 4*.) While the global health and economic disruptions affected the suite of renewable energy policies implemented during the year, such measures also evolved in response to greater action on climate change, the falling costs of renewables, evolving grid and system integration demands, and the changing needs and realities of different jurisdictions.

In jurisdictions with high shares of installed renewable energy, decision makers typically focused policy development on ensuring that support for renewables was cost effective, and on the technical and market integration of renewables. (→ See *Systems Integration section in this chapter*.) In less-mature renewable energy markets and in some developing and emerging economies, policy efforts prioritised outcomes such as boosting

renewable energy capacity and generation to meet demand, promoting energy security and providing increased access to energy.<sup>6</sup> (→ See *Distributed Renewables chapter*.)

Policies to advance the production and use of renewables can be targeted at any and all end-use sectors, including buildings, industry, transport and electricity generation. Most renewable energy policy in 2020 continued to focus on a single sector, although at least five countries unveiled comprehensive climate change policies that included support for renewables across multiple sectors. Trade policy also continued to have an impact on the production, exchange and development of renewable energy products, as well as on the demand for renewables within specific countries.<sup>7</sup> (→ See *Box 4*.)

A significant amount of renewable energy policy making continued to occur at the municipal level. However, this chapter covers mainly policy enacted at the regional, national and state/provincial levels of governance. Municipal policy is discussed in detail in the *REN21 Renewables in Cities Global Status Report*.

i See [www.ren21.net/cities](http://www.ren21.net/cities).

### SIDEBAR 3. Renewable Energy in COVID-19 Stimulus Packages

In response to the COVID-19 crisis, governments around the world announced more than USD 12 trillion in financial stimulus, including at least USD 732.5 billion in energy-related support. Although some stimulus packages included incentives for renewables, as of April 2021 this comprised only around USD 264 billion of the total amount provided by governments globally, compared to more than USD 309 billion in fossil fuel stimulus. (→ See Figure 49 in Investment chapter.) Direct support for coal included India's USD 6.75 billion coal infrastructure support package and the Republic of Korea's USD 2.5 billion bailout of Doosan Heavy Industries, a coal plant manufacturer. Direct support for oil and gas included USD 4.4 billion in loans and loan guarantees to a Canadian pipeline and GBP 1.3 billion (USD 1.7 billion) in low-interest loans to oil and gas companies in the United Kingdom.

Nevertheless, examples of "green recovery" efforts did emerge. At a regional level, around 30% of the European Union's (EU) EUR 750 billion (USD 921 billion) COVID-19 stimulus package was dedicated to "clean recovery" and renewables, including renewable electricity generation, energy retrofits of buildings, renewable heat, renewable hydrogen and electric vehicles (EVs)<sup>i</sup>. China, India and the Republic of Korea also committed to renewable energy investments, although those countries also supported coal in their recovery plans. Colombia's plan included raising COP 16 billion (USD 4.6 million) to accelerate 27 renewable energy and related transmission projects.

In the power sector, governments provided around USD 95 billion in response to COVID-19. This was largely to ensure the continuation of services and to reduce consumers' bill burdens rather than to incentivise renewables<sup>ii</sup>, although several countries provided funds for new renewable power capacity. Israel's recovery plan included a commitment of ILS 6.5 billion (USD 2 billion) to build 2 gigawatts (GW) of new solar PV capacity. Nigeria's stimulus plan allocated around USD 620 million for a programme to install solar PV home systems for 5 million households. In the United States, the USD 900 billion relief package included extensions of the production and investment tax credits for solar PV and onshore wind power, a new tax credit for offshore wind power, USD 1.7 billion for low-income homeowners to install renewable energy, and USD 4 billion in research and development (R&D) funding for solar power, wind power, hydropower and geothermal energy.

In the buildings and industry sectors, the largest share of energy-related stimulus aid was aimed at spurring investments in renewable heat in buildings and raising the energy efficiency of existing buildings. France's COVID-19 stimulus package included EUR 7 billion (USD 8.6 billion) to support building renovations – including those encouraging renewable heat – as part of a wider target to renovate the country's entire building stock by 2050.



In the transport sector, aviation was the largest stimulus recipient, but only three countries – Austria, France and Sweden – included "green" conditions for aviation stimulus<sup>iii</sup>. At least four countries provided COVID-19 relief for electric transport and hydrogen for transport, although not necessarily linked to renewable energy. The Republic of Korea's recovery package included KRW 2.6 trillion (USD 2.4 billion) in support of EVs and hydrogen cars. France's plan allocated EUR 11 billion (USD 13.5 billion) for EVs, including support for charging stations. Germany's stimulus package included EUR 5.9 billion (USD 7.3 billion) in subsidies for EVs and charging infrastructure as well as EUR 7 billion (USD 8.6 billion) for renewable hydrogen for decarbonising heavy transport and industry. Part of Spain's EUR 3.8 billion (USD 4.6 billion) aid package for the auto industry included measures to electrify public transport, a target to increase the number of EV charging points to 50,000 by 2023 and 800,000 by 2040, funding for EV charging and subsidies for purchasing low-emission cars.

i Member States are expected to invest funds in the seven priority areas of: clean energy technologies; energy-efficient building renovations; sustainable transport; broadband roll-out; digitalisation of public administration; cloud computing capacities; and mainstreaming digital skills into education systems. In line with the European Green Deal, EU countries have agreed to explicitly include clean energy transitions at the heart of their economic recovery.

ii Excluding the EU plan for economic recovery, new renewable electricity plants, mostly wind and solar PV, received only around USD 10 billion from announced stimulus packages.

iii Austria required Austrian Airlines to abolish air routes that can be reached by train in far fewer than three hours and to commit to additional emission reduction goals, France's USD 7.7 billion support for Air France required 50% emission reduction and a minimum of 2% renewable fuel by 2030, and Sweden imposed conditions of 25% emission reduction by 2025 on Scandinavian Airlines.

Source: See endnote 5 for this chapter.

#### BOX 4. Trade Policy, Local Content Requirements and Renewables

In 2020, several jurisdictions unveiled policies to stimulate the local production of renewable energy equipment. In Africa, Mali exempted equipment such as solar panels, wind turbine blades and pump turbines from paying value-added tax (VAT). Burkina Faso launched a Solar Cluster initiative to establish a domestic solar PV industry by offering long-term financial backing for solar PV projects and providing networking and training opportunities for the country's solar industry. Uganda's revised draft National Energy Policy committed to formulating innovative financing mechanisms for geothermal and solar PV through different financial interventions, including income tax deductions, exemptions from VAT and customs tax, and accelerated depreciation tax incentives.

India put forward an expedited manufacturing plan to incentivise domestic solar cell manufacturing capacity and planned to impose new tariffs of 40% on imports of solar modules and 25% on solar cells starting in April 2022. The Indian government also approved a "production-linked incentive" plan to enhance the country's manufacturing capabilities and exports, including domestic high-efficiency solar PV module manufacturing and advanced chemistry cell batteries.

Turkey's new regulations for solar panel imports (which require calculating the import duty on solar modules per kilogram rather than by square metre) are perceived to favour Turkish manufacturers of solar PV panels, as high-efficiency modules generally are heavier than they were a few years ago. Saudi Arabia announced a plan to increase local content in domestic renewable energy industry chains.

Other jurisdictions eased import requirements for renewable energy equipment in 2020. The Brazilian government introduced a measure to remove a 12% levy for some solar equipment (modules, inverters and trackers). The government of Bangladesh added EUR 200 million (USD 246 million) during the year to its Green Transformation Fund, which offers loans for the import of "environmentally friendly" products and energy efficiency components from Europe. In Senegal, to accelerate the electrification of rural areas, the government exempted equipment<sup>i</sup> for the production of solar PV power from the VAT.

- i The exempted products include solar panels, inverters, solar thermal collectors, batteries, solar lamp kits, solar water heaters and charge regulators. Packages comprising a battery, solar panel, and a lantern or a solar panel, a water pump and controller also are included among the VAT-exempted products.

Source: See endnote 7 for this chapter.



## RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

Policies enacted to help mitigate climate change can directly or indirectly stimulate renewable energy deployment by mandating a reduction or elimination of greenhouse gas emissions, phasing out or banning the use of fossil fuels and/or increasing the costs of energy from fossil fuels relative to renewables. Climate change policies that indirectly support renewables include targets to reduce greenhouse gas emissions, the development of and participation in carbon pricing and emission trading programmes, and fossil fuel bans or phase-outs. In some cases, climate change policies also are designed to directly stimulate the deployment of renewables.

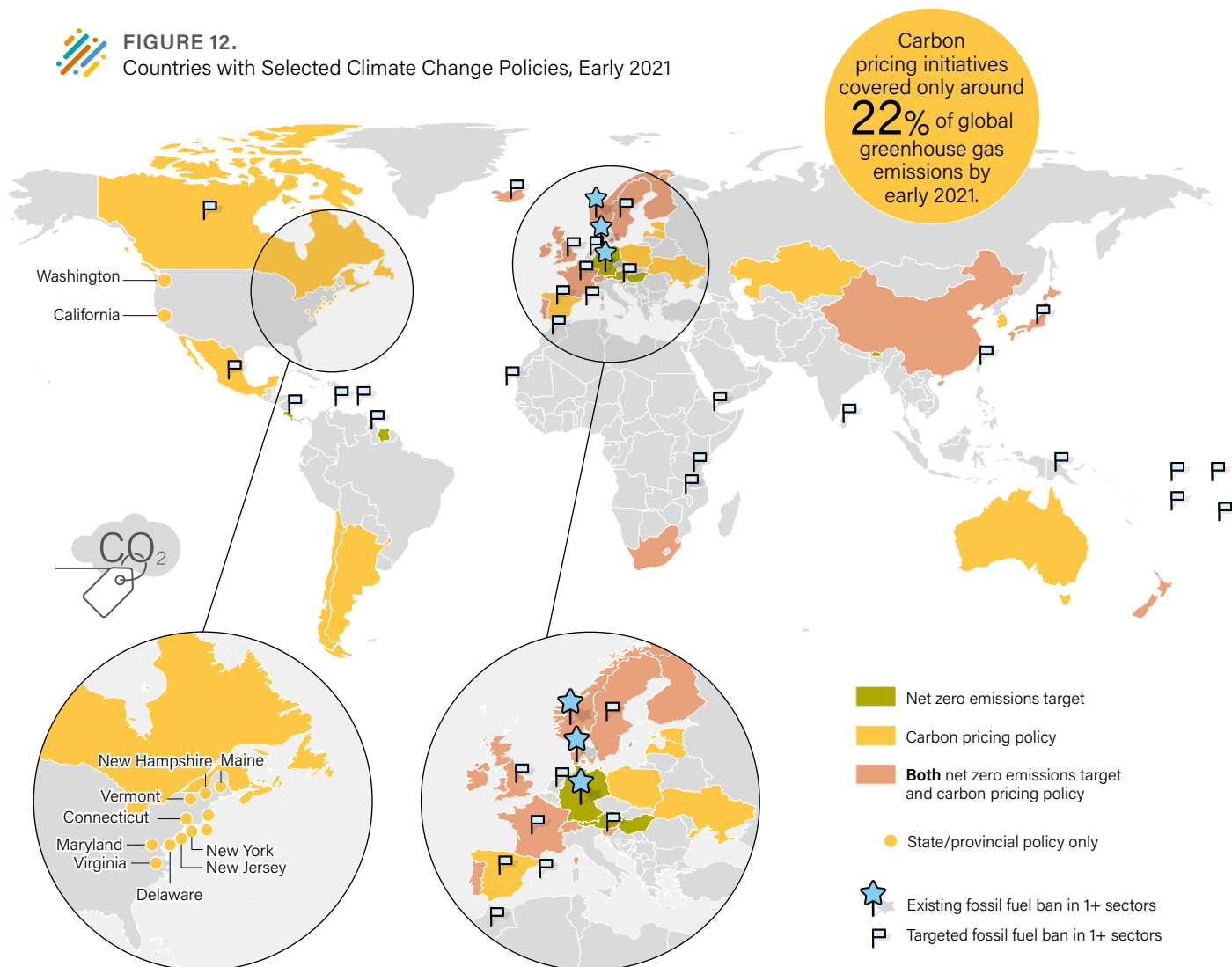
### CLIMATE POLICIES THAT INDIRECTLY SUPPORT RENEWABLES

Although the COVID-19 crisis was the central political focus of 2020, commitments to climate change mitigation also were prominent during the year. Overall, 2020 was an important milestone for climate change policy, with many countries' greenhouse gas targets for the year expiring, countries setting new targets, and numerous countries committing to carbon neutrality. For example, signatories to the Paris Agreement were supposed to submit updated (or new) Nationally Determined Contributions (NDCs)<sup>i</sup> towards reducing emissions by the end of 2020, and at least 40 countries plus the EU met this deadline.<sup>8</sup>

Numerous countries worldwide also implemented additional climate change policies during 2020, including setting greenhouse gas emission targets, adopting carbon pricing or emission trading programmes, and announcing fossil fuel bans or phase-outs. (→ See Figure 12.)

i Nationally Determined Contributions (NDCs) describe efforts by each country to reduce greenhouse gas emissions and adapt to the impacts of climate change. Article 4 of the Paris Agreement requires each Party to prepare, communicate and maintain successive NDCs that it intends to achieve. By the end of 2020, countries with an initial NDC covering the period to 2025 were required to produce an NDC that extends to 2030, and those that already contained a 2030 target were required to update their NDCs. In 2020, 44 countries plus the EU met this deadline.

**FIGURE 12.**  
Countries with Selected Climate Change Policies, Early 2021



Note: Carbon pricing policies include emission 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. Fossil fuel ban data include both targeted and existing bans across the power, transport and heating sectors. Jurisdictions marked with a flag have some type of fossil fuel ban in one or more sector. See GSR 2021 Data Pack for details. Not all cities with policies are shown; see REN21 *Renewables in Cities 2021 Global Status Report* for more comprehensive city policies.

Source: Based on World Bank, Energy Climate Intelligence Unit, IEA Global Electric Vehicle Outlook and REN21 Policy Database. See Reference Tables R4, R6 and R9 in GSR 2021 Data Pack. See endnote 8 for this chapter.



**Greenhouse gas emission targets** mandate a reduction in overall emissions and can include net zero and “carbon-neutral” targets<sup>i</sup>. During 2020, new emission reduction commitments were spread across nearly all continents, covering around 47% of total global emissions.<sup>9</sup> (→ See Table 4.) Some of the most significant carbon neutrality pledges occurred in Asia, with China aiming to become carbon neutral by 2060, Japan by 2050 and the Republic of Korea by 2050 (including a pledge to replace coal with renewables).<sup>10</sup>

<sup>i</sup> “Net zero” refers to achieving a net balance between greenhouse gas emissions produced and those removed from the atmosphere. 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 carbon capture and storage and thus does not necessarily include the use of renewables. “Carbon-neutral” means having a balance between emissions of carbon and the absorption of carbon from the atmosphere (by way of carbon sinks).





**TABLE 4.**  
New Net Zero Emission and Carbon-Neutral Targets Set by Countries/Regions in 2020

Net zero emission targets				
Country/region	2019 CO <sub>2</sub> emissions (kilotonnes)	2019 CO <sub>2</sub> emissions (% of world total)	Target year	Legal status
<b>EU-27</b>	<b>2,939,069</b>	7.73%	2050	Proposed
Austria	72,363	0.19%	2040 <sup>1</sup>	In law/policy document
Canada	584,846	1.54%	2050	Proposed
Hungary	53,183	0.14%	2050	In law/policy document
Jamaica	7,442	0.02%	2050	Pledge
Lao PDR	6,783	0.02%	2050	Pledge
Maldives	913	<0.001%	2030 <sup>2</sup>	Pledge
Mauritius	4,332	0.01%	2070	Pledge
Nepal	15,019	0.04%	2050	NDC
United Kingdom	364,906	0.96%	2050 <sup>3</sup>	In law/policy document
The Vatican	N/A	N/A	2050	Pledge

Carbon-neutral targets				
Country/region	2019 CO <sub>2</sub> emissions (kilotonnes)	2019 CO <sub>2</sub> emissions (% of world total)	Target year	Legal status
Argentina	199,414	0.52%	2050	NDC
Barbados	3,827	0.01%	2030	In law/policy document <sup>4</sup>
China	11,535,200	30.34%	2060	Pledge
Japan	1,153,717	3.03%	2050	Pledge
Kazakhstan	277,365	0.73%	2060 <sup>5</sup>	Pledge
Korea, Republic of	651,870	1.71%	2050	NDC
Malawi	1,616	<0.001%	2050	Pledge
Nauru	N/A	N/A	2050	Pledge
Slovenia	15,365	0.04%	2050	National plan/strategy
South Africa	494,862	1.30%	2050 <sup>6</sup>	National plan/strategy

Notes: Net zero emissions can refer to all greenhouse gas emissions or only carbon emissions, and involves emissions declining to zero. Carbon neutral refers to the balancing of carbon emissions caused by an entity with funding an equivalent amount of carbon savings elsewhere. Although carbon neutrality is sometimes considered to be a synonym for net zero carbon emissions, carbon neutrality can be achieved at the domestic level by using offsets from other jurisdictions, whereas net zero does not necessarily include this feature. Some of these countries – along with Colombia, Kenya and Peru – also adopted other targets less than carbon-neutral/net zero (see GSR 2021 Data Pack for full dataset).

- 1 Austria's target is for "climate neutrality".
- 2 Target to be reached with adequate international support and assistance.
- 3 Adopted in 2019.
- 4 Published in 2019.
- 5 Target could be advanced if the country raises USD 10 billion annually from other nations to help finance the transition.
- 6 South Africa's target is a net zero carbon emissions target.

N/A = data not available

Source: See GSR 2021 Data Pack.

New emission reduction commitments during 2020 covered around

**47%**

of total global emissions.

**Carbon pricing and emission trading programmes** have the potential to indirectly increase the deployment of renewables by increasing the relative cost of energy from fossil fuels. By the end of 2020, at least 64 national and state/provincial governments (up from 57 in 2019) had adopted or committed to carbon pricing policies through either direct taxation or a cap-and-trade programme.<sup>11</sup> During the year, Montenegro introduced a cap-and-trade system for major greenhouse gas emitters, and in Mexico a pilot emission trading programme began operating as part of a process to establish a more complete trading system.<sup>12</sup> New Zealand strengthened its emission trading programme by placing a finite cap on the total emission permits that will be issued under the programme.<sup>13</sup>

**Bans and phase-outs of fossil fuels** are other indirect climate change policies that can stimulate the uptake of renewables in different (or multiple) end-use sectors. In 2020, the most common type of fossil fuel ban enacted at the national and state/provincial levels was on coal. Since coal typically is used for electricity generation, **coal bans** can indirectly stimulate generation from renewables. (→ *See Reference Table R6 in GSR 2021 Data Pack.*) In Europe, both Austria and Sweden closed their last coal-fired power plants in 2020 as part of phase-out plans.<sup>14</sup> Although Germany's scheme to phase out hard coal was already under way, the government implemented the Coal Phase-Out Act during the year, which lays out a strategy to gradually reduce the use of coal-powered energy by 2038.<sup>15</sup>

In Asia, Japan committed to accelerating the closure of roughly two-thirds of its older, lower-efficiency coal-fired power plants by around 2030, and made pledges to further promote renewables.<sup>16</sup> The government of the Philippines announced a moratorium on all applications for new coal-fired power plants, and Pakistan announced an end to the construction of new coal plants (although plants under construction were expected to be completed).<sup>17</sup>

In the buildings sector, **bans or support for phasing out fossil fuels for heating** (such as heating oil and fossil natural gas) may indirectly stimulate the use of renewables for space and water heating. Many of these bans occur at the municipal level. (→ *See Reference Table R4 and Reference Table R9 in GSR 2021 Data Pack, and Renewables in Cities Global Status Report.*) At the national level, Germany's new Buildings Energy Act places limits on the installation of oil heating systems beginning in 2026.<sup>18</sup> The government of Finland included in its 2020 budget EUR 45 million (USD 55 million) in grants to phase out oil heating in both residential and municipal buildings.<sup>19</sup> The United Kingdom announced a ban on gas fuels for heating in all new homes, although no deadline was provided.<sup>20</sup> Slovenia's National Energy and Climate Plan included a commitment to ban the sale and installation of new heating oil boilers after 2022.<sup>21</sup>

In the transport sector, **bans on fossil fuels for road transport** can incentivise biofuels-based transport as well as electric vehicles, which could facilitate greater use of renewable electricity in the sector. **Bans on internal combustion engine vehicles** (or targets for 100% EVs)

similarly incentivise EVs. (→ *See Reference Table R8 in GSR 2021 Data Pack.*) During 2020, as part of its new "green growth" strategy, the government of Japan announced that it would take actions to eliminate petrol vehicles in the next 15 years (although no target was set).<sup>22</sup> Scotland's updated Climate Change Plan includes a commitment to phase out sales of new petrol and diesel cars and vans by 2030.<sup>23</sup>

At the state level, California (US) is requiring all new passenger vehicles (cars and trucks) sold in the state to be zero emission<sup>i</sup> by 2035, while all medium- and heavy-duty vehicles sold must be zero emission by 2045 – the first such policy in the world targeting trucks and vans.<sup>24</sup> Massachusetts (US) announced a ban on the sale of new petrol vehicles by 2035.<sup>25</sup> (→ *See Transport section in this chapter for more details.*)

Many cities also have adopted policies that either ban or heavily restrict the use of fossil fuels for road transport<sup>ii</sup>, as well as policies that incentivise **non-motorised travel**. In addition to vehicle bans and EV targets, cities increasingly have used **low-emission zones** (LEZs) to restrict certain types of vehicles from entering city centres.<sup>26</sup> In 2020, governments placed a strong emphasis on walking and cycling infrastructure, as "pop-up" bike lanes were added during pandemic-related lockdowns and allocations were made for cycling infrastructure funding, subsidies and other incentives.<sup>27</sup> (→ *See Transport section in Global Overview chapter, and Renewables in Cities Global Status Report.*)

At least two countries **withdrew support for fossil fuel exploration** in 2020. Denmark announced that it will end all new domestic oil and gas exploration by 2050.<sup>28</sup> The United Kingdom announced an end to all public financing for international fossil fuel projects, including support for oil, most fossil-based natural gas<sup>iii</sup> and coal exploration and other operations starting in 2021.<sup>29</sup> However, this announcement does not include the UK's domestic oil and gas exploration.<sup>30</sup> Some countries also have begun engaging in so-called "subsidy swaps" that shift public funding away from fossil fuels to more sustainable alternatives.<sup>31</sup> (→ *See Sidebar 4.*)

## Bans and phase-outs

of fossil fuels grew in popularity during 2020, particularly for coal.

i A zero-emission vehicle, or ZEV, is a vehicle that does not produce any direct tailpipe emissions. ZEVs may have a conventional internal combustion engine but also must be able to operate without using it. ZEVs include battery electric vehicles, hydrogen fuel cell vehicles and plug-in hybrid electric vehicles.

ii Cities include the Australian Capital Territory (Canberra) (ZEVs by 2021); London (100% zero-emission transport by 2050); Los Angeles (100% ZEVs by 2050); New York City (100% ZEVs by 2050); San Francisco (electrify all private forms of transport); and Toronto (all transport in the city to be low carbon).

iii Exceptions will be made for some natural gas-fired power plants.

## SIDEBAR 4. “Subsidy Swaps” as a Means to Shift Financial Support Towards Renewables

Across the energy sector, technologies that enjoy access to grants, tax breaks and other forms of government support have a clear market advantage over those that do not. Direct subsidies to the oil, gas and coal industries amounted to more than USD 478 billion globally in 2019, and both direct and indirect<sup>i</sup> subsidies for fossil fuel production have continued to grow, increasing an estimated 38% or more that year. In the lead-up to the fifth anniversary of the Paris Agreement, in December 2020 a group of 10 governments<sup>ii</sup> spanning nearly all continents released a joint statement calling on world leaders to phase out fossil fuel subsidies.

Some fossil fuel subsidy schemes are designed to offset the falling margins and loss of competitiveness that fossil fuels have experienced in the face of ever-lower renewable energy costs. These subsidies have impeded the rapid transition to renewables that is necessary to achieve global climate and development goals. However, in recent years momentum has grown behind the idea of accelerating the transition through so-called subsidy swaps that shift public funding away from fossil fuels, which are increasingly seen as detrimental to both public health and the environment. (→ See *Feature chapter in GSR 2020*.)

Subsidy swaps generally involve elements of the following:

- reducing and removing fossil fuel subsidies and/or increasingly taxing fossil fuels;
- generating a greater share of tax revenues from environmental taxation (e.g., carbon pricing policies);
- reallocating a share of savings and tax revenues to renewable energy, energy efficiency and related infrastructure;
- mitigating negative social impacts through allocations targeted at specific population groups<sup>iii</sup>; and
- ensuring that all reallocations of funds are broadly supportive of an energy transition.



Many of these measures are reflected in the wider trends in power generation capacity in recent years. Since 2015, net installations of renewable capacity have outpaced those of both fossil fuel and nuclear power capacity combined. (→ See *Global Overview chapter*.)

Although most subsidies tend to be captured by the rich, efforts to reform fuel subsidies that support lower-income groups (such as subsidised heating oil) can sometimes be controversial. Rises in fuel prices could end up being regressive (having a greater impact on those with lower incomes) and risk reducing people’s ability to meet basic energy needs. Through the design of adequate complementary measures, however, fossil fuel subsidies can be removed without limiting energy access. For example, a subsidy swap from kerosene to solar lighting can benefit poorer households while also lowering emissions, reducing reliance on fossil fuels and improving health through cleaner air.

India’s subsidy policy has broadly followed the logic of a subsidy swap. One analysis found that the country’s subsidies for all energy types fell from USD 35 billion in 2014 to USD 26 billion in 2019. Over this period, the energy subsidies that remained were increasingly allocated towards “clean energy” and transport. India has been able to lower subsidies for kerosene, a key fuel for poor households, in part by better targeting the beneficiaries of support for alternative fuels, in combination with expanding electrification and clean cooking. Although the Indian government has set a target for 450 GW of renewable energy capacity by 2030, fossil fuel subsidies in the country are still greater than financial support for renewables.

During 2020, some government responses to the COVID-19 crisis became a testing ground for the subsidy swap approach. Recovery packages have the potential to greatly shape future energy systems, as subsidies and bailouts could either derail or accelerate the energy transition. International organisations have called for using post-pandemic recovery packages as an opportunity to phase out fossil fuel subsidies, although so far very few governments have acted on this advice. Most new and amended energy policies introduced in 2020 sent a mixed signal: while there was a great deal of support for renewables in some recovery packages, many governments chose to further prop up fossil fuels. (→ See *Sidebar 3 in this chapter*.)

i Direct subsidies involve actual payment of funds to individuals and/or industries, while indirect subsidies do not involve actual cash outlays but encompass other financial benefits such as price reductions.

ii Costa Rica, Denmark, Ethiopia, Finland, New Zealand, Norway, Sweden, Switzerland, the United Kingdom and Uruguay.

iii For example, targeted allocations could include “lifeline” tariffs for those identified as lacking basic energy access, grants for renewable energy systems for those not connected to the grid, or reducing income taxes for low-income earners funded by reforming fossil fuel subsidies. See International Institute for Sustainable Development, *Getting on Target: Accelerating Energy Access Through Fossil Fuel Subsidy Reform* (Winnipeg, Canada: 2018), <https://www.iisd.org/system/files/publications/getting-target-accelerating-energy-access.pdf>.

Source: IISD. See endnote 31 for this chapter.

### CLIMATE PLANS THAT DIRECTLY SUPPORT RENEWABLES

While most climate change policies do not include renewable energy support directly, in some cases, climate change policies are designed to directly stimulate the deployment of renewables. During 2020, at least six governments at the regional, national and/or provincial or state levels adopted comprehensive, cross-sectoral climate policies that included direct support for renewables, in addition to elements of one or more of the indirect support policies mentioned previously.

For example, the EU's 2020 commitment to reduce greenhouse gas emissions 55% by 2030 included earmarking EUR 1 trillion (USD 1.2 trillion) in funding for the European Green New Deal.<sup>32</sup> This strategy aims to transform Europe into a climate-neutral continent by 2050 by undertaking actions across all parts of the economy, including investing in renewable electricity generation, renewables in buildings and electrification of transport (which would facilitate increased renewable electricity in the sector).<sup>33</sup>

At the country level, France and the United Kingdom also committed to various renewable energy policies as part of comprehensive climate change plans. France's new national energy plan (Programmation pluriannuelle de l'énergie) includes targets for renewable generation capacity for 2023 and 2028, a target for renewable hydrogen<sup>ii</sup> to comprise 10% of the industrial hydrogen mix by 2023 (and 20-40% by 2028), targets for energy efficiency in buildings, and targets of 660,000 EVs by 2023 (and 3 million by 2028) and 100,000 public EV charging stations by 2023.<sup>34</sup>

The United Kingdom's "10 point plan" for a green industrial revolution allocates around GBP 12 billion (USD 16 billion) in government investments to decarbonise the country.<sup>35</sup> It includes an offshore wind power target of 40 GW by 2030 (up from the 10 GW installed currently) in addition to providing GBP 1.3 billion (USD 1.8 billion) for EV charging infrastructure, grants for zero- or ultra-low-emission vehicles, funding for cutting emissions from aviation and maritime activities, funding for energy efficiency for homes and public buildings, and a new target to install 600,000 heat pumps in homes and public buildings.<sup>36</sup> In addition, the plan calls for phasing out sales of new petrol and diesel cars and vans by 2030 (moved up from the previous target year of 2035).<sup>37</sup>

During 2020, only 6 governments adopted comprehensive, cross-sectoral climate policies that included direct support for renewables.

In **Asia**, the Republic of Korea's Green New Deal outlines plans for the country to reach its 2050 target for carbon-neutrality.<sup>38</sup> They include introducing a carbon tax, expanding solar PV and wind power capacity to 42.7 GW by 2025 (up from 12.7 GW in 2019), installing solar PV on 225,000 public buildings, targeting 1.13 million EVs and 200,000 hydrogen-powered vehicles by 2025, providing funding for 45,000 EV recharging stations and 450 hydrogen refuelling units, and installing 4,000 public EV charging stations and 65 hydrogen charging stations by 2035.<sup>39</sup>

In **Africa**, Zimbabwe launched new renewable energy and biofuels policies to guide investments in renewables as a way to achieve the country's target of a 33% reduction in greenhouse gas emissions (compared to business as usual) by 2030.<sup>40</sup> The National Renewable Energy Policy includes a target of 1.1 GW of installed renewable electricity capacity by 2025 (or 16.5% of the country's total electricity supply) and 2.1 GW by 2030, along with tax breaks for renewable generation facilities and a requirement for all new buildings to host solar PV systems.<sup>41</sup> The Biofuels Policy commits to an ethanol blending mandate of up to 20% by 2030 and the introduction of biodiesel blending of up to 2% by 2030.<sup>42</sup>

In **North America**, Canada released a climate plan that includes a commitment to increase the carbon tax from CAD 50 (USD 39) per tonne in 2022 to CAD 170 (USD 133) per tonne by 2030, as well as CAD 15 billion (USD 11.7 billion) in funding for buildings, industry and transport.<sup>43</sup> The Canadian province of Quebec adopted a CAD 6.7 billion (USD 5.2 billion) climate change plan that includes a target to reduce emissions 37.5% below 1990 levels by 2030, a target of carbon neutrality by 2050, a ban on sales of new petrol passenger vehicles (cars, sport utility vehicles, vans and pick-up trucks for personal use) by 2035, targets for EVs and biofuels in transport, and funding for renewable heating and cooling in buildings.<sup>44</sup>



i EU Member States had to submit by 1 January 2020 their first long-term strategies covering specific sector plans, including electricity, industry, transport, heating/cooling and buildings, agriculture, waste and land use, and land-use change and forestry.  
 ii See Glossary.



## HEATING AND COOLING IN BUILDINGS



The buildings sector – including both commercial and residential buildings – is a significant energy end use and contributor to global greenhouse gas emissions.<sup>45</sup> Energy is consumed in buildings for climate control (space heating and cooling), water heating, cooking, lighting, and the powering of appliances and electronics. A variety of policies exist at the national and provincial/state levels related to direct and indirect heating and cooling with renewables, including thermal renewable energy (geothermal, solar thermal), biomass-based energy and renewable electricity (which can be used to power heating and cooling appliances such as heat pumps) (→ see *Power section in this chapter*).

Heating and cooling demand in buildings accounts for around 25% of total final energy consumption, and although most of this consumption is currently met by fossil fuels, there is significant potential for greater use of renewables.<sup>46</sup> Bioenergy (including renewable gases<sup>i</sup>) is the largest renewable source of heating and cooling in buildings<sup>ii</sup> today, but other sources include geothermal and solar thermal energy, as well as renewable electricity<sup>iii</sup>.<sup>47</sup> Despite the vast potential of renewables, policies designed to advance their use in heating and cooling remain less common than those in the power or transport sectors.

Policy makers can advance the production and use of renewable energy to heat and cool buildings through legislated targets, financial incentives, mandates (including building energy codes), policies that support the electrification of heating and cooling, and policies that support renewable district heating. Policies that indirectly encourage renewable heating and cooling include fossil fuel bans or phase-outs, fuel taxes and net zero emission standards for buildings. (→ See *Renewable Energy and Climate Change Policies section in this chapter*.)

In 2020, as in previous years, policy developments in heating and cooling for buildings remained scarcer than policies directed at electricity generation and transport. Although some developments occurred (including financial incentives, energy efficiency and electrification of heating and cooling), by year's end only 19 countries had committed to **renewable heating and/or cooling targets** for buildings (down from 49 countries in 2019, due to 2020 targets coming to term without being replaced by later targets), whereas 137 countries had renewable power targets.<sup>48</sup> Meanwhile, only 10 countries had renewable heat support policies covering all sectors (residential, industrial, commercial and public facilities) by the end of the year. (→ See *Figure 13, and Reference Tables R4, R6 and R9 in GSR 2021 Data Pack*.) Interest in cooling has increased with the rising demand for cooling, particularly in developing countries, but this has not yet translated into more policies and targets for renewable cooling.<sup>49</sup> **Financial incentives for buildings** – including grants, rebates, tax incentives and loan programmes – were the most commonly used measures to encourage renewable heating and cooling in buildings during 2020. (→ See *Reference Table R9 in GSR 2021*

*Data Pack*.) All of the new developments occurred in Europe. For example, Italy raised the tax-deductible “eco-bonus” benefit for building insulation and replacement of heating and cooling systems in apartment buildings and family homes (from 50% to 110%) and extended the benefit to the end of 2022.<sup>50</sup> Lithuania provided EUR 14 million (USD 17 million) to reimburse building owners who convert old, inefficient boilers to more energy-efficient installations that use renewable heat sources (including biofuel boilers and heat pumps).<sup>51</sup>

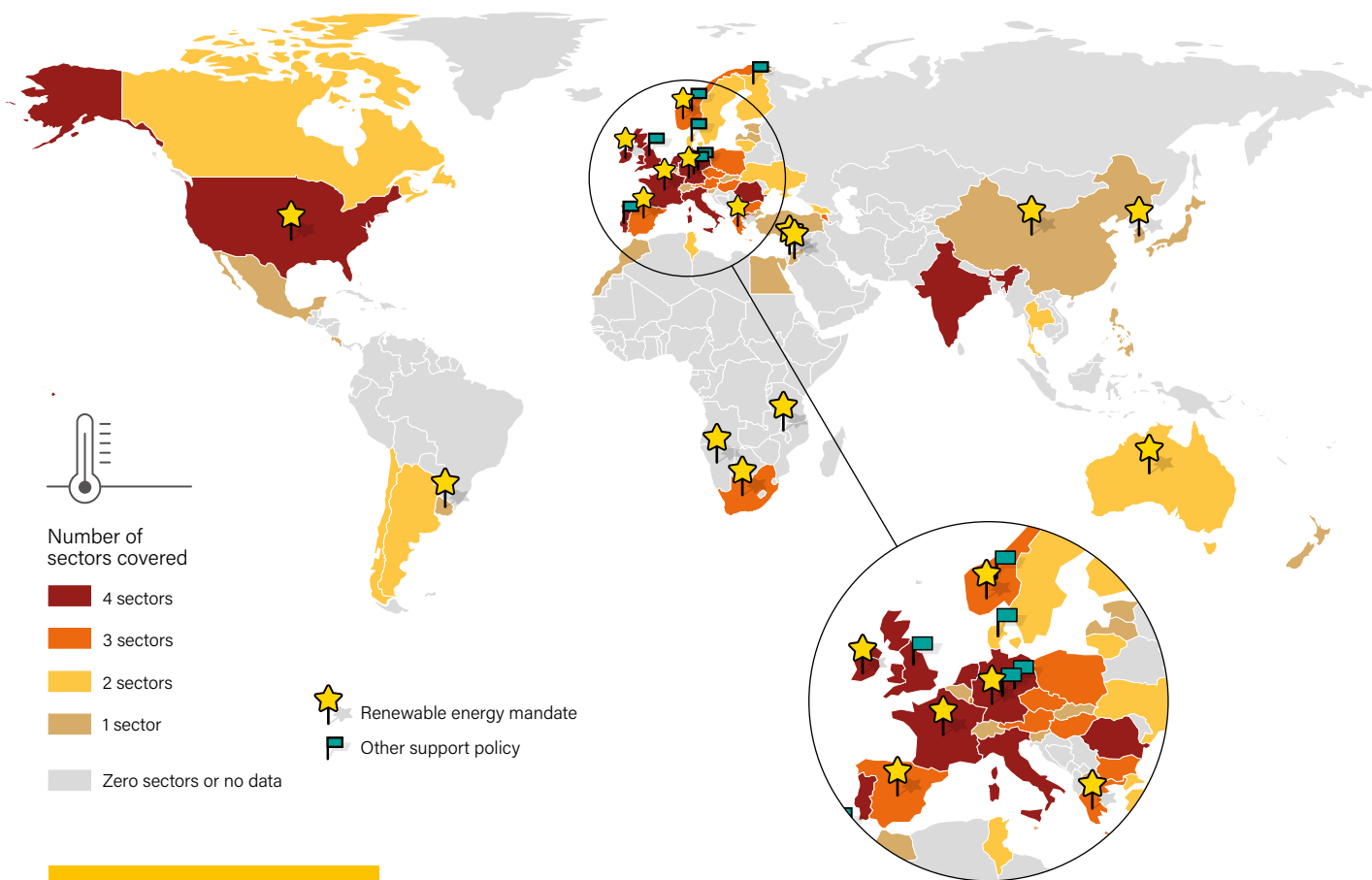
The Netherlands' subsidy programme scheme for renewables (Renewable Energy Production Incentive Scheme, SDE++), which compensates for the difference between the cost of the technologies and the market value of the product, was broadened to include renewable heat (such as geothermal, biomass and solar thermal systems).<sup>52</sup> Scotland provided GBP 1 million (USD 1.4 million) for projects using “low-carbon” heat and/or renewable electricity solutions for buildings, and the United Kingdom extended its Domestic Renewable Heat Incentive Scheme to 31 March 2022.<sup>53</sup> Portugal launched a new EUR 4.5 million (USD 5.5 million) energy efficiency programme that provides incentives for decarbonisation and energy efficiency in buildings, including to retrofit them with renewables.<sup>54</sup>

Mandatory **building energy codes** that require the deployment of renewable energy systems can play a key role in the uptake of renewable heating and cooling, particularly in new construction and retrofits.<sup>55</sup> Even when renewables are not explicitly required in building energy codes, these codes can have a positive effect on the energy demand of buildings because they typically require energy efficiency improvements.<sup>56</sup> By the end of 2020, 67 countries had in place mandatory or voluntary building energy codes (down from 73 in 2019).<sup>57</sup> At least 40 countries have mandatory codes for both residential and non-residential buildings.<sup>58</sup>



- i Renewable gases include biogas, biomethane, renewable natural gas and renewable hydrogen produced from renewable electricity (electrolysis). Because renewable gases can replace fossil gas, they can leverage existing gas networks.
- ii Mainly through the use of wood and pellet stoves and boilers and in district heating networks.
- iii The electrification of heating is only renewable to the extent that the electricity used is generated from renewable sources.

**FIGURE 13.** Sectoral Coverage of National Renewable Heating and Cooling Financial and Regulatory Policies, as of End-2020



Only **10 countries** had renewable heat support policies covering all sectors as of end-2020.

Note: Sectors include residential, industrial, commercial and public facilities. Policy types used for map shading include investment subsidies/grants, rebates, tax credits, tax deductions, loans and feed-in tariffs. Renewable energy mandates are the obligation to meet a certain renewable standard for heat, such as the use of a specified technology. Other support policies include fossil fuel bans, support for phasing out fossil fuels, CO<sub>2</sub> pricing for heat and support for R&D. Figure does not show policies at the local level; for local level data, see REN21 *Renewables in Cities Global Status Report*, [www.ren21.net/cities](http://www.ren21.net/cities).

Source: REN21 Policy Database. See Reference Table R9 in GSR 2021 Data Pack.

While not all of the codes included renewable energy requirements, at least 2 new renewable energy requirements were added to building energy codes in 2020 (in contrast to 2019 when no such requirements were added), only at the sub-national level. A requirement adopted in 2018 for all new homes in California to be equipped with solar panels came into effect in 2020, while the state of Washington announced additional energy credit options for builders incorporating solar power.<sup>59</sup> Conversely, some jurisdictions added restrictions for renewable energy in their building codes, such as Minnesota, which prohibits placing solar panels within 0.9 metres of a roof edge as a safety precaution – a measure that is estimated to shrink the available space for solar PV by at least 20%.<sup>60</sup>

**Electrification** of heating and cooling can increase the penetration of renewables in the buildings sector if the electricity used is generated from renewable sources. Globally,

electrification of heating and cooling is increasing, with around 11% of global electricity generation used by electric heaters, boilers and heat pumps for buildings.<sup>61</sup> In 2020, policy makers gave greater attention to policies targeting the electrification of heating and cooling in buildings. Denmark provided tax incentives for the use of renewable electricity to heat buildings (while also raising taxes on fossil fuels for heating) and allocated DKK 2.3 billion (USD 0.38 billion) for the replacement of oil and natural gas boilers with renewable heat.<sup>62</sup>

At a sub-national level, British Columbia (Canada), which generated nearly 95% of its electricity from renewables in 2020, temporarily doubled rebates for residential heat pumps.<sup>63</sup> In the United States, California provided USD 45 million for electric heat pump water heaters, and New Mexico reinstated a USD 6,000 tax credit for households and businesses to install solar PV panels or solar thermal systems to heat water.<sup>64</sup> The Australian



## INDUSTRY



In addition to using electricity, some industrial processes utilise thermal energy (heat) to meet various needs. Like buildings, thermal energy demand (both direct thermal energy and electricity for heat) in industrial processes accounts for around 25% of global final energy consumption.<sup>75</sup> This demand can be met directly by thermal energy from renewables (including biomass, solar thermal and geothermal energy) or indirectly from renewable electricity, for example via heat pumps (provided that the electricity used is generated from renewable sources). Renewable hydrogen also can be used to meet certain energy demands in industry<sup>iii,76</sup> (→ See *Sidebar 5 and Table 5*.) Currently, bioenergy accounts for nearly all of the renewable heat use in industry (almost 90% in 2019).<sup>77</sup>

Renewable energy solutions to provide low-temperature heat for industrial uses are widely available. However, for industries that require high-temperature heat, such as steel and cement, renewable technologies have not yet reached scale to be competitive with fossil fuels. Thus, government support through policy, targets, and research, development and demonstration (RD&D) remains important. Nevertheless, by the end of 2020, only 32 countries had some form of renewable heating and cooling policy for industry (unchanged from 2019). (→ See **Reference Table R9** in *GSR 2021 Data Pack*.)

The most common form of policy support during 2020 was **financial incentives**. For example, the United Kingdom offered GBP 139 million (USD 189 million) to support industry efforts to cut greenhouse gas emissions, including switching from fossil-based gas to renewable hydrogen for fuel-heavy industry.<sup>78</sup> The Netherlands offered a subsidy for companies in the industrial sector to generate renewable electricity, heat and gas for their own use.<sup>79</sup> Denmark allocated DKK 2.5 billion (USD 413 million) in subsidies for 10 years for electrification and energy efficiency improvements in industry, as well as DKK 2.9 billion (USD 479 million) for biogas and other renewable gases for those parts of industry where renewable electricity cannot be utilised directly.<sup>80</sup> Although not specific to industry, Scotland announced interest-free loans of GBP 1,000 to GBP 100,000 (USD 1,358 to USD 135,772) for small and medium-sized enterprises to install renewables for heating (including biomass boilers, solar thermal technologies and electric heat pumps).<sup>81</sup>

In the agricultural sector, most policy during the year was aimed at improving irrigation systems. Jamaica committed to powering all irrigation systems operated by the National Irrigation Commission solely with solar PV within two years.<sup>82</sup> Egypt announced plans to invest EGP 184 million (USD 11.6 million) to modernise several irrigation systems, including equipping them with solar PV to improve electricity supply.<sup>83</sup> Canada, as part of its new climate plan, committed to investing CAD 166 million (USD 130 million) to support its agriculture sector to develop “clean technologies” (including renewables).<sup>84</sup>

Capital Territory committed AUD 500 million (USD 383 million) to build a hospital powered entirely with renewables, including a 100% renewable electric heating and cooling system.<sup>65</sup>

**Renewable district heating** can provide an entry point for renewables to reach end-users. In 2020, the European Commission approved a EUR 150 million (USD 184 million) programme to support the conversion of district heating systems in Romania from fossil fuels to renewables.<sup>66</sup> Poland launched a programme offering owners of district heating networks co-financing in the form of grants and loans to add renewable energy or waste heat to their systems.<sup>67</sup>

Policies targeting **energy efficiency** often are cost-effective options for decreasing the thermal demand of buildings.<sup>68</sup> In 2020, the EU launched a “renovation wave” that aims to reduce building emissions 60% by 2030 by doubling the yearly rate of energy-related building renovations.<sup>69</sup> The renovation wave includes an acknowledgement of the contribution of on-site renewables to achieve higher energy efficiency requirements.<sup>70</sup> Another European initiative, set to begin in 2022, is intended to facilitate collaboration between experts and entrepreneurs on buildings, including energy efficiency.<sup>71</sup> In the United Kingdom, England’s new Green Homes Grant scheme provides homeowners the opportunity to receive a government subsidy for two-thirds of the cost of energy efficiency improvements.<sup>72</sup>

Israel’s new national energy efficiency plan includes funding to make buildings more energy efficient over the next 10 years, including by ensuring that imported electrical products are more energy efficient, integrating energy ratings into new buildings and requiring contractors to publish energy efficiency ratings when they sell.<sup>73</sup> At a sub-national level, the US state of Washington implemented a Property Assessed Clean Energy (PACE)<sup>ii</sup> loan programme to finance energy efficiency and renewable energy retrofits for existing and new buildings.<sup>74</sup>

i Up to a maximum of GBP 5,000 (USD 6,788) per household, or up to GBP 10,000 (USD 13,577) for low-income homeowners.

ii See Glossary.

iii In some cases, hydrogen also can be used as a feedstock for chemical processes.



## SIDEBAR 5. Policy Support for Renewable Hydrogen

Renewable hydrogen is an energy carrier produced through renewables-driven electrolysis or gasification using renewable feedstocks. Hydrogen can either be combusted directly for use in heat or transport, or used to generate electricity via fuel cells. Apart from its potential to be stored and converted to electricity when needed, hydrogen provides an opportunity to increase the penetration of renewables beyond the power sector, mainly in industry and transport but also in buildings. (→ See *Systems Integration chapter*.) In 2020, nearly all hydrogen produced and used worldwide continued to be manufactured with natural gas for use as an industrial feedstock.

A number of governments made policy announcements during the year in support of hydrogen, although not all of these committed to pursuing renewable hydrogen<sup>i</sup>. However, several notable policy developments related to renewable hydrogen occurred, particularly in Europe and Australia (as in 2019) but also in Latin America.

In Europe, the EU introduced a new hydrogen strategy, including a goal of 6 GW of electrolyser capacity powered by renewable electricity by 2024 and 40 GW of renewable hydrogen electrolyser capacity by 2030<sup>ii</sup>. Germany launched its own hydrogen strategy, including plans to increase hydrogen production capacity to 5 GW by 2030 and 10 GW by 2040 using surplus electricity from renewable energy sources. Germany also committed to investing up to EUR 7 billion (USD 8.6 billion) to promote renewable hydrogen production and use.

The United Kingdom announced GBP 28 million (USD 38 million) in funding for five hydrogen production projects, one focused on using offshore wind power to generate renewable hydrogen. Norway allocated NOK 3.6 billion (USD 420 million) to support the move from “grey” hydrogen (produced from fossil fuels) to “blue” hydrogen (fossil fuels with carbon capture and storage) and finally to “green” hydrogen (renewable hydrogen). Spain unveiled a plan to boost renewable hydrogen

production and set a target of 300-600 MW of capacity by 2024 and 4 GW by 2030. Scotland announced GBP 100 million (USD 136 million) for new electrolysers and set a target for 25 GW of renewable hydrogen by 2050.

In Australia, the government committed AUD 70 million (USD 54 million) to support the deployment of at least two new renewable hydrogen projects and established a new AUD 300 million (USD 230 million) fund to invest in the country’s renewable hydrogen industry. At a state level, Tasmania announced a Renewable Hydrogen Action Plan and AUD 50 million (USD 38 million) for renewable hydrogen; the Northern Territory unveiled a strategy to become a hub for renewable hydrogen technology research, production and manufacturing; and Queensland announced AUD 10 million (USD 7.7 million) over four years (in addition to the original AUD 15 million (USD 12 million) Hydrogen Development Fund) to support the renewable hydrogen industry.

In Latin America, Chile unveiled a national green hydrogen strategy that aims to develop the country into a global producer and exporter by 2040. The strategy consists of a commitment to develop regulation for the use and production of renewable hydrogen, to analyse global best practices related to renewable hydrogen, and to convene government and the private sector to develop a roadmap and action plan by 2025 that will identify cofinancing opportunities with the private sector. Chile’s strategy also updates the country’s NDC by setting out a target for renewable hydrogen to reduce greenhouse gas emissions 18-27% by replacing fossil fuels.

- i For example, Canada and France developed national hydrogen strategies but did not commit to the development of renewable hydrogen specifically.
- ii By 2030, the EU wants 40 GW of electrolysers installed within its borders and another 40 GW in place in nearby countries that can export to the EU. The EU’s strategy does not shut out “blue hydrogen” (fossil-based hydrogen with carbon capture and storage) as a means of phasing in hydrogen while the cost of renewable hydrogen decreases.

Source: See endnote 76 for this chapter.







**TABLE 5.**  
Targets and Policies for Renewable Hydrogen, 2020

Note: This table includes details only on *renewable* hydrogen targets and policies. For additional details, see GSR 2021 Data Pack.

Jurisdiction	Target	Policy/Programme
European Union	6 GW electrolyser capacity and 1 million tonnes production by 2024; 40 GW and 10 million tonnes by 2030	<b>Hydrogen Strategy</b> provides framework to establish <b>European Clean Hydrogen Alliance</b> , including an investment agenda and support for scaling up value chain. The strategy targets production as well as end-use in industry.
Australia		<b>Renewable Hydrogen Deployment Funding Round</b> will provide AUD 70 million (USD 54 million) to support at least two projects. <b>Advancing Hydrogen Fund</b> of AUD 300 million (USD 230 million) supports new projects nationwide.
<i>New South Wales</i>		<b>Electricity Investment Bill</b> includes AUD 50 million (USD 38 million) over 10 years to develop renewable hydrogen sector. Parts of NSW will be designated renewable energy zones.
<i>Northern Territory</i>		<b>Renewable Hydrogen Strategy</b> outlines a plan for development of local industry, resource management infrastructure, fostering demand for exports and domestic applications, support for innovation and regulation to guide industry.
<i>South Australia</i>		AUD 17 million (USD 13 million) in grants and AUD 25 million (USD 19 million) in loans provided to four projects. <b>Hydrogen Action Plan</b> outlines plan to facilitate investments in infrastructure; establish regulatory framework; and support trade, supply capabilities, innovation, workforce development and energy system integration.
<i>Tasmania</i>	Production to start by 2022	<b>Renewable Hydrogen Industry Development Funding Program</b> allocates AUD 50 million (USD 38 million) to support industry development, including financial assistance for renewable electricity supply and concessional loans.
<i>Victoria</i>		<b>Hydrogen Investment Program</b> supports development of industry through market testing, policy development and targeted investment programme.
<i>Western Australia</i>	Up to 10% blend in gas pipelines and networks by 2030	<b>Renewable Hydrogen Strategy and Roadmap</b> include funding for grants to study production for export, use in mining operations, blending with natural gas and use as transport fuel.
<i>Queensland</i>		<b>Hydrogen Strategy</b> includes the AUD 15 million (USD 11 million) <b>Hydrogen Industry Development Fund</b> , providing funding for investors developing projects to increase supply of renewable hydrogen.
Canada		
<i>Quebec</i>		Hydro-Quebec's (public utility) <b>Strategic Plan 2020-24</b> supports R&D for production using hydroelectricity.
Chile	5 GW electrolyser capacity and 200 kilotonnes of production by 2025; 25 GW by 2030	Up to USD 50 million to help finance pilot projects that may not be initially competitive while operating at a small scale. A task force will help with provision of permits and development of pilot programmes.
France <sup>1</sup>	6.5 GW electrolyser capacity; 20-40% renewable by 2030; 10% renewable in industry by 2023	EUR 2 billion (USD 2.5 billion) from its coronavirus recovery plan by 2022 for pilot and regional projects, and EUR 7 billion (USD 8.6 billion) for development of industry by 2030.
Germany	5 GW electrolyser capacity and 14 TWh production per year by 2030; 10 GW and 28 TWh production per year by 2035-2040	<b>National Hydrogen Strategy</b> includes EUR 310 million (USD 380 million) by 2023 for research and innovation; EUR 9 billion (USD 11 billion) to stimulate use in transport, industry, heating and other applications; and EUR 7 billion (USD 8.6 billion) to increase capacity.
Netherlands	0.5 GW electrolyser capacity by 2025; 3 to 4 GW by 2030	<b>SDE++ (Stimulation of Sustainable Energy Transition)</b> subsidy scheme extended to include renewable hydrogen production.
<i>Northern Netherlands</i>	6 GW electrolyser capacity by 2024; 40 GW by 2030	
Norway		A portion of NOK 3.6 billion (USD 380 million) green restructuring package to support renewable hydrogen projects.
Portugal	10% to 15% in natural gas networks; 2 GW to 2.5 GW electrolyser capacity; 50 to 100 fuelling stations by 2030	EUR 7 billion (USD 8.6 billion) investment in renewable hydrogen by 2030.
Spain	4 GW electrolyser capacity and 25% in industry by 2030	EUR 1.5 billion (USD 1.8 billion) support for the period 2021-2023.
United Kingdom	5 GW electrolyser capacity by 2030	GBP 12 billion (USD 15 billion) plan to heat homes with renewable hydrogen. <b>Hydrogen Supply programme</b> allocates a portion of GBP 28 million (USD 36.5 million) for two projects.
United States		USD 64 million for 18 projects.

<sup>1</sup> France's targets are for "decarbonised" hydrogen, which may include hydrogen produced by nuclear energy.

Source: See GSR 2021 Data Pack at [www.ren21.net/gsr-2021](http://www.ren21.net/gsr-2021).

# TRANSPORT



Globally, the transport sector has the lowest share of renewable energy and accounts for around one-quarter of global energy-related greenhouse gas emissions.<sup>85</sup> Although renewable energy policies in the sector have been expanding, most policies continue to focus on road transport, with few directly supporting renewables in rail, aviation and shipping. As of the end of 2020, the share of renewables in the transport sector was 3.7%, unchanged from the year before. (→ See *Global Overview chapter*.) This section covers renewable energy transport policies enacted at the national and provincial/state levels. (→ See **Reference Table R8** in *GSR 2021 Data Pack*.)

## ROAD TRANSPORT

Policies to incentivise renewables in road transport include policies directly supporting biofuels and the use of renewable electricity in electric vehicles, as well as some climate change policies, such as fossil fuel bans, carbon pricing and requirements for "zero-emission" vehicles. (→ For *climate policies that support renewables*, see *Renewable Energy and Climate Change Policy section* in this chapter.)

### Biofuels in Road Transport

In 2020, biofuels continued to make the largest contribution of renewable energy to the road transport sector. Policies supporting the production or use of biofuels include biofuel blending targets, biofuel blending mandates, support for

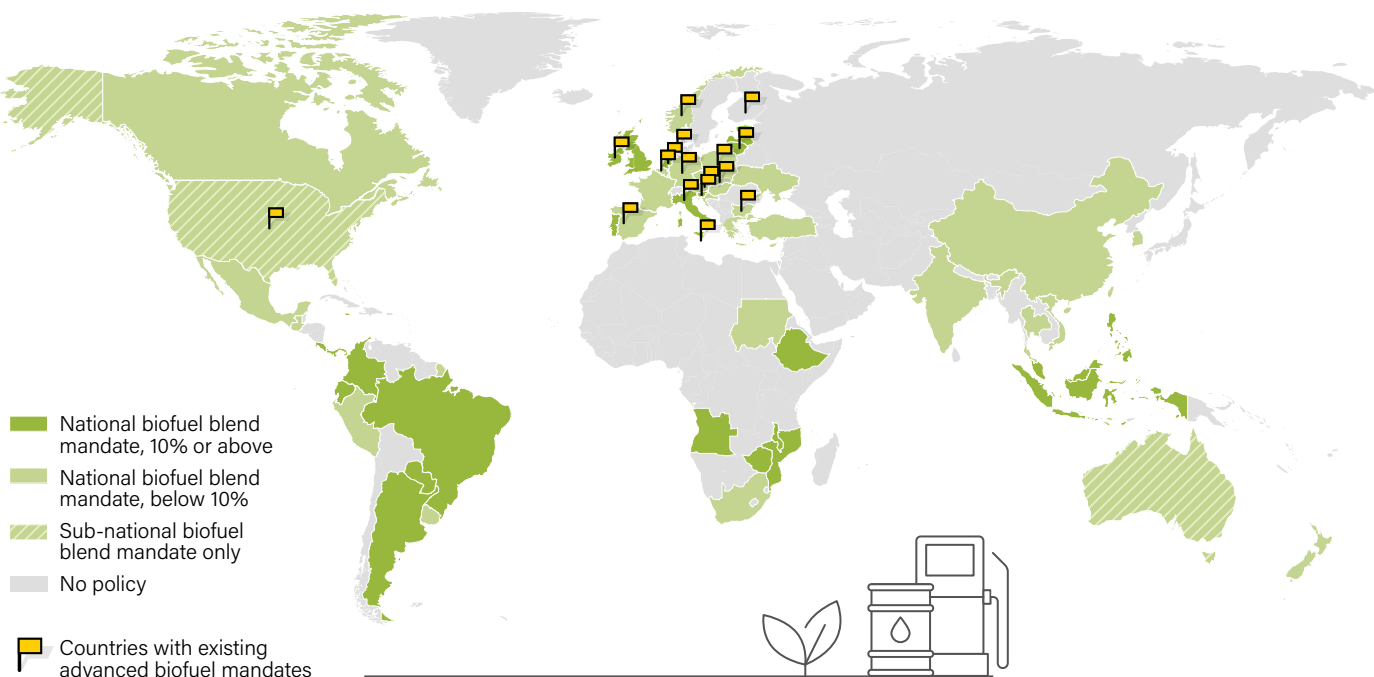
advanced biofuels, financial incentives, public procurement programmes, and support for biofuel production, fuelling and blending infrastructure.

At least three new **biofuel blending targets** were announced in 2020. The United States set a target for biofuels to make up 15% of US transport fuels by 2030 and 30% by 2050.<sup>86</sup> Zimbabwe launched a national biofuels policy, which includes targets for ethanol blending of up to 20% and for biodiesel blending of up to 2% by 2030.<sup>87</sup> Paraguay established a law requiring biodiesel blending of 4% in 2021 and 5% in 2022, up from 3% in 2020.<sup>88</sup>

**Biofuel blending mandates** remained the most widely used policies for ensuring renewable content in road transport. Overall, 65 countries had blending mandates as of the end of 2020 (unchanged since 2017). (→ See *Figure 14* and **Reference Table R8** in *GSR 2021 Data Pack*.) While no new countries added biofuel blending mandates during 2020, some that already had a policy either added new mandates or targets or strengthened existing ones.

At least 28 countries revised their existing mandates during the year. Early in 2020, Brazil increased its minimum biodiesel blend from 11% to 12% (although, as a result of the COVID-19 crisis, the country later temporarily reduced it to 10%).<sup>89</sup> Belgium increased its biofuel blending mandate from 8.5% to 9.55%, while Cyprus raised its mandate from 5% to 7.3%.<sup>90</sup> Indonesia increased its biofuel blending mandate to 30%, up from 20%.<sup>91</sup> At the sub-national level, Ontario (Canada) raised its petrol blending mandate from 5% to 10%.<sup>92</sup>

**FIGURE 14.** National and Sub-National Renewable Transport Mandates, End-2020



Note: Shading shows countries and states/provinces with mandates for either biodiesel, ethanol or both.

Source: REN21 Policy Database. See Reference Table R8 in *GSR 2021 Data Pack*.

By the end of 2020, 11 countries (and the EU) had targets in place for **advanced biofuels** (up from 10 countries in 2019), and 17 countries had mandates in place for advanced biofuels. (→ See **Reference Table R8** in *GSR 2021 Data Pack*.) Only one new country, Latvia, adopted an advanced biofuels target in 2020: the country's national energy and climate plan (NECP) included a target of 3.5% advanced biofuels and biogas in the transport sector's final energy consumption by 2030.<sup>93</sup>

**Financial incentives** supporting the production and use of biofuels are less common than blending mandates but were extended in some countries. Sweden extended its tax exemption for liquid biofuels to the end of 2021, and Iowa (US) extended a fuel tax incentive for diesel sold in the state containing at least 11% biodiesel.<sup>94</sup> Thailand announced plans to revoke the seven-year time frame for ending biofuel subsidies and to instead maintain the subsidies until sometime between 2022 and 2026.<sup>95</sup>

Some jurisdictions implemented **public procurement programmes** to support biofuels. At the national level, the Finnish postal service committed to using renewable diesel to fuel its light delivery fleet.<sup>96</sup> Additional public procurement initiatives related to transport took place at the local level, although more often for EVs than for biofuels. (→ See *Renewables in Cities 2021 Global Status Report*.)

Some jurisdictions promote biofuels for road transport by **supporting biofuel production and infrastructure**. In 2020, Paraguay's government granted "Free Zone"<sup>i</sup> treatment for an advanced biofuels plant to produce renewable diesel and renewable aviation kerosene.<sup>97</sup> Brazil's RenovaBio programme became fully operational in 2020, with decarbonisation credits being sold in the nation's stock exchange.<sup>98</sup>

The United Kingdom announced funding for four plants producing advanced biofuels.<sup>99</sup> The United States committed up to USD 75 million over five years for research on sustainable bioenergy crops, and up to USD 100 million for ethanol and biodiesel transport fuelling and biodiesel distribution facilities.<sup>100</sup> At a sub-national level, Iowa committed USD 3 million to its biofuel infrastructure programme for 2021.<sup>101</sup>



## Electric Vehicles

Electric vehicle<sup>ii</sup> policies became increasingly popular in 2020. Although these are not renewable energy policies by themselves, EVs can increase the penetration of renewables in transport to the extent that the electricity used to charge them is generated from renewable sources. Policies to support EVs include targets, financial incentives, public procurement, funding for charging infrastructure, free parking and preferred access for EVs. Financial incentives and support for EV charging were the most common forms of EV policy implemented during 2020. (→ See **Reference Table R8** in *GSR 2021 Data Pack*.)

As in 2019, most of the EV policies implemented in 2020 lacked a **direct link to renewable electricity**, although the number of policies that do have a direct link increased from two countries to three<sup>iii</sup> by year's end. Japan announced plans to increase subsidies for EVs under the condition that the vehicles are charged with renewable electricity – a policy type that previously was found only in Austria.<sup>102</sup> Additional support linking EVs to renewable electricity occurred through state-owned and -operated transport companies. India's West Bengal Transport Corporation committed to using solar PV electricity to recharge its EVs.<sup>103</sup> In the United States, the Delaware Transit Corporation provided USD 3.1 million to install solar PV at its operations facility to help power electric buses.<sup>104</sup>

In jurisdictions with high shares of grid-connected renewable electricity, EV policies and targets can indirectly support renewable energy use in the transport sector even if not directly linked in the same policy, as long as the jurisdiction is simultaneously targeting increasing shares of renewable electricity.

By the end of 2020, at least 52 national or state/provincial jurisdictions had targets for EVs, up from 38 in 2019, although not always also targeting high renewable electricity shares.<sup>105</sup> (→ See *Figure 15*, and **Reference Tables R8 and R6** in *GSR 2021 Data Pack*.) At least 19 jurisdictions had targets for full bans on sales of internal combustion engine vehicles (or for 100% sales of EVs), including two adopted during 2020. (→ See *Renewable Energy and Climate Change Policy* section in this chapter.) At least 31 other jurisdictions had lower targets for EVs, including 6 adopted during 2020. Pakistan launched a plan to bring 500,000 electric motorcycles and rickshaws and more than 100,000 electric cars, buses and trucks into its transport system by 2025, with a target of 30% of all vehicles running on electricity by 2030.<sup>106</sup> Denmark committed to a target of at least 775,000 electric or hybrid cars by 2030.<sup>107</sup>

By the end of 2020,  
only 11 countries had  
targets in place for  
**advanced  
biofuels.**

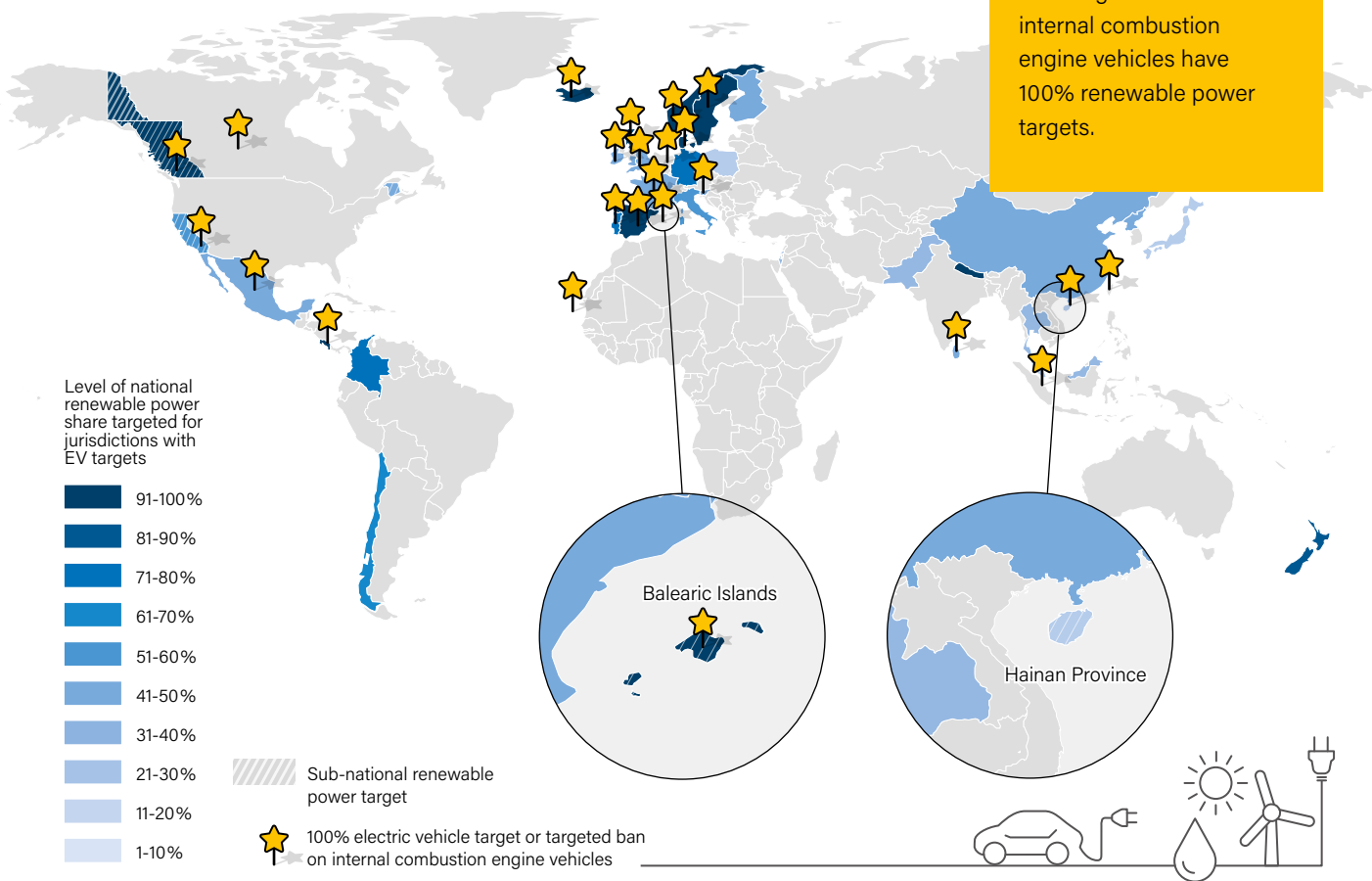
i The Free Zone guarantees the maintenance of the legal conditions of the project for 30 years and contributes to the competitiveness of the project.

ii In this section, EVs are defined as battery electric vehicles and plug-in hybrids.

iii Austria, Germany and Japan

**FIGURE 15.** Targets for Renewable Power and Electric Vehicles, as of End-2020

Only **8 countries** with targeted bans on internal combustion engine vehicles have 100% renewable power targets.



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. Nepal and Quebec show actual renewable power shares; both jurisdictions along with Iceland and Norway have already achieved nearly 100% renewable power. Electric vehicle targets vary; for details, see Reference Tables R6 and R8 in GSR 2021 Data Pack.

Source: REN21 Policy Database. See Reference Tables R6 and R8 in GSR 2021 Data Pack.

In 2020, several countries introduced **financial incentives for EVs** as part of their COVID-19 recovery packages. (→ See *Sidebar 3*.) Among new financial incentives for EVs that were unrelated to COVID-19, Poland introduced purchase subsidies for electric cars, vans and taxis.<sup>108</sup>

Several governments announced plans for **public procurement of EVs**. In Australia, the state government of New South Wales tripled its public fleet procurement targets for hybrids and EVs to around 900 new hybrid or EVs annually, with around 300 of these vehicles being all-electric.<sup>109</sup> The US state of New York committed to providing USD 16.4 million for its public transport authorities to procure electric buses.<sup>110</sup>

In 2020, at least 7 governments implemented **policies to support EV charging**. In the United States, California provided USD 233 million to install public EV charging stations, and Hawaii passed a law to provide grants for adding and upgrading charging infrastructure.<sup>111</sup>

Some jurisdictions developed an **integrated set of policies to promote EV adoption**. As part of its 10-year climate plan, Greece pledged EUR 100 million (USD 123 million) for purchase subsidies for EVs (including electric taxis and motorbikes) and for the installation of public EV charging stations across the country, as well as tax deductions for EV charging.<sup>112</sup> El Salvador enacted a new law establishing preferential tax treatment for electric and hybrid vehicles and ensuring dedicated EV parking spaces in public (and some private) lots.<sup>113</sup> At the sub-national level, New Jersey (US) passed a law aimed at electrifying the state's transport sector, which included a target for 85% of vehicles sold to be electric by 2040, financial incentives of up to USD 5,000 for EV purchases and a commitment to install 1,400 public EV chargers.<sup>114</sup>



## RAIL, AVIATION, SHIPPING AND PORTS

Although rail, aviation and shipping are the fastest growing transport sectors and account for a rising share of total final energy use in transport, they continue to receive much less policy attention than road transport. This is in part because road transport remains responsible for most transport energy use, and because renewable fuel options for these other sectors remain costlier than fossil fuels.<sup>115</sup> Additional challenges include the fragmented, international nature of rail, aviation and shipping, which makes co-ordinated actions more difficult, and the lack of commercially available renewable technologies that can be applied cost-effectively at scale.<sup>116</sup>

Most renewable energy initiatives in the **rail** sector are aimed at supporting renewable electricity. In 2020, just two countries enacted new policies and targets to advance the use of renewables in rail transport. India set a target to electrify 7,000 rail kilometres by 2020-2021 and to electrify all routes on its broad-gauge rail network by 2023, while also advancing plans to integrate rising amounts of renewable power capacity for its operations as well as efficiency and other sustainability improvements.<sup>117</sup> France's national railway company committed to meeting a portion of its electricity needs using renewable electricity and signed a renewable electricity power purchase agreement to provide around 2% of the electricity consumption of all national passenger trains.<sup>118</sup> In the private sector, UK-based Network Rail became the first railway organisation to set a science-based target in line with the Paris Agreement's goal to limit global temperature rise to 1.5 degrees Celsius above pre-industrial levels.<sup>119</sup>

During 2020, no jurisdictions adopted new targets to advance the use of renewables in **shipping**, and only one country added renewable energy policy support in the sector. The Netherlands announced plans obliging suppliers of heavy fuel oil and diesel for inland shipping to take part in its renewable

fuel scheme.<sup>120</sup> A few jurisdictions advanced policy support for the use of renewables in **ports**. The Spanish Port Authority of Valencia committed to building 8.5 MW of solar PV at two of its ports on Spain's coast, and Portugal and the Netherlands signed a memorandum of understanding to connect Portugal's renewable hydrogen project with a seaport in the Netherlands.<sup>121</sup>

Only one country had a new biofuel blending policy for **aviation** by year's end, with Norway's blending mandate of 0.5% biofuels in all aviation fuel entering into force in 2020.<sup>122</sup> By year's end, only four countries had biofuel targets for the aviation sector.<sup>i</sup> However, other plans to support renewables in aviation advanced. For example, the EU held a public consultation for its draft plan (ReFuelEU) to cut emissions 55% (replacing a previous target of 40%) and to scale up the use of renewable biojet fuel (also called sustainable aviation fuel), including through a blending mandate, auctioning mechanism, funding and monitoring.<sup>123</sup>

At the national level, France was in the process of adopting legislation as part of its 2021 budget that would require planes that refuel in the country to use at least 1% sustainable aviation fuel from 2022, with the blend increasing to 2% by 2025, 5% by 2030 and 50% by 2050.<sup>124</sup> Germany published a draft law that would require airlines to increase sustainable aviation fuel of non-biogenic origin to 0.5% by 2025, 1% by 2028 and 2% by 2030.<sup>125</sup> Sweden planned to introduce an emission reduction requirement for aviation fuel sold in the country of 0.8% in 2021 and increasing to 27% by 2030.<sup>126</sup> Meanwhile, the United Kingdom's Jet Zero Council, a public-private partnership, began supporting sustainable aviation fuel through R&D.<sup>127</sup>

Alongside the somewhat slow public policy support for renewables in the rail, shipping and aviation sectors, several private sector players moved forward on their own to implement initiatives and programmes to support the uptake of renewables in transport. (→ See *Transport section in Global Overview chapter*.)



i Countries with existing 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)

## POWER



As in previous years, the power sector continued to receive the most renewable energy policy attention in 2020. Policies to support renewable electricity generation include targets, renewable portfolio standards (RPS), feed-in policies (tariffs and premiums), auctions and tenders, renewable energy certificates (RECs, or Guarantees of Origin – GOs), net metering, financial incentives (such as grants, rebates and tax credits) and policies to encourage self-consumption – as well as various enabling policies.

A global trend in the power sector is the increasing decentralisation of power generation. The uptake of renewable distributed generation<sup>i</sup> is accelerating, particularly for larger commercial and industrial consumers but also for residential consumers; however, it still accounts for only a small share of electricity generation worldwide.<sup>128</sup>

**Targets** continued to be a popular form of intervention to spur investments in both centralised and distributed renewables. By the end of 2020, 137 countries had some form of renewable electricity target (down from 166 countries in 2019). (→ **See Reference Table R6** in *GSR 2021 Data Pack*.) In addition, many electric utilities<sup>ii</sup> (both private and government-owned) have set targets for increasing shares of renewable power.<sup>129</sup> (→ *See Box 5*.)

Of the countries and states/provinces that set new renewable power targets in 2020, 2 set targets for 100% (or more) renewable electricity. Austria's new target for 100% renewable electricity by 2030 represents an almost 50% increase of renewable electricity from 2020 levels.<sup>130</sup> Nauru committed to 100% renewable energy by 2050, in line with its target for net zero greenhouse gas emissions by that year.<sup>131</sup> At the sub-national level, the governor of Rhode Island (US) signed an executive order for renewables to provide all of the state's electricity by 2030.<sup>132</sup> The Australian state of Tasmania announced a renewable power target of 200% by 2040, to be fulfilled in part by exporting excess renewable power to other parts of the country.<sup>133</sup>

### BOX 5. Utility-Led Activity to Support Renewables

In some places, electric utilities are responsible for the infrastructure needed to deliver electricity to consumers, and they may own the generation systems as well. Utilities thus have an important role to play in enabling increased uptake and integration of renewables. In some jurisdictions, utilities' roles and responsibilities are changing in response to both the proliferation of distributed energy resources and rising electrification of transport and heating.



Utilities can play a key role in encouraging the integration and use of renewables by implementing their own renewable energy targets. For example, Ørsted in Denmark set a target for more than 99% renewable energy generation by 2025 and had already reached a 75% share as of 2018. In Uruguay, UTE set a target of 100% renewable electricity generation, 98% of which was achieved by 2017. Greece's biggest power utility (51% government owned) pledged to shut down most of its coal-fired plants by 2023 and committed EUR 3.4 billion (USD 4.2 billion) to expand its use of renewables and modernise the Greek distribution grid.

At a sub-national level, by the end of 2020 at least 19 US utilities had committed to targets of 50% or 100% renewable generation in the coming decades, including at least 6 that have set net zero emission targets. While some have committed to phasing out "coal-only" plants, many still plan to continue building natural gas plants and infrastructure and are relying largely on offsets to reach net zero goals.

Source: See endnote 129 for this chapter.

i Distributed generation, also called decentralised generation, refers to generation of electricity from sources at a relatively small scale and 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).

ii A utility is defined as an entity engaging in the generation and/or delivery of energy (including, but not limited to, electricity and natural gas) to consumers in a specific geographical area/jurisdiction. Because utilities can be generators, distributors and retailers of energy, they often own and operate network infrastructure. Utilities can be publicly or privately held, and in many cases governments or municipalities still hold a large (or majority) stake in a private utility. Utilities traditionally have been state-owned, vertically integrated monopolies. However, since the 1990s many jurisdictions have adopted reforms including unbundling of the energy sector and liberalisation of the energy market, generally giving consumers more choice in electricity and gas suppliers.

Many other countries set targets in 2020 for renewable electricity shares lower than 100%, demonstrating the scope of ambition among governments around the world. Zimbabwe set a target for 16.5% renewable installed power capacity by 2025 and 30% by 2030.<sup>134</sup> Saudi Arabia announced a target of 50% renewable electricity generation by 2030, and Israel set a target of 30% renewable electricity by 2030, with an intermediate target of 20% for 2025.<sup>135</sup> Papua New Guinea committed in its updated NDC to raising the share of grid-connected renewable power capacity from 30% in 2015 to 78% in 2030 (although down from its earlier target of 100% renewable electricity by 2030), conditional upon funding support from other nations.<sup>136</sup>

In Asia, the Republic of Korea's ninth long-term energy plan included targets for expanding the share of renewables in the electricity mix from 15.1% in 2020 to 40% by 2034.<sup>137</sup> Japan announced a target for 50% renewable electricity generation by 2050 as a means of achieving its carbon neutrality goal.<sup>138</sup> In Uzbekistan, a new strategy on electrical generation includes targeted shares of 8% solar power and 7% wind power in total electricity generation by 2030.<sup>139</sup>

Several targets were set or revised in Europe. The United Kingdom announced a new wind power capacity goal that boosts the previous target for 30 GW of offshore wind by 2030 to 40 GW.<sup>140</sup> Hungary's new climate change strategy sets a target for 90% fossil fuel-free electricity production by 2030 (to be achieved through nuclear as well as renewable power).<sup>141</sup> Regionally, the

EU raised its offshore wind power capacity target to 60 GW by 2030 (up from the existing 2020 capacity of 25 GW) and 300 GW by 2050, and set targets for ocean power capacity of 1 GW by 2030 and 40 GW by 2050 (up from the existing 2020 capacity of around 11 MW).<sup>142</sup>

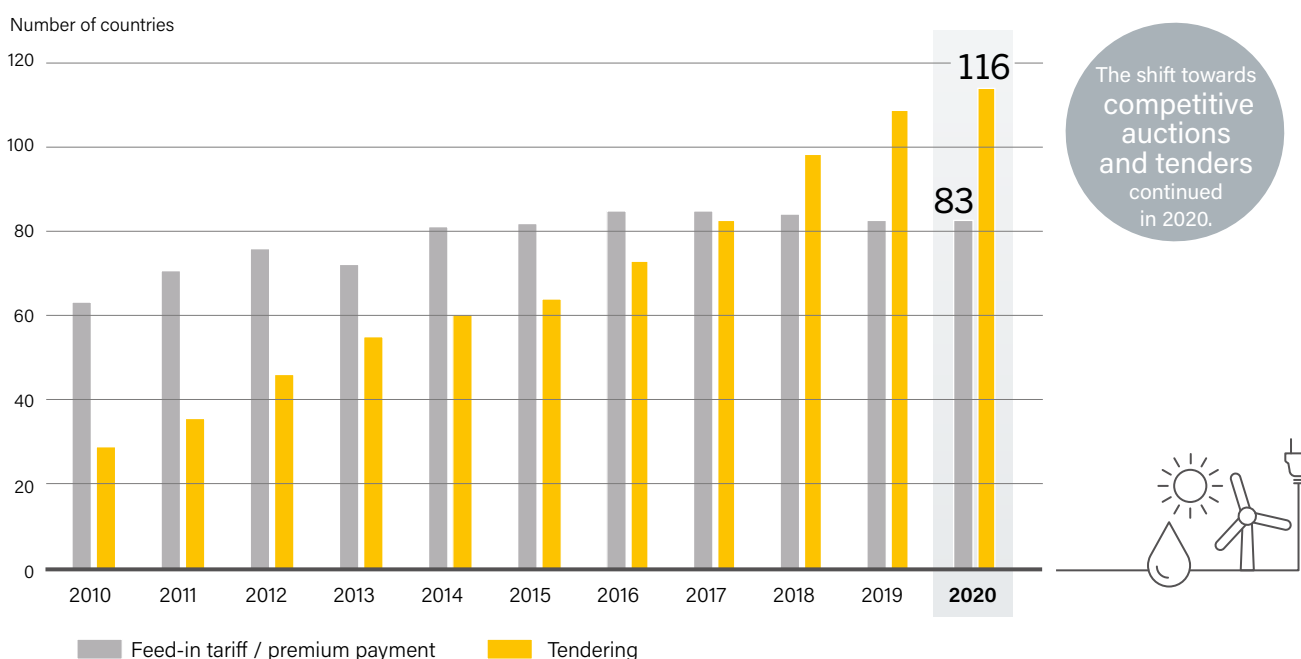
In the United States, the state of Arizona approved a plan for 100% "carbon-free" power by 2050 (including nuclear as well as renewables).<sup>143</sup> Virginia set a 100% carbon-free electricity target through its **renewable portfolio standard (RPS)**, as well as targets for scaling up investment in energy efficiency, energy storage, and solar and wind power.<sup>144</sup> Virginia joined at least 8 other US jurisdictions<sup>i</sup> that had already made 100% carbon-free electricity RPS commitments (many of which include 100% renewable electricity), and at least 12 additional states were considering such commitments by mid-2020.<sup>145</sup>

**Feed-in policies**<sup>ii</sup>, including feed-in tariffs (FITs) and feed-in premiums (FIPs), can be used to promote both large-scale (centralised) and small-scale (decentralised) renewable power generation. Although these remain among the most widely used policy mechanisms for supporting renewable power, the trend continued away from administratively set feed-in pricing policies to the use of competitive tenders or auctions for large-scale power generation.<sup>146</sup> (→ See Figure 16.) FITs nevertheless remained popular in 2020 and by year's end were in place in 83 jurisdictions at the national and state/provincial levels (unchanged from 2019). (→ See Reference Table R10 in GSR 2021 Data Pack.)

i US states and jurisdictions with 100% renewable or "carbon-free" electricity targets include California, Hawaii, Maine, Nevada, New Mexico, New York, Virginia, Washington and the District of Columbia.

ii 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.

**FIGURE 16.**  
Renewable Energy Feed-in Tariffs and Tenders, 2010-2020



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.

Source: REN21 Policy Database. See Reference Tables R10-R11 in GSR 2021 Data Pack.

During 2020, at least nine countries took new action on renewable energy feed-in policies. In at least four countries, these policy changes were to support or maintain existing programmes. Japan committed to transitioning its FIT to a FIP programme<sup>i</sup> starting in 2022, and Vietnam set new rates for its FIT programme, ensuring its continuation following a period of policy uncertainty<sup>ii</sup>.<sup>147</sup> Turkey, which previously had planned to end its FITs in 2020, allocated TRY 3.9 billion (USD 570 million) to the programme and extended it until 30 June 2021.<sup>148</sup> Moldova approved 15-year FITs for renewable energy projects of 1 MW or less.<sup>149</sup>

In contrast, at least five countries, almost exclusively in Europe, cut back support for FITs by either reducing existing payments or cancelling their programmes in favour of auctions or tenders. The Czech government announced retroactive cuts for FITs granted to existing solar PV, wind and hydropower projects, and France retroactively cut FIT contracts signed between 2006 and 2010 for solar PV projects larger than 250 kilowatts (kW).<sup>150</sup>

Ukraine reduced its FIT payments for some wind and solar projects<sup>iii</sup> and announced that, starting in 2022, the FIT for ground-mounted solar projects of 1 MW-plus would be replaced by the country's auction regime (which came into force in January 2020).<sup>151</sup> Switzerland provided CHF 470 million (USD 532 million) to eliminate the waiting list for FIT contracts for small-scale solar PV systems, but also announced plans to replace FITs for large-scale solar PV with an auction mechanism.<sup>152</sup> Outside of Europe, China announced plans to phase out FITs for solar PV starting in 2021.<sup>153</sup>

Meanwhile, at least 33 countries held renewable energy **auctions or tenders** at the national or sub-national levels during 2020 (down from 41 countries in 2019). At least 3 of these auctions or tenders were technology-neutral. (→ **See Reference Table R11 in GSR 2021 Data Pack.**) Many of the auctions and tenders took place in Africa, including in Angola, Chad, Djibouti and Nigeria, continuing the trend from previous years.<sup>154</sup>

At least 6 countries<sup>iv</sup> adopted renewable energy auctions or held auctions for the first time. For example, the Slovak Republic launched its first technology-neutral, large-scale renewable energy auction.<sup>155</sup> Bhutan launched its first tender for renewable power capacity to build the country's first solar PV plant, and the Philippines published a policy governing "green energy" auctions, the first of which was expected to be held in 2021.<sup>156</sup> Croatia introduced a tender scheme in which renewable energy and co-generation projects will be awarded a FIP above spot market prices.<sup>157</sup>

Some governments modified their auction design in 2020. Germany launched its first tender under a new technology-neutral innovation auction programme, which grants a fixed market premium on top of spot market prices (instead of the sliding FIP awarded via traditional renewable energy auctions).<sup>158</sup> The UK government decided to allow solar PV, onshore wind power, hydropower, landfill gas, sewage gas and energy from waste to participate in the country's 2021 power capacity auction, for the first time since 2015.<sup>159</sup>

At least 4 countries strengthened support for feed-in policies in 2020, while 5 countries cut back support.

Most **net metering policies** compensate the owners of renewable power systems for surplus electricity fed into the grid. These policies often do not distinguish between centralised/decentralised and large-/small-scale generation, although in some jurisdictions the focus is exclusively on small-scale or distributed renewable energy. Of the net metering policies that do not distinguish between size or type of generation, 7 new programmes were added in 2020, bringing the total number of countries, states and provinces with net metering policies to 72 by year's end (compared to 70 in 2019).

During 2020, Botswana launched a new net metering programme for both large and small rooftop solar PV systems.<sup>160</sup> Tunisia issued a decree allowing private companies that generate renewable power for their own use to sell any excess generation to the national utility under net metering rules.<sup>161</sup> Zimbabwe launched a net metering programme for rooftop solar PV, and Saudi Arabia established a new net billing programme for small-scale (1 kW to 2 MW) distributed solar PV.<sup>162</sup> At the sub-national level, Kerala (India) introduced a net metering programme for residential systems under 1 MW, and the US state of Virginia expanded its net metering cap from 1% to 6%.<sup>163</sup>

Despite the popularity of net metering in many places, some jurisdictions have begun to transition away from these programmes or have modified them to charge customers fees for participating<sup>v</sup>. Dubai (United Arab Emirates) announced that its net metering programme will no longer apply to large-scale, groundmounted projects and capped the maximum capacity for rooftop PV systems at 2,080 kW.<sup>164</sup> Egypt confirmed plans to impose a "merger fee" on net-metered solar PV systems in the country, although as of October 2020 the fee had not yet been determined.<sup>165</sup> The Belgian region of Wallonia also announced a fee for net-metered systems, which the government will reimburse at least partially until 2024.<sup>166</sup>

i Under Japan's FIT programme, the purchase price for the end-user of electricity is determined at a fixed rate regardless of the variation in market prices. Under the new FIP programme, renewable energy projects will receive a certain premium on top of the market price for the electricity that they generate starting in 2022.

ii Vietnam increased the FIT for biomass power projects and set new FIT rates for utility-scale, rooftop and floating solar PV installations.

iii Ukraine reduced FIT payments by: 7.5% for solar projects with installed capacity below 1 MW and wind projects commissioned during 2015-2019; 15% for solar projects with installed capacity exceeding 1 MW; and 2.5% for plants that begin operation up to the end of 2022.

iv The six countries that held auctions for the first time in 2020 were Bhutan, Croatia, Mozambique, Myanmar, Philippines and the Slovak Republic. See Reference Table R11 in GSR 2021 Data Pack.

v Typically, under a net metering arrangement, customers have lower electricity bills because they generate a portion of their own power. However, these customers may not be covering as much of the costs to maintain grid infrastructure as those who do not self-generate, and these costs are then shifted to these other customers. Some governments have chosen to counteract this by charging a fee to net-metered customers.



Some US states have pulled back from net metering, either implementing caps or adopting successor policies. For example, Kentucky committed to establishing new crediting structures based on dollar value rather than kilowatt-hour netting.<sup>167</sup> Virginia enacted a bill directing regulators to develop a net metering successor when a certain installed capacity threshold is reached, while Illinois hit its net metering cap and initiated a process to transition away from net metering.<sup>168</sup> Utah established a net metering successor that provides compensation at a rate between the retail cost and the avoided cost for exported energy.<sup>169</sup> New York approved an alternative to net metering for residential and small commercial customers that will include new monthly fees, but it delayed implementation to 2022 due to the COVID-19 crisis.<sup>170</sup> Arkansas regulators allowed utilities to propose net metering alternatives beginning in 2023.<sup>171</sup>

**Financial incentives for renewable power** were especially important in 2020 as a result of the COVID-19 pandemic. While many of these incentives were tied to economic recovery packages, not all were. For example, the EU, as part of its Green New Deal, released details of a new financing mechanism intended to bring together renewable energy investors and project developers through regular public tenders and to allow Member States to invest in renewables projects in other countries.<sup>172</sup>

Within Europe, Austria doubled the budget for its residential solar subsidy programme (capacities up to 5 kW), bringing the rebate for installed grid-connected capacity to EUR 250

(USD 307) per kW and for systems integrated into buildings to EUR 350 (USD 429) per kW.<sup>173</sup> Greece allocated EUR 850 million (USD 1,044 million) for homeowners to install solar PV systems and energy storage on residences.<sup>174</sup> The Netherlands doubled the funding available under its green energy subsidy programme to EUR 4 billion (USD 4.5 billion), and Spain provided EUR 181 million (USD 222 million) for renewable energy projects in seven regions.<sup>175</sup>

Switzerland provided CHF 470 million (USD 532 million) to expand renewable energy, with a focus on new solar PV systems, and allocated CHF 46 million (USD 52 million) to its residential and commercial rooftop rebate programme to stimulate demand.<sup>176</sup> The United Kingdom, meanwhile, set out plans to become the world leader in wind energy, including committing GBP 160 million (USD 217 million) to upgrade ports and infrastructure along coastlines to increase offshore wind power capacity.<sup>177</sup>

Elsewhere, Colombia made it easier to access tax incentives for renewables by halving the time required to secure tax deductions, customs exemptions and accelerated depreciation rates for renewable power technologies.<sup>178</sup> Turkey slashed the administrative fee charged to owners of rooftop solar PV systems (10-100 kW), reducing it from TRY 529 (USD 72) to TRY 278 (USD 38).<sup>179</sup> Jordan launched a programme offering 30% rebates for installing residential solar PV systems below 3.6 kW, and Israel committed ILS 80 billion (USD 25 billion) to additional solar PV deployment to support a target of 30% renewable power by 2030.<sup>180</sup>



i Renewable energy generated will count towards the targets for both the host and the contributing states, with the split based on the share of investment.

At a sub-national level, the Indian state of Uttar Pradesh announced subsidies for residential solar rooftop projects (between 1 kW and 10 kW), depending on the project size and location.<sup>181</sup> In Australia, New South Wales unveiled a AUD 32 billion (USD 25 billion) plan to deliver 12 GW of new renewable energy capacity and 2 GW of storage capacity by 2030, and Victoria adopted an interest-free loan programme for landlords that will provide subsidies of up to AUD 3,700 (USD 2,835) for installing a rooftop solar PV system.<sup>182</sup>

China, in contrast, reduced some financial incentives for renewables in 2020. It ended funding completely for new offshore wind farms and halved its budget for subsidising new solar power from CNY 3 billion (USD 460 million) to CNY 1.5 billion (USD 230 million).<sup>183</sup> Company efforts to meet deadlines in China for the phase-out of the onshore wind power feed-in tariff resulted in a spike in wind power investment during the year.<sup>184</sup> (→ See *Investment chapter*.) However, China also committed to increasing grants for solar and wind power starting in 2021.<sup>185</sup>

In addition to net metering, other policies to encourage **renewable self-consumption** have evolved as residential, commercial and industrial power consumers become more interested in generating their own power. In 2019, California became the first jurisdiction to make solar PV mandatory for newly constructed homes starting in 2020, although some loopholes exist.<sup>186</sup> The German state of Bremen passed similar legislation in 2020 to require solar PV on new homes and public buildings.<sup>187</sup>

**Tradeable renewable energy certificates** (RECs, also called Guarantees of Origin or GOs in Europe)<sup>i</sup> also can be used to support renewable electricity, although concerns have been raised about additionality.<sup>ii,188</sup>

Several countries and regions across all major continents already permit the use of RECs, and in 2020 a few more countries allowed their use.<sup>189</sup> Bahrain announced the issuance of the country's first-ever REC, through an electronic platform.<sup>190</sup> In West Africa, companies were able at the start of the year to begin purchasing RECs documented by the International REC Standard.<sup>191</sup>

Support for renewables in **community energy** increased in at least 5 countries during 2020.

## COMMUNITY ENERGY ARRANGEMENTS

Through small-scale **community energy arrangements**, residents, businesses and others located within a relatively small geographic area are able to develop, own, operate, invest in and/or benefit from a renewable energy project.<sup>iii</sup> Policy support plays a crucial role in these arrangements and includes measures supporting self-consumption, virtual net metering<sup>iv</sup> and various forms of shared ownership<sup>v</sup> of renewables, including community solar.<sup>192</sup>

In 2020, Chile introduced rules giving people who own small-scale solar PV systems for self-consumption the option of supplying power to multiple consumers, thereby creating “energy communities”<sup>vi,193</sup> France similarly updated its legislation to allow consumers and producers of renewables to create energy communities on low-voltage networks.<sup>194</sup> Italy launched a pilot programme that allows homes, businesses and public entities with rooftop solar PV systems of 200 kW or less to own, generate, sell, store and distribute renewable energy; to boost the development of these energy communities, the government provides a 20-year tariff of EUR 0.10 to EUR 0.11 (USD 0.12 to USD 0.14) per kWh of power shared among members.<sup>195</sup> Montenegro made it possible for individuals who generate renewable electricity to store and sell surplus power to others, either individually or through aggregation with other generation systems.<sup>196</sup> At a sub-national level, the US state of Virginia established a multi-family shared solar programme in 2020.<sup>197</sup>



i RECs are market-based instruments that represent the property rights to the environmental, social and other non-power attributes of renewable electricity generation. A REC certifies the ownership of 1 megawatt-hour of renewable electricity. Unbundled RECs may be bought and sold separately from the physical sale of electricity.

ii A unit (for example, a REC or a greenhouse gas emission reduction) is considered “additional” if it arises because of the incentives associated with the existence of a specific policy rather than as part of a business-as-usual practice.

iii Communities may vary in size and shape (for example, schools, neighbourhoods, city governments, etc.), and projects vary in technology, size, structure, governance, funding and motivation. See REN21’s *Renewables in Cities Global Status Report*.

iv 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.

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

vi These energy communities will enable users to co-ordinate a shared solar PV array with a single grid connection to inject surplus power back into the electricity network, and also allow for distributed systems to be connected at different locations from their consumers.



## SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

As the penetration of variable renewable energy (VRE) sources such as solar and wind power increases, maintaining the reliability of power systems may become more challenging and costly.<sup>198</sup> Successful integration of VRE is critical to ensuring an efficient and effective power system.<sup>199</sup> (→ See *Systems Integration chapter*.) Increasingly, jurisdictions with relatively high shares of VRE (both large-scale/centralised and small-scale/decentralised generation) have implemented policies to ensure more successful VRE integration. This includes policies related to the design and operation of power markets, transmission and distribution system enhancements, and policies supporting energy storage.<sup>200</sup>

Changes to **power market rules** can increase system flexibility and control and make it easier for both centralised and distributed VRE, as well as energy storage systems, to participate in electricity markets. For example, in 2020 the US Federal Energy Regulatory Commission expanded its access rules to enable renewable distributed energy generators and energy storage to compete in regional wholesale electric markets, alongside large-scale generators.<sup>201</sup>



Policies to **improve electricity infrastructure**, including policies aimed at expanding or modernising transmission and distribution systems, also can facilitate VRE integration and boost resilience.<sup>202</sup> In 2020, India's government-owned transmission company approved seven new transmission projects to support renewable generation projects in the country.<sup>203</sup> South Africa's public utility Eskom announced plans for transmission expansion to strengthen the grid and to connect 30 GW of additional capacity, much of it expected to come from renewable energy projects.<sup>204</sup> In the United Kingdom, energy utility regulator Ofgem unveiled a five-year funding package that provides more than GBP 3 billion (USD 4.1 billion) for transmission grid upgrades to ensure that the network can manage rising levels of VRE.<sup>205</sup> In Australia, a number of states including New South Wales, Queensland and Victoria announced that they would strengthen transmission networks to support the deployment of planned Renewable Energy Zones.<sup>206</sup>

Policies that **promote energy storage deployment** also help with successful VRE integration, since storage can make it easier to balance the supply and demand of renewable generation and minimise the curtailment of electricity.<sup>207</sup> In 2020, Turkey's government introduced new rules for the grid connection of energy storage systems to encourage storage projects linked to rooftop solar PV.<sup>208</sup> New South Wales (Australia) announced funding for four large-scale battery projects to support renewables as the state transitions away from coal.<sup>209</sup>

Policies supporting **solar-plus-storage** explicitly link solar PV and energy storage. In 2020, both Austria and Italy provided financial support for solar-plus-storage installations. Austria launched a EUR 36 million (USD 44 million) rebate programme for small solar-plus-storage installations, and the regional government of Lombardy (Italy) allocated EUR 20 million (USD 25 million) in rebates to promote energy storage coupled with residential and commercial solar PV.<sup>210</sup>



**TABLE 6.**  
Renewable Energy Targets and Policies, 2020

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 <sub>2</sub> , VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
<b>High Income Countries</b>													
Andorra		●	●									●	
Antigua and Barbuda	E, P	●											
Australia	P, P*(N), T*	●	◐	●	◐	◐	●	●	◐			●, ● <sup>6</sup> , ● <sup>7</sup> , ● <sup>*</sup>	
Austria	E, P, HC(O), T	●	●			★		●		★ <sup>6</sup>	●	●, ● <sup>6</sup> , ● <sup>7</sup>	
Bahamas, The	E, P	●											
Bahrain	E, P	●	●					★	●			●	
Barbados <sup>1</sup>	E, P	●										●	
Belgium	E, E*, P(O), P*(O), HC, T	●		◐	◐	★		●	●	● <sup>6</sup>	●	◐	
Brunei Darussalam	E	●										◐	
Canada	P*	●	◐	◐	◐	●, ◐, ★*		★	◐	● <sup>6</sup> , ★	● <sup>6</sup>	●, ● <sup>6,7</sup> , ● <sup>*</sup> , ● <sup>7</sup>	
Chile	P	●	●	●				●	◐, ○	● <sup>6</sup>	● <sup>6</sup>	●, ● <sup>6</sup>	
Croatia	E, P(O), HC(O), T	●	● <sup>6</sup>			★			○			● <sup>6</sup>	
Cyprus	E(N), P(O), HC(O), T(N)	●	●			★			●			● <sup>6</sup>	
Czech Republic	E, P(O), HC(O), T	●	●						●	● <sup>6</sup>	●	★	
Denmark	E, P(N), HC(O), T(O)	●	● <sup>6</sup>			★	● <sup>8,9</sup>	●	◐, ○	● <sup>6</sup>	●	●, ● <sup>6</sup> , ★	
Estonia	E, P, HC, T	●	●			★			◐, ○			●, ● <sup>6</sup>	
Finland	E, P(O), HC(O), T	●	●			★				★ <sup>6,7</sup> , ● <sup>7</sup>	●	●, ● <sup>6</sup> , ★	
France	E, P(N), HC, T	●	★			★	●	●	◐, ○	● <sup>6</sup>	● <sup>6</sup>	★	
Germany	E, P(N), HC(O), T	●	●				● <sup>9</sup>	●	◐, ○	●	●	●, ● <sup>6</sup> , ★	
Greece	E, HC(O), P, T	●	●			★	● <sup>8</sup>	●	●	● <sup>6</sup>	●	●, ● <sup>6,7</sup> , ★	
Hungary	E(N), P(N), HC(O), T(N)	●	●			★			◐, ○	●	●	● <sup>6</sup>	
Iceland	E(O), T(O), HC(O), P(O)	●											
Ireland	E, P(N), HC(O), T(O)	●	●			★	● <sup>8</sup>	●	◐, ○	★ <sup>6</sup>		★ <sup>6,7</sup>	
Israel	E(N), P(N), T	●	●				●		◐, ○	● <sup>6</sup>		●, ● <sup>6,7</sup> , ★	
Italy	E, P, HC(O), T	●	●			★			◐, ○	●	● <sup>6</sup>	●, ● <sup>6,7</sup> , ★	
Japan	E, P	●	★						◐, ○	●	●	●, ● <sup>6</sup>	
Korea, Republic of	E, P	●		●	●	●	●	●	◐, ○	★	●	● <sup>6</sup>	
Kuwait	P	●										● <sup>6</sup>	
Latvia	E(N), P(O), HC(O), T(N)	●	●			★				●		● <sup>6</sup>	
Liechtenstein		●											
Lithuania	E, P, HC, T(O)	●	● <sup>6</sup>			★	● <sup>8</sup>		◐, ○	● <sup>6</sup>		●, ● <sup>6</sup>	
Luxembourg	E, P(O), HC, T	●	●			★			◐, ○			●, ● <sup>6</sup>	
Malta	E, P(O), HC(O), T	●	●			★			●	●		● <sup>6</sup>	
Mauritius	P	●								●		● <sup>6</sup>	
Monaco		●											
Nauru		●											
Netherlands	E, P(O), HC, T(O)	●	● <sup>6</sup>			★	● <sup>8</sup>	●	●	★ <sup>6</sup>	● <sup>6</sup>	●, ● <sup>6</sup> , ★, ★	
New Zealand	P	●		◐						★		● <sup>6</sup>	
Norway	E(O), P(O), T(O), HC(O)	●		●		● <sup>7</sup>	● <sup>9</sup>	●	●	●		● <sup>6</sup>	
Oman	P(N)	●											
Palau	E(O), P	●		●									
Panama	E	●	●			●			●	●	●	●	
Poland	E, P, HC(O), T	●	●			★		●	◐, ○	●		●, ● <sup>6</sup> , ★	
Portugal <sup>2</sup>	E, P, HC(O), T(N)	●	●			★	●	●	◐, ○	●		●, ● <sup>6</sup>	
Qatar	P	●											
Romania	E(N), P(O), HC(N), T(N)	●			★	★		●				● <sup>6</sup>	
San Marino		●	●										
Saudi Arabia	P	●			●, ★								
Seychelles	E, P	●								●	●	●	
Singapore	P(O)	●										●	
Slovak Republic	E, P(O), HC(O), T	●	●			★		●	○	● <sup>7</sup>		● <sup>6</sup>	
Slovenia	E(N), P(O), HC(N), T(N)	●				★		●				● <sup>6</sup>	
Spain <sup>3</sup>	E(N), P(N), HC(O), T(N)	●		★	★		●		◐, ○	★	●	●, ● <sup>6</sup> , ★	
St. Kitts and Nevis		●											
Sweden	E(N), P, HC(O), T(O)	●						○		●	●	●	
Switzerland	P	●						●			★	● <sup>6</sup>	
Taipei, China	P	n/a	●								★		
Trinidad and Tobago	P	●								●	●		
United Arab Emirates	P, P*(O)	●			★*				●, ◐			◐	
United Kingdom	E(O), P(N), P*(O), T(N), HC(O)	●	◐	●		★	● <sup>8</sup>	●	●, ◐	●		●, ● <sup>6,7</sup> , ★, ★*	
United States	T(N), P*(N)	●	◐	★*	★*	◐, ★	●, ◐	◐	◐, ◐	●	● <sup>7</sup> , ● <sup>7</sup> , ★, ★*	● <sup>6,7</sup> , ★, ★*	
Uruguay		●								●, ★, ★*		● <sup>6</sup>	

Note: Please see key on last page of table.



**TABLE 6.**  
Renewable Energy Targets and Policies, 2020 (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 <sub>2</sub> , VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates	
<b>Upper-Middle Income Countries</b>														
Albania	E, T(O)	●	●	●	●	●		●	●	○	●	●	●	●
Argentina	E, P	●	●	●	●	●					● <sup>5</sup>	● <sup>5</sup>	●	● <sup>6</sup>
Armenia	E, P	●	●	●										● <sup>5</sup>
Azerbaijan	P(N)	●												●
Belarus	P	●	●	●							●			●
Belize	P	●								●				
Bosnia and Herzegovina	E(O), HC(O), T(O), P	●	●							●				
Botswana	P	●			★					●	○	●		●
Brazil	P, T	●			●	★				●		●		●
Bulgaria	E, P(N), HC, T(N)	●	●			★								● <sup>5</sup>
China	E(N), P(N), HC(O), T(O)	●	●	★		★	●		●	● <sup>7</sup>	●	●	●	● <sup>6,7</sup>
Colombia	E, P	●								●	○	●		●
Costa Rica	P	●			●	●				●		● <sup>5</sup>		
Cuba	P	●												
Dominica		●												
Dominican Republic	E, P	●			●					●		●		●
Ecuador		●	●			●				●		●		●
Equatorial Guinea		●												
Fiji	E, P	●										●	●	
Gabon	E, P	●												
Georgia	E	●												● <sup>5</sup>
Grenada	P	●			●							●		
Guatemala	P	●			●	●				●		●		
Guyana	P	●												
Indonesia	E, P, T	●	●	●		●				●		●		●
Iran	P(O)	●	●									★	●	●
Iraq	P(O)	●								●				
Jamaica	P	●			●	●				●	○	●	●	
Jordan	E, P, HC(O)	●	●		●		●			●		●		● <sup>6</sup>
Kazakhstan	P	●	●					●		●				●
Kosovo	E(O), P(O), HC(O)	n/a	●											
Lebanon	E, P(O), HC	●			●							● <sup>5</sup>		● <sup>5</sup>
Libya	E, P, HC(O)	✕										●		
Macedonia, North	E, P, HC(O), T(O)	●	●									● <sup>5</sup>		● <sup>5</sup>
Malaysia	P, HC(O), T(O)	●	●	●	★	●				●		●		●
Maldives	E, P(O)	●	●							●				
Marshall Islands	E, P(O)	●										●		
Mexico	E(O), P(O), HC, T(O)	✕			●	★				●		★	●	● <sup>6</sup> , ★
Montenegro	E(O), P(O), HC(O), T(O)	●	●							●		★		
Namibia	P	●					●							
Paraguay	T(N)	●				●						●		
Peru		✕	●	●	●	●				●		●		●
Russian Federation	E(O), P	●	●							●				●
Samoa	E	●												
Serbia	E(O), P, HC(O), T(O)	✕	●											●
South Africa	P	●		●		●	●			●		●		● <sup>5</sup>
St. Lucia	P	●			●							●		
St. Vincent and the Grenadines <sup>1</sup>	P(O)	●			●									
Suriname	P	●			●					●				
Thailand	E, P, HC, T	●	●			●				●			●	★, ● <sup>5</sup> , ★ <sup>7</sup>
Tonga	P	●								●				
Turkey	P, HC	●	★		●	●	● <sup>5</sup>		●	○		★		● <sup>5</sup>
Turkmenistan		●												
Tuvalu	E, P(O)	●												
Venezuela		●												

Note: Please see key on last page of table.

**TABLE 6.**  
Renewable Energy Targets and Policies, 2020 (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 <sub>2</sub> , VAT or other taxes	Investment or production tax credits	Energy production payment
<b>Lower-Middle Income Countries</b>												
Algeria	P	●	●					●			●	●
Angola	P	●	●		●							●
Bangladesh	E, P(N)	●						●			●	★
Benin	E, P	●						●				
Bhutan	E, P, HC	●						○				
Bolivia	P	●	●	●				●		●	●	●
Cabo Verde	P	●		●				●	★	●	●	
Cambodia	E	●						●				
Cameroon	P	●						●				
Comoros	E, P	●						●				
Congo, Republic of	P	●						●				
Côte d'Ivoire	P	●						●				
Djibouti	E, P	●						●				
Egypt	E, P	●	●	●				●		● <sup>6</sup>		●
El Salvador		●						●		●	●	●
Eswatini	P	●						●				
Ghana	P	●	●	●	●		●	●		●		●
Honduras	E, P	●						●		●		
India	E, P, P*, HC, T	●	●	●, ★*	●		●	●, ○, ○		●	●	● <sup>6</sup> , ★ <sup>7*</sup>
Kenya	E, P, HC	●	●	●				●		●	●	●
Kiribati	E, P	●						●				
Kyrgyzstan		✕		●						●		●
Lao PDR	E	●						●				
Lesotho	P	●		●				●	★	●	●	●
Mauritania	E(O), P(O)	●										
Micronesia, Federated States of	E(O), P(O)	●		●								
Moldova	E(O), P(O), HC(O), T(O)	●	●	●				●				●
Mongolia	E, P	●	●					●, ○		●		● <sup>6</sup>
Morocco	P, HC(O)	●		●								● <sup>6</sup>
Myanmar	P	●						○		●		●
Nepal	E(O), P	●	●				●	●		●		●
Nicaragua	P	●	●					●		●		●
Nigeria	P(N)	●	●	●				●		●		●
Pakistan	E, P(N)	●	●	●			●	●		●		●
Palestine, State of <sup>5</sup>	E, P(O)	●	●	●				●		●		●
Papua New Guinea	E, P	●						●				●
Philippines	E, P	●	★	●	●	●		○		●	●	●, ★ <sup>6</sup>
São Tomé and Príncipe	P	●										
Senegal	P	●	●	●				●		●		●
Solomon Islands	E, P	●						●				●
Sri Lanka	P(N), T(O)	●	●	●	●			●		●		●
Tanzania	E, P	●	●	●				●		●		●
Timor-Leste	E, P	●						●				●
Tunisia	E, P	●		★				●, ○		●		● <sup>6</sup>
Ukraine	E, P(O), HC(O), T(O)	●	★	●	●			●		●	★	● <sup>6</sup>
Uzbekistan	E, P(N)	●						●, ○		★		●
Vanuatu	E, P	●	●					●				●
Vietnam	E(N), P(N), T	●	★	●	●	●	●	●, ○		●	★	●
Zambia		●	●					●				●
Zimbabwe	T(N), P	●		★	●			●, ○		●		●

Note: Please see key on last page of table.

**TABLE 6.**  
Renewable Energy Targets and Policies, 2020 (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 <sub>2</sub> , VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
<b>Low Income Countries</b>													
Afghanistan	E, P	●											
Burkina Faso	E, P	●									●	●	●
Burundi	E, P	●											
Central African Republic	P	●											
Chad	P	●											
Congo, Democratic Republic of	E, P	●											
Eritrea	P	●											
Ethiopia	E, P	✕				●							
Gambia	E, P	●									●		
Guinea	E, P	●									●		
Guinea-Bissau	E, P	●											
Haiti	E, P	●											●
Korea, Democratic People's Republic		●											
Liberia	E, P, T	●									●		
Madagascar	E, P	●									●		
Malawi	E, P, HC	●				●	●				●		●
Mali	E, P	●									★		●
Mozambique	P, HC, T	●				●				○	●		●
Niger	E, P(O)	●									●		
Rwanda	E	●	●								●	●	●
Sierra Leone	P, HC	●											
Somalia	P	●											
South Sudan	E, P	✕											
Sudan	E, P	●				●							
Syria	P	●	●		●						●	●	
Tajikistan	P(O)	●	●								●		●
Togo	E, P(O)	●									●		
Uganda	P	●	●								★		●
Yemen	E(O), P, T(O), HC(O)	●											

#### Targets

- E** Energy (final or primary)
- P** Power
- HC** Heating or cooling
- T** Transport
- \* Indicates sub-national target
- (R)** Revised
- (N)** New
- (O)** Removed or came to term
- ✕ Renewable energy not included in NDC

#### Policies

- ★ New (one or more policies of this type)
- ★\* New sub-national
- ☆ Revised (from previously existing)
- ☆\* Revised sub-national
- Existing national policy or tender framework (could include sub-national)
- ◐ Existing sub-national policy or tender framework (but no national)
- National tender held in 2020
- ◑ Sub-national tender held in 2020
- Existing national policy or tender framework (could include sub-national)
- ◐ Existing sub-national policy or tender framework (but no national)
- National tender held in 2020
- ◑ Sub-national tender held in 2020

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 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 12,536 or more, "upper-middle" is USD 4,046 to USD 12,535, "lower-middle" is USD 1,036 to USD 4,045 and "low" is USD 1,035 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 2021. 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: REN21 Policy Database. See GSR 2021 Data Pack at [www.ren21.net/gsr-2021](http://www.ren21.net/gsr-2021).



**Ørsted's strategic suppliers are asked to disclose their own emissions, set science-based carbon reduction targets and use 100% renewable electricity in manufacturing, among other key requirements.**





# 03 MARKET AND INDUSTRY TRENDS

## KEY FACTS

- Modern bioenergy provided 5.1% of total global final energy demand in 2019, accounting for around **half of all renewable energy in final energy consumption**.
- Modern bioenergy for **industrial process heat** grew around 16% between 2009 and 2019, while **bio-heat demand in buildings** grew 7% over the same period.
- In 2020, **global biofuel production fell 5%**, with ethanol production down 8%, while biodiesel production rose slightly to meet increased demand in Indonesia, the United States and Brazil.
- **Bioelectricity production grew 6%** in 2020, with China the major producer.

## BIOENERGY



Bioenergy involves the use of biological materials for energy purposes. A wide range of materials can be used, including residues from agriculture and forestry, solid and liquid organic wastes (including municipal solid waste (MSW)<sup>i</sup> and sewage), and crops grown especially for energy.<sup>1</sup> Many different processes can convert these feedstocks into heat, electricity and fuels for transport (biofuels). While some of these processes are fully established, others are in the earlier stages of development, demonstration and commercialisation.<sup>2</sup>

### BIOENERGY MARKETS

Biomass provides energy for heating in industry and buildings, transport and electricity production. Overall, bioenergy accounted for an estimated 11.6%, or 44 exajoules (EJ), of total final energy consumption in 2019 (latest available data).<sup>3</sup> More than half of this total bioenergy came from the traditional use of biomass<sup>ii</sup>, which provided around 24.6 EJ of energy for cooking and heating in developing and emerging economies, notably in Sub-Saharan Africa.<sup>4</sup>

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

ii The traditional use of biomass for heat involves burning woody biomass or charcoal, as well as dung and other agricultural residues, in simple and inefficient devices to provide energy for residential cooking and heating in developing and emerging economies.

The amount of biomass used for heating has grown 11% since 2009.

Other more modern and efficient uses of bioenergy<sup>i</sup> provided around half of all renewable energy in final energy consumption in 2019 – an estimated 19.5 EJ, or 5.1% of total global final energy demand.<sup>5</sup> (→ See Figure 17.) Modern bioenergy provided around 13.7 EJ for heating (7.3% of the global energy

supply used for heating), 4.0 EJ for transport (3.3% of transport energy needs) and 1.7 EJ for global electricity supply (2.1% of the total).<sup>6</sup> Modern bioenergy use has increased most rapidly in the electricity sector – up 27% between 2010 and 2019 – compared to around 15% growth for transport use and less than 5% for bio-heat.<sup>7</sup>

### BIO-HEAT MARKETS

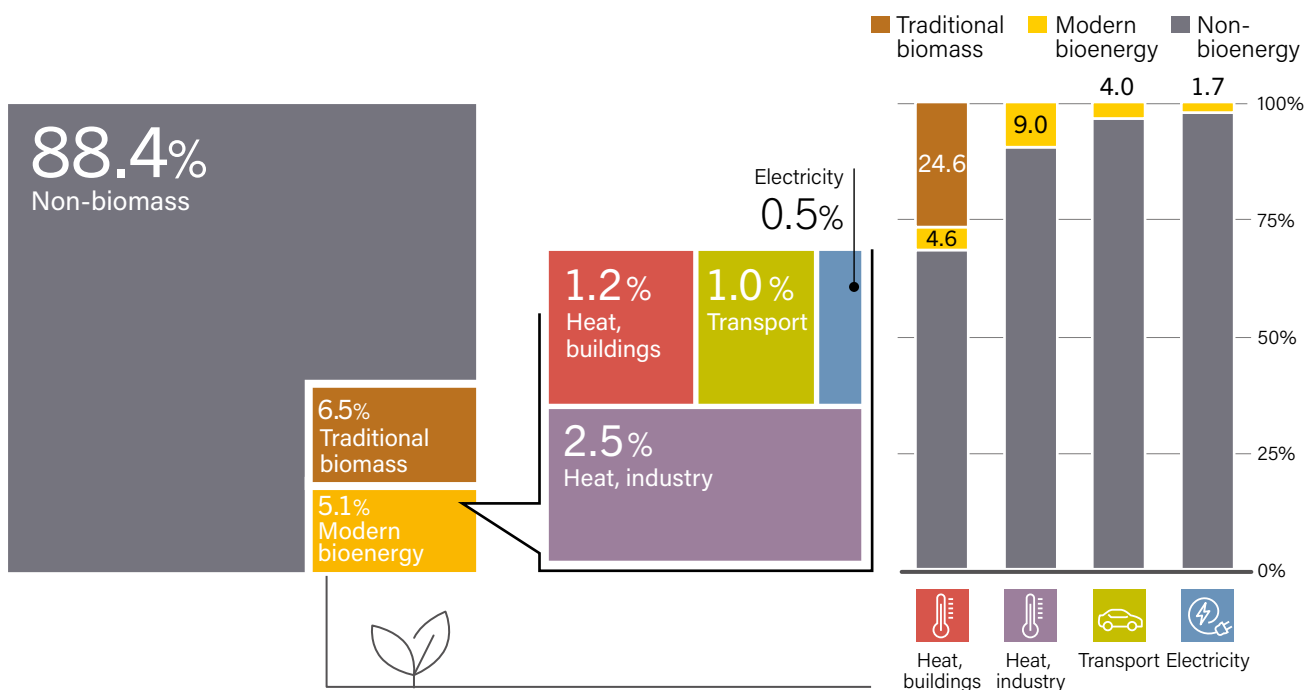
The use of biomass for heating has changed relatively little in recent years.<sup>8</sup> (→ See Figure 18.) The traditional use of biomass in developing and emerging economies is to supply energy for cooking and heating in traditional open fires or inefficient stoves.<sup>9</sup> (→ See Distributed Renewables chapter.) The amount of biomass used in these applications has decreased some 9% since 2009, from 27.0 EJ to an estimated 24.6 EJ in 2019.<sup>10</sup>

Because of the negative effects of the traditional use of biomass on local air quality and public health, as well as the unsustainable nature of much of the biomass supply, governments and international organisations are making significant global efforts to improve access to cleaner fuels for cooking and heating.<sup>11</sup> These fuels include fossil-based liquefied petroleum gas (LPG), electricity, and cleaner forms of biomass, such as ethanol fuels and wood briquettes and pellets.<sup>12</sup>

**Modern bioenergy** can provide heat efficiently and cleanly for industry and for residential, public and commercial buildings. The final user can consume biomass directly to produce bio-heat in a stove or boiler. Alternatively, bio-heat can be produced in a dedicated heat or district heating plant (including through the co-generation of electricity and heat using combined heat and power (CHP) systems) and distributed through the grid to final

i Modern bioenergy is any production and use of bioenergy that is not classified as “traditional use of biomass.” See footnote ii on previous page.

**FIGURE 17.** Estimated Shares of Bioenergy in Total Final Energy Consumption, Overall and by End-Use Sector, 2019



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. Buildings and industry categories include bioenergy supplied by district energy networks.

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

consumers. 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.<sup>13</sup>

In 2019 (latest data available), modern bioenergy applications provided an estimated 13 EJ of direct heat, an 11% increase from 2009.<sup>14</sup> In addition to the direct use of bio-heat in industry and buildings, bioenergy provided some 0.7 EJ to **district heating systems** in 2019; 51% of this was used in industry and agriculture and the remainder in buildings.<sup>15</sup> Bioenergy is the major source of renewable heat in district heating systems, accounting for 95% of all renewable heat supplied.<sup>16</sup> Its contribution grew 57% between 2010 and 2019.<sup>17</sup>

In 2019, 9.1 EJ of biomass was used to provide heat for industry and agriculture, meeting a combined 9.5% of these sectors' heat requirements.<sup>18</sup> Bio-heat demand in the two sectors has grown 16% since 2009.<sup>19</sup> Modern bioenergy provided 4.7 EJ to the buildings' sector in 2019, or around 5.0% of its heat demand.<sup>20</sup> The amount of bio-heat provided to buildings has increased 7% since 2009.<sup>21</sup>

Although final data for 2020 were not available at the time of publication, total energy use for heating was expected to decrease around 3.1% due to the economic effects of the

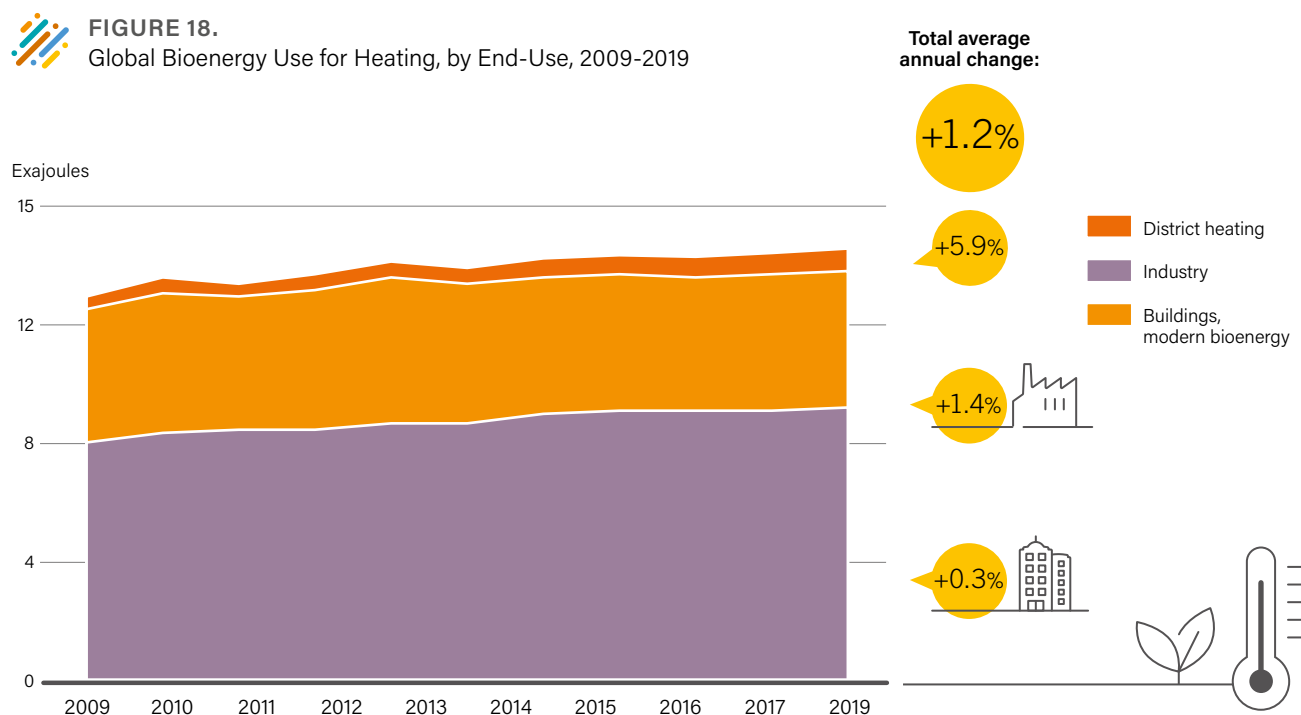
COVID-19 pandemic.<sup>22</sup> The decline was expected to be highest in industry, down a projected 4.1%, due to the curtailment of industrial production in most regions (except China).<sup>23</sup> The use of bioenergy for industrial heat was expected to fall by the same percentage, but to hold its market share.<sup>24</sup> Heat use in buildings was projected to decrease 1.8%, with most of the decline occurring in commercial heating because of increased working and schooling from home.<sup>25</sup> Total bioenergy consumption in 2020 was expected to remain at 2019 levels.<sup>26</sup>

**Industry** use of biomass for heat production is primarily in bio-based industries, such as paper and board, sugar and other food products, and wood-based industries. These industries often use their wastes and residues for energy, including the "black liquor" produced in paper manufacture.<sup>27</sup>

Bioenergy is not yet widely used in other industries. However, biomass and waste fuels met around 6% of the cement industry's global energy needs in 2019.<sup>28</sup> In Europe, these fuels provided around 25% of the energy used in cement making in 2019.<sup>29</sup> The use of biomass and waste fuels for cement production in China is also growing.<sup>30</sup>

Bioenergy use for industrial heating is concentrated in countries with large bio-based industries, such as Brazil, China, India and the United States. Brazil uses large quantities of sugarcane

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



Source: Based on IEA. See endnote 8 for this section.



residue (bagasse) from sugar and ethanol production to generate heat in CHP systems, producing an estimated 1.6 EJ in 2019.<sup>31</sup> India, also a major sugar producer, was the second largest user of bioenergy for industrial heat (1.4 EJ), followed by the United States (1.3 EJ), which has an important pulp and paper industry.<sup>32</sup>

Biomass can produce heat for space heating in buildings 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 developed economies as well as in developing and emerging ones.<sup>33</sup> This can be a significant source of local air pollution if inefficient appliances and/or poor-quality fuels are used.<sup>34</sup> Stringent national regulations are being introduced to control emissions from small combustion facilities. Systems that can meet these requirements are commercially available, but at a higher cost.<sup>35</sup> Larger-scale systems, such as those used for district heating, can meet air quality requirements more easily and economically.

Modern use of bio-heat in buildings has been concentrated in the European Union (EU), which accounted for 47% of this total use in 2019, increasing 2% during the year to 3.8 EJ.<sup>36</sup> Policy measures that aim to promote renewable heat alternatives to meet the requirements of the EU Renewable Energy Directive (RED) – such as capital grants for biomass heating systems – have generated the growth in biomass use. Limiting the use of oil and natural gas for heating also plays an important role in stimulating alternative heat sources including biomass.<sup>37</sup> France, Germany, Italy and Sweden accounted for around half of the EU’s bio-heat demand in 2019.<sup>38</sup>

Most of the biomass fuel used to heat buildings is in the form of logs and wood chips. However, the use of wood pellets for heating has been growing rapidly and was up 6% globally in 2019, to around 19.2 million tonnes (345 petajoules, PJ).<sup>39</sup> The bulk of the pellets (77%) were used in residences, with the rest consumed at commercial premises.<sup>40</sup> The EU remained the largest user (16.4 million tonnes or 294 PJ), with Italy still the world’s largest market for pellet heating (3.4 million tonnes), followed by Denmark and Germany (2.3 million tonnes each), France (1.8 million tonnes) and Sweden (1.2 million tonnes).<sup>41</sup> 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 2019.<sup>42</sup>

North America was the second leading user of bioenergy in buildings in 2019. More than 1.8 million US households (1.4% of the total) relied on wood or wood pellets as their primary heating fuel, and an additional 8% used wood as a secondary heat source.<sup>43</sup> Use was concentrated in rural areas, with one in four rural US households combusting wood for primary or secondary space heating.<sup>44</sup> Total wood use in the US residential sector amounted to 0.55 EJ.<sup>45</sup> In Canada, the residential heating sector used some 0.13 EJ of bio-heat from wood fuels in 2019.<sup>46</sup> North America was the second largest regional market for pellets for building heating, up 4% in 2019 to 2.6 million tonnes (47 PJ).<sup>47</sup> Smaller-scale markets were found in non-EU Europe (0.9 million tonnes) and Asia (0.3 million tonnes), principally in the Republic of Korea (0.2 million tonnes) and Japan (0.1 million tonnes).<sup>48</sup>

Europe leads in the use of bioenergy in district heating. District heating (from all sources) supplied around 12% of the EU’s heat demand in 2018.<sup>49</sup> The residential sector was the major user of district heat (45%), followed by the industrial (33%) and commercial and services (21%) sectors.<sup>50</sup> District heating meets at least 30% of heat demand in seven countries, including a 45% share in Denmark.<sup>51</sup>

This provides an important market opportunity for biomass, which supplied around 25% of all district heating in Europe in 2018 (620 PJ).<sup>52</sup>

Sweden was the largest user of bioenergy for district heating (130 PJ) in 2018, followed by Germany, Denmark and Finland (75 PJ each) and France (69 PJ), where the use of bioenergy grew 35% between 2015 and 2019, promoted by the Fonds Chaleur support system.<sup>53</sup> Lithuania has the highest share of district heat from biomass (65%, or 23 PJ); the country’s use of bioenergy for this purpose has grown three-fold since 2010, driven mainly by the need to reduce dependency on imported oil to lower costs and improve energy security.<sup>54</sup> Bioenergy use has led to a 60% reduction in Lithuania’s carbon dioxide (CO<sub>2</sub>) emissions from heating.<sup>55</sup>



## TRANSPORT BIOFUEL MARKETS

Global production<sup>i</sup> of liquid biofuels decreased 5% in 2020, dropping from 4.0 EJ (161 billion litres) in 2019 to 3.8 EJ (152 billion litres), as overall demand for transport fuels fell as a consequence of the COVID-19 pandemic.<sup>56</sup> While ethanol volumes declined sharply in 2020, biodiesel production and use held steady.<sup>57</sup> Lower transport demand for diesel fuel was offset by higher blending requirements and other factors, and the production and use of hydrotreated vegetable oil (HVO)<sup>ii</sup> increased significantly.

The United States remained the world's leading biofuel producer, with a 36% share in energy terms, despite a reduction in the country's ethanol production.<sup>58</sup> The next largest producers were Brazil (26%) followed by Indonesia (7.0%), Germany (3.4%) and China (3.0%).<sup>59</sup> In total, in 2020, ethanol accounted for around 61% of biofuel production (in energy terms), fatty acid methyl ester (FAME) biodiesel for 33%, and HVO for 6%.<sup>60</sup> (→ See Figure 19.) Other biofuels included biomethane<sup>iii</sup> and a range of advanced biofuels, but their production remained low, estimated at less than 1% of total biofuels production.<sup>61</sup>

Global production of ethanol decreased 8%, from 115 billion litres in 2019 to 105 billion litres in 2020.<sup>62</sup> Ethanol is produced primarily from corn<sup>iv</sup>, sugar cane and other crops. The United States and

Brazil, the two leading producers, accounted for 51% and 32%, respectively, of global production, followed by China, India, Thailand and Canada.<sup>63</sup>

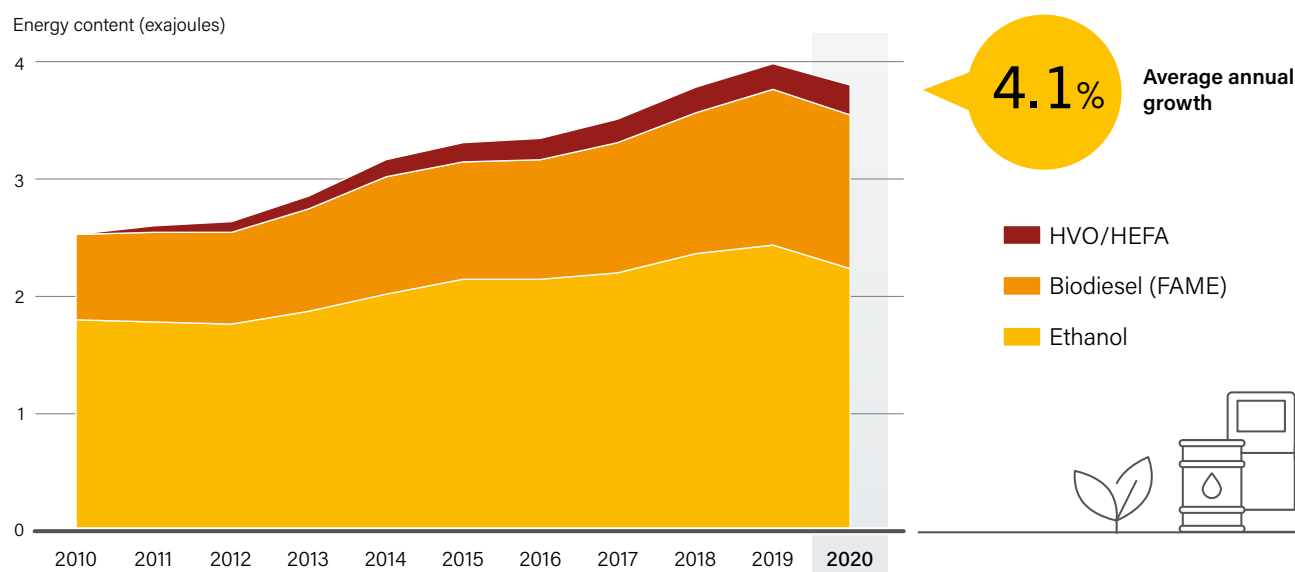
US ethanol production fell 11% in 2020 to 53.2 billion litres, the lowest level since 2014, from 59.7 billion litres in 2019.<sup>64</sup> The country's ethanol consumption fell 12%, mirroring the 13% decline in petrol use in transport as blending opportunities were constrained and ethanol prices fell.<sup>65</sup> Many ethanol producers reduced output due to lower demand, negative operating margins and limited storage capacities.<sup>66</sup>

Ethanol production in Brazil decreased 6% to 34.0 billion litres, down from 36.0 litres in 2019.<sup>67</sup> Overall, petrol consumption in the country fell some 11% due to declining demand.<sup>68</sup> The drop in petrol use directly influences ethanol sales, as all petrol in Brazil contains 27% ethanol by volume.<sup>69</sup> Low oil prices also affect the competitiveness of 100% ethanol, which is widely available in the country.<sup>70</sup> Most Brazilian ethanol comes from sugar cane, with some 350 sugar ethanol mills operating nationwide.<sup>71</sup>

Although ethanol production dropped sharply in 2020, biodiesel production remained steady.

- i This section concentrates on biofuel production, rather than use, because available production data 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 do exist, particularly for biodiesel.
- ii Hydrotreated vegetable oil is also referred to as hydroprocessed esters and fatty acids (HEFA). It is also called renewable diesel, especially in North America.
- iii Often referred to as renewable natural gas (RNG), especially in North America. See Glossary.
- iv The meaning of the word "corn" varies by 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.

**FIGURE 19.** Global Production of Ethanol, Biodiesel and HVO/HEFA Fuel, by Energy Content, 2010-2020



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

Source: See endnote 60 for this section.

However, a growing share of ethanol is produced from corn, and as of mid-2020 some 16 corn ethanol production plants were in operation and 7 more under construction.<sup>72</sup> Most of the plants can process both sugar cane and corn. Corn-based ethanol production in Brazil more than doubled in 2020, to 2.5 billion litres.<sup>73</sup>

China's ethanol production increased 3% to 4.0 billion litres in 2020 to meet growing domestic demand.<sup>74</sup> Petrol demand in the country fell some 7%, but growth in ethanol demand continued as 10% ethanol blends (E10) were extended to more provinces.<sup>75</sup> Production capacity doubled between 2017 and 2020, and several large new plants were in development.<sup>76</sup>

Ethanol production in India fell some 8% in 2020 to 1.8 billion litres, as petrol demand dropped 13% and as lower oil prices reduced the affordability of ethanol relative to unblended gasoline.<sup>77</sup> Canadian ethanol production remained stable in 2020, at 1.8 billion litres, while in Thailand, production fell 9% to 1.5 billion litres.<sup>78</sup>

Global production of biodiesel increased slightly (less than 1%) to 46.8 billion litres in 2020, up from 46.5 billion litres in 2019.<sup>79</sup> Its production is more widely distributed than that of ethanol; 11 countries account for 80% of global biodiesel production, compared to just 2 countries for ethanol.<sup>80</sup> This is due to the wider range of biodiesel feedstocks that can be processed, including vegetable oils from palm, soy, and canola, and a range of wastes and residues, including used cooking oil. In 2020, Indonesia was again the lead biodiesel producer (17% of the global total), followed by the United States (14.4%) and Brazil (13.7%).<sup>81</sup> The next largest producers were Germany (7.4%), France (5.0%) and the Netherlands (4.6%).<sup>82</sup>

Despite an estimated 12% reduction in demand for diesel for transport, Indonesia's biodiesel production grew 11% in 2020, to 8.0 billion litres.<sup>83</sup> In the face of growing dependency on imported oil, the blending level in the country is being increased gradually to prioritise domestically produced biodiesel, primarily from palm oil. The diesel blending level was increased from 20% to 30% in January 2020 and was expected to rise to 40%.<sup>84</sup>



While total US diesel demand fell 5% in 2020 due to the impacts of the COVID-19 pandemic, biodiesel production in the country rose more than 3% to 6.8 billion litres, boosted by the federal Renewable Fuel Standard (RFS2) and by California's Low Carbon Fuel Standard (LCFS).<sup>85</sup> In addition, the federal Biodiesel Blender's Tax Credit was reintroduced.<sup>86</sup> Increased duties on biodiesel imports from Indonesia and Argentina also favoured US domestic biodiesel production.<sup>87</sup>

In Brazil, biodiesel production rose 9% to a record 6.4 billion litres to meet increased domestic demand.<sup>88</sup> The country's biodiesel blending requirement increased from 11% to 12% and was scheduled to rise to 15% by 2023.<sup>89</sup>

In Germany, reduced diesel fuel use limited biodiesel demand, and production fell an estimated 9% to 3.5 billion litres in 2020, down from 3.8 billion litres in 2019.<sup>90</sup> Production in France also declined slightly to 2.4 billion litres, while production in the Netherlands stayed stable at 2.1 billion litres.<sup>91</sup>

Argentina dropped from fifth to ninth place among producers as biodiesel production decreased some 35% to 1.6 billion litres, with US duties on biodiesel imports discouraging trade.<sup>92</sup>

HVO production, a process of hydrogenating bio-based oils fats and greases, continued to grow sharply in 2020, rising 12% to an estimated 7.5 billion litres, up from 6.5 billion litres in 2019.<sup>93</sup> While early production capacity was concentrated in Finland, the Netherlands and Singapore, HVO capacity in the United States has increased rapidly in recent years, in line with the surging US market for these fuels.<sup>94</sup> HVO use in the country is heavily incentivised by the RFS2, by California's LCFS and by the availability of an investment tax credit.<sup>95</sup> US use of HVO under the RFS2 grew some 48% in 2020, to 3.5 billion litres (114 PJ).<sup>96</sup>

**Biomethane** is used as a transport fuel mainly in Europe and the United States (the largest producer and user of biomethane for transport).<sup>97</sup> US production and use of biomethane is also stimulated by the RFS2 (which includes biomethane in the advanced cellulosic biofuels category) and by California's LCFS, thereby qualifying for a premium.<sup>98</sup> US biomethane use under the RFS2 increased 24% in 2019 to around 41 PJ.<sup>99</sup>

In Europe, the use of biomethane for transport increased 74% in 2019 to 14 PJ (latest data available).<sup>100</sup> Sweden remained the region's largest biomethane consumer, using nearly one-third of the total, followed by the United Kingdom (where biomethane use increased five-fold in 2019), Germany and Italy (where use rose from nearly zero to 1.7 PJ in 2019).<sup>101</sup>

Although efforts to develop other "advanced biofuels" continued,

and some new production capacity was installed (→ see *Industry section in this chapter*), these fuels have been produced and used only in small quantities to date. For example, the contribution of cellulosic ethanol under the US RFS2 scheme declined by a factor of five in 2020 to below 0.2 PJ.<sup>102</sup>

The United States and Brazil, the two leading producers of biofuels, account for around 80% of global production.

## BIO-POWER MARKETS

Global bio-power capacity increased an estimated 5.8% in 2020 to around 145 gigawatts (GW), up from 137 GW in 2019.<sup>103</sup> China had the largest capacity in operation by the end of 2020, followed by the United States, Brazil, India, Germany, the United Kingdom, Sweden and Japan.<sup>104</sup>

Total bioelectricity generation rose some 6.4% to around 602 terawatt-hours (TWh) in 2020, from 566 TWh in 2019.<sup>105</sup> (→ See Figure 20.) China remained the leading producer of bio-power, followed by the United States and then Germany, Brazil, India, the United Kingdom and Japan.<sup>106</sup>

In line with the provisions of the country's 13th Five-Year Plan (2016-2020), China's bio-power capacity rose 26% to 22.5 GW in 2020, up from 17.8 GW in 2019.<sup>107</sup> Generation increased 23% to more than 111 TWh.<sup>108</sup> In 2020, 77 additional projects, with a combined capacity of 1.7 GW, were approved for financial support in 20 provinces.<sup>109</sup> They included projects using municipal waste (1.2 GW), agroforestry raw materials (0.5 GW) and biogas power generation (21 megawatts, MW).<sup>110</sup>

The United States had the second highest national bio-power capacity and generation in 2020.<sup>111</sup> The country's 16 GW capacity did not change significantly.<sup>112</sup> Generation fell 2.5% to 62 TWh, continuing the trend of recent years.<sup>113</sup>

Brazil was the third largest producer of bioelectricity globally, with most of the country's generation based on sugarcane bagasse.<sup>114</sup> Brazil's generation fell an estimated 10% to 50 TWh in 2020, as sugar production and the related electricity generation was reduced.<sup>115</sup>

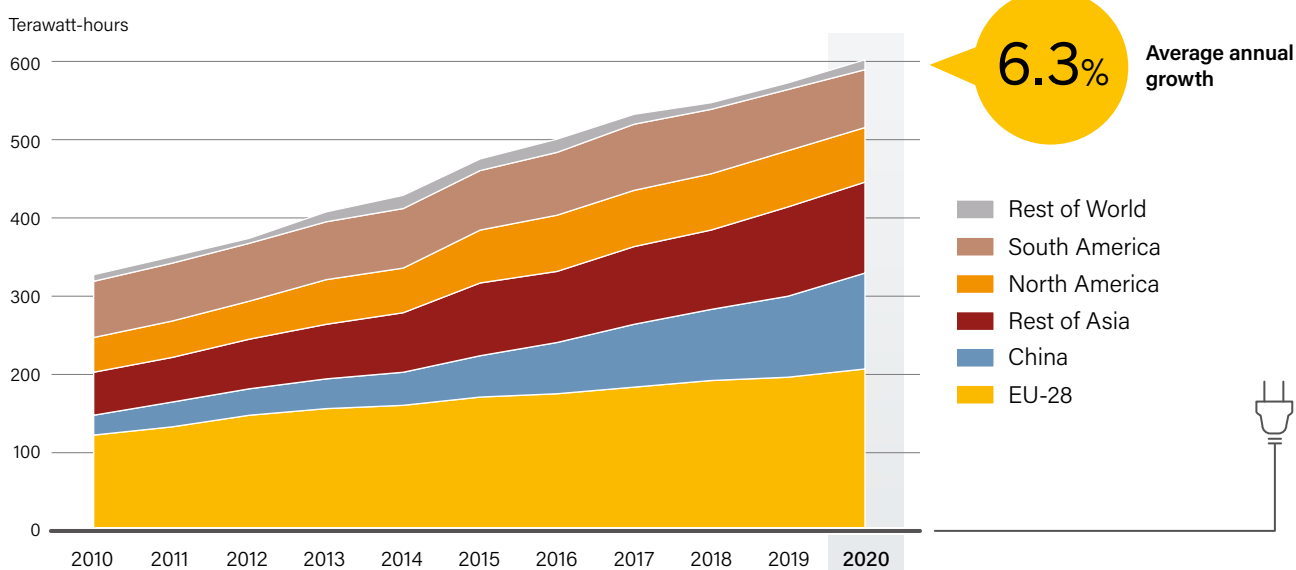
In the EU, bio-power capacity grew around 4% in 2020 to 48 GW, and generation increased 4% to 205 TWh, providing 6% of all generation.<sup>116</sup> This increase occurred as countries pushed to meet the region's mandatory national targets for 2020 under the RED.<sup>117</sup> Germany remained the region's largest bioelectricity producer, mainly from biogas: capacity increased 400 MW in 2020 to 10.4 MW, and generation rose 0.8% to 51 TWh.<sup>118</sup> Generation surged in the Netherlands (up 90%) to 11 TWh as the volume of wood pellets co-fired in large power stations increased significantly, supported by the SDE feed-in premium scheme and to help the country meet its obligations under the EU RED.<sup>119</sup>

In the United Kingdom, bio-power capacity grew 135 MW to 8.0 GW.<sup>120</sup> Generation rose 5.5% to 39.4 TWh, with increases in large-scale pellet-fired generation, biogas and MSW plants.<sup>121</sup>

In Asia, Japan's growth in bio-power capacity and generation grew slowly during 2020, with capacity rising 9% to 5.0 GW, and generation increasing to 25 TWh.<sup>122</sup> In the Republic of Korea, bio-power capacity rose 3% to 2.7 GW, with generation up 30% to 12.3 TWh, supported by the Renewable Energy Certificate Scheme and feed-in tariffs.<sup>123</sup> In India, bio-power capacity increased marginally to 10.5 GW, and generation remained stable at 45 TWh.<sup>124</sup>

The use of internationally traded pellets produced from wood and agricultural by-products for power generation continued to grow. In 2019, 18 million tonnes of pellets were used for power generation, up 7% from the previous year.<sup>125</sup> Nearly three-quarters of the pellets were used in the EU, particularly in the United Kingdom (8.5 million tonnes), Denmark (2.0 million tonnes) and the Netherlands, where use more than doubled to 0.8 million tonnes.<sup>126</sup> The rest were used in Japan (1.5 million tonnes) and the Republic of Korea (0.9 million tonnes).<sup>127</sup>

**FIGURE 20.**  
Global Bioelectricity Generation, by Region, 2010-2020



Source: See endnote 105 for this section.



## BIOENERGY INDUSTRY

### Solid Biomass Industry

The companies that make up the solid biomass industry range from small, locally based entities that manufacture and supply smaller-scale heating appliances and their fuels, to major regional and global players involved in the supply and operations of large-scale district heating and power generation technology.

Most solid biomass projects rely on local feedstocks, such as wood residues and sugarcane bagasse, which can be used where they are produced. The growth in biomass pellet production to serve international markets for heat and electricity production is an important development in the sector, enabling countries to scale up the use of bioenergy even when they have limited national biomass resources.

In 2019, global production of biomass pellets reached an estimated 59 million tonnes.<sup>128</sup> Production data for China are uncertain but reached an estimated 20 million tonnes in 2018.<sup>129</sup> Production in the rest of the world grew 9% to 39.4 million tonnes in 2019.<sup>130</sup> The EU remained the largest regional producer (17 million tonnes), with production rising 5% that year.<sup>131</sup> Production from other European countries rose 17% to over 4 million tonnes, with production in the Russian Federation up 21%.<sup>132</sup> North American production increased 12% to 12.4 million tonnes.<sup>133</sup>

Excluding China, 19 million tonnes (5,326 PJ) of biomass pellets were used worldwide to provide heat in the residential and commercial sectors.<sup>134</sup> Pellets also provided an estimated 7.5% of the biomass used to heat buildings.<sup>135</sup> Worldwide, 18 million tonnes (31 PJ) were used for power generation, CHP production and other industrial purposes in 2019.<sup>136</sup>

The United States was the world's largest exporter of wood pellets in 2020.<sup>137</sup> While US pellet production decreased 2% to 9.3 million tonnes, exports rose 1% to 6.8 million tonnes.<sup>138</sup>

The wood pellet market for power generation continued to grow in the EU, where power producers can co-fire pellets with coal or convert coal plants, or build new plants that operate entirely on

pellets.<sup>139</sup> The market also expanded in Japan and the Republic of Korea, stimulated by favourable support schemes.<sup>140</sup> By the end of 2020, Japan's Ministry of Economy, Trade and Industry had approved 70 projects with a capacity of nearly 8 GW under the feed-in tariff.<sup>141</sup>

Debate continues regarding the carbon savings and other environmental impacts related to pellet production from forestry materials and their use in power generation.<sup>142</sup> Starting in 2020, the sustainability provisions in the EU's RED included solid biomass, setting tighter sustainability criteria; as of 2021, minimum greenhouse gas reduction thresholds also were set for new projects seeking national support.<sup>143</sup> Sustainability criteria are being put in place in Japan as well, which is expected to reduce the use of palm-based products but increase the use of certified wood pellets.<sup>144</sup>

### Liquid Biofuels Industry

The liquid biofuels industry produces ethanol, FAME biodiesel and increasingly HVO. Together, these comprise nearly all current global biofuels production and use. In addition, the industry is developing and commercialising new types of biofuels designed to serve new markets, notably for the aviation and marine sectors. These offer improved results in terms of greenhouse gas footprints and other sustainability criteria. There is a growing interest in the production of bio-materials and chemicals as part of the shift to a broader bioeconomy.<sup>145</sup> (→ See Box 6.)

In 2020, the industry was negatively affected by the lower demand for transport fuels during the COVID-19 pandemic, which constrained production and reduced profitability. At the height of the 2020 crisis, more than half of US ethanol industry production capacity was idled.<sup>146</sup> For example, ADM announced that it would idle four of its plants for at least four months in mid-2020.<sup>147</sup> Global ethanol prices fell 28% between January 2020 and April 2020, before recovering to within 5% of the January value by year's end.<sup>148</sup> In Brazil, ethanol demand was constrained and prices fell as much as 19% in 2020, with more sugar cane used for sugar than for ethanol production.<sup>149</sup>

By contrast, markets for FAME biodiesel were less affected by the pandemic. Although fossil diesel demand also fell, biodiesel





## BOX 6. Bioenergy and the Bioeconomy

While bioenergy can directly replace fossil fuel use for heating, transport and electricity generation, biomass-based materials also could play an expanded role in the move to a sustainable bioeconomy. This would lower greenhouse gas emissions by reducing the use of fossil-based feedstocks for materials such as plastics and by replacing energy-intensive materials such as concrete and steel with wood- and agricultural-based materials.

Policy emphasis on recycling bio-based materials (within a circular economy) has increased, as has industry interest in developing a wider range of high-value-added products based on sustainably produced biomass feedstocks. Policy measures are being developed to promote the bioeconomy concept. The EU has drafted an integrated bioeconomy strategy, which it views as contributing to the European Green Deal, and the US Renewable Chemicals Act, introduced in 2020, provides tax credits for bio-based chemical production.

The growth of bioplastics is also a relevant trend. In 2020, these represented around 1% of the more than 368 million tonnes of plastic produced annually worldwide. Bioplastics that are also biodegradable, such as polylactic acid (PLA), polyhydroxyalkanoates (PHA) and starch-based plastics, account for 60% of global bioplastics production.

Industrial investment and engagement in bioplastics production grew in 2020. Braskem (Brazil), the world's largest bioplastics producer, produced 200,000 tonnes of polyethylene from ethanol that year. UPM (Finland) also announced a EUR 550 million (USD 644 million) investment in a German plant that will convert wood to bio-monoethylene glycol (BioMEG) and monopropylene glycol (BioMPG), intermediates used to produce plastics utilised as fibre and packaging material.

Source: See endnote 145 for this section.

levels were maintained due to higher incentives or increased blending mandates in key producing countries, such as the United States, Brazil and Indonesia.<sup>150</sup> Biodiesel production in Argentina was affected by import duties in the United States.<sup>151</sup>

HVO production capacity rose sharply in 2020, driven by attractive market incentives, particularly those provided by the US RFS2 and California's LCFS and under the EU's RED.<sup>152</sup> Many plans for new capacity were announced.<sup>153</sup> Total HVO production capacity reached an estimated 9.2 billion litres (0.3 EJ) in 2020.<sup>154</sup> When taking into account both the expansion of existing facilities and new production sites, the additional capacity under construction or being planned was estimated to reach more than 41 billion litres (equivalent to 1.1 EJ per year) at the end of 2020.<sup>155</sup> With these new projects, total existing and planned HVO capacity is expected to exceed that of FAME biodiesel and to equate to around 60% of 2020 ethanol production, underscoring a significant evolution of biofuels in transport.<sup>156</sup>

Most of the existing and planned capacity is based on treating vegetable oils, animal fats and other by-products with hydrogen to produce HVO/HEFA, which then can be refined to produce fuels with the same properties as fossil-based diesel, jet fuel and other hydrocarbon products, including biopropane. When these feedstocks are wastes or by-products (such as used cooking oil, animal fats or tall oil), the greenhouse gas savings associated with their use are much higher than for virgin vegetable oils, such as palm or canola oil.<sup>157</sup> The fuels then qualify for higher credits under biofuels support schemes. For example, under the California LCFS, HVO from used cooking oil qualifies for a credit up to twice that for HVO produced from soy oil.<sup>158</sup> Under the EU RED, waste- and residue-based fuels are counted twice towards national targets and can earn double credits under national support schemes in member countries.<sup>159</sup>

In 2020, several companies that produce HVO fuels announced that new capacity was available or planned. For example, Phillips 66 (US) announced plans to extend production capacity at its UK Humberside plant from 57 million litres to 460 million litres per year and to convert the Rodeo facility at its San Francisco oil refinery to produce HVO and jet fuel.<sup>160</sup> The Rodeo facility would be one of the world's largest such plants, producing 4 billion litres of the fuels from used cooking oils, fats, greases and soy oils starting in 2024.<sup>161</sup>

Other oil majors are undertaking similar refinery conversions. Total (France) announced plans in 2020 to convert its Grandpuits refinery in the Seine-et-Marne department of France to produce biojet fuel, with an investment of EUR 500,000 (USD 0.6 million).<sup>162</sup> This complements Total's La Mède plant, which was converted in 2019 to produce 570 million litres of HVO and biojet from palm oil and waste fats and oils.<sup>163</sup> ENI (Italy) converted its refineries in Venice and Sicily to make HVO and is more than doubling its capacity in Venice to more than 1.6 billion litres.<sup>164</sup> Marathon Oil (US) planned to convert its North Dakota plant to HVO by the end of 2020, with an annual production capacity of 700 billion litres, along with its Martinez refinery (California), which is expected to reach an HVO capacity of some 3 billion litres by 2022.<sup>165</sup> While most HVO projects are in the United States and Europe, Pertamina (Indonesia) is developing two projects in Indonesia, which will produce a combined 1.5 billion litres of HVO from palm oil under the country's strategy to increase the share of biofuels in diesel to 40%.<sup>166</sup>

Production of  
**HVO biodiesel**  
rose sharply in 2020,  
driven by attractive market  
incentives in the United  
States and Europe.

In addition to these projects, which hydrogenate oils and fats, several other technological approaches that use a wider range of feedstocks are being demonstrated and commercialised. Projects designed to produce HVO and jet fuels by gasifying MSW or forestry residue feedstocks and synthesising the resulting gas via the Fischer-Tropsch process are under development. Their aggregate capacity is over 1 billion litres of fuel and includes the use of feedstocks such as forestry and timber residues and processed MSW, which is less expensive and thus produces cheaper fuel.<sup>167</sup>

The Red Rock Biofuels (US) project in Lakeview, Oregon (US) will convert 166,000 dry tonnes of waste woody biomass into 60 million litres of drop-in jet, diesel and petrol fuels to be supplied under eight-year off-take agreements with FedEx and Southwest Airlines.<sup>168</sup> The project is based on gasification and Fischer-Tropsch technology provided by Velocys (UK). Velocys has launched a project at Immingham (UK) in collaboration with British Airways PLC and Shell (Netherlands) to produce jet fuels from MSW and is developing another in the US state of Mississippi that will use paper and timber residues from local industries.<sup>169</sup> In 2020, Fulcrum Energy (US), which is developing two MSW projects in the United States, began work to produce jet fuel from MSW in Japan, in collaboration with Japan Airlines Marubeni, JXTX Nippon OIL and JGC Japan.<sup>170</sup>

Three projects involving pyrolysis of wastes and other feedstocks were under way in Canada and in the Netherlands at year-end 2020.<sup>171</sup> The Lieksa plant of Green Fuel Nordic Oy (Finland), with a capacity of 24 million litres per year, also began supplying fuel oil (for heat) produced by the pyrolysis of wood residues.<sup>172</sup>

Other approaches include the conversion of ethanol to fuels such as biojet. In 2020, the FLITE consortium, led by SkyNRG (Netherlands) and Lanzatech (US), initiated a project in the Netherlands to build an ethanol-to-biojet facility to convert waste-based ethanol to sustainable aviation fuel, producing more than 30,000 tonnes per year.<sup>173</sup> The project received EUR 20 million (USD 23 million) in grants from the EU's Horizon 2020 programme.<sup>174</sup>

Only a small number of facilities producing ethanol from cellulosic materials were operating successfully worldwide by the end of 2020.<sup>175</sup> During the year, construction was under way at Clariant's (Switzerland) planned plant in Romania, and the company also has licensed its technology for projects in Bulgaria and China.<sup>176</sup>

Despite the sharp drop in air travel and related fuel use in 2020, the market for sustainable aviation fuels (SAF) – biofuels tailored for use in aircraft engines – continued to expand, with seven fuel pathways approved for use by year's end.<sup>177</sup> As of 2020, 45 airlines had used SAF, and 7 airlines were actively investing in SAF production capacity.<sup>178</sup>

Some 100 million litres of SAF was expected to be available for use in 2021.<sup>179</sup> The availability of these fuels has increased at airports, with continuous supply established in 2020 at San Francisco International Airport and at London Luton Airport.<sup>180</sup>

**Biomethane production** is rising, and accounts for around 1% of total global fossil gas demand.

## GASEOUS BIOMASS INDUSTRY

The gaseous biomass industry is involved mainly in producing and using gas produced by the anaerobic digestion of biomass feedstocks, which produces biogas, a mixture of methane, CO<sub>2</sub> and other gases.<sup>181</sup> The same process occurs in waste landfills, and the resulting landfill gas can be collected and used – providing energy while also reducing emissions from the landfill site. The gases can be used directly for heating or power generation. Alternatively, the methane component can be separated and compressed and used to replace fossil gas by injecting it into gas pipelines or for transport purposes. Biomethane production totalled an estimated 1.4 EJ in 2018, or just over 1% of total global fossil gas demand.<sup>182</sup>

Biogas can be used at a small scale in developing economies as a sustainable fuel source for cooking, heating and electricity production and to improve energy access. (→ See *Distributed Renewables chapter*.) In developed economies, most biogas is used for power generation or in CHP systems, often stimulated by favourable feed-in tariffs and other support mechanisms.<sup>183</sup> The energy content of biogas upgraded to biomethane and used for transport or injection into gas grids, primarily in the United States and Europe, rose to around 170 PJ in 2020.<sup>184</sup> Stimulating this development are incentives that favour biomethane production over power production, notably under the US RFS2 and the California LCFS, which offer larger incentives than those for power or heat generation.<sup>185</sup>

US biomethane production capacity rose sharply in 2020, with many new projects based on landfill gas, cattle waste, and other wastes and residues. In total, 157 production facilities were in operation during the year (up 78% from 2019), with another 76 projects under construction and 79 projects in the planning phase.<sup>186</sup> The total operating production capacity in 2020 was more than 60 PJ.<sup>187</sup>



Recent projects illustrate that both specialist companies and energy majors are involved in the rapidly growing US biomethane sector.<sup>188</sup> In August 2020, Republic Services and Aria Energy (both US) announced a start-up project to process and purify landfill gas from the South Shelby (Tennessee) landfill site; BP will then inject the gas into the interstate natural gas pipeline grid and market it to renewable energy customers.<sup>189</sup> In September 2020, Fortistar and Rumpke Waste and Recycling (both US) started building a landfill gas project in Shiloh, Ohio that will extract and capture waste methane and transform it into biomethane for distribution to natural gas vehicle fuelling stations.<sup>190</sup>

In 2020, Aemetis (US) completed construction of two dairy digesters and a pipeline to supply biomethane to provide fuel for biomethane trucks and buses.<sup>191</sup> Verbio (Germany) announced the installation of an anaerobic digester at the former DuPont cellulosic ethanol plant in Nevada, which will now use 100,000 tonnes of corn stover annually to produce biomethane with the energy equivalent of 80 million litres of petrol.<sup>192</sup>

Biogas and biomethane installations also have grown rapidly in Europe, which in 2020 was home to at least 18,855 biogas plants producing 176 TWh, as well as 726 biomethane plants with a total capacity of 64 PJ (an increase of 66 biomethane plants and 4 PJ compared to 2019).<sup>193</sup> Recent projects include Gasum's (Finland) construction of two new biogas plants in Sweden: a 120 gigawatt-hour (GWh) plant that will produce liquefied biogas from manure and food waste slurry from a local pretreatment plant, and a 70 GWh plant established alongside a local farmer co-operative that will use manure and other agricultural waste products.<sup>194</sup> Weltec Biopower (Germany), working with Agripower France, a local agroindustrial firm, commissioned a EUR 11 million (USD 13 million) biomethane plant in Normandy, France that processes around 70,000 tonnes of substrates to produce biogas, which is then refined into biomethane.<sup>195</sup> The plant's raw material mix, comprising inexpensive waste and other byproducts from the agriculture and food industry, is gathered from within a seven-kilometre radius.<sup>196</sup>

The market continued to expand in China, where the national energy plan prioritises the growth of biogas and biomethane. Construction was under way on two EnviTec Biogas projects: one in Henan province, where the state-run PowerChina Group is the prime contractor, and the other operated by Shanxi Energy & Traffic Investment in Qinxian province.<sup>197</sup> Once completed, the Qinxian plant's four digesters are expected to convert agricultural waste such as corn stover into around 0.5 PJ of biogas per year, which then will be upgraded into biomethane.<sup>198</sup>

Growing demand from delivery companies for clean fuels is boosting the biomethane market. The UK supermarket company ASDA ordered 202 biomethane-fuelled Volvo FH tractors in 2020 and aims to convert all of its trucks from diesel to biomethane by 2024, after in-house trials showed that biomethane reduced CO<sub>2</sub> emissions more than 80%.<sup>199</sup> Air Liquide (France) also will provide biomethane at six of its sites.<sup>200</sup>

### BIOENERGY WITH CARBON CAPTURE AND STORAGE OR USE

The capture and storage of carbon dioxide emitted when bioenergy is used is a key feature of many low-carbon scenarios.<sup>201</sup> Removing from the atmosphere the CO<sub>2</sub> that is produced during bioenergy production, which is considered part of the carbon cycle, offers a dual benefit resulting in net negative emissions.<sup>202</sup> Although policy makers have shown increasing interest in such options, strong policy drivers that might make such efforts economically attractive are lacking. Thus, very few projects demonstrating these technologies have operated at scale to date.<sup>203</sup>

Additional pilot-scale carbon capture projects were conducted during 2020. Drax Power (UK) successfully demonstrated carbon capture using a novel technology at its large-scale bio-power plant in the United Kingdom and has begun planning for large-scale application.<sup>204</sup> In the United States, Power Tap is producing hydrogen for use as a transport fuel by reforming biomethane and capturing the CO<sub>2</sub> that is released.<sup>205</sup>



## KEY FACTS

- An estimated 0.1 GW of new geothermal power generating capacity came online in 2020 – significantly less than in recent years – with just one country (Turkey) representing the bulk of new installations.
- Direct use of geothermal energy for thermal applications continues to grow around 8% annually, but the market remains geographically concentrated, with only four countries (China, Turkey, Iceland and Japan) representing three-quarters of all direct geothermal use.
- The main focus continued to be on technological innovation, such as new resource recovery techniques and seismic risk mitigation, with the aim of improving the economics, lowering the development risk and strengthening prospects for expanded geothermal resource development.

## GEOHERMAL POWER AND HEAT



### GEOHERMAL MARKETS

Geothermal resources are harnessed for energy applications through two primary pathways (similar to solar- and bioenergy), 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<sup>i</sup>. Geothermal electricity generation was around 97 TWh in 2020, while direct useful thermal output was about 128 TWh (462 PJ)<sup>ii</sup>. In some instances, geothermal plants produce both electricity and heat for thermal applications (co-generation), but this option depends on location-specific thermal demand coinciding with the geothermal resource.

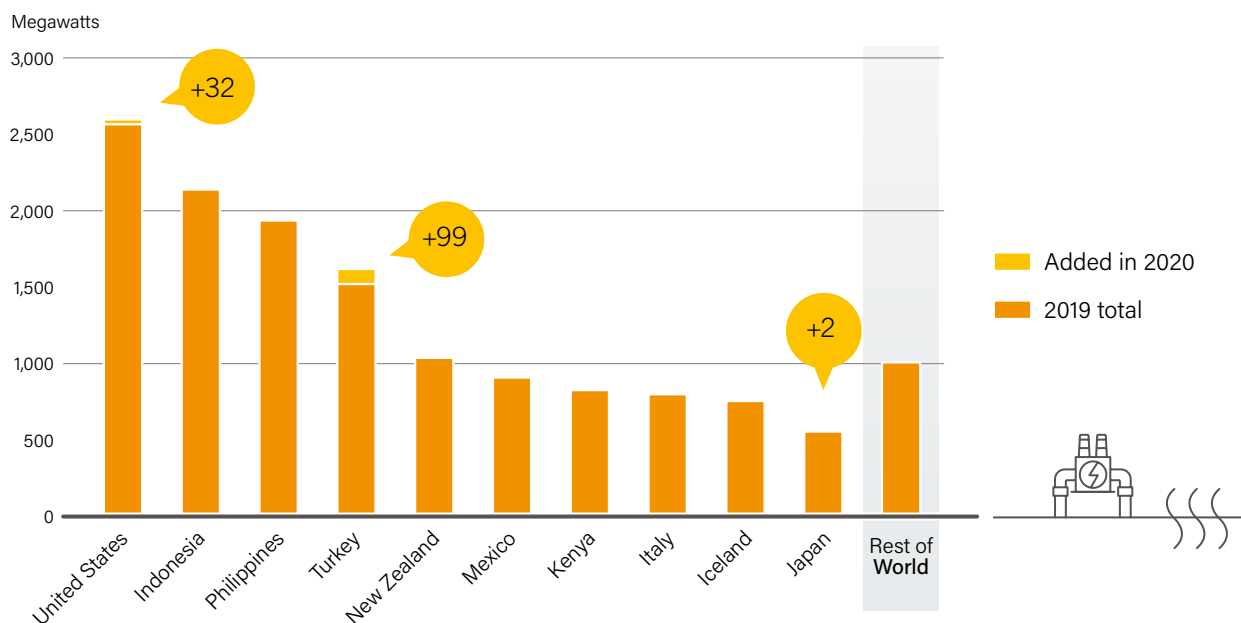
An estimated 0.1 GW<sup>iii</sup> of new **geothermal power** generating capacity came online in 2020, bringing the global total to around 14.1 GW.<sup>2</sup> The distinct feature of 2020 was the disproportionately small growth in capacity relative to recent years (attributable in part to pandemic-related disruption), with almost all new facilities located in Turkey. Other countries that added minor amounts of geothermal power capacity in 2020 were the United States and Japan.<sup>3</sup> (→ See Figure 21.)

- i The two pathways cross downstream when geothermal resources are used for electricity generation, because 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 21.

Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2020



Note: Figure shows 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.

Source: See endnote 3 for this section.



The 10 countries with the largest stock of geothermal power capacity at the end of 2020 were the United States, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Kenya, Italy, Iceland and Japan.<sup>4</sup> 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-up<sup>i</sup> wells to replenish steam flow over time. For example, the effective net<sup>ii</sup> generation capacity in the United States was 2.6 GW at the end of 2020, whereas the gross nameplate generator capacity was 3.7 GW.<sup>5</sup>

Turkey's geothermal capacity expansion in 2020 (net of any deratings) was reported to be 99 MW, which was the country's smallest annual increment since 2014 and less than half the mean annual additions for the preceding five years.<sup>6</sup> However, new capacity installations reported during the year amounted to around 128 MW, all in the last quarter.<sup>7</sup> Five binary-cycle<sup>iii</sup> power plant commissions were announced for the month of October, ranging from 3.5 MW to 26 MW.<sup>8</sup>

Each of these plants, including the 20 MW Nezihe Beren facility, qualified for Turkey's highest national feed-in tariff for geothermal installations due to local content manufacturing.<sup>9</sup> Following an identical addition in 2019, the Pamukören complex added another 32 MW unit in December.<sup>10</sup> Also, the Efeler complex was expanded at least 25 MW by the end of the year.<sup>11</sup> All of Turkey's new geothermal power plants are located in Western Anatolia (along with all existing capacity), with most concentrated in an area extending less than 100 kilometres.<sup>12</sup> In 2020, Turkey still ranked fourth globally for total geothermal power capacity, with 1.6 GW.<sup>13</sup> Geothermal power supplies around 3% of the country's electricity.<sup>14</sup>

The technology-specific feed-in tariff (FIT) in place since 2011 has been instrumental in Turkey's geothermal energy development.<sup>15</sup> Revisions to the FIT were anticipated throughout 2020, possibly causing some projects to be rushed to completion before the scheduled expiration of the FIT at year's end (but this was extended to mid-2021 on account of the pandemic).<sup>16</sup> A new FIT introduced in early 2021, around one-third lower than the existing tariff, abandoned the USD-based structure for the local currency, for both the basic tariff and the local content increment.<sup>17</sup>

The United States holds an enduring global lead in installed geothermal power capacity despite being a relatively stagnant market in recent years. Minor changes in 2020 raised the country's net geothermal capacity by around 32 MW, bringing total net operating capacity to 2.6 GW.<sup>18</sup> After more than 30 years of operation, the Steamboat Hills power plant in Nevada saw its capacity rise by around 19 MW (to 84 MW) following

refurbishment that included the replacement of all generating equipment as well as resource modifications.<sup>19</sup> The upgrades are expected to increase the plant's productivity and efficiency while reducing maintenance costs per unit of output.<sup>20</sup> In November, the Puna geothermal power plant in Hawaii, which had been disabled by a volcanic eruption in 2018, resumed partial operation.<sup>21</sup> Geothermal power in the United States generated as much as 16.9 TWh<sup>iv</sup> in 2020, a notable increase of 9.4% over 2019, representing around 0.4% of US net electricity generation.<sup>22</sup>

In Japan, following the completion of two plants in 2019, some small additions saw light in 2020. The renovation of the Otake geothermal plant in Oita Prefecture improved efficiency and raised its capacity by 2 MW to 14.5 MW.<sup>23</sup> The upgrade improved stability and efficiency of operation by incorporating bi-level steam pressure to feed a single turbine.<sup>24</sup> Elsewhere, two 150 kW low-temperature binary modules were installed: a bottoming-cycle unit at an existing high-temperature geothermal plant to more fully use the available thermal energy, and a unit at a traditional Japanese spa.<sup>25</sup>

Indonesia, which ranks second to the United States for installed geothermal capacity, did not manage to complete any facilities in 2020 due to pandemic-related delays to three projects that previously were planned to come online that year.<sup>26</sup> The delayed projects, now expected online in 2021, are the 45 MW Sorik Marapi Unit 2 in North Sumatra (Unit 1 completed in 2019), the 90 MW Rantau Dadap and the 5 MW Sokoria Unit 1.<sup>27</sup> In all, Indonesia aimed to complete nearly 200 MW of geothermal power capacity in 2021.<sup>28</sup> A potential danger associated with geothermal energy exploration and extraction is the uncontrolled or excessive release of noxious gases. During preparations for commissioning of the Sorik Marapi Unit 2 in early 2021, procedural failures led to the release of hydrogen sulphide gas in concentrations that caused multiple injuries and five deaths among nearby residents.<sup>29</sup>



- 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 geothermal field. See endnote 5 for this section.
- iii 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.
- iv Based on net generation of 15.5 TWh in 2019, revised from 16 TWh as reported in early 2020. Likewise, generation for 2018 was first reported as 16.7 TWh but later revised to 16 TWh. The implied growth of 9.4% may be found to be smaller, if 2020 generation figures are later revised downward, as was the case for the preceding two years. See endnote 22 for this section.

Along with Turkey, Indonesia has been a relatively strong and consistent market with around 700 MW added since 2015 and a total installed capacity of 2.1 GW.<sup>30</sup> Geothermal power supplied 14.1 TWh of electricity to Indonesia in 2019, or 4.8% of the country's total generation that year.<sup>31</sup>

As part of an effort to more than double the renewable share of Indonesia's electricity supply to 23% by 2025, the government committed to absorbing some of the early exploration risk by taking over exploratory drilling from private developers going forward.<sup>32</sup> The objective is to accelerate progress towards long-term geothermal energy targets by improving geothermal data before again auctioning off development areas to developers, starting in 2023.<sup>33</sup> Combined with new reimbursements for exploration activities, the government expects these changes to reduce the risk premium on new projects, leading to lower electricity rates for consumers.<sup>34</sup> Exploratory drilling was planned for three areas in 2021 but later reduced to two due to budget constraints.<sup>35</sup> Indonesia's geothermal resources are located mainly in mountainous conservation areas and far from load centres, further complicating development.<sup>36</sup>

With no capacity added since 2018, the Philippines still ranks third for total installed capacity, at 1.9 GW, although dependable capacity is reported to be somewhat less (1.8 GW).<sup>37</sup> To spur investment in geothermal power, the government moved in 2020 to allow full foreign ownership in renewable energy projects.<sup>38</sup> Nonetheless, with five prospective geothermal areas up for auction until early 2021, no foreign firms had placed bids by the end of 2020.<sup>39</sup> The local geothermal industry awaits the implementation of a risk mitigation fund by the government to ameliorate the risk of pursuing the mostly low-enthalpy resources that are up for exploration.<sup>40</sup> New discoveries of high-enthalpy resources in the country are considered unlikely, and for existing known resources, mountainous terrain adds to project costs, while permitting is complicated by laws protecting ecologically sensitive areas and rural populations.<sup>41</sup>

New Zealand's geothermal electricity sector has been relatively inactive over the last five years, following a period of rapid growth in the use of geothermal energy in the prior decade.<sup>42</sup> While the country has not added any capacity since 2018, geothermal power has remained at nearly 18% of the generation mix since 2015, in large part because the country has seen no growth in electricity demand during the last decade.<sup>43</sup>

Demand growth was expected to be dampened further in 2021 by the proposed closing of an aluminium smelter.<sup>44</sup> However, the successful appraisal of a new geothermal field confirmed the viability of the proposed 152 MW Tauhara plant, to be built by 2023 near Taupō on the North Island.<sup>45</sup> The developer considers the field to be especially attractive because its associated CO<sub>2</sub> emissions are just one-eighteenth those of a coal-fired unit.<sup>46</sup> By early 2021, New Zealand's 32 MW Ngawha plant was commissioned after three years of construction.<sup>47</sup>

Worldwide, the capacity for **geothermal direct use**<sup>i</sup> – direct extraction of geothermal energy for thermal applications – increased by an estimated 2.4 gigawatts-thermal (GW<sub>th</sub>) (around 8%) in 2020, to an estimated 32 GW<sub>th</sub>.<sup>48</sup> Geothermal energy use for thermal applications grew an estimated 11.3 TWh during the year to an estimated 128 TWh (462 PJ).<sup>49</sup>

Geothermal heat has varied direct applications. Bathing and swimming remains the largest category, comprising around 44% of total use in 2019 (latest available consolidated data), and it is growing around 9% annually on average.<sup>50</sup> Second, but with the fastest growth, was space heating (around 39% of direct use), expanding around 13% annually on average.<sup>51</sup> 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%).<sup>52</sup>

The top countries for geothermal direct use (in descending order) in 2020 were China, Turkey, Iceland and Japan, which together represented roughly 75% of the global total.<sup>53</sup> (→ See Figure 22.)

## Geothermal direct use capacity

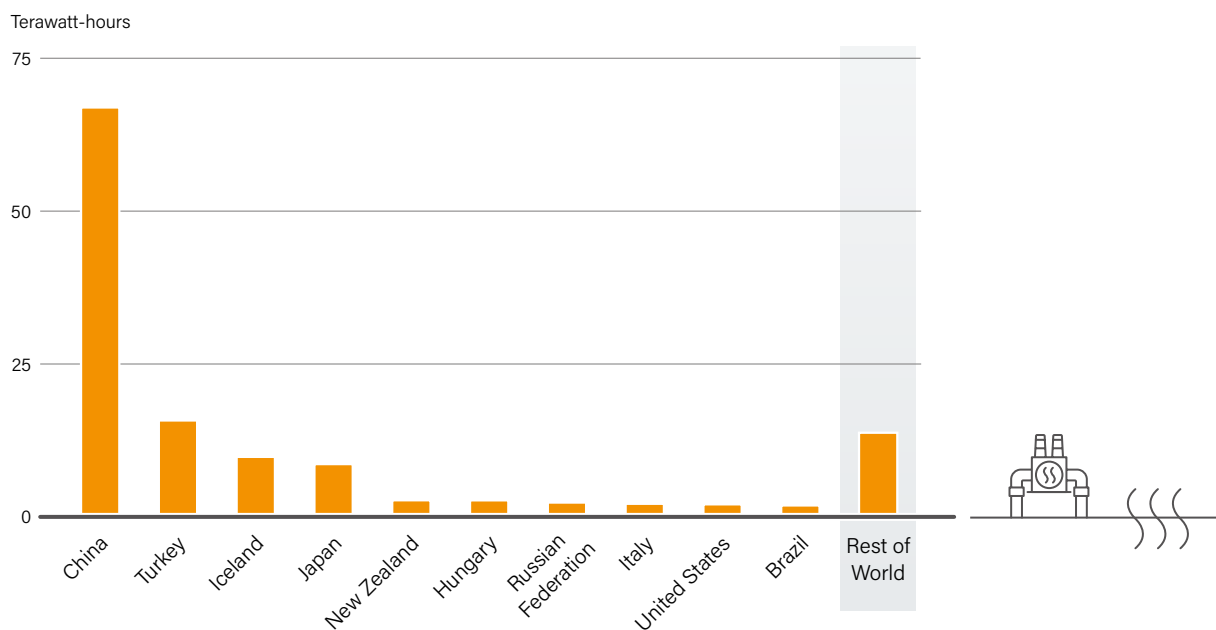
increased by around 8% in 2020, to an estimated 32 GW<sub>th</sub>.



<sup>i</sup> 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.)



**FIGURE 22.**  
Geothermal Direct Use, Estimates for Top 10 Countries and Rest of World, 2020



Source: See endnote 53 for this section.

China is both the largest user of geothermal heat (47% of the total) and the fastest growing market, with its installed capacity growing more than 18% annually on average during 2015 through 2019, and consumption growing more than 21% annually on average.<sup>54</sup> 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.<sup>55</sup> As of 2019, China had an estimated 14.2 TW<sub>th</sub> of installed geothermal capacity for direct use (excluding heat pumps), with 7 TW<sub>th</sub> allocated to district heating, 5.7 TW<sub>th</sub> serving bathing and swimming applications, and the rest used for food production and other industry.<sup>56</sup> Most of China's hydrothermal resources are relatively low enthalpy; of the 546 production wells drilled during the period 2015 through 2019, 94% had a wellhead temperature below 100°C.<sup>57</sup>

Other top countries (Turkey, Iceland and Japan) have experienced more moderate capacity growth of around 3-4% annually (consumption growth of 3-5%).<sup>58</sup> In Turkey, geothermal development is devoted mainly to electricity generation, while investment in direct use has contracted somewhat over the last decade.<sup>59</sup> Iceland has significant thermal demand served by district heat networks and continues limited drilling of reinjection and make-up wells for those systems as well as for existing power plants.<sup>60</sup> In Japan, more than 80% of direct use is believed to be associated with bathing facilities located near geothermal springs, but due to limited data gathering, information is lacking on immediate prospects for further

development.<sup>61</sup> The remaining 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.<sup>62</sup>

Some of the most active markets for direct use do not have access to high-enthalpy resources and often endure higher costs and greater technical challenges to access geothermal heat. 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 2020 with notable new development in France, Germany and the Netherlands.

In Germany, Munich completed drilling in 2020 for what will be the country's largest geothermal plant, exceeding 50 megawatts-thermal (MW<sub>th</sub>) and expected to provide heat for more than 80,000 city residents.<sup>63</sup> By use of absorption chillers, the plant also will contribute to the city centre's district cooling network, which was undergoing expansion during the year.<sup>64</sup> In addition, plans were under way for what would be the seventh geothermal facility serving the municipality since the first plant came online in 2004.<sup>65</sup>

France continues to see growing use of localised geothermal resources, mostly for district heating. In the greater Paris region, several geothermal district heating systems have been developed in recent years, with new projects started or announced in 2020. In August, drilling commenced in Vélizy-Villacoublay, southwest of central Paris, on a system that is expected to meet 66% of the energy demand of the local district heat network, serving the equivalent

of 12,000 dwellings; the project was aiming for completion in 2021.<sup>66</sup>

In the eastern suburbs of Paris, the communities of Champs-sur-Marne and Noisiel advanced work on the construction of a joint heating network following a drilling phase. Expected for completion

in late 2021, the geothermal district heating project will supply heat to the equivalent of 10,000 homes across the two municipalities; the renewable energy component of the supply is expected to be 82%.<sup>67</sup> For another project in the nearby communities of Drancy and Bobigny, four wells were drilled in 2020 and distribution of geothermal heat began in early 2021.<sup>68</sup> The project is expected to supply the equivalent of 20,000 homes when completed, displacing 60% of the fossil fuels currently used on the network.<sup>69</sup>

A once-promising geothermal project in the Alsace region of France came to an apparent end in late 2020, and its fate could have repercussions for geothermal development in the area going forward.<sup>70</sup> After a series of earthquakes over the course of a year, attributed to geothermal drilling and associated well stimulation on the northern outskirts of Strasbourg, local authorities ordered the final shutdown of the Vendenheim facility in December, along with three other permitted projects in the area.<sup>71</sup> Local authorities claimed that the operator had exceeded permitted well pressures for stimulation as well as the authorised well-drilling depth, reaching beyond the sandstone strata into the deeper bedrock, which increased the risk of seismic activity.<sup>72</sup>

Problems associated with induced seismic activity also affected projects in the Netherlands. A Dutch geothermal greenhouse operation was declared bankrupt in 2020 after two years of inactivity following seismic disturbances in 2018.<sup>73</sup> Although the operator claimed that the earthquakes near the project were unrelated, Dutch regulators declared continued operations too risky.<sup>74</sup> The operator observed that unlike other Dutch geothermal projects that tap only the porous sandstone layer, the drilling in this case penetrated deep bedrock in the search for greater hydrothermal flow.<sup>75</sup>

In the Netherlands, geothermal energy output grew 10% in 2020 (following 51% growth in 2019), to 6.2 PJ, driven mostly by drilling activity in the preceding year.<sup>76</sup> The country's use of geothermal energy is generally limited to greenhouse horticulture, but expansion into district heating and industrial applications is anticipated, pending the construction of heat networks but also the need to overcome political, financial and social barriers to uses beyond horticulture.<sup>77</sup> Multiple drilling operations were under way or completed in 2020.<sup>78</sup>

As Dutch mining laws and regulations pertaining to geothermal exploration and development were being reviewed in 2020, the country's geothermal industry raised concerns about regulatory uncertainty and any associated project delays.<sup>79</sup>

## Technology innovations

promise expanding project viability and are attracting investment from the oil and gas majors.

## GEOHERMAL INDUSTRY

In a year of project delays as well as both meagre and highly concentrated market growth, the geothermal industry found promise in the pursuit of new technology. Technological innovation, such as new resource recovery techniques and seismic risk mitigation, continued to be the industry's main focus towards achieving improved economics, lower development risk and overall better prospects for expanded geothermal resource development around the world. However, industry hopes to expand development beyond the relatively few and concentrated centres of existing activity remained largely unfulfilled, as in years past. While high costs and project risks continue to create a drag on investment in most places, especially in the absence of government support (i.e., feed-in tariffs and risk mitigation funds), certain pockets of industry innovation attracted new investment from established entities in the energy industry.

In some markets, the real or perceived risk of induced seismic activity related to geothermal development appears to present a specific risk to individual geothermal developers, if not a systemic risk to the industry (as evidenced by recent events in France and the Netherlands). Beyond the projects directly affected, collateral damage has emerged in the form of cancellations of other nearby projects (i.e., Alsace) and of shaken public confidence.<sup>80</sup> The prevalence of such events has grown with the increased application of hydraulic fracturing (well stimulation), as was used in the Vendenheim project in Strasbourg. Before that, earthquakes associated with such enhanced geothermal systems (EGS)<sup>i</sup> in Switzerland (Basel in 2006 and St. Gallen in 2013) caused severe setbacks for Swiss geothermal prospects.<sup>81</sup> Yet a solution is needed if geothermal energy use is to expand significantly beyond the relatively few locations in the world that enjoy the most valuable, medium-to-high enthalpy geothermal resources.<sup>82</sup>

Driven by the early setbacks and the need to rekindle local geothermal development, Swiss researchers continue to pursue technological and procedural solutions to the problem of induced seismic activity. In late 2020, Geo-Energie Suisse AG (GES) proved the concept of forming a sufficiently permeable "heat exchanger" reservoir at a depth of 4-5 kilometres through a process of multi-stage (incremental steps) stimulation that minimises the probability of induced seismic events.<sup>83</sup> Further validation of the technology will be conducted at the US test site FORGE<sup>ii</sup> in Utah. GES anticipates that these findings will improve government confidence in a currently suspended geothermal pilot project for the technology in the canton of Jura.<sup>84</sup>

Across Germany, the Netherlands and Italy, industry actors and research institutions worked to draw attention to the potential of geothermal energy to aid in the renewable energy transition (particularly to meet thermal energy demand) and to highlight the need for additional support policies. In Germany, geothermal industry and research institutions came together under the banner of "Heat transition through geothermal energy" (Wärmewende durch Geothermie).<sup>85</sup> The Dutch geothermal

i EGS encompasses the use of hydraulic fracturing of hot rock to create the conditions for a geothermal reservoir. Specifically, the objective is to attain a combination of heat, permeability and flow of geothermal fluid that is sufficient to make extraction economical for heat and/or electricity generation.

ii Frontier Observatory for Research in Geothermal Energy.





industry also indicated that the sector will be critical to the pending heat transition in the Netherlands, while drawing attention to the alleged lack of financial incentives and to the perceived un-level playing field, relative to other technologies.<sup>86</sup> The Italian Geothermal Union similarly claimed that ineffective incentives and national legislation had severely slowed Italy's geothermal development and jeopardised industrial know-how.<sup>87</sup>

The persistent but variable emissions of CO<sub>2</sub> and hydrogen sulphide from open-loop geothermal facilities remain a concern. In most instances, CO<sub>2</sub> emissions are far below those from fossil fuel facilities, but they are non-negligible nonetheless, and sometimes geothermal plant emissions can rival those of coal-fired power plants.<sup>88</sup> Significant progress has been made in recent years to advance the process of sequestering CO<sub>2</sub>. The Icelandic company Carbfix, with its international partners, has developed a process to permanently capture and store CO<sub>2</sub> by imitating and accelerating the natural process through which dissolved CO<sub>2</sub> reacts with sub-surface rock formations to form stable carbonate minerals.<sup>89</sup> In 2020, an agreement was reached to build a CO<sub>2</sub> sequestration plant in Iceland capable of removing 4,000 tonnes of atmospheric CO<sub>2</sub> per year, combining the Carbfix method with the direct air capture technology for CO<sub>2</sub> removal provided by Climeworks of Switzerland.<sup>90</sup>

When resource exploration disappoints and precludes conventional hydrothermal projects, new technologies may help. For example, in Gertetsried, Germany, a developer drilled two wells, starting in 2013 (the first being the deepest geothermal well in Europe to date, at over 6,000 metres), that proved unable to produce enough hydrothermal flow to make a conventional geothermal power project viable.<sup>91</sup> Eavor Technologies (Canada) joined the project in 2020 to deploy its new modular closed-loop technology, which is well suited for the

local geothermal conditions and thus to improve viability of the site.<sup>92</sup> Eavor's technology, first demonstrated in Alberta (Canada) in early 2020, uses directional drilling techniques developed in the oil and gas industry to create a closed-loop system that circulates a working fluid to extract heat from bedrock without bringing geothermal fluid (brine) to the surface. In addition to eliminating surface emissions of CO<sub>2</sub> and hydrogen sulphide, the thermosiphon effect (bringing hot fluid up on one side as cold fluid descends on the other) of the closed-loop design reportedly mitigates the energy demand from pumping that is associated with other geothermal techniques.<sup>93</sup>

Such innovations have gained the attention of the oil and gas majors. In early 2021, Eavor Technologies completed a USD 40 million funding round including investments from BP Ventures and Chevron Technology Ventures, among others.<sup>94</sup> Chevron also announced investment in Baseload Capital A.B. (Sweden), whose projects include the deployment of modular "heat power" units by Climeon (Sweden) for low-temperature electricity generation from geothermal or other sources of excess heat (including both of the units installed in Japan in 2020).<sup>95</sup>

The industrial entities that provide the technology for geothermal energy capture and conversion (excluding drilling) comprise a relatively small group. The power unit (turbine) manufacturers include Atlas Copco (Sweden), Exergy (Italy, subsidiary of Tica Group of China since 2019), Fuji Electric (Japan), Mitsubishi and its subsidiary Turboden (Japan/Italy), Ormat (US) and Toshiba (Japan).<sup>96</sup> 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).<sup>97</sup> Ormat Technologies and Exergy supplied most of the binary-cycle plants that were completed during the year.<sup>98</sup>

## KEY FACTS

- The **global hydropower market expanded in 2020** but did not recover from several years of deceleration.
- **China added 12.6 GW of hydropower capacity in 2020**, its largest addition of the previous five years, and regained the lead from Brazil in commissioning new hydropower capacity.
- **Hydropower faced challenges** including operational and technical factors, environmental and social acceptability, a global decline in wholesale electricity prices, and adverse climate impacts on hydropower production and infrastructure.

## HYDROPOWER



### HYDROPOWER MARKETS

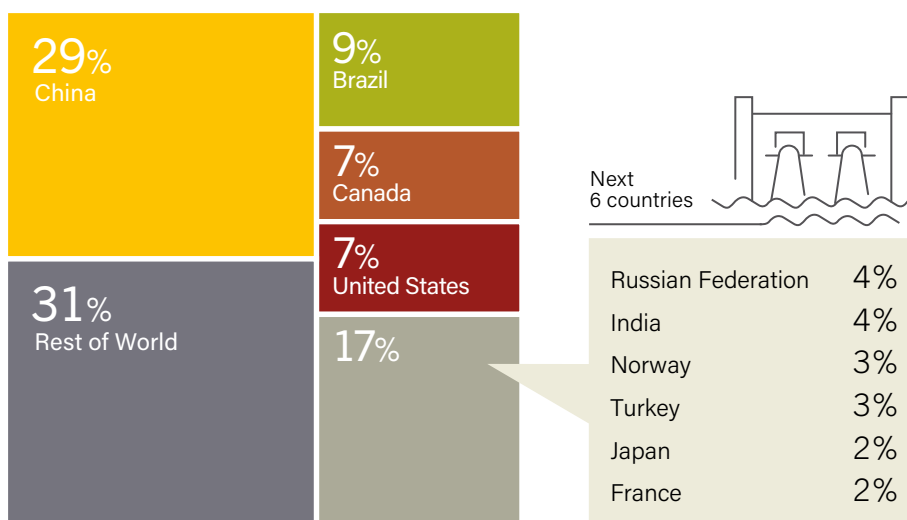
Despite a 24% increase in capacity additions, driven mainly by China<sup>i</sup>, the global hydropower market did not recover in 2020 following several years of deceleration.<sup>1</sup> The effects of the COVID-19 pandemic were notable, with the market slowing as construction was halted temporarily, component supply chains were disrupted, and energy demand fell.<sup>2</sup> Capacity additions for the year totalled an estimated 19.4 GW, bringing the total installed capacity to 1,170 GW<sup>ii</sup>.<sup>3</sup> The top 10 countries for total capacity did not change and were, in order of installed capacity: China, Brazil, Canada, the United States, the Russian Federation, India, Norway, Turkey, Japan and France, together representing more than two-thirds of the global total.<sup>4</sup> (→ See Figure 23 and **Reference Table 2** in GSR 2021 Data Pack.)

China regained the lead from Brazil in commissioning new hydropower capacity (both large and small installations), followed by Turkey, India, Angola and the Russian Federation.<sup>5</sup> (→ See Figure 24.) As large and economically viable hydrological

i China's share represented 65% of global total capacity additions; if China is excluded, worldwide installed capacity decreased 44% between 2019 and 2020.

ii Where possible, all capacity numbers exclude pure pumped storage capacity unless otherwise specified. Pure pumped storage plants are not energy sources but rather 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.

**FIGURE 23.** Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2020



Source: See endnote 4 for this section.

resources become more limited, markets increasingly have developed the remaining untapped potential that is available mainly from marginal resources and pumped storage.<sup>6</sup>

Global pumped storage capacity (which is counted separately from hydropower capacity) increased 1.5 GW (0.9%) in 2020, primarily from new installations in China and Israel.<sup>7</sup>

Global hydropower generation increased 1.5% in 2020 to reach an estimated 4,370 TWh, representing around 16.8% of the world's total electricity generation.<sup>8</sup> While some yearly variations in global hydropower generation are due to changes in installed capacity, most are the result of fluctuations in weather patterns and in local operating conditions<sup>i</sup>.

China added 12.6 GW of hydropower capacity in 2020, its highest amount in the previous five years, reaching 338.7 GW by year's end.<sup>9</sup> The country's capacity increased 15% during the 2015-2020 period, and new hydropower plants represented 7% of China's total newly installed power generation capacity in 2020.<sup>10</sup> The largest additions included the 1.6 GW Datengxia plant in the Guangxi Zhuang autonomous region, with eight 200 MW turbines, and the five 850 MW units commissioned at the Wudongde plant between Yunnan and Sichuan provinces.<sup>11</sup> Wudongde will be the seventh largest plant in the world upon completion, with 10.2 GW of total installed capacity.<sup>12</sup>

Other hydropower projects in China included the completed reconstruction of the 1.5 GW Fengman plant and the ongoing construction of the 16 GW Baihetan mega project, with commissioning

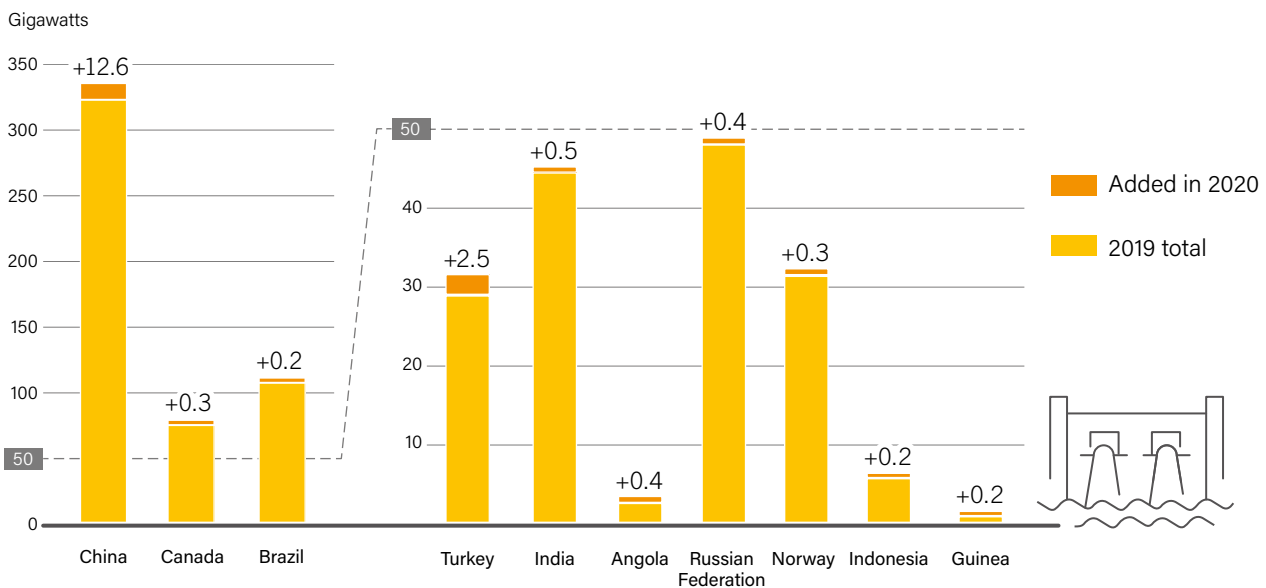
scheduled for 2021.<sup>13</sup> China's total hydropower output reached 1,360 TWh, up 4.1% from 2019 and representing 18% of the country's electricity supply; meanwhile, the Three Gorges Dam set a new world record for annual electricity output in 2020.<sup>14</sup>

China added 12.6 GW of hydropower capacity in 2020, its highest amount in the previous five years.



<sup>i</sup> Fluctuations in weather patterns lead to modifications in hydrological conditions. Hydropower operations may vary due to price fluctuations in electricity markets, the contribution to grid stability through balancing services using storage capacities (reservoirs) and water supply management.

**FIGURE 24.** Hydropower Capacity and Additions, Top 10 Countries for Capacity Added, 2020



Source: See endnote 5 for this section.



Turkey added 2.5 GW of new hydropower capacity – its largest increase since 2013 – for a total of 30.9 GW.<sup>15</sup> The fast pace of commissioning was driven in part by the pending expiration of the country’s feed-in tariff scheme, applying to facilities brought online before the end of the year.<sup>16</sup> By early 2021, a new FIT was announced for 2021-2025 that reduced the hydropower tariff by around one-third.<sup>17</sup> The largest hydropower facilities that went online in 2020 were the 540 MW Yusufeli dam, the 500 MW Lower Kaleköy plant, the 420 MW Çetin plant and the 1.2 GW Ilisu dam (the second largest dam in the country, located on the Tigris River, which began production after some delays).<sup>18</sup>

The intense drought in the Black Sea region in 2020 reduced Turkey’s hydropower production 12% compared to 2019.<sup>19</sup> Hydropower represented nearly one-third of the country’s power capacity mix by the end of 2020 and around 56% of the new power generating capacity added that year.<sup>20</sup>

India added 473 MW of net hydropower, for a total capacity of 45.8 GW.<sup>21</sup> The government has promoted hydropower as a source of grid stability and flexibility, with a target of 70 GW of installed capacity by 2030.<sup>22</sup> Around 13 GW of capacity was under construction in 2020.<sup>23</sup> After eight years of delays following protests related to safety concerns and other potential negative impacts, construction resumed on the 2 GW Subansiri project along the Assam-Arunachal Pradesh border.<sup>24</sup> In mid-2020, the government proposed a draft Electricity (Amendment) Bill to boost India’s renewables sector.<sup>25</sup> The bill includes provisions that define a minimum percentage of electricity that public sector companies<sup>i</sup> must purchase from hydropower sources, in addition to introducing a purchase obligation and providing incentives.<sup>26</sup>

Indonesia added 240 MW in 2020 for a total installed capacity of 6.1 GW, and Lao People’s Democratic Republic (PDR) added 180 MW to reach nearly 7.4 GW.<sup>27</sup> The 260 MW Don Sahong

project, commissioned in 2019, began commercial operations, and commissioning was completed on the first unit of the 70 MW Xelalong 1 plant.<sup>28</sup> In Vietnam, 119.5 MW of hydropower was added in 2020, bringing the total installed capacity to 17.1 GW.<sup>29</sup> The commissioning of the 220 MW Thuong Kon Tum hydropower plant and the expansion of the 1,920 MW Hoa Binh plant, both expected by the end of the year, were postponed to 2021.<sup>30</sup>

In Uzbekistan, several facilities were finalised with modernisation of the 15 MW Kadyrinskaya 3 plant, two power plants totalling 22.4 MW on the South Ferghana Canal and a 15 MW plant on the Bozsu Canal.<sup>31</sup> In Georgia, the Shuakhevi installation on the Adjaristsqali River, the country’s largest hydropower plant built since 1978<sup>ii</sup>, began commercial operations, adding 178 MW to the grid; the facility is one of two plants in a 187 MW scheme.<sup>32</sup> Georgia ended 2020 with a total installed capacity of 3.4 GW, representing around 80% of the country’s power generating capacity and 76% of its electricity production.<sup>33</sup>

The European hydropower market has reached near-maturity, and possibilities for new, large installations are limited. Norway added 324 MW of capacity – with nearly half of this consisting of plants of less than 10 MW – in addition to several larger facilities, including a 77 MW plant.<sup>34</sup> The country’s total installed capacity reached 32 GW in 2020, representing 89% of national electricity production.<sup>35</sup> In France, the 97 MW Romanche-Gavet plant was commissioned after a decade of construction, replacing six power plants and five dams built around 1910.<sup>36</sup> To reduce the facility’s visual impact, the developers located the plant underground and replaced the previous structures with a single dam; in addition, local species were replanted along the dam banks for ecological restoration.<sup>37</sup> In Albania, which relies entirely on hydropower generation and electricity imports, the 197 MW Moglicë plant – the second of two plants that are part of the 269 MW Devoll Hydropower Scheme – started delivering electricity.<sup>38</sup>

The Indian government has promoted hydropower as a source of **grid stability and flexibility.**



i The public sector companies subject to renewable power purchase obligations are power distribution companies, energy producers and certain consumers.  
 ii The 1,300 MW Engurhesi hydropower plant was completed in 1978, and the 130 MW Zhinvalhesi plant was completed in 1986.



Installed capacity in the Russian Federation reached 48.5 GW after 380 MW was added in 2020.<sup>39</sup> The largest project to come online was the 346 MW Zaramagskaya plant in North Caucasus.<sup>40</sup> New small hydropower plants in the region also added more than 22 MW of capacity across four facilities.<sup>41</sup> The sixth of seven units was commissioned at the Ust-Khantayskaya facility under renovation in the Krasnoyarsk region, where 63 MW units are being replaced with 73 MW units to increase the installed capacity to 511 MW.<sup>42</sup>

Several projects were completed in Africa, including in Angola, Ghana and Guinea. Angola continues to focus its long-term electrification strategy on hydropower, with more than 4 GW planned or under study.<sup>43</sup> To achieve this, generation facilities are being developed, upgraded or restored.<sup>44</sup> Angola added 401 MW of hydropower capacity in 2020, bringing the sixth (and final) unit of the Laúca plant into commercial operation to reach an installed plant capacity of 2.1 GW.<sup>45</sup> By year's end, Angola's total installed capacity was 3.8 GW.<sup>46</sup>

In Malawi, the Phalombe 3 MW plant reached its final phase before commissioning, and the last two units at the 8.2 MW Ruo-Ndiza hydroelectric power station were commissioned.<sup>47</sup> In Rwanda, four installations came online in 2020: three of these totalled slightly more than 2 MW, while the 9.8 MW Giciye III came online after 18 months of construction.<sup>48</sup> Rwanda's total installed capacity reached 121 MW by year's end.<sup>49</sup> In Uganda, the Bukinda 6.6 MW facility was commissioned, and the 600 MW Karuma project along the Nile River in the western region was nearing completion after years of delays as well as recent pandemic-related challenges.<sup>50</sup> Once commissioned, the Karuma plant will increase Uganda's total hydropower capacity to more than 1.5 GW and will provide power to neighbouring Rwanda, northern Tanzania, Kenya and the Democratic Republic of the Congo through new regional transmission lines.<sup>51</sup>

In Ethiopia, the more than 6 GW Grand Ethiopian Renaissance Dam moved towards completion, despite a lack of agreement with Egypt and Sudan on filling and operating the dam.<sup>52</sup> The Ethiopian government considers this facility fundamental to the country's economic development, as half of the population lacks access to the grid, and electricity supply blackouts are frequent.<sup>53</sup> In line with this economic objective, the launch of commercial operations at the 254 MW Genale Dawa 3 hydropower project increased Ethiopia's overall power capacity around 6%.<sup>54</sup> The country's year-end hydropower installed capacity was 4.1 GW.<sup>55</sup>

In Guinea, 225 MW came online after the commissioning of two units of the Souapiti dam, bringing the country's total installed capacity to 0.7 GW.<sup>56</sup> Ghana finalised the retrofit of the 160 MW Kpong facility, one of three large hydropower facilities in the country, for a total installed capacity of 1.6 GW.<sup>57</sup> Ghana's first small-scale plant, the Tsatsadu micro-hydro project, funded primarily by the Bui Power Authority and by contributions from development funds, also was fully commissioned.<sup>58</sup> The Ghanaian Parliament authorised construction of the 60 MW Pwalugu multi-purpose dam project<sup>i</sup> on the Volta River.<sup>59</sup>

Brazil, Canada and the United States, the largest hydropower markets in the Americas, together added nearly 0.5 GW of capacity in 2020.<sup>60</sup> In Canada, the two large projects expected during the year were delayed largely because of the pandemic. The commissioning of the 695 MW Keeyask generation project near Hudson's Bay (owned by Manitoba Hydro and four Indigenous groups<sup>ii</sup>) was pushed to 2021 after Indigenous groups erected blockades, preventing workers from entering when activities resumed.<sup>61</sup> In the province of Newfoundland and Labrador, the first 206 MW unit at the 824 MW Muskrat Falls facility on the Churchill River came online in late 2020, and commissioning began on the second unit.<sup>62</sup> By year's end, Canada had around 82 GW of hydropower capacity, providing around 60% of the country's electricity supply.<sup>63</sup>

The United States commissioned 148 MW of capacity in 2020, primarily following the replacement of turbines and generators at the 122 MW Wanapum Dam, as well as a 3 MW expansion at Shoshone Falls.<sup>64</sup> Two new installations totalling less than 30 MW were added, and a 6 MW facility was retired.<sup>65</sup> This resulted in a slight increase in the US total installed capacity, to 79.9 GW.<sup>66</sup> After a three-year decline, generation rose to 291 TWh, representing 7.2% of the country's total electricity supply.<sup>67</sup>

In Latin America, the 104 MW Patuca III plant, the second largest hydropower plant in Honduras and the country's first project financed by China, went into operation, increasing Honduras' total installed capacity to around 0.8 GW.<sup>68</sup> In Colombia, installed capacity increased slightly from the previous year, with 24 MW of additions and a total capacity of 11.9 GW by year's end.<sup>69</sup> Preparations also began at the 2.4 GW Hidroituango project to install the first two turbines after a 2018 accident that flooded and damaged the powerhouse, displacing around 600 residents and destroying infrastructure along the Cauca River.<sup>70</sup>



i The dam will store water to generate electricity from hydropower, irrigate agricultural fields downstream and provide a flood protection system for populations living in the White Volta basin.

ii The Indigenous peoples who own part of the project include the Tataskweyak Cree Nation, War Lake First Nation, York Factory First Nation and Fox Lake Cree Nation.

Brazil, after nearly a decade of adding capacity in the gigawatt range, commissioned only 213 MW in 2020, mainly divided among small-scale facilities of 11 MW or less.<sup>71</sup> This sharp contraction from the previous year was due to rising environmental concerns associated with the country's remaining exploitable hydropower potential.<sup>72</sup> By the end of 2020, Brazil had 109 GW of hydropower capacity, representing 62% of its total operational power capacity.<sup>73</sup>

Brazil's ageing hydropower fleet<sup>i</sup> has negatively affected the reliability of the country's electricity supply, causing frequent service disruptions.<sup>74</sup> In 2017, outages at hydropower plants reduced total electricity production by 65 TWh, which is the equivalent of 67% of the overall energy losses in Brazil's electrical transmission and distribution system.<sup>75</sup> One study estimated that rehabilitating the seven hydropower plants that were least available that year due to forced outages would provide an additional 1.9% of overall hydropower energy.<sup>76</sup>

Peru commissioned the 20 MW Manta hydropower plant with an investment of USD 43.6 million.<sup>77</sup> Commercial operation of the 84 MW La Virgen plant on the Tarma River was delayed after fieldwork was halted for three months in the second quarter of the year.<sup>78</sup> Chile commissioned 206 MW in 2020.<sup>79</sup>

Globally, the pumped storage installed capacity increased 1.5 GW in 2020, bringing the total capacity to 160 GW.<sup>80</sup> Israel's first pumped storage facility (300 MW) started operation during the year, and in China 1,200 MW of pumped storage was commissioned.<sup>81</sup> Additional large pumped storage projects in the pipeline include Greece's 680 MW Amfilochia complex, Scotland's 1.5 GW Cloire Glass facility and Turkey's first pumped storage facility, the 1 GW Eğirdir.<sup>82</sup> In India, two identical hybrid projects secured financing: the Pinnapuram and Saundatti facilities each have pumped storage capacity of 1.2 GW combined with 4 GW total of solar and wind power capacity.<sup>83</sup>

With most of Australia's hydropower potential already developed, pumped storage is an increasingly important component of the country's energy expansion, especially its plans to integrate variable renewable energy (VRE) sources.<sup>84</sup> The Snowy 2.0 project, which aims to expand the existing Snowy scheme by 2 GW, received government approval to build related infrastructure, and the Ravine substation was commissioned to power this construction.<sup>85</sup> In Tasmania, Lake Cethana was identified as the first pumped storage project of the Battery of the Nation initiative, with capacity nearing 600 MW.<sup>86</sup> The 500 MW Dungowan and 400 MW Big-T projects under development aim to support VRE integration, providing firm power and grid services.<sup>87</sup>

In Portugal, the 880 MW Gouvães<sup>i</sup> pumped storage facility was on track for commissioning in 2021, and construction also began on one of Vietnam's first pumped storage projects, the 1.2 GW Bac Ai project.<sup>88</sup> The 250 MW Hatta pumped storage facility in the United Arab Emirates also progressed, with the service tunnels completed and construction of the upper dam under way.<sup>89</sup> In China, the 3.6 GW Fengning project began storing water in its lower reservoir; upon completion, the facility is expected to be the world's largest pumped storage installed capacity, with a record 12 reversible 300 MW turbines<sup>iii,90</sup>

## HYDROPOWER INDUSTRY

The hydropower industry continued to face challenges and opportunities in 2020, augmented by the pandemic-induced recession<sup>iv</sup> as well as by new opportunities stemming from the growing recognition of renewables as a valuable component of a sustainable economic recovery.<sup>v,91</sup> The challenges included operational and technical factors, environmental and social acceptability, a global decline in wholesale electricity prices, and adverse climate impacts on hydropower production and infrastructure.<sup>92</sup> Among the opportunities for industry expansion were technology improvements and increased performance, the remaining untapped potential of smaller resources, synergies with VRE and increased needs for grid flexibility.



i As of 2018, 31% of Brazilian hydropower plants were more than 40 years old.

ii Gouvães will be the first of three plants in the 1.2 GW Tâmega complex, with an estimated project investment of more than EUR 1.5 billion (USD 1.8 billion).

iii The Huizhou and Guangdong pumped storage plants hold the current record for the largest number of turbines, with eight each.

iv With the large decrease in electricity demand, wholesale prices for hydropower fell, jeopardising revenues and capital flows; greenfield development and critical modernisation projects were halted; and current and new government programmes designed to support the sector were postponed or cancelled. See endnote 91 for this section.

v Technologies related to the energy transition (renewables, electric vehicles and battery storage) and digitalisation are among the sectors that have generated the most interest from investors in the post-COVID-19 market.

The disruptive effect of the pandemic-induced recession had an impact on most of the world's major hydropower technology providers<sup>i</sup>. Voith Hydro suffered from a slowing market and reported a 46% decline in orders and a 17% decline in sales.<sup>93</sup> The Americas represented the largest share of Voith's sales, followed by Asia and Europe.<sup>94</sup> GE Hydro Solutions, representing more than 25% of total installed capacity worldwide, reported lower-than-expected revenues.<sup>95</sup> Andritz Hydro registered a 12% decline in revenues but nearly the same level of order intake as in 2019.<sup>96</sup>

Although renewable energy was underrepresented in government recovery packages in 2020, some plans aimed to boost economic growth, create jobs and cut greenhouse gas emissions. The International Energy Agency included hydropower modernisation in its three-year recovery proposal, which calls for spending around USD 20 billion annually over this period to support continued generation and to boost the creation of skilled jobs.<sup>97</sup> Similarly, the International Hydropower Association (IHA) and the International Renewable Energy Agency joined forces to foster development of the 850 GW of hydropower capacity expected to be needed by 2050 to achieve the climate goals of the Paris Agreement.<sup>98</sup>

The modernisation and refurbishment of hydropower plants continued in 2020 and was expected to remain a priority. Worldwide, tens of thousands of ageing water storage facilities have reached their end-of-life, and the 52% of global hydropower capacity that was installed before 1990 could be due for major rehabilitation.<sup>99</sup> Across Europe, North America, Central Asia and Latin America, the refurbishment of ageing facilities has resulted in improved operational efficiency and enhanced resource use.<sup>100</sup> Refurbishment and improvement of the 3.1 GW Yacyretá plant on the Argentina/Paraguay border increased its capacity by 735 MW, and at the 14 GW Itaipu plant on the Brazil/Paraguay border a USD 660 million digitalisation project was announced

to replace the original analog technology.<sup>101</sup> In Australia, Voith announced a collaboration with Snowy Hydro to use acoustic sensing equipment, combined with cloud-based data collection and analysis and remote surveillance, to monitor hydropower assets in order to detect malfunctions before they occur and to optimise preventive maintenance.<sup>102</sup>

With the rising penetration of variable renewables in electricity production, grid operators increasingly are looking for resources to boost the flexibility of generation. Hydropower and pumped storage can provide the flexibility and support services that the grid requires through quick ramping and other grid service capabilities, with a lower emission profile than fossil fuel generation assets.<sup>103</sup> Hydropower generators contribute greatly to grid reliability, but their primary revenue stream (market energy prices) does not always compensate for the other ancillary services that they can provide (such as inertial response and voltage regulation). These ancillary services could come at the expense of displacing the maximum operating capacity of the plant to support them.<sup>104</sup>

In the United States, the California Independent System Operator (CAISO) signed contracts in 2019 to explicitly compensate for the inertial and primary frequency response services supplied by hydropower.<sup>105</sup> Under current US market conditions, the cost-benefit ratio of delivering ancillary services versus power generation is under study, and market mechanisms are emerging to monetise other grid services that hydropower provides.<sup>106</sup> In 2019, the UK electricity system operator held its first tender for "grid stability" and in early 2020 it awarded a contract to the 440 MW Cruachan pumped storage station to supply synchronous compensation.<sup>107</sup> The Cruachan facility began providing inertia in mid-2020, using a world-first approach<sup>ii</sup> estimated to save consumers up to GBP 128 million (USD 174 million) over the six-year period.<sup>108</sup>



More than half of  
global  
hydropower  
capacity  
could be due for major  
rehabilitation.

i Major technology providers included Andritz Hydro (Austria), Bharat Heavy Electricals (India), Dongfang Electric (China), GE (US), Harbin Electric (China), Hitachi Mitsubishi Hydro (Japan), Impsa (Argentina), Power Machines (Russian Federation), Toshiba (Japan) and Voith (Germany).

ii The Stability Pathfinder approach aims to provide inertia and other vital services without generating unnecessary electricity by using technologies such as pumped storage, gas-fired power stations and synchronous condensers. Five six-year contracts were awarded in the first stage in early 2020.



In West Africa, a study found that with adequate management and operation of current and future facilities, hydropower flexibility can support VRE integration while displacing fossil fuel plants.<sup>109</sup> The industry is embracing these trends as projects combining large amounts of solar and wind with hydropower or pumped storage are emerging and costs are becoming competitive.<sup>110</sup> The 500 MW Dungowan pumped storage plant in New South Wales, Australia was designed as part of the 4 GW Walcha Energy Project to provide grid support services and firm power.<sup>111</sup> Relatively low wind power prices in locations such as Québec, Canada, where hydropower is abundant, can shift the dispatching approach by encouraging the use of wind when it is available and storing water until it is needed.<sup>112</sup>

Projects combining hydropower reservoirs and floating solar PV increased in 2020.<sup>113</sup> The major benefits of these hybrid systems include reduced evaporation, lower energy infrastructure costs and generation complementarity due to seasonality.<sup>114</sup> In some cases, this approach is proposed to compensate for the declining performance of some hydropower plants.<sup>115</sup> Other synergies being explored include using hydropower to power hydrogen electrolyzers. Construction of one of the largest electrolyzers using hydropower, with capacity nearing 90 MW, was announced in Canada, while small-scale hydrogen production facilities were being pursued in Iceland.<sup>116</sup>

Innovations in 2020 included the deployment of the world's largest hydropower turbine, a 1 GW turbine at the Baihetan facility built by China Three Gorges Corporation.<sup>117</sup> Advances at small facilities included the use of fish-friendly installations that limit the diversion of river flow by using submerged generators or low-head turbines with blades designed to allow safe fish passage.<sup>118</sup> The US market demonstrated increased commercial viability for pumped storage through an innovative configuration

for closed-loop pumped installations<sup>ii</sup> that reduces project costs, environmental impacts and development time.<sup>119</sup>

The industry also is addressing the sustainability of hydropower, using an integrated resource management approach to focus on load balancing, water quality and water supply for non-energy needs (such as irrigation, flood control, sediment management and responding to other requirements from communities and natural resources).<sup>120</sup> Lao PDR and other countries along the Mekong River have experienced frequent extreme low water flows due to reduced rainfall and flow modifications upstream caused by hydropower operations. To promote and co-ordinate sustainable management of the basin, the Mekong River Commission released the Hydropower Mitigation Guidelines to provide risk management and mitigation guidance during the early stages of hydropower facility design.<sup>121</sup> Poor management has resulted in tensions among countries along the Mekong, Nile, Tigris and other rivers.<sup>122</sup> To address the inherent risks facing the industry, particularly in heavily hydropower-dependent regions, hydropower must be transformed into a resilient energy source in the face of climate change.<sup>123</sup>

In 2020, in response to environmental concerns, areas of the Balkans including the Federation of Bosnia and Herzegovina, Montenegro and the Serbian region of Sokobanja faced a surge of restrictions on small hydropower developments.<sup>124</sup> The region's hydropower industry launched an initiative in early 2021 to implement international good practices in development, in line with the IHA Hydropower Sustainability Tools.<sup>125</sup> Another sustainability initiative led by the IHA, the Hydropower Sustainability Assessment Fund, aims to help hydropower developers and operators assess the environmental, social and governance performance of projects that are under preparation and development or already in operation.<sup>126</sup>



i Operators can benefit from more stable yearly generation, as solar will produce more than hydropower in the dry season, and the reverse will occur during the rainy season.

ii The novel closed-loop installation design required the use of a submersible pump turbine in a vertical "well" to replace the traditional underground powerhouse, which is one of the most expensive and riskiest components of this type of facility.



## KEY FACTS

- Ocean power **generation continued to rise in 2020**, surpassing 60 GWh.
- The industry is now moving from **small-scale demonstration and pilot projects towards semi-permanent installations** and arrays of devices.
- **Maintaining revenue support** for ocean power technologies is considered paramount if the industry is to achieve greater maturity.



## OCEAN POWER



### OCEAN POWER MARKETS

The oceans contain the largest untapped source of renewable energy. While ocean power technologies<sup>i</sup> represent the smallest share of the renewable energy market, they are steadily advancing towards commercialisation. Deployments in 2020 added around 2 MW, bringing the total operating installed capacity to an estimated 527 MW at year's end.<sup>1</sup> Two tidal barrages using mature turbine technologies<sup>ii</sup> represent more than 90% of total installed capacity: the 240 MW La Rance station in France (installed in 1966) and the 254 MW Sihwa plant in the Republic of Korea (2011).<sup>2</sup>

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, which has significant resources. However, generous revenue support and ambitious research and development programmes in Canada, the United States and China are spurring increased development and deployment elsewhere.<sup>3</sup> In 2020, the EU set an ambitious target for 40 GW of ocean power capacity by 2050, including at least 100 MW of pilot projects by 2025 and 1 GW by 2030.<sup>4</sup>

**Tidal stream** devices are approaching maturity, and pre-commercial projects are under way. Device design for utility-scale generation has converged on horizontal-axis turbines mounted on the sea floor or attached to a floating platform.<sup>5</sup> These devices have demonstrated considerable reliability in performance, with total generation surpassing 60 GWh by the end of 2020 (up from 45 GWh the year before).<sup>6</sup> A range of other concepts are under development, designed to meet specific applications or environmental conditions, such as providing power to remote communities or at low-energy sites.

**Wave power** devices remain in the prototyping phase, and there is no convergence on design yet owing to the complexity of extracting wave energy from a variety of wave conditions and the wide range of possible operating principles.<sup>7</sup> 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).<sup>8</sup>

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, floating solar PV or floating wind.

ii These are the same in-stream technologies used in some types of hydropower plants.

## OCEAN POWER INDUSTRY

The ocean power industry faced significant challenges in 2020 as the COVID-19 pandemic slowed manufacturing, delayed deployments and interfered with maintenance schedules. Most planned deployments were postponed to 2021, although some deployments took place and power generation continued despite reduced maintenance. In total, seven **tidal stream** devices were successfully deployed in 2020, including a three-turbine array, a large commercial-scale turbine and smaller demonstration deployments.

In China, the China Three Gorges Corporation (CTG) manufactured a 500 kW tidal turbine, designed by SIMEC Atlantis Energy, and deployed it between two islands in Zhoushan archipelago.<sup>9</sup> The CTG also made progress on the Zhoushan tidal current energy project, deploying a 300 kW turbine.<sup>10</sup> Another project, led by Zhejiang Zhoushan LHD New Energy Corporation Limited (LHD), achieved cumulative power generation exceeding 1.95 GWh in October 2020.<sup>11</sup> The modular device currently comprises two vertical-axis turbines of 400 kW and 600 kW, and LHD is working on adding a 1 MW turbine and increasing the capacity of the platform to 4.1 MW.<sup>12</sup> The main structure, now completed, was planned to be deployed in the first quarter of 2021.<sup>13</sup> The project will be the first to benefit from a temporary feed-in tariff of EUR 0.33 (USD 0.40) per kWh, introduced in 2019.<sup>14</sup>

In the United States, Verdant Power installed a 105 kW array of three tidal power turbines at its Roosevelt Island Tidal Energy Project site in New York's East River, marking the first licensed tidal power project in the country.<sup>15</sup> As of January 2020, the array had operated continuously for three months, achieving 100 megawatt-hours (MWh) of generation in its first 85 days.<sup>16</sup> In Igiugig, Alaska, the Ocean Renewable Power Company (ORPC, US) redeployed its 35 kW RivGen Power System, a submerged cross-flow river current turbine.<sup>17</sup> Combined with microgrid electronics and energy storage, the system will reduce diesel use in Igiugig Village by an estimated 90%.<sup>18</sup> OPRC also continued construction on a second RivGen device, targeting deployment in summer 2021, and received USD 3.7 million in funding from the Department of Energy's Advanced Research Projects Agency.<sup>19</sup>

Two deployments took place in the United Kingdom in 2020. Nova Innovation (UK) completed the installation of its 100 kW turbine in the Shetland Islands.<sup>20</sup> This is the first of three turbines deployed as part of the EnFAIT (Enabling Future Arrays in Tidal) project, a EUR 20 million (USD 24.6) effort to demonstrate a viable cost-reduction pathway for tidal energy.<sup>21</sup> Nova Innovation also continued to successfully operate its 0.3 MW array in the Bluemull Sound in Shetland, where the turbines have generated without incident since 2016.<sup>22</sup> DesignPro Renewables (Ireland) successfully completed deployment and testing of its 60 kW DPR60 turbine at Kirkwall in the Orkney Islands, Scotland.<sup>23</sup>

Minesto (Sweden) installed and commissioned its 100 kW DG100 tidal kite system<sup>i</sup> in the Vestmannastrandir strait, Faroe Islands.<sup>24</sup> By December, it had successfully delivered electricity to the Faroese grid under a 2019 power purchase agreement (signed with the Faroese utility company SEV) for up to 2.2 MW of installed tidal capacity.<sup>25</sup> Minesto also is seeking the necessary permits to deploy a 100 kW device at the EDF-owned Paimpol Bréhat site in France.<sup>26</sup> Minesto received EUR 14.9 million (USD 18.3 million) in EU funding through the Welsh European Funding Office in 2019 and completed work in 2020 on its Holyhead assembly hall, which will serve as a hub for engineering and operational activities.<sup>27</sup> An array of up to 80 MW capacity is planned for the Holyhead Deep site, eight kilometres off the coast of north-west Wales.<sup>28</sup>

Scotland's MeyGen tidal stream array (the world's largest at 6 MW), owned and operated by SIMEC Atlantis Energy (UK), surpassed 35 GWh of electricity generation in 2020.<sup>29</sup> Having entered its 25-year operational phase in 2018, it generated continuously in 2019, the longest period of uninterrupted generation to date from a commercial-scale tidal array.<sup>30</sup> In 2020, the array faced operational challenges, and three turbines were retrieved for servicing in April 2021.<sup>31</sup> SIMEC holds a seabed lease that would allow it to build the project out to 398 MW.<sup>32</sup> SIMEC also shipped a 500 kW turbine to Japan for installation in early 2021 as part of Kyuden Mirai Energy's demonstrator project in the country's Goto islands.<sup>33</sup>

Tidal stream devices generated **15 GWh** of electricity in 2020.



<sup>i</sup> 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.

In Canada, the government of Nova Scotia offered a feed-in tariff of between CAD 385 and CAD 530 (USD 301 and USD 415) per MWh for demonstration projects.<sup>34</sup> As of the end of 2020, five Canadian developers were approved for a total of up to 22 MW.<sup>35</sup> During the year, NewEast Energy obtained an 800 kW permit under Nova Scotia's demonstration permits programme, which issued permits for a total of 9.3 MW of capacity (of the 10 MW available).<sup>36</sup> Canada committed substantial new funding to tidal projects in 2020, investing CAD 28.5 million (USD 22.3 million) in Sustainable Marine Energy's floating tidal array (up to 9 MW) and CAD 4 million (USD 3.1 million) in Nova Innovation's 1.5 MW array in the Bay of Fundy.<sup>37</sup>

DP Energy and Sustainable Marine Energy (both Canada) continued to advance the Uisce Tapa project under development at the Fundy Ocean Research Centre for Energy (FORCE). The CAD 117 million (USD 91.5 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 23.3 million).<sup>38</sup> BigMoon Power successfully applied to occupy a vacant berth at FORCE.<sup>39</sup> Other provinces also are making progress on ocean power, particularly as a means to provide electricity to remote communities.<sup>40</sup>

Several projects have been progressing in France. The HydroQuest 1 MW marine tidal turbine prototype was deployed at Paimpol-Bréhat in April 2019 and connected to the national grid in June 2019, and has operated continuously since then.<sup>41</sup> Featuring a dual vertical-axes design, this cross-flow turbine turns irrespective of the flow direction, enabling the device to be fixed to its foundation without any efficiency loss. DesignPro Renewables continued testing its 25 kW turbine at the dedicated SEENEOH test site on the Garonne River, where it has been deployed since September 2018.<sup>42</sup> SABELLA (France) is planning to redeploy its grid-connected D10-1000 tidal energy converter on Ushant Island in 2021 and is also working with Morbihan Hydro Energies (France) to deploy two 250 kW turbines in the Gulf of Morbihan.<sup>43</sup> In Normandy, the government approved the transfer of a 12 MW lease in Raz Blanchard to Normandie Hydroliennes, a consortium of partners including SIMEC Atlantis Energy and the Development Agency for Normandy.<sup>44</sup>

In the Netherlands, the Dutch company Tocardo acquired the 1.25 MW Oosterschelde Tidal Power Plant and subsequently resumed full continuous operation.<sup>45</sup> The plant comprises five of Tocardo's T-2 tidal turbines mounted on a sluice gate of the Oosterschelde storm surge barrier.

Two **wave power** deployments took place in 2020, with most planned deployments delayed by stalled manufacturing and pandemic-related lockdowns during the year.

In China, a consortium led by the Guangzhou Institute of Energy Conversion deployed a full-scale 500 kW wave energy converter. The Sharp Eagle-Zhoushan converter combines electricity generation with aquaculture and was deployed as part of the Wanshan megawatt-level Wave Energy Demonstration Project, supported by the Ministry of Natural Resources.<sup>46</sup> The Penghu device, based on the Sharp Eagle, completed its 18-month testing period in December 2020.<sup>47</sup> Construction also began on a second 500 kW device, Changshan.<sup>48</sup>

Building on a successful scale test in Denmark, Danish company Wavepiston tested a full-scale device at the Oceanic Platform of the Canary Islands (PLOCAN, Spain). The initial phase of the 200 kW project was deployed in December 2020.<sup>49</sup> The system pressurises sea water, which can then be used to drive a turbine or can be pumped through a reverse osmosis system to obtain desalinated water. A second device that will produce both electricity and fresh water was slated for deployment in 2021.<sup>50</sup>

Existing deployments continued to operate through 2020, passing some significant milestones. The 296 kW Mutriku wave plant in Spain, commissioned in 2011, surpassed a cumulative 2 GWh of electricity production.<sup>51</sup> At the SEM-REV test site in France, the Wavegem hybrid wave and solar platform designed by GEPS Techno reached 18 months of offshore testing, which began in August 2019.<sup>52</sup>

US company Ocean Power Technologies (OPT) reported continuous operation of its device, deployed in the Adriatic Sea, during its first 18 months.<sup>53</sup> The device was leased by Eni, which in March 2020 opted to extend the lease for an additional 18 months.<sup>54</sup> Amid international travel restrictions that delayed deployment of a device in Chile, OPT contracted with SeaTrepid International (US) to conduct a remote installation, training local engineers virtually on technical procedures and installation requirements.<sup>55</sup>

Many companies focused on technology and project development in 2020. For example, Bombora Wavepower (UK) delayed a planned deployment but accelerated design work on a 3 MW project scheduled for deployment in Lanzarote, Spain in 2022.<sup>56</sup> Bombora also entered into an agreement with Technip FMC (UK) to develop a floating offshore wind foundation incorporating wave energy.<sup>57</sup> The first phase of the project will integrate 4 MW of wave power and 8 MW of wind power on a shared floating platform.<sup>58</sup>

Wave Swell Energy (Australia) finalised construction of its 200 kW device, scheduled for deployment on King Island, Tasmania in early 2021.<sup>59</sup> Also in Australia, Carnegie Clean Energy continued to develop its CETO 6 device, after restructuring following the company's entry into voluntary administration in 2018.<sup>60</sup> Carnegie also is developing a wave predictor that uses machine learning to predict wave characteristics up to 30 seconds before they reach the device, thereby increasing efficiency.<sup>61</sup>

US-based company Oscilla Power is finishing construction of a 100 kW device, expected to be installed in Hawaii in 2021.<sup>62</sup> The company also entered the planning stages of a 1 MW demonstration project, targeting deployment off the coast of Kerala in southern India.<sup>63</sup> In the United States, the OEbuoy device developed by Ocean Energy (Ireland), which was transported from the state of Oregon to Hawaii in 2019, is expected to be deployed in 2021.<sup>64</sup>

The EU aims to install  
**40 GW**  
of ocean power  
capacity by 2050.



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. REDstack (Netherlands) successfully tested its reverse electrodialysis (RED) technology and was planning a first demonstration plant.<sup>65</sup> Akuo Energy (France) announced plans to develop an OTEC plant on Bora Bora, French Polynesia, as part of the EU-funded project, Integrated Solutions for the Decarbonization and Smartification of Islands (IANOS).<sup>66</sup> Puerto Rico (US) is in the early stages of developing the Puerto Rico Ocean Technology Complex (PROtech) and aims to invest an estimated USD 300 million to build a 5 MW to 10 MW OTEC plant by mid-2027.<sup>67</sup>

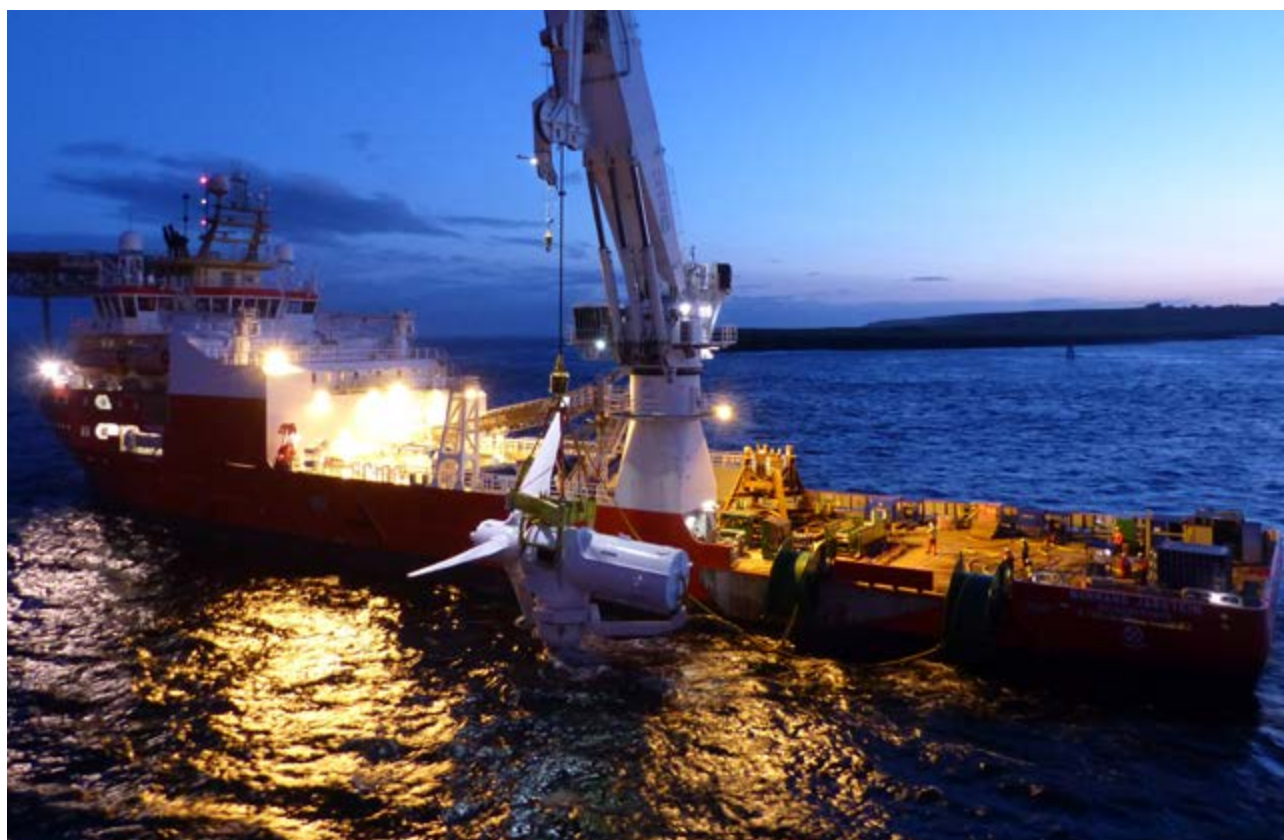
The Ocean Thermal Energy Association was recently reinvigorated, and a group of member countries of the International Energy Agency's Ocean Energy Systems collaboration are working to assess the current status and global potential of OTEC, with a white paper expected in 2021.<sup>68</sup>

Technology improvements and steep cost reductions are still needed for ocean power to become competitive in utility markets. The industry has not yet received the clear market signals it needs to take the final steps to commercialisation.<sup>69</sup> 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.<sup>70</sup> Dedicated revenue support is considered paramount for increasing investment certainty by providing predictable returns until the industry achieves greater maturity.

The 2020 announcement of two large private investments provide some positive indications. CorPower Ocean (Sweden) secured EUR 9 million (USD 11 million) in equity funding, and SIMEC Atlantis concluded a share placement agreement, raising an initial investment of GBP 2 million (USD 2.7 million), with the option of increasing this to GBP 12 million (USD 16 million).<sup>71</sup> The UK government is expected to reform its Contract for Difference (CfD) mechanism, separating ocean power from offshore wind, thereby increasing price competitiveness.<sup>72</sup>

As of 2018, more than EUR 6 billion (USD 7.4 billion) had been invested in ocean power projects worldwide, of which 75% was from private finance.<sup>73</sup> A 2018 European Commission implementation plan estimated that EUR 1.2 billion (USD 1.5 billion) in funding was needed by 2030 to commercialise ocean power technologies in Europe, requiring equal input from private sources, national and regional programmes, and EU funds.<sup>74</sup> The industry is collaborating to develop a common evaluation framework for ocean power technologies, aiming to provide clarity for all stakeholders, including public and private investors.<sup>75</sup>

Deploying ocean energy at scale also will require streamlined consenting processes.<sup>76</sup> Uncertainty regarding environmental interactions often has led regulators to mandate significant data collection and strict environmental impact assessments, which can be costly and threaten the financial viability of projects and developers.<sup>77</sup> Current scientific knowledge suggests that the deployment of a single device poses little risk to the marine environment, although the impacts of multi-device arrays are not well understood.<sup>78</sup> This calls for an "adaptive management" approach that responds to new information over time, supported by more long-term data and greater knowledge sharing across projects.<sup>79</sup>





## KEY FACTS

- **Solar PV had another record-breaking year in 2020.** Anticipated policy changes drove much of the growth in the top three markets – China, the United States and Vietnam – but several other countries saw noteworthy expansion.
- Favourable economics have boosted interest in **distributed rooftop systems**. In South Australia, the growth of distributed solar PV has made the state's power system the first large-scale system in the world to approach the point at which rooftop solar PV effectively eliminates demand for electricity from the grid.
- The solar PV industry rode a roller coaster in 2020, driven largely by **pandemic-related disruptions**, as well as by accidents at polysilicon facilities in China and a shortage of solar glass. These disruptions, due in large part to heavy reliance on China as the world's dominant producer, combined with concerns about possible forced labour in polysilicon production, led to calls in many countries for the creation of local supply chains.
- New actors entered the sector. **Competition and price pressures** continued to motivate investment to improve efficiencies, reduce costs and improve margins.

## SOLAR PHOTOVOLTAICS (PV)



### SOLAR PV MARKETS

Solar PV had another record-breaking year, with new installations reaching as much as an estimated 139 GW<sub>DC</sub><sup>i</sup>; this brought the global total to an estimated 760 GW<sub>DC</sub>, including both on-grid and off-grid capacity.<sup>1</sup> These preliminary global numbers are uncertain, and the level of uncertainty is increasing year-by-year.

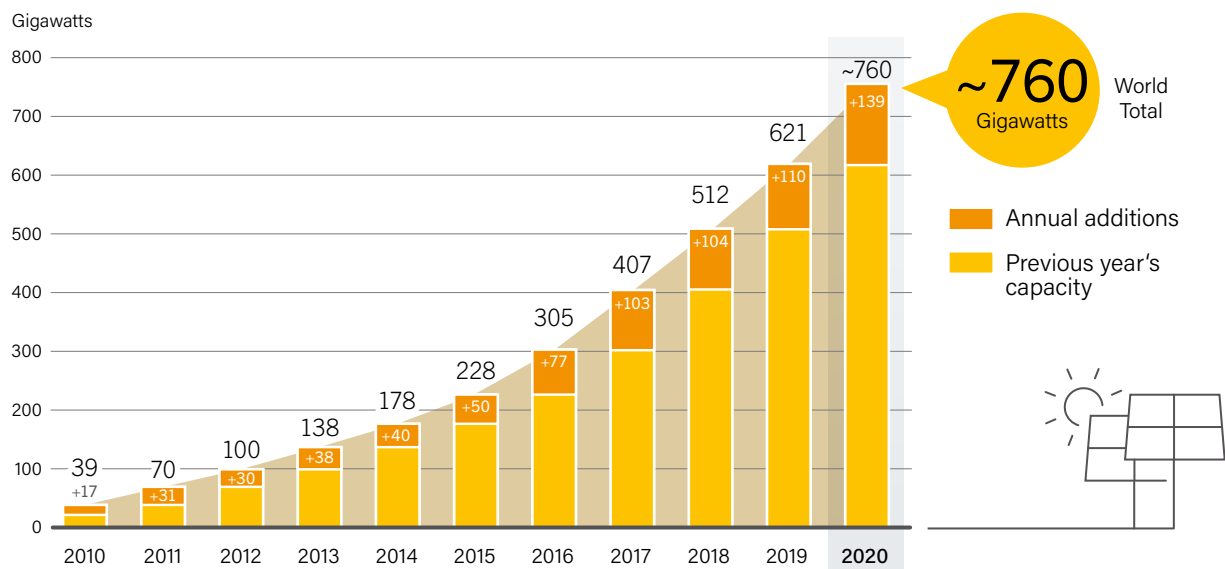
Business closures, stay-at-home orders and restrictions on movement related to the COVID-19 pandemic all reduced electricity consumption and shifted daily demand patterns.<sup>2</sup> The pandemic also resulted in delays in shipping and deliveries of solar panels and related hardware, in customer acquisitions, and in project permitting and construction, exacerbating existing challenges in some markets.<sup>3</sup> Yet, while growth in some markets was below the strong expectations going into 2020, solar PV managed to achieve the largest increase in capacity ever seen in a single year.<sup>4</sup> The distributed<sup>ii</sup> sector was affected more than the utility sector, but several countries saw surges in residential demand.<sup>5</sup> Looming policy changes at the end of the year drove much of the growth in the top three markets (China, the United States and Vietnam), but several other countries also experienced noteworthy market expansion.<sup>6</sup> (→ See Figure 25.)



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. Data are preliminary and a range of estimates exists; global estimates in text are based on data from International Energy Agency Photovoltaic Power Systems Programme and Becquerel Institute. See endnote 1 in this section for further details.

ii Distributed refers to systems that provide power to grid-connected consumers, or directly to the grid, but on distribution networks rather than on bulk transmission or off-grid systems. See endnote 5 for this section. For more on distributed off-grid systems for energy access, see Distributed Renewables chapter.

**FIGURE 25.**  
Solar PV Global Capacity and Annual Additions, 2010-2020



Note: Data are provided in direct current (DC). Totals may not add up due to rounding.  
Source: Becquerel Institute and IEA PVPS. See endnote 6 for this section.

Demand for solar PV is spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of locations, both for residential and commercial applications and increasingly for utility-scale projects – even without accounting for the external costs of fossil fuels.<sup>7</sup> This also is becoming the case for solar-plus-storage in an increasing number of markets.<sup>8</sup> In 2020, an estimated 20 countries added at least 1 GW of new solar PV capacity, up from 18 countries in 2019, and all continents contributed significantly to global growth.<sup>9</sup> By the end of 2020, at least 42 countries had a cumulative capacity of 1 GW or more.<sup>10</sup>

Solar PV plays a meaningful role in electricity generation in a growing number of countries. By the end of 2020, at least 15 countries had enough capacity in operation to meet at least 5% of their electricity demand with solar PV.<sup>11</sup> Solar PV accounted for around 11.2% of annual generation in Honduras and for notable shares also in Germany (10.5%), Greece (10.4%), Australia (9.9%), Chile (9.8%), Italy (9.4%) and Japan (8.5%), among others.<sup>12</sup> Spain and the United Kingdom broke solar generation records early in the year, due largely to new capacity as well as to higher output resulting from clearer air during COVID lockdowns; clearer skies during lockdowns also enabled nearly 10% more sunlight to reach solar panels in Delhi and contributed to increased output in the United Arab Emirates.<sup>13</sup> However, smoke from wildfires in Australia and the US state of California had the reverse effect on output, while also negatively affecting solar variability and forecasting.<sup>14</sup>

There are still **challenges** to address for solar PV to become a major electricity source worldwide, including policy and regulatory instability in many countries, unreliable or insufficient grid infrastructure, and financial and bankability challenges.<sup>15</sup> As the level of penetration rises, the variability of 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.<sup>16</sup> In general, opposition to solar PV deployment from local incumbents is lower than a decade ago, with many utilities now actively engaged in solar PV deployment and operations, including distributed generation; however, opposition persists in several countries and among some actors, particularly in the fossil and nuclear energy industries.<sup>17</sup>

The cost-competitiveness of solar PV is increasingly a driver of investment, but generally it is insufficient on its own.<sup>18</sup> In most countries, there is still a need for adequate **regulatory frameworks and policies** governing grid connections to overcome cost or investment barriers in some markets and to ensure a fair and level playing field.<sup>19</sup> Government policies continued to propel most of the global market in 2020, with feed-in tariffs (FITs) and tenders the leading policy drivers of the centralised market, and FITs and incentivised self-consumption or net metering the primary drivers of the distributed market.<sup>20</sup> (→ See *Distributed Renewables* chapter for off-grid solar and related policies for energy access.)

i In the United States, tax credits also continued to play an important role. See endnote 20 for this section.

Self-consumption continued to represent an important and growing share of the market for new distributed systems in several countries.<sup>21</sup> 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 2020; interest in this segment is considerable and growing rapidly.<sup>22</sup>

For the eighth consecutive year, Asia<sup>i</sup> eclipsed all other **regions** for new installations, accounting for nearly 58% of global additions; even excluding China, Asia was responsible for around 23% of new capacity in 2020.<sup>23</sup> Asia was followed by the Americas (18%), which moved ahead of Europe (16%).<sup>24</sup> China continued to dominate the global market (and solar PV manufacturing), with a share of nearly 35% (up from 27% in 2019).<sup>25</sup>

The top five national markets – China, the United States, Vietnam, Japan and Germany – were responsible for almost 66% of newly installed capacity in 2020 (up from 58.5% for the top five in 2019 but down from around 75% in 2018, as the global market becomes somewhat less concentrated); the next five markets were India, Australia, the Republic of Korea, Brazil and the Netherlands.<sup>26</sup> The annual market size required to rank among the top 10 countries remained at around 3 GW.<sup>27</sup> The leading countries for cumulative solar PV capacity continued to be China, the United States, Japan, Germany and India, and the leaders for capacity per capita were Australia, Germany and Japan.<sup>28</sup> (→ See *Figure 26*.)

**China** added 48.2 GW of solar PV capacity in 2020 (including 32.7 GW of centralised and 15.5 GW of distributed<sup>iii</sup> solar PV), making the year second only to 2017 (52.9 GW) for annual additions.<sup>29</sup> The market increase of 60% – driven largely by pending changes to the country's FIT structure – followed two consecutive years of contraction, and came despite project construction delays early in 2020 caused by pandemic-related labour shortages and supply chain disruptions.<sup>30</sup> The central, eastern and southern regions of China accounted for about 36% of additions, with 64% in the western and northern regions.<sup>31</sup> The leading provincial installers were Guizhou (5.2 GW), Hebei (4.9 GW) and Qinghai (4.1 GW).<sup>32</sup> At year's end, China's total grid-connected capacity exceeded 253.4 GW, well above the official 13th Five-Year Plan (2016-2020) target for the year (105 GW).<sup>33</sup>

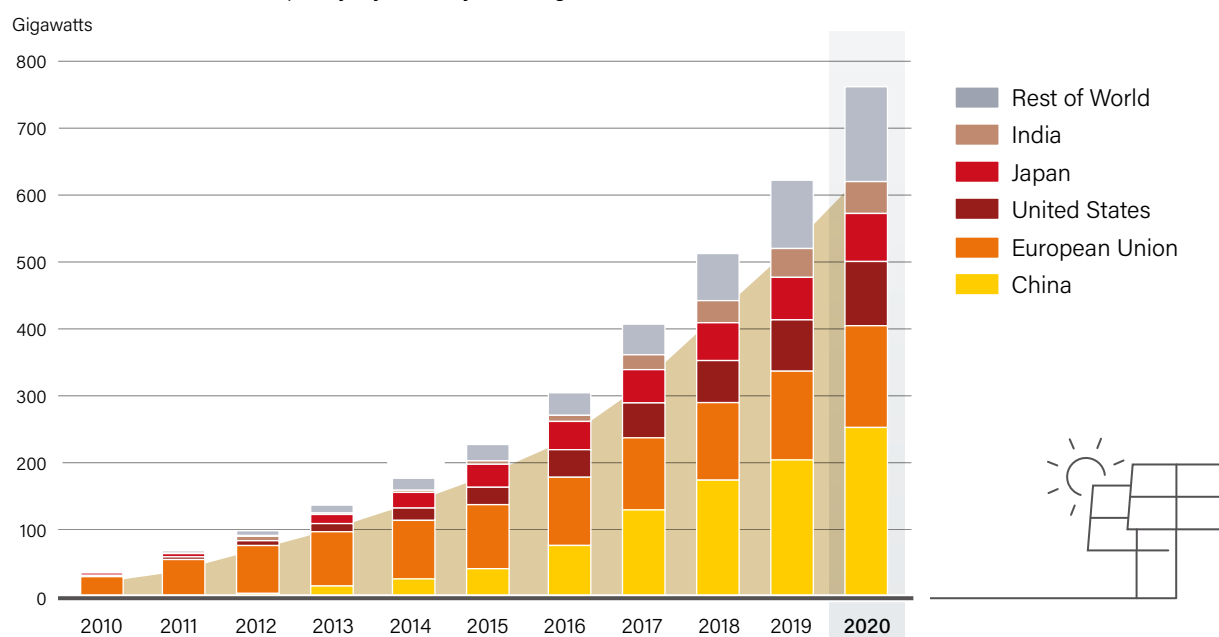
A major driver of China's solar PV market was a rush to install projects before the national FIT was phased out at year's end for centralised as well as commercial and industrial distributed systems.<sup>34</sup> The policy changes result from a mounting deficit in China's Renewable Energy Development Fund, which has caused a backlog of outstanding FIT payments for existing projects (only worsened by the pandemic), and from the central government's belief that solar (and wind) power is capable of competing without subsidies with coal-fired power.<sup>35</sup>

i Note that Turkey is considered to be part of the Asia region for purposes of the GSR.

ii This is the capacity addition of the Netherlands, which ranked tenth for annual installations.

iii "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 29 for this section.

**FIGURE 26.**  
Solar PV Global Capacity, by Country and Region, 2010-2020



Note: Data are provided in direct current (DC). European Union includes the United Kingdom throughout the 2010-2020 period. Germany's share of the EU total has declined from over 58% in 2010 to just under 36% in 2020 due to growth in other EU markets.

Source: See endnote 28 for this section.

China's market for centralised utility systems (greater than 20 MW) expanded considerably, up nearly 83% in 2020.<sup>36</sup> The increase is thanks in part to the completion of enormous hybrid projects – combining solar PV, wind power and energy storage – by some of the biggest state-owned companies.<sup>37</sup> China's largest solar-plus-storage project (2.2 GW of solar PV plus nearly 203 MW of battery storage) was connected to the grid in late 2020 in the desert of Qinghai province.<sup>38</sup> Total distributed installations also rose (27%) during the year, with annual additions of residential systems almost doubling relative to 2019 (to 10.1 GW) and more than making up for a decline in commercial and industrial installations (5.4 GW).<sup>39</sup> Most of the residential capacity was added in Shandong province (4.57 GW) and Hebei greater area (4.1 GW).<sup>40</sup>

Vietnam added an estimated 11.1 GW in 2020, up from 4.8 GW in 2019 and 0.1 GW in 2018.

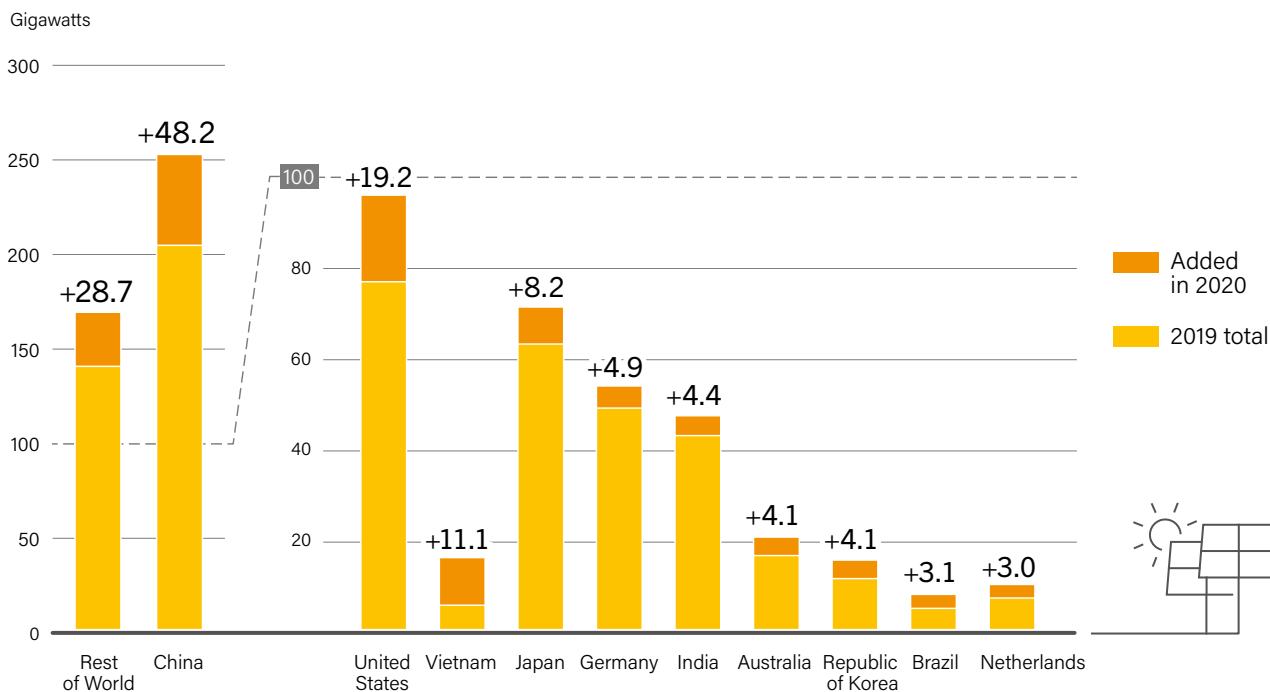
Curtailment of solar energy in China averaged 2% for the year, unchanged from 2019, although the average rate was higher during pandemic-related lockdowns in January (2.8%) and February (5.6%) due to reduced electricity consumption.<sup>41</sup> The curtailment rate continued to be highest in northwest China, particularly in Xinjiang and Gansu, but the region's annual

average declined to 4.8%.<sup>42</sup> Minimising curtailment is a national priority and is considered particularly important for utility-scale "grid parity" projects, which were introduced in 2019 to help China move away from subsidies.<sup>43</sup> China's output from grid-connected systems increased more than 16% in 2020, to 261 TWh, bringing solar PV's share of electricity generation (from grid-connected sources) to 3.4% in 2020 (up from 3% in 2019).<sup>44</sup>

The central and provincial governments are focused increasingly on renewable energy integration. In 2020, China's central government issued guidance to ensure that renewable electricity is consumed locally, to the extent possible, and governments at all levels increasingly link solar PV support and bidding rounds to energy storage and local grid capacities.<sup>45</sup> By the end of 2020, one-third of China's provinces mandated that new solar PV installations be combined with energy storage.<sup>46</sup>

**Vietnam** saw another surge in installations: after adding 4.8 GW in 2019 (up from 106 MW in 2018 and 8 MW in 2017), the country brought an estimated 11.1 GW into operation in 2020, raising it to third place globally for additions and eighth for total solar PV capacity.<sup>47</sup> (→ See Figure 27, and Reference Table R15 in GSR 2021 Data Pack.) Whereas growth in 2019 was driven by the pending expiration of Vietnam's FIT1 scheme, which encouraged large ground-mounted projects, most of the increase in 2020 was in rooftop systems, racing to qualify for the FIT2 before it expired at year's end.<sup>48</sup>

**FIGURE 27.** Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2020



Note: Data are provided in direct current (DC).  
Source: See endnote 47 for this section.



In total, nearly 83,000 rooftop systems were installed in Vietnam in a single year, increasing rooftop capacity from less than 0.4 GW to 9.7 GW (with 6.7 GW connected in December alone), and bringing the country's total solar PV capacity to 16.4 GW.<sup>49</sup> Vietnam's interest in solar PV is largely to meet rising electricity demand – which has increased 10% annually on average in recent years due to population growth and economic expansion – as well as to ensure energy security and reduce carbon emissions.<sup>50</sup> The rapid growth in solar generation has placed additional stress on the country's underdeveloped grid, leading to curtailment, and as of early 2021 Vietnam was considering options for financing necessary system upgrades.<sup>51</sup>

The third largest market in Asia and the fourth largest globally was Japan.<sup>52</sup> Following four years of contraction, Japan added 8.2 GW (up more than 16%) for a total of 71.4 GW – surpassed only by China and the United States.<sup>53</sup> However, Japan's market continued to face challenges related to land availability and grid constraints, which are helping to keep the country's large-scale solar PV costs among the highest in the world.<sup>54</sup> In 2020, the country's FIT was revised to focus support on systems for locally consumed generation (self- and community-consumption), the ability to isolate in the event of blackouts, and agricultural PV (see later discussion).<sup>55</sup> Solar PV accounted for an estimated 8.5% of Japan's total electricity generation in 2020, up from 7.4% in 2019, with the highest local contributions in Shikoku (13%) and Kyushu (14%).<sup>56</sup>

India's solar PV market contracted again, to the lowest level in five years, and investments in the solar sector were down 66% relative to 2019.<sup>57</sup> Despite the ongoing decline, India ranked sixth globally for additions and fifth for total capacity.<sup>58</sup> Around 4.4 GW<sup>i</sup> of solar PV capacity was added during the year, bringing the national total to 47.4 GW.<sup>59</sup> In the large-scale market, pandemic-related lockdowns and labour shortages delayed project construction and auctions.<sup>60</sup> These setbacks further aggravated existing challenges, such as the lack of transmission infrastructure and land permits, the reluctance of distribution companies to sign power purchase agreements (PPAs) (due to expectations that project bids at auction will continue to fall at a rapid pace), the extension of duties

on imported solar equipment and the cancellation of some projects awarded under earlier auctions due to regulatory delays.<sup>61</sup>

The rooftop market (1.3 GW) in India has been hampered by inconsistent government policy and restrictions, as well as by uncertainties related to the pandemic and pressure by distribution companies to discontinue net metering and adopt grid usage charges.<sup>62</sup> After falling through much of 2020, demand for rooftop systems rose towards the end of the year as government incentives enticed residential consumers, and as the commercial and industrial sectors (the primary rooftop markets) saw solar as a means to reduce their operational costs.<sup>63</sup>

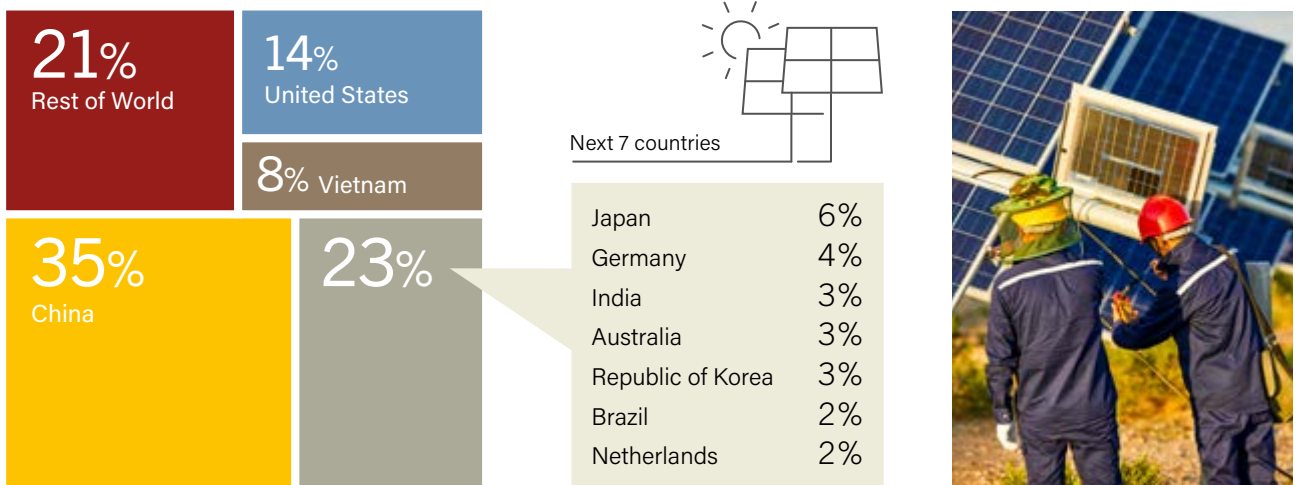
**Other Asian countries** that added substantial capacity in 2020 included the Republic of Korea (4.1 GW), Chinese Taipei (1.7 GW) and the Philippines (1.1 GW).<sup>64</sup> The Republic of Korea moved up two steps in the global rankings for capacity added, to eighth place, and continued to rank ninth for total capacity (15.9 GW).<sup>65</sup> Turkey added an estimated 1 GW for a total of 9.5 GW.<sup>66</sup> The Turkish market was driven by a new net metering law and self-consumption, representing a shift away from the traditional market of megawatt-scale projects.<sup>67</sup> Pakistan also added capacity, as did Kazakhstan, which held auctions and brought online at least two large projects in 2020.<sup>68</sup>

The **Americas** represented around 18% of the global market in 2020, due largely to the **United States**, which continued to rank second globally for both new installations and total capacity.<sup>69</sup> (→ See Figure 28.) The country added a record 19.2 GW – up 43% over 2019 and 27% above the previous peak in 2016 – for a total approaching 96 GW.<sup>70</sup> Solar PV was the leading source of new power capacity for the second consecutive year, accounting for 43% of all US power capacity additions in 2020 (compared with 4% a decade earlier), the largest share to date.<sup>71</sup> The market continued to be more geographically diverse, with 27 states adding more than 100 MW, even as the top states for additions remained California (3.9 GW), Texas (3.4 GW) and Florida (2.8 GW).<sup>72</sup> Utility-scale solar PV (87.7 TWh) plus grid-connected small-scale systems (41.7 TWh) generated a total of 129.5 TWh, or 3.2% of US net generation in 2020.<sup>73</sup>



i For details on India, see endnote 59 for this section.

**FIGURE 28.** Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2020



Note: Totals may not add up due to rounding.  
 Source: See endnote 69 for this section.

The US market was led by the utility-scale sector, which was up 67% to nearly 14 GW, for a year-end total of 59.8 GW.<sup>74</sup> The significant jump came as developers rushed to qualify for the federal investment tax credit (ITC) before the expected rate reduction at the end of the year (the rate ended up being extended for two years in December 2020).<sup>75</sup> The volume of new projects announced in 2020 reached 30.6 GW, bringing the pipeline of US utility-scale solar PV projects under contract at year's end to 69 GW.<sup>76</sup> Growth in this sector is driven by several factors, including self-enforced utility carbon reduction plans, the expansion of state-level mandates through renewable portfolio standards (RPS laws), and large corporations with renewable or carbon reduction goals (→ see *Feature chapter*).<sup>77</sup>

Non-residential<sup>i</sup> installations declined (down 4%) for the third consecutive year and faced the worst pandemic-related delays of any sector, adding 2.1 GW for a total of 16.7 GW.<sup>78</sup> In contrast, the residential market rose 11% compared with 2019, with a record 3.2 GW added for a total of 19.1 GW.<sup>79</sup> The pandemic caused great disruption in this sector as well, with installers laying off thousands of employees and some filing for bankruptcy, and it forced many installers to shift sales from in-person to online and to make serious price cuts.<sup>80</sup> Battles to weaken state net metering laws also continued during the year.<sup>81</sup> Despite the challenges, the market picked up considerably in the second half of 2020 due in part to increased interest in home improvements.<sup>82</sup> Residential solar PV with battery installations also rose, particularly in California following rolling power outages due to massive wildfires.<sup>83</sup>

Demand for solar-plus-storage systems was up in all US sectors in 2020. It accounted for nearly 6% of behind-the-meter solar systems and for more than one-fourth of all contracted utility-scale projects.<sup>84</sup> Utility commissions in some states (e.g., Nevada) established goals for

energy storage procurement, and some utilities brought into operation new solar-plus-storage plants, while others released solicitations for new capacity.<sup>85</sup> Interest in energy storage for large-scale plants has been driven by falling costs (of both solar generation and batteries) combined with rising solar energy penetration, which improves the business case for projects that can dispatch this power to meet evening peak demand.<sup>86</sup> Demand is also growing for hybridised solar and wind power plants, encouraged by falling costs and looming tax credit deadlines, and as a means to optimise land use and transmission capacity and to increase revenue.<sup>87</sup> (→ See *Systems Integration chapter*.)

A handful of countries in **Latin America and the Caribbean** continued to expand their solar PV capacity, despite challenging economic conditions, thanks largely to an abundance of solar resources, falling prices and favourable policies in some countries.<sup>88</sup> The region's top four installers in 2020 were Brazil (adding 3.1 GW), Mexico (1.5 GW), Chile (0.8 GW) and Argentina (0.3 GW).<sup>89</sup>

Increased interest in home improvements during the pandemic helped drive demand for **new residential systems** in several countries.

<sup>i</sup> Includes commercial, government, non-profit and community solar PV systems.



Brazil maintained its regional lead for annual additions and surged past Mexico (5 GW) for total capacity, ending the year with 7.7 GW.<sup>90</sup> Annual installations in Brazil were up 68.6% over 2019.<sup>91</sup> For the second year running, Brazil's distributed segment (defined as less than 5 MW) led the market for capacity added (2.5 GW), investments and job creation, driven by a national net metering regulation and electricity prices rising above inflation rates.<sup>92</sup> Residential systems accounted for the largest portion of distributed installations (74.4%), but commercial and rural systems also saw rising shares.<sup>93</sup>

During 2020, the debate regarding proposed changes to Brazil's net metering mechanism was interrupted as the National Congress turned its focus to the pandemic, but a new legal framework for distributed generation was under development in early 2021 and expected to soon become law.<sup>94</sup> Public energy auctions for large-scale power plants were postponed, also due to the pandemic, but new tenders (including for solar PV) were scheduled for the years 2021-2023.<sup>95</sup> Large projects also moved ahead in the private sector: Brazil's largest-ever solar PPA was signed in March for the 330 MW Atlas Casablanca plant, which will provide electricity for Anglo-American mining operations.<sup>96</sup>

The mining industry also helped drive new installations in **Chile**, where a copper mining company signed a PPA in 2020 for around-the-clock solar energy (with battery storage) to cover 12% of the Collahuasi mine's electricity needs.<sup>97</sup> Also in Chile, an existing plant reportedly became the world's first utility-scale solar PV facility licensed to deliver commercial ancillary services to the grid.<sup>98</sup> Chile's solar PV capacity was approaching 3.5 GW at year's end, with another 3.9 GW under construction.<sup>99</sup>

**Europe** followed the Americas for additions in 2020, with more than 22 GW added for a year-end total of 162.7 GW, maintaining

its second-place regional ranking for total operating capacity.<sup>100</sup> Installations in the EU-27 were up significantly relative to 2019, and noteworthy additions also occurred elsewhere in the region.<sup>101</sup> The Russian Federation nearly doubled its operating capacity, adding more than 0.7 GW for a total of 1.9 GW.<sup>102</sup> The United Kingdom added 0.5 GW, above installations in the previous year but well below the 2015 peak (4.1 GW), bringing total capacity to 13.9 GW.<sup>103</sup> However, several additional large-scale projects without direct subsidies were under construction in the country, some incorporating energy storage to access higher market prices.<sup>104</sup> As part of the effort to accelerate decarbonisation, the UK government announced plans to reopen access to Contracts for Difference<sup>i</sup> auctions for solar PV (and onshore wind power), for the first time since 2015.<sup>105</sup>

Installations in the EU-27 were well below expectations due to the pandemic; nevertheless, 2020 turned out to be the region's second-best year on record, and solar PV provided more new power capacity than any other generating technology.<sup>106</sup> Around 19.3 GW was brought online, raising total solar PV capacity by about 15%, to 140.5 GW.<sup>107</sup> Most EU markets have moved beyond FITs and are propelled by the competitiveness of solar generation – in many EU Member States, solar PV is now the cheapest incremental source of electricity and the fastest to install.<sup>108</sup> Economic competitiveness is elevating interest in self-consumption and corporate renewable power sourcing (including via direct bilateral PPAs), and is encouraging governments that are looking to meet national renewable energy targets through tenders.<sup>109</sup> At the same time, new challenges are emerging, including access to grid connections, land availability and planning permission (particularly in areas that already have a large installed base), and a shortening of PPA time periods with the shift towards merchant projects<sup>ii,110</sup>

i The Contracts for Difference (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 Merchant projects are those with no regulated or contracted income. The electricity generated is sold into competitive wholesale markets.



In 2020, 22 of the 27 EU Member States added more capacity than they had installed in 2019; even so, nearly three-fourths of new capacity came online in only five countries.<sup>111</sup> Germany regained its top position (held for most of the past two decades) from Spain, and was followed by the Netherlands (3 GW), Spain (2.8 GW), Poland (2.6 GW) and Belgium (1 GW).<sup>112</sup> The top EU countries<sup>i</sup> for total capacity at year's end were Germany, Italy, Spain, France and the Netherlands.<sup>113</sup>

Small-scale rooftop systems alone accounted for **6.5%** of Australia's total electricity generation in 2020.

Germany saw another large jump in installations (up 27%), with nearly 4.9 GW added for a total approaching 53.9 GW.<sup>114</sup> The commercial segment saw slower growth in 2020, but still expanded slightly and accounted for 59% of the total market.<sup>115</sup> The large-scale segment (>750 kW, mostly ground-mounted) accounted for less than 18% of the market, but it saw substantial growth (up 61%) as a result of special tenders.<sup>116</sup> Demand for residential rooftop systems (<10 kW) nearly doubled relative to 2019, and the sector accounted for 23% of the annual market (up from 15%) as homeowners became increasingly motivated by environmental concerns and the desire for energy independence and electric mobility.<sup>117</sup> More than half of the new rooftop systems (<10 kW) were installed with battery storage.<sup>118</sup>

The 52 GW cap<sup>ii</sup> on solar PV systems under Germany's feed-in law was officially removed in July, only weeks before the limit was reached.<sup>119</sup> In late 2020, the federal government set new targets for 83 GW by 2026 and 100 GW by 2030 under the new Renewable Energy Sources Act (EEG).<sup>120</sup> As solar PV penetration continues to rise, feed-in management is playing an increasingly important role. The EEG includes specific requirements for solar systems, depending on plant size, to enable the grid operator to remotely modulate the amount of electricity fed into the grid, as needed.<sup>121</sup> Solar PV produced an estimated 50.6 TWh in 2020, accounting for 10.5% of Germany's electricity generation.<sup>122</sup>

The Netherlands has seen steady market growth for several years, driven by net metering for residential and small business systems and tendering for larger plants.<sup>123</sup> More than 3 GW was added in 2020 (nearly half of which was commercial rooftop systems) for a total of 10.2 GW.<sup>124</sup> Interest in floating solar PV plants and solar carports increased during the year, and the country's largest ground-mounted plant (110 MW) became operational.<sup>125</sup> For all of 2020, grid-connected solar PV covered around 6.6% (7.92 TWh) of the country's electricity demand.<sup>126</sup>

Spain added around 2.8 GW in 2020 for a total of 12.7 GW.<sup>127</sup> Whereas much of the capacity added in 2019 had been due to tenders held in 2017, in 2020 a large portion of installations was private PPAs for projects without direct public support.<sup>128</sup> This marks the first time that such a sizeable amount of capacity has

been grid-connected in Europe without a government subsidy or auction programme.<sup>129</sup> Spain's self-consumption market expanded nearly 30%, with tremendous growth in the residential sector.<sup>130</sup> Solar PV capacity accounted for 6.1% of Spain's electricity generation in 2020, up from 3.5% in 2019.<sup>131</sup>

The annual market in Poland more than doubled in 2020 (2.6 GW added for a total of 3.9 GW), driven by favourable self-consumption policies and low-interest loans.<sup>132</sup> Industrial consumers have started turning to renewables, including solar PV, in place of coal-fired generation.<sup>133</sup> Other notable developments in Europe included: Switzerland saw a record market increase (up at least 30%), driven in part by a rising desire for energy self-sufficiency; in Denmark a solar initiative was under way to enable more than 400,000 residents to become shareholders in solar parks (totalling 1 GW) across Denmark and Poland; and Lithuania reportedly became the first country in the world to launch an online platform that enables consumers to buy electricity from a remote solar panel.<sup>134</sup>

In the **South Pacific**, Australia continued to be the largest market by far, ranking seventh globally for both additions and total capacity.<sup>135</sup> The first half of 2020 was challenging due to devastating bushfires, delays in finalising grid connections as well as the pandemic, all of which caused a lull in utility-scale installations early in the year.<sup>136</sup> But the fires also affected thousands of kilometres of transmission and distribution lines, which drove interest in – and policies supporting – micro grids and stand-alone power systems, particularly solar PV, in remote and rural areas.<sup>137</sup> Overall, Australia added an estimated 4.1 GW of solar PV capacity in 2020 for a total exceeding 20.4 GW.<sup>138</sup> Despite the impacts of fires on solar output across much of the country, solar PV generation rose more than 24%, to 22.5 TWh, or 9.9% of Australia's total; small-scale rooftop systems alone accounted for 6.5% of total generation.<sup>139</sup>

The rooftop sector continued to contribute most of the capacity added in Australia, with new records set for both solar PV and home battery storage installations.<sup>140</sup> More than 2.6 GW of solar PV systems under 100 kW was installed on rooftops of homes and small businesses in 2020, up from about 2.3 GW in 2019, for a total exceeding 13 GW.<sup>141</sup> Households added an estimated 23,796 small-scale battery systems (up 5% over 2019), with a combined capacity of 238 MWh.<sup>142</sup>

The surge in demand for both solar PV and home storage systems in Australia was driven by several factors, including concerns about climate change, rising electricity costs, supportive policies, the desire for energy independence and pandemic-related impacts (home energy bills rose due to remote work, even as solar prices continued to fall, and people had more time to devote to home improvements).<sup>143</sup> By one estimate, nearly 2.7 million homes and businesses across the country had rooftop solar systems by the end of 2020.<sup>144</sup> As of early 2021, the share of dwellings with solar PV systems exceeded 20% in every state and territory except Tasmania; the top three were Queensland (41%), South Australia (40.3%) and Western Australia (33.2%).<sup>145</sup>

i The United Kingdom ranks third in Europe for total capacity, following Germany and Italy.

ii Exceeding the 52 GW cap would have ended feed-in payments for new systems up to 750 kW. The revised law, passed in December, maintains the feed-in payment for systems up to 300 kW. See endnote 119 for this section.



The state of South Australia has achieved one of the highest levels of solar penetration in the world and faces a widening mismatch between supply and demand. On many days, the amount of electricity entering the grid is well above the level of demand, making the state's power system the first large-scale system in the world to approach zero operational demand due to the growth of distributed solar PV, and requiring a number of measures to maintain grid stability and manage the electricity system.<sup>146</sup> In response, new tariffs were introduced to encourage a shift in consumption to peak solar hours, as well as new technical requirements that enable the market operator to turn off systems remotely.<sup>147</sup>

Across Australia, transmission infrastructure has not kept pace with the growth of renewables, especially large-scale solar (and wind) power projects.<sup>148</sup> Grid challenges, including insufficient system strength and congestion combined with a lack of clarity about state and federal policies, have resulted in delayed and cancelled renewable power projects, and have raised barriers to investment.<sup>149</sup> In early 2020, frustration over grid congestion led Victoria to break away from national electricity market rules in order to enact legislation to upgrade transmission infrastructure and prioritise storage and other projects to ensure a resilient energy system.<sup>150</sup>

To address challenges related to utility-scale projects in particular, the Australian Energy Market Operator (AEMO) was developing plans in 2020 for several Renewable Energy Zones (REZs) across five Australian states; the REZs will host solar and wind power projects co-located with energy-intensive industry, along with energy storage and strong grid connections.<sup>151</sup> In addition, Australia has seen a surge in small utility-scale systems (especially around 5 MW), which are relatively easy to grid-connect and face fewer transmission constraints.<sup>152</sup>

Other markets in the South Pacific remained small in comparison. In 2020, New Zealand commissioned a 1 MW floating array atop a wastewater treatment lake, the country's largest installation, and the Cook Islands, Fiji, Micronesia, New Caledonia, Papua New Guinea and the Kingdom of Tonga were among the small island states setting targets, commencing pilot programmes or launching tenders for solar PV (plus storage in many cases) in their efforts to reduce reliance on fuel imports and provide universal electricity access.<sup>153</sup> Fiji has seen rapid growth in commercial rooftop systems since 2015 and, in 2020, moved closer to its target of 100% renewable energy with plans to add at least 15 MW to the national grid.<sup>154</sup> As of 2020, Micronesia generated more than 11% of its electricity with solar PV.<sup>155</sup>

The **Middle East and Africa** combined added an estimated 4 GW in 2020 for a year-end total as high as 24 GW.<sup>156</sup> An increasing number of countries across the region had net metering policies in place (e.g., Israel, United Arab Emirates) or introduced or passed new laws to that effect (e.g., Egypt, Ghana, Kenya, Morocco, Nigeria).<sup>157</sup> Several countries also published requests for qualification (Saudi Arabia), floated tenders or awarded capacity for solar PV projects (e.g., Israel, Malawi, Syria, Tunisia, United Arab Emirates, Zimbabwe).<sup>158</sup>

In the Middle East, social impacts of the pandemic, combined with a decline in oil and gas prices<sup>i</sup>, slowed progress in the planning and completion of new solar PV projects.<sup>159</sup> At the same time, the pandemic highlighted the importance of energy security and increased awareness of and political support for more-sustainable energy sources.<sup>160</sup> The largest installers in the region were Israel (0.6 GW), Oman (0.4 GW) and the United Arab Emirates (at least 0.3 GW).<sup>161</sup> Dubai (UAE) completed phase 3 (totalling 0.8 GW) of its Mohammad Bin Rashid Solar Park, Jordan brought online a 46 MW plant, and Oman's first renewable independent power producer (125 MW) began commercial operations.<sup>162</sup> Oman also announced plans for a 3.5 GW project to produce hydrogen with solar PV and is targeting thousands of residential rooftop installations in Muscat.<sup>163</sup>

Focus on distributed rooftop generation is increasing across the Middle East as a means to provide energy access and to reduce electricity bills for residential, commercial and industrial consumers.<sup>164</sup> In 2020, Saudi Arabia launched its first regulatory framework for 1-2 MW grid-connected systems, and several other countries in the region were creating initiatives to advance distributed solar PV in the commercial and industrial sectors.<sup>165</sup> At year's end, the top countries in the Middle East for total operating capacity were the United Arab Emirates (almost 3 GW), Israel (2.5 GW) and Jordan (1.5 GW).<sup>166</sup>



<sup>i</sup> The decline in oil and gas prices decreased revenue in some countries, while falling energy prices due to lower demand also reduced the incentive to shift to renewable energy. See endnote 159 for this section.

Across Africa, as costs of solar PV (as well as batteries) fall, solar PV is viewed increasingly as a means to achieve a variety of objectives, depending on the country. These include improving reliability and security of electricity supply, diversifying the energy mix (and either reducing energy imports or increasing exports), providing energy access, and meeting rising electricity demand while limiting the growth of CO<sub>2</sub> emissions.<sup>167</sup> (→ See *Distributed Renewables* chapter for more on solar PV for energy access.) Interest in solar energy for hospitals and other critical facilities also increased as part of national responses to the pandemic.<sup>168</sup> Considerable challenges remain, including a lack of suitable financing tools, lack of transparency, ongoing subsidies for fossil fuels in many countries, social and political unrest in some countries, and a heavy reliance on tenders for new capacity combined with a race to the bottom in bid prices.<sup>169</sup> Yet, some of the challenges (such as lack of regulatory frameworks for independent power producers and weak transmission grids) are helping to drive commercial and industrial markets for distributed solar PV.<sup>170</sup>

Ground-mounted systems are **growing ever larger** as developers work to further reduce the price of solar electricity through economies of scale.

Several countries across Africa commissioned new capacity in 2020. West Africa's largest plant (50 MW) came online in Mali, where hydropower accounts for around half of the country's installed capacity but provides increasingly variable output due to hydrological changes.<sup>171</sup> Medium-to-large projects were commissioned or began construction in several other countries, including Egypt, Ethiopia, Ghana, Somalia and South Africa.<sup>172</sup> The Egyptian government's gradual removal of subsidies on retail electricity prices is increasing the appeal of distributed solar PV for residential, commercial and industrial uses.<sup>173</sup> At year's end, Africa's top countries for total capacity were South Africa with 3.8 GW (added 1.1 GW), Egypt with around 2 GW and Algeria with 0.5 GW.<sup>174</sup>

Around the world, favourable economics are raising interest in distributed rooftop systems, which gained market share relative to large utility-scale projects, from around 35% in 2019 to around 40% in 2020; this was due mainly to strong growth in Vietnam, as well as increases in Australia, Germany and the United States.<sup>175</sup> Utility-scale capacity also rose during the year, and the size and number of large-scale projects continued to grow.<sup>176</sup> (Even the size of distributed systems is trending larger in many countries.<sup>177</sup>) The move towards **ever-larger ground-mounted systems** is due at least in part to the growing use of tenders and auctions, and increasingly also to PPAs, as developers work to further reduce the price of solar electricity through economies of scale in construction and in operations and maintenance.<sup>178</sup>

During 2020, around 80 plants of 50 MW and larger were completed (exceeding 21 GW in combined capacity), and such plants were operating in at least 49 countries<sup>i</sup> by year's end.<sup>179</sup> Developers completed at least 30 projects with capacity of 200 MW or larger.<sup>180</sup> In addition to those mentioned earlier, new facilities included Spain's 500 MW Nuñez de Balboa, Europe's then-largest solar PV plant, which will serve several clients through PPAs; and India's 2.2 GW<sup>ii</sup> Bhadla solar park, which became the world's largest with the completion of an additional 300 MW.<sup>181</sup> Numerous other large projects around the globe were either under way, completed construction or came online.<sup>182</sup>

If ground-mounted solar PV plants are well-designed and -built, competition over land can be reduced, and studies have shown that they can help to conserve biodiversity; however, large-scale ground-mounted plants can cover vast areas and their increasing numbers and scale are raising concerns about potential impacts on ecosystems and landscapes, grid-connection challenges and the use of agricultural lands and groundwater supplies (for cleaning).<sup>183</sup> As a result, there is increasing interest in alternatives. The potential for rooftop solar systems remains enormous, and many countries have established large rooftop programmes and targets.<sup>184</sup> There are also several **niche markets** that minimise land requirements, including building-integrated PV (BIPV), which is progressing only slowly, and the emergence of plans among mainstream auto manufacturers, particularly in Asia, to incorporate solar cells into electric vehicles.<sup>185</sup> Several BIPV projects were completed during 2020, including in India and the United States; in Europe the sector is driven mainly by France and Italy, which have targeted support schemes.<sup>186</sup>

The relatively small market for **floating solar** also continued its rapid expansion, driven by the limited availability and high costs of land in many places, as well as by design innovations that are helping to reduce costs.<sup>187</sup> Floating projects bring new risks and generally higher costs than ground-mounted facilities, but they also provide benefits (e.g., reducing land use for solar projects, reducing evaporation), especially where land is scarce or where they can be combined with hydropower.<sup>188</sup> Economies of scale in project sizes are helping to reduce associated costs.<sup>189</sup>



i Countries that added their first plants of 50 MW and larger in 2020 include Mali and Oman. See endnote 179 for this section.  
 ii This project totals 2,245 MW (45 MW larger than China's plant in Quinghai).

Most floating solar PV projects are sited in Asia, but they can be found in virtually every region.<sup>190</sup> By one estimate, more than 60 countries had such projects under way or in operation, and total global capacity reached around 2.6 GW in 2020.<sup>191</sup> Projects that became operational during the year included: in the Netherlands, Europe's largest floating plant (27.4 MW) was connected to the regional grid; in Ghana, the first section (5 MW) of a floating project was connected to the transmission system of a dam on the Black Volta River; and Chile's largest floating project was deployed under the country's net billing scheme.<sup>192</sup> As of early 2021, the largest floating solar plant in operation was a 181 MW plant off the west coast of Chinese Taipei.<sup>193</sup> Interest in moving offshore is rising, despite the additional challenges associated with currents, waves and salt water.<sup>194</sup>

**Agricultural PV** – the use of the same site for both energy and crop production – also is a rapidly emerging sector that can address concerns associated with land use, especially with the growing availability of bifacial systems (see later discussion),<sup>195</sup> Rising interest in this sector is also driven by concerns about potential impacts of climate change on crops and livestock.<sup>196</sup> While costs are higher relative to traditional ground-mounted systems, several studies have highlighted the advantages, including improved crop yields, reduced evaporation, rainwater harvesting (with modules), provision of shade for livestock or crops and protection against extreme weather events, prevention of wind and soil erosion, as well as additional income for farmers associated with electricity production.<sup>197</sup> Agricultural PV projects have been deployed for a number of years in Japan, the Republic of Korea and India, where there are active programmes to encourage deployment, and numerous pilot projects were under way during 2020 across Europe, China, Israel and the United States.<sup>198</sup>

## SOLAR PV INDUSTRY

The solar PV industry rode a rollercoaster in 2020, with shockwaves of disruption driven largely by the pandemic. In early 2020, China – the dominant producer and global supplier of solar PV cells and modules – closed manufacturing and distribution facilities in several provinces.<sup>199</sup> As China began reopening by the second quarter, further disruption was triggered by pandemic-forced halts in the construction of solar projects in Europe, then the United States and elsewhere; at the same time, widespread economic closures reduced electricity demand and created uncertainties over future wholesale prices in many countries, slowing investment in new projects and the signing of PPAs.<sup>200</sup> By the third quarter, restrictions were eased and project construction resumed in many markets.<sup>201</sup> Also, however, starting mid-year, accidents at polysilicon facilities in Xinjiang, China, as well as a shortage of solar glass, drove up module prices.<sup>202</sup> Despite the many challenges, new actors continued to enter the sector, and competition and price pressures have motivated investment in technologies across the value chain to improve efficiencies, reduce the levelised cost of energy (LCOE) and improve margins.<sup>203</sup>

In response to COVID-related challenges, **several countries supported their domestic solar industries** by extending completion deadlines for awarded capacity or modifying tenders (e.g., Germany, France, India), or by extending deadlines for projects to receive incentives (e.g., the United States).<sup>204</sup> Spain's Royal Decree explicitly included solar PV as a key part of the national economic recovery, as did Italy's Relaunch Decree, while national and state governments in India took steps to support solar PV (and wind power) operations and new investment, including granting must-run status to insulate generators from declining electricity demand.<sup>205</sup> (→ See *Policy Landscape* chapter.)



## Agricultural PV

is rapidly emerging as an option for addressing concerns related to land-use as well as for mitigating the potential impacts of climate change on crops and livestock.

i Glass prices rose sharply due to a combination of stagnating supply and the global year-end rush for solar PV installations, combined with rising interest in larger modules as well as bifacial panels. Stagnating supply resulted from a cap on glass production capacity in China (home to 90% of global production capacity) in response to past overcapacity in the building industry as well as environmental concerns associated with glass production. By one estimate, shortages pushed up global solar glass prices more than 70% between July and November 2020. See endnote 202 for this section.



Disrupted supply chains and other pandemic-related challenges also elevated calls in many countries and regions for the **creation of local supply chains** to reduce heavy reliance on a limited number of manufacturers in a single region (Asia, and mostly China).<sup>206</sup> Governments acted through both trade policy and the direct promotion of manufacturing in an attempt to regain some control over the supply and price of solar products.

In the United States, tariffs on solar-related imports from China and several other countries continued throughout 2020.<sup>207</sup> In November, the on-off exemption for bifacial cells and modules was again revoked, and new duties were imposed on silicon metal imports from Bosnia, Herzegovina, Iceland and Kazakhstan.<sup>208</sup>

India extended the safeguard duty on imported solar cells and modules for another year and, in December 2020, imposed a countervailing duty on solar glass imported from Malaysia.<sup>209</sup> The country also promoted increased self-reliance through the “Make in India” initiative, and launched tenders and incentives linked to the development of domestic cell and module manufacturing capacity.<sup>210</sup>

In 2020, the European Commission began working with industry to promote and support solar research and development, as well as investment in manufacturing of solar technology along the whole value chain.<sup>211</sup> The governments of Turkey as well as several countries in the Middle East also were encouraging the development of domestic industries.<sup>212</sup> In Egypt, for example, a project was launched to develop a sand-to-cell complex to boost local manufacturing.<sup>213</sup> Several additional countries had measures in place to encourage domestic production or to penalise the use of foreign-made products.<sup>214</sup>

At the start of 2020, China announced that it would extend duties on polysilicon from the United States and the Republic of Korea for five more years to build a self-sufficient domestic industry.<sup>215</sup> China accounted for about 80% of global polysilicon production as of 2020, up from 26% in 2010.<sup>216</sup>

More than 45% of the world’s **polysilicon** is produced at facilities in China’s Xinjiang province, with producers drawn to the region by low costs of labour and energy (mostly coal-fired generation).<sup>217</sup> In late 2020, concerns arose among investors and others across the industry regarding allegations of the use of forced labour for polysilicon production in Xinjiang.<sup>218</sup> Although the Chinese government and China’s solar industry trade group have denied these claims, solar industry groups in the United States and Europe have called for increased transparency and the upholding of human rights throughout the global supply chain, and concerns have been raised in Australia and Japan as well.<sup>219</sup>

In response to these concerns, the top trade group for the US solar industry began publicly encouraging companies to move their supply chains out of Xinjiang and, in late 2020, announced that it was developing a supply chain traceability protocol.<sup>220</sup> The leading industry group in Europe called for strengthening the EU solar industrial base to help diversify and improve Europe’s position in the solar supply chain.<sup>221</sup> The situation has further highlighted the high dependence of the industry on a relatively small number of manufacturers, located in a single region.<sup>222</sup>

Globally, **average module prices** fell 8% between late 2019 and the end of 2020, from an average USD 0.36 per watt-peak (Wp) to USD 0.33 per Wp.<sup>223</sup> This was despite shortage-induced price increases for both polysilicon and glass, which module manufacturers could not pass along to consumers.<sup>224</sup> By one estimate, the global benchmark LCOE<sup>i</sup> of utility-scale solar PV declined 4% from the second half of 2019 until early 2020, to USD 50 per MWh.<sup>225</sup>

In 2020, **tenders and auctions** again saw bid prices<sup>ii</sup> drop to new lows.<sup>226</sup> The lowest bid prices were seen in Portugal, Abu Dhabi (UAE) (USD 13.5 per MWh) and Qatar (just under USD 15.7 per MWh), for the country’s first utility-scale project.<sup>227</sup> Portugal’s second solar auction, for a total 700 MW under three separate remuneration categories (including a new category for solar-plus-storage), saw a winning bid at USD 13.2 per MWh for a 10 MW solar PV system plus storage<sup>iii</sup>.<sup>228</sup>



i Energy costs vary widely according to solar resource, regulatory and fiscal framework, trade policies, project size, customer type, the costs of capital, land and labour, exchange rates 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. In addition, price is not equal to cost and is influenced by several factors unrelated to the costs of production including government support policies, competing technologies, level of competition, price expectations and end-user tastes. See endnote 225 for this section.

ii Note that bid levels do not necessarily equate with costs. Bid levels differ from market to market due to varying auction designs, policies and risks, among other factors.

iii Under the auction’s rules, Portugal’s winning projects in the Fixed Premium for Flexibility remuneration modality are required to build energy storage capacity accounting for at least 20% of tendered solar capacity to address variability, provide flexibility and other grid regulation services, and to compensate the network for peaking power prices in the spot market for 15 years. See endnote 228 for this section.



India set its own low bid record (USD 26.9 per MWh) in a Gujarat auction, following a continuous decline in bid prices across the country throughout the year.<sup>229</sup> Average tariffs awarded during 2020 were below those in 2019 and among the lowest in the world, driven by a mix of government support policies, bidder assumptions about future equipment prices, and the participation of international developers with access to low-cost financing.<sup>230</sup>

Falling bids in tenders and auctions have prompted efforts to renegotiate prices under existing PPAs, an additional challenge to the industry. In India, attempts to renegotiate prices in several states have left institutions and investors reluctant to finance projects under government PPAs.<sup>231</sup> In South Africa, the state-owned utility Eskom announced plans to renegotiate PPAs with renewable independent power producers from the first two bid rounds of the national procurement programme.<sup>232</sup> Similar renegotiation efforts were under way in Saudi Arabia during 2020.<sup>233</sup>

Outside of locations with a low cost of finance and excellent solar resources, such as Abu Dhabi or Qatar, a broad range of experts believe that very low bids, such as Portugal's winning price, often are driven by extreme competition and the desire to access grid connections and markets.<sup>234</sup> In such instances, low bids are thought to be possible only because firms make 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.<sup>235</sup> In 2020, manufacturers and developers across much of the solar PV industry experienced low margins.<sup>236</sup>

**Direct bilateral PPA prices** saw mixed developments during the year. In North America, average PPA prices rose throughout 2020, after falling continuously since early 2018, due to grid connection delays, permitting challenges, the step-down of the federal investment tax credit as of January 2020, as well as pandemic-related challenges.<sup>237</sup> An exception was seen in New

Mexico, with record-low prices for a solar PV plant (USD 15 per MWh) and a solar-plus-storage facility (USD 21 per MWh), which together will replace a natural gas steam plant<sup>i</sup> due to be retired in 2022.<sup>238</sup> In Europe, PPA prices declined slightly, at least in the fourth quarter, with the lowest price reported in Spain (EUR 35, or USD 43, per MWh).<sup>239</sup> Prices also were low in Germany, Denmark and Sweden, due at least in part to high levels of renewable energy penetration, which depressed electricity market prices.<sup>240</sup>

**Global shipments** of cells and modules were down in the first half of the year, but for all of 2020 they increased 7% relative to 2019.<sup>241</sup> Of the estimated 131.7 GW of cell/module volume shipped in 2020, around 86% was shipped by Chinese firms (including their facilities in Southeast Asia).<sup>242</sup> The top 10 companies accounted for 71% of shipments, and all were Chinese based with the exception of US-based First Solar (with 4%).<sup>243</sup> First Solar continued to dominate global thin film shipments, which accounted for 5% of the year's total cell/module shipments.<sup>244</sup>

Despite the challenges in 2020, many companies achieved major increases in **production capacity** during the year. Most of the expansions occurred in China, but there was activity elsewhere as well.<sup>245</sup> For example, Mexican solar module manufacturer Solarever opened the first module assembly line (500 MW per year) of three at its third facility in Mexico, and Turkey's Kalyon facility (500 MW per year) came online, with processes for manufacturing ingots, wafers, cells and modules.<sup>246</sup>

By the end of 2020, global crystalline and thin film commercial cell production and module assembly capacities<sup>ii</sup> were estimated to be 203.7 GW (cell) and 248.6 GW (module), up 33% and 34% respectively over 2019.<sup>247</sup> An estimated 66% of commercial<sup>iii</sup> cell production capacity and 60% of module assembly capacity was located in China; the United States and Europe each were home to around 1% of cell capacity and 2% of module capacity, and most of the rest was elsewhere in Asia (particularly Malaysia and Vietnam) with much of that owned by Chinese firms.<sup>248</sup>

## Manufacturers and developers

across much of the solar PV industry experienced low margins in 2020.



i Four additional solar PV-plus-storage plants in New Mexico, due for commissioning in mid-2022, will replace a large coal-fired generator in the US state. The utility will pay in the range of USD 18-25 per MWh. See endnote 238 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 Commercial capacity is not the same as nameplate capacity of the equipment, which is the stated capacity under ideal conditions. P. Mints, SPV March Research, *The Solar Flare*, 26 February 2021, p. 7.

Throughout the year, manufacturers announced plans to further increase production capacity in 2021 and beyond.<sup>249</sup> Most planned expansion was by Chinese producers of polysilicon, wafers, cells and modules.<sup>250</sup> Tongwei Solar, for example, revealed plans to expand polysilicon production and to raise its cell production capacity from 20 GW to 30 GW in 2021, with a goal of expanding to 60 GW by 2022.<sup>251</sup>

Elsewhere, several European manufacturers looking to regain market share opened or announced plans for new facilities in Europe.<sup>252</sup> For example, Ecosolifer AG (Hungary) started commercial production of heterojunction<sup>i</sup> (HJT) cells at a 100 MW factory, the Hevel Group (Russian Federation) launched HJT cell production, and Meyer-Burger Technology (Switzerland) announced that it would shift from merely selling its production equipment to using its technology to manufacture HJT cells and modules, with plans to scale up to 5 GW module production capacity in Germany by 2026.<sup>253</sup> In Africa, Mondragon Assembly (Spain) provided assembly lines for new module production facilities in Algeria and Egypt.<sup>254</sup>

The year also saw **consolidation** among manufacturers and installers, driven by pandemic-related challenges as well as longer-term concerns. In China, the pandemic resulted in the closure of several relatively small solar manufacturers, relieving the central government of its plans to eliminate them.<sup>255</sup> The largest solar PV manufacturer to fall in 2020, Yingli (China), was the world's biggest panel maker as recently as 2013.<sup>256</sup> Aggressive borrowing alongside a plunge in solar prices led to years of losses and rising debt; the company entered restructuring in 2020 and was brought under government control and renamed "New Yingli".<sup>257</sup>

In addition, Panasonic (Japan) and Tesla (US) ended their partnership and, in early 2021, Panasonic, which entered the solar sector in 2008, announced plans to cease all production of cells and modules by 2022, due to the pandemic and highly competitive pricing.<sup>258</sup> A subsidiary of Inventec (Chinese Taipei)

announced that it would end cell production in 2021, due to margin constraints.<sup>259</sup> SunPower (US), another long-lived manufacturer of cells and modules, spun off its panel manufacturing and sales to Maxeon (Singapore) and, in early 2021, announced plans to close its remaining US panel manufacturing facility to focus on solar and battery sales and services.<sup>260</sup> First Solar (US) sold its operation and maintenance business in North America due to falling margins to focus on module manufacturing.<sup>261</sup>

Also in 2020, the leading US residential solar, battery storage and energy services company, Sunrun, acquired Vivent (US), a leading competitor, representing the largest rooftop solar consolidation yet.<sup>262</sup> In August, solar manufacturer Hanwha Q Cells (Republic of Korea) acquired energy storage solutions company Growing Energy Labs, Inc. (GELI, US) to expand into the US solar-plus-storage market.<sup>263</sup>

As in the wind power industry, **new actors** including fossil fuel companies continued to enter the solar sector.<sup>264</sup> Several European oil and gas companies are acquiring existing solar PV projects as investments or are constructing and operating new projects.<sup>265</sup> In 2020, BP announced a partnership with Chinese module manufacturer JinkoSolar to provide clean energy for commercial and industrial customers in China, and Spanish gas grid operator Enagás signed an agreement with Anpere Energy (Spain) to jointly produce hydrogen with solar PV, with plans to inject hydrogen into Spain's gas network.<sup>266</sup>

Other fossil fuel companies are engaging in research and development (R&D) or moving into production. US oil and gas company Hunt Consolidated announced that its R&D work with perovskite cells had achieved efficiency performance levels of 18%; as of late 2020, the company owned the largest portfolio of perovskite solar patents in the United States and one of the largest in the world.<sup>267</sup> In India, state-owned Coal India (the world's largest coal producer) received approval in December to set up an integrated solar wafer manufacturing facility.<sup>268</sup>



i HJT combines advantages of conventional crystalline silicon solar cells with good absorption and other benefits of amorphous silicon thin film technology.

Competition and price pressures have encouraged **investment in solar PV technologies** across the entire value chain, particularly in solar cells and modules, to further improve efficiencies and reduce the LCOE.<sup>269</sup> As in previous years, several new record cell and module efficiencies were achieved during 2020.<sup>270</sup> Monocrystalline<sup>i</sup> cell technology – which lost its lead to multicrystalline in 2002 and retook it in 2019 – continued to gain market share (up 26 percentage points to 88% of shipments), and it accounted for all expansions of silicon ingot crystallisation capacity in 2020.<sup>271</sup> As the cost differential between technologies has fallen, a higher priority has been placed on the higher efficiency potential of monocrystalline technology.<sup>272</sup>

Economics also have played a role in driving ever larger wafers and modules.<sup>273</sup> Manufacturers started enlarging wafers (used to make solar cells) around 2017 to optimise costs, and because it was the easiest way to increase the power of modules.<sup>274</sup> By 2020, most of the sector was increasing sizes again and, by year's end, most major module manufacturers were preparing to produce panels based on larger wafers.<sup>275</sup> The rapid shift has left many smaller companies behind and has raised manufacturing costs throughout the supply chain.<sup>276</sup> As a result, by early 2021 Trina and several other large module manufacturers were working to standardise wafer sizing.<sup>277</sup>

Demand for higher-efficiency modules helped to steer a shift towards passivated emitter rear cell (PERC)<sup>ii</sup> technology, which accounted for the majority of cell shipments in 2020.<sup>278</sup> Yet, while monocrystalline PERC has been the focus of most manufacturing capacity expansions in recent years, the industry is already looking beyond PERC, with the first large manufacturers starting to produce new cell technologies that promise even higher efficiencies and output and offer the potential to improve margins.<sup>279</sup> Passivated contact cells<sup>iii</sup> (TOPCon) might be the next evolutionary step, requiring the upgrading of PERC production lines, while HJT cell technology (which requires completely new production lines) also offers higher efficiencies and can be manufactured at low temperatures and with fewer production steps than other high-efficiency cell technologies.<sup>280</sup>

The industry is rapidly shifting to **new cell technologies** to increase cell efficiencies and output and to improve margins.

Researchers also continued working to circumvent the theoretical efficiency limits of silicon-based solar cells by stacking cells of different types and developing more efficient cell technologies.<sup>281</sup> Perovskites<sup>iv</sup>, in tandem with crystalline silicon or a thin film base, continued to attract substantial research funding in an effort to move closer to commercialisation.<sup>282</sup> Oxford PV (UK) set a new record for perovskite-silicon tandem cell efficiency (29.5%) and started ramping up production at its facility in Germany.<sup>283</sup> Saule Technologies (Poland) began printing perovskite cells with inkjet printers, with plans to supply a Swedish construction company (Skanska Group) in 2021 for use on building façades.<sup>284</sup> Researchers continued to focus on a number of challenges, including addressing the long-term stability issues and lead content of perovskites, developing new cell designs and encapsulation strategies, and bringing down costs.<sup>285</sup>

Improvements in cell technology and module design have enabled the development of modules with higher power ratings.<sup>286</sup> Manufacturers were pushing 400 W in 2019, and several introduced modules with ratings of 500 W and higher during 2020.<sup>287</sup> Raising the power rating increases electricity output per module, thereby reducing the number needed for a project, reducing space requirements and associated shipping, land, installation and other costs.<sup>288</sup>

Interest continued to increase in bifacial modules, which capture light on both sides, and offer potential gains in output and thus a lower LCOE.<sup>289</sup> Power gains range from 5% to as much as 30% depending on cell technology, system design and location.<sup>290</sup> Uncertainties about the performance of bifacial systems are falling away as the increasing number of systems in operation demonstrates the benefits.<sup>291</sup> However, a growing demand for bifacial modules, which generally are made with two glass panes (unlike most traditional modules), contributed to a shortage in solar glass supply, helping to push up prices in the second half of 2019.<sup>292</sup>



- 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 area) than multi- or poly-crystalline cells, which are made of multi-faceted or multiple crystals. See endnote 271 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 Tunnel-oxide passivated contact (TOPCon) cells adapt a sophisticated passivation scheme to advance cell architectures for higher efficiencies. See endnote 280 for this section.
- iv Perovskite solar cells include perovskite (crystal) structured compounds that are simple to manufacture, can be made at low temperatures, and are expected to be relatively inexpensive to produce. Perovskites can be printed onto substrates of other materials or made as thin sheets. They have achieved considerable efficiency improvements in laboratories. See endnote 282 for this section.



The scale of manufacturing and demand is such that solar PV has become the major driver of growth in polysilicon production and accounts for a large and growing share of global demand for glass and other materials and resources.<sup>293</sup> As with other energy technologies and electronics, solar panels are resource intensive, relying heavily on aluminium, copper and silver, and on smaller amounts of minerals such as zinc, indium and lead.<sup>294</sup> Between 2010 and 2020, solar PV use of silver more than doubled, with the industry's share of global demand rising from 5.7% to more than 11%, even as silver use per cell declined 80%.<sup>295</sup>

Once produced, solar panels have technical lifetimes of 25-30 years or longer.<sup>296</sup> Nonetheless many solar plants are already being repowered<sup>i</sup>, and the volume of **decommissioned panels** in the coming decade is expected to be large.<sup>297</sup> Repowering is due mainly to ageing components, particularly inverters, but the opportunity to increase output per installation (made possible by rapid technology advances and falling prices) is leading many developers to replace panels much earlier.<sup>298</sup>

There is a growing market for second-hand panels (which might or might not be recycled later), but most decommissioned, damaged or faulty solar panels go to existing waste treatment or recycling facilities that do not yet recover many of the materials that represent some of their potential value (e.g., silver, copper and silicon) and environmental impact (e.g., lead).<sup>299</sup> Nearly 95% of a solar panel is recyclable but, for now, many materials that could be reclaimed do not cover the costs of recycling.<sup>300</sup> It is a matter of economics and volume: finding markets for the reclaimed materials and scaling up treatment lines to drive down per-unit costs, both of which require a relatively high volume of solar panels that have reached the end of life.<sup>301</sup>

Mandates on producers to collect and recycle panels (such as takeback legislation), and required financing, can create

the guaranteed supply of panel waste that is needed to make recycling economical.<sup>302</sup> As of 2020, only the EU and the US states of New York and Washington mandated solar panel recycling.<sup>303</sup> Japan required facilities of 10 kW or larger (installed under the FIT system) to pay into a decommissioning fund for 10 years after 2022; some Australian states had bans on electronic waste in landfills (and South Africa has a similar ban, due to take effect in August 2021); and other countries were considering or in the process of developing requirements.<sup>304</sup>

As of early 2021, only Europe had a single treatment line (in France) that is dedicated to recycling of crystalline silicon panels.<sup>305</sup> Other facilities in Europe (e.g., in Belgium, Germany, Italy and Spain) have integrated the treatment of silicon-based solar panels into existing treatment lines (for laminated flat glass products, for example).<sup>306</sup> A handful of facilities operate in other countries: Japan has at least two facilities; India has a pilot recycling plant; and, in the United States, a small number of industry-driven facilities can handle parts of panels, and thin film manufacturer First Solar has in-house capabilities.<sup>307</sup> In Australia, Reclaim PV is testing a pyrolysis process and starting to ramp up a nationwide collection network, and other companies in Australia are working on recycling.<sup>308</sup> In China, leading manufacturers have begun to research options.<sup>309</sup>

On a related note, in 2020 the Republic of Korea introduced carbon footprint rules for solar modules – new projects will be prioritised according to their life-cycle emissions; the rules are similar to those applied in France<sup>ii</sup> for large-scale tenders.<sup>310</sup> In addition, several companies from across the solar PV value chain launched the Ultra Low-Carbon Solar Alliance in 2020, pledging to build market awareness and to accelerate the deployment of solar PV modules with lower embodied carbon to reduce the carbon footprint of solar systems.<sup>311</sup>



i In the United States, for example, utility-scale projects generally pay for themselves in about seven years; repowering the project resets the clock on the federal investment tax credit. See endnote 297 for this section.

ii France's tenders for large-scale solar PV plants prioritise projects using modules with low carbon footprints.



## KEY FACTS

- **CSP markets grew slowly in 2020** as a result of increasing cost competition from solar PV, the expiry of CSP incentive programmes and operational issues at existing facilities. Spain and the United States, the market leaders in cumulative installed CSP capacity, have not added new capacity in seven and five years, respectively.
- **More than 1 GW of new capacity was under construction in 2020** in the United Arab Emirates, China, Chile and India, although construction did not begin on any new projects. China was the only country to add new capacity during the year.
- CSP costs fell 50% during the 2010s, and there are several **examples of CSP facilities with thermal energy storage co-located with solar PV** to lower costs and increase capacity factors.

## CONCENTRATING SOLAR THERMAL POWER (CSP)

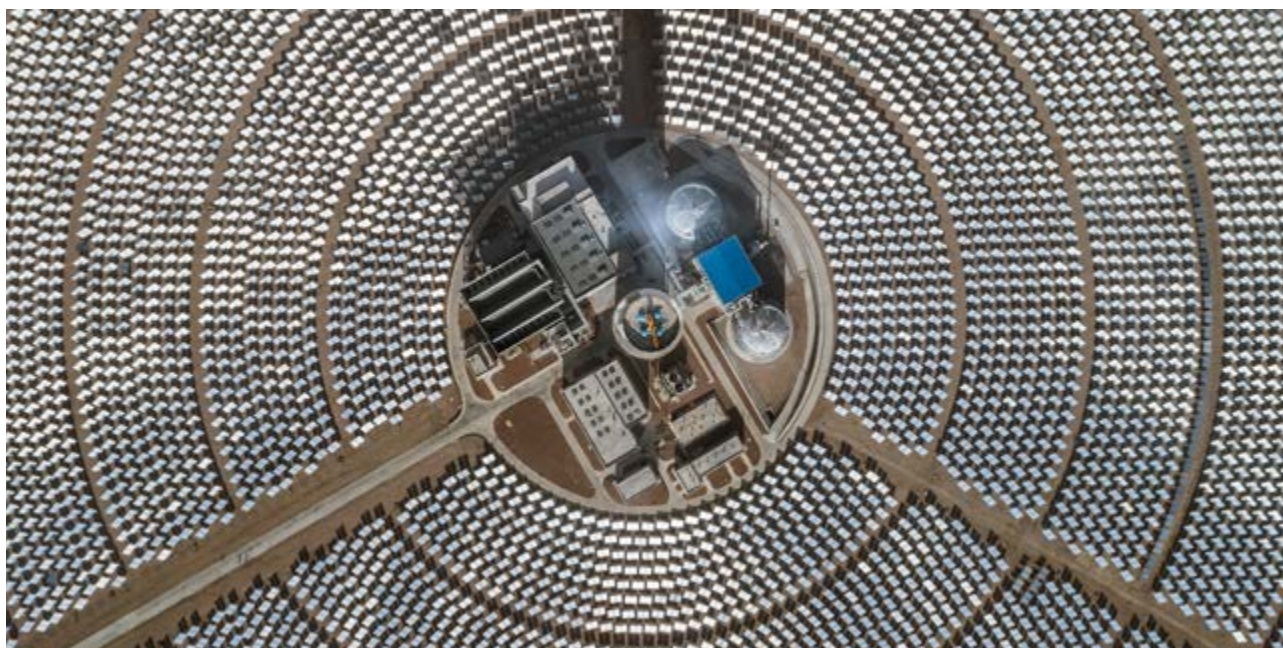


### CSP MARKETS

Global CSP<sup>i</sup> capacity grew just 1.6% in 2020 to 6.2 GW, with a single 100 MW parabolic trough project coming online in China.<sup>1</sup> This was down from the 600 MW commissioned in 2019 and was, along with 2017, the lowest annual market growth in over a decade.<sup>2</sup> (→ See *Figure 29* and **Reference Table R16** in *GSR 2021 Data Pack*.) Reduced market growth comes on the back of several challenges faced by the CSP sector in recent years, including increasing cost competition from solar PV, the expiry of CSP incentive programmes and a range of operational issues at existing facilities.<sup>3</sup> Market growth also was impacted by construction delays and stoppages in China, India and Chile.<sup>4</sup>

More than 1 GW of CSP projects was under construction during 2020 in the United Arab Emirates, China, Chile and India, although no new projects commenced construction during the year.<sup>5</sup> This was the seventh consecutive year in which no new CSP capacity came online in Spain, still the market leader in cumulative operating CSP capacity. The United States, which ranks second in cumulative capacity, has seen no new capacity additions in five years.<sup>6</sup>

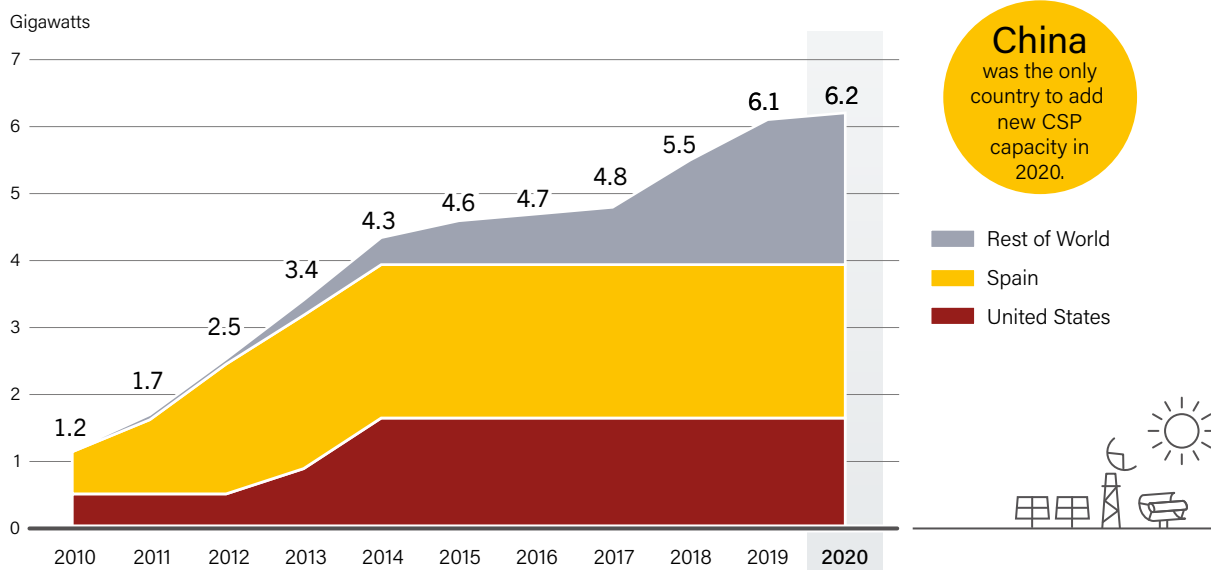
The majority of projects under construction during 2020 were based on parabolic trough technology.<sup>7</sup> At year's end, the plants under construction worldwide included just over 1 GW of trough systems, just under 0.3 GW of tower systems and a 14 MW Fresnel system.<sup>8</sup> With the exception of two hybrid CSP-natural gas plants,<sup>ii</sup> all of these plants are to include thermal energy storage (TES).<sup>9</sup>



i CSP is also known as solar thermal electricity (STE).

ii These hybrid plants are integrated solar combined-cycle (ISCC) facilities, hybrid plants that use both solar energy and natural gas to produce electricity.

**FIGURE 29.** Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2010-2020



Source: See endnote 2 for this section.

In China, the 100 MW CSNP Royal Tech Urat project commenced operations in January 2020, bringing the country's total installed capacity to 520 MW.<sup>10</sup> The project, based on parabolic trough technology, incorporates 10 hours or around 1,000 MWh<sup>i</sup> of thermal storage based on molten salts, and is the largest of the country's 10 operational CSP facilities.<sup>11</sup> A number of CSP plants were under construction in China during 2020, although several were delayed or taken over by new owners and contractors due to a range of implementation challenges.<sup>12</sup>

In the United Arab Emirates, construction continued on the Mohammed bin Rashid Al Maktoum Solar Park, consisting of a 600 MW parabolic trough facility (11 hours; 6,600 MWh), and a 100 MW tower facility (15 hours; 1,500 MWh).<sup>13</sup> A key milestone was achieved with the commissioning of the 262-metre solar tower, the highest in the world.<sup>14</sup> Once operational, the facility will bring cumulative CSP capacity in the United Arab Emirates to 800 MW.<sup>15</sup> Elsewhere in the Middle East, construction continued on the 50 MW Duba 1 Integrated Solar Combined Cycle project in Saudi Arabia.<sup>16</sup>

Several CSP facilities totalling around 300 MW were being built in India in recent years, although some projects faced protracted delays, and anticipated completion dates remained unclear.<sup>17</sup> The country operated 225 MW of CSP capacity as of end-2020.<sup>18</sup>

Chile was the only other country with CSP capacity under construction during the year, in the form of the 110 MW Cerro Dominador tower project (17.5 hours; 1,925 MWh).<sup>19</sup> The plant, which will be the first commercial CSP facility in Latin America

The world's largest CSP project, at 700 MW, was under construction in the United Arab Emirates.



<sup>i</sup> 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.

and is expected to be operational in 2021, achieved several construction milestones in 2020 including installation of the 220-metre solar tower and the commencement of salt melting.<sup>20</sup>

While no CSP capacity was added on the African continent, the 800 MW Midelt CSP project in Morocco was approaching the construction phase, and the tendering process for Zambia's first CSP project, a 200 MW parabolic trough facility, was completed and contractors were subsequently appointed to carry out the project's civil construction works.<sup>21</sup> In neighbouring Botswana, a new integrated resource plan released in 2020 targets 200 MW of CSP capacity by 2026.<sup>22</sup>

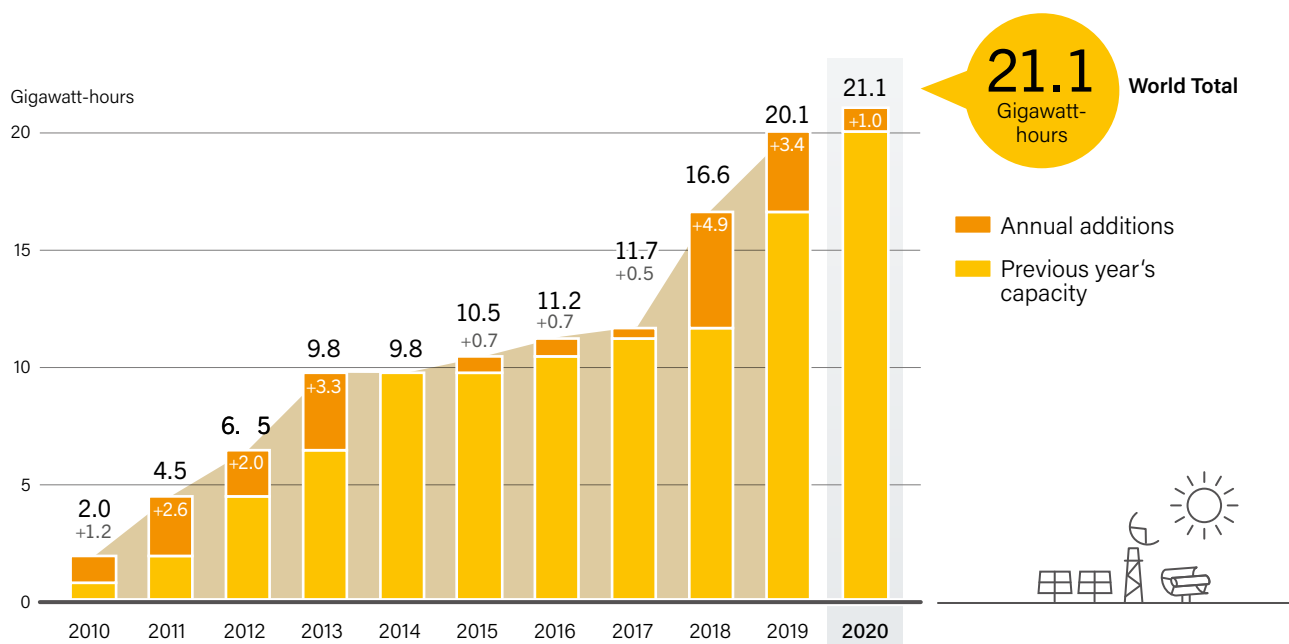
For cumulative capacity in operation, Spain remained the global leader with 2.3 GW at the end of 2020.<sup>23</sup> With no new capacity additions in seven years, Spain's share of global CSP capacity in operation declined from a high of nearly 80% in 2012 to just under 40% by the end of 2020.<sup>24</sup> However, production from the existing CSP fleet has increased in recent years as a result of operational improvements, and a draft energy and climate plan released by the Spanish government during 2020 targets the procurement of 600 MW of new CSP capacity by 2025.<sup>25</sup> There were also plans to enhance the performance of several Spanish CSP plants by retrofitting them with energy storage.<sup>26</sup> Following Spain in cumulative CSP capacity was the United States with just over 1.6 GW of commercially operational CSP, or just under 30% of global capacity.<sup>27</sup>

At the end of 2020, an estimated 21 GWh of thermal energy storage, based almost entirely on molten salts<sup>i</sup>, was operating in conjunction with CSP plants across five continents.<sup>28</sup> (→ See Figure 30.) Of the 24 CSP plants completed globally since the end of 2014, only two do not incorporate TES: an integrated solar combined-cycle (ISCC) facility in Saudi Arabia and the Megalim plant in Israel.<sup>29</sup> TES capacity, installed mainly alongside CSP, represents a significant proportion of global non-pumped hydropower energy storage capacity: while global installed solar PV capacity is more than 100 times greater than CSP, the quantity of TES installed at CSP facilities around the world is almost double that of utility-scale batteries.<sup>30</sup>



i 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 30.**  
Thermal Energy Storage Global Capacity and Annual Additions, 2010-2020



Source: See endnote 28 for this section.



### CSP INDUSTRY

After several years of diversification of the CSP industry beyond Spain and the United States to markets across Africa, the Middle East and Asia, the majority of construction activity in the sector was concentrated in the United Arab Emirates and China. CSP projects that either entered operations or were under construction during 2020 involved lead developers and investors from Saudi Arabia, China, India and the United States.<sup>31</sup> Contractors were based in China, Spain, the United States and India, with Chinese companies involved in almost half of the completed or active projects.<sup>32</sup> By contrast, before 2015 most CSP companies hailed from the United States and Spain.<sup>33</sup>

The Saudi company ACWA Power remained the leading CSP project developer in 2020, with more than 700 MW of projects under construction.<sup>34</sup> Other notable developers, investors or owners of CSP plants that either entered operations or were under construction during the year included Royal Tech (China), EIG Global Partners (United States) and at least six other developers from around the world.<sup>35</sup> Some of the leading companies involved in the engineering, procurement and construction of CSP facilities included Abengoa (Spain), Acciona (Spain), Brightsource (US), China Shipbuilding New Power Company (China) and Shanghai Electric (China).<sup>36</sup>

During the decade prior to 2020, CSP costs decreased 68%, the largest decline for all renewable energy technologies with the exception of solar PV, which experienced a more than 80% cost decline over the same period.<sup>37</sup> CSP costs have improved as a result of multiple factors, including technological innovation, improved supply chain competitiveness, as well as increased growth in CSP capacity in high irradiance regions which, along with increased TES capacity, has boosted the overall capacity factor of the global CSP fleet.<sup>38</sup>

In many cases CSP and TES capacity are co-located with solar PV capacity to lower costs and increase capacity values.

For example, the Cerro Dominador plant in Chile is being built alongside an existing 100 MW solar PV plant.<sup>39</sup> Other developments aim to integrate CSP, TES and solar PV more closely: in Morocco, the Midelt plant will be the first to incorporate an electric heater to allow for storage of energy from the adjacent solar PV facility using the molten salt storage system.<sup>40</sup> The hybridisation of CSP with solar PV reflects a shift away from direct competition between CSP and other generation resources to a more integrated and complementary approach that emphasises the unique benefits of CSP systems that include TES, such as long-duration energy storage.<sup>41</sup>

In some cases, older CSP plants without energy storage are being retrofitted with TES to greatly improve their overall functionality and economics. Some estimates indicate that the costs of implementing new TES at existing CSP plants are much lower than the costs of implementing equivalent battery capacity with existing solar PV.<sup>42</sup>

Several research and development activities focused on CSP and TES were under way in 2020. Areas of development included the integration of CSP and TES with other generation and storage technologies, the improved reliability of mechanical systems, the use of alternative heat transfer mediums and the application of more efficient power conversion cycles.<sup>43</sup> The US Department of Energy announced USD 39 million in funding to support a pilot CSP project that aims to demonstrate improved efficiencies through the application of a supercritical carbon dioxide power cycle.<sup>44</sup>

Several CSP plants are being located alongside solar PV facilities to lower overall costs and boost capacity factors.





## KEY FACTS

- An estimated 25.2 GW<sub>th</sub> of new solar thermal capacity came online in 2020, with **China, Turkey, India, Brazil and the United States** leading in new installations.
- Residential, commercial and industrial clients in **at least 134 countries operated 501 GW<sub>th</sub>**, enough to provide heat equivalent to the energy content of 239 million barrels of oil.
- China and Germany took the lead from Denmark in **solar district heating**, thanks to policy support in both countries.
- A new generation of manufacturers of **innovative concentrating collectors** unveiled the first demonstration or commercial projects.

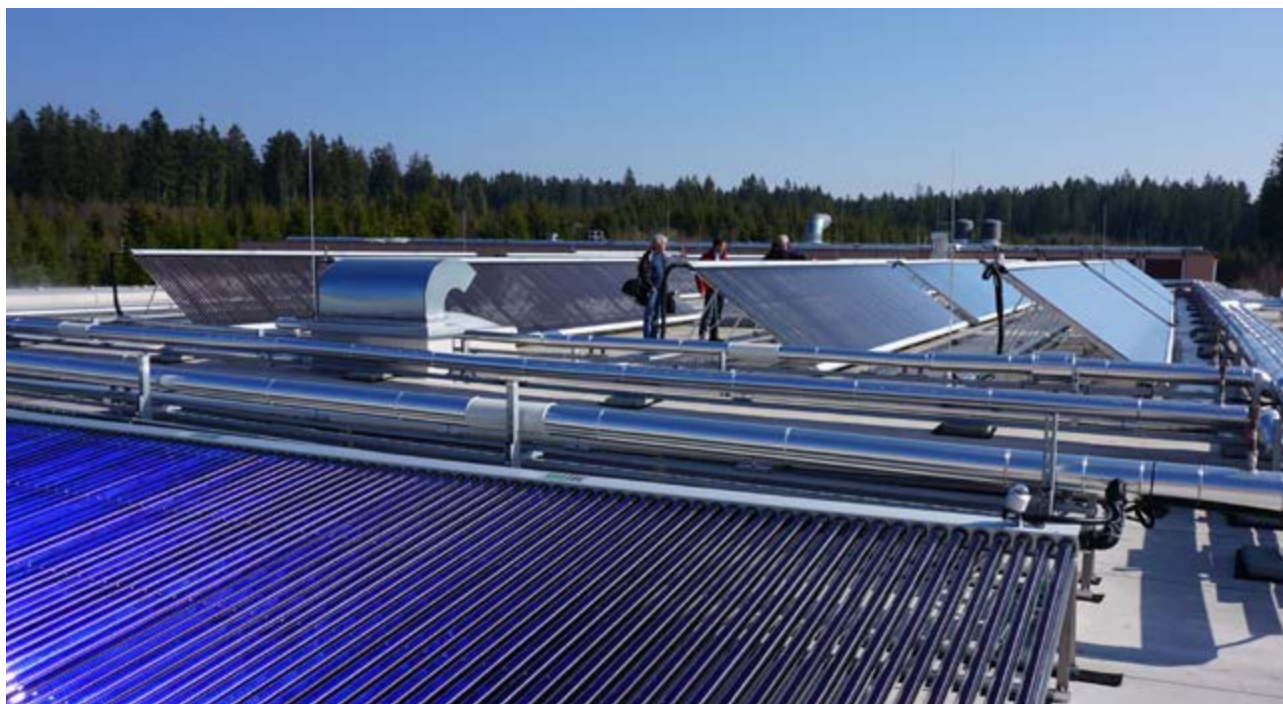
## SOLAR THERMAL HEATING



The global solar thermal market continued a gradual decline in 2020, with an estimated 25.2 GW<sub>th</sub> of capacity added<sup>i</sup> worldwide, down 3.6% from 26.1 GW<sub>th</sub> in 2019.<sup>i</sup> Most large solar thermal markets were constrained by challenges associated with COVID-19, such as pandemic-related restrictions and postponed investment decisions by commercial clients, including industries and hotels. However, the reduction was smaller than expected due to various stabilising factors.

In most of the largest solar thermal markets, continuous business in the construction sector during the pandemic helped maintain a steady demand for systems. In many countries, the effects of trade and travel restrictions on the solar thermal market were offset at least partly by higher demand from residential owners who spent more time at home and invested in infrastructure improvements.<sup>2</sup> In markets that depend strongly on subsidies, changes in policy support in 2020 had a much greater influence (positive or negative) on solar thermal demand than did the pandemic.<sup>3</sup>

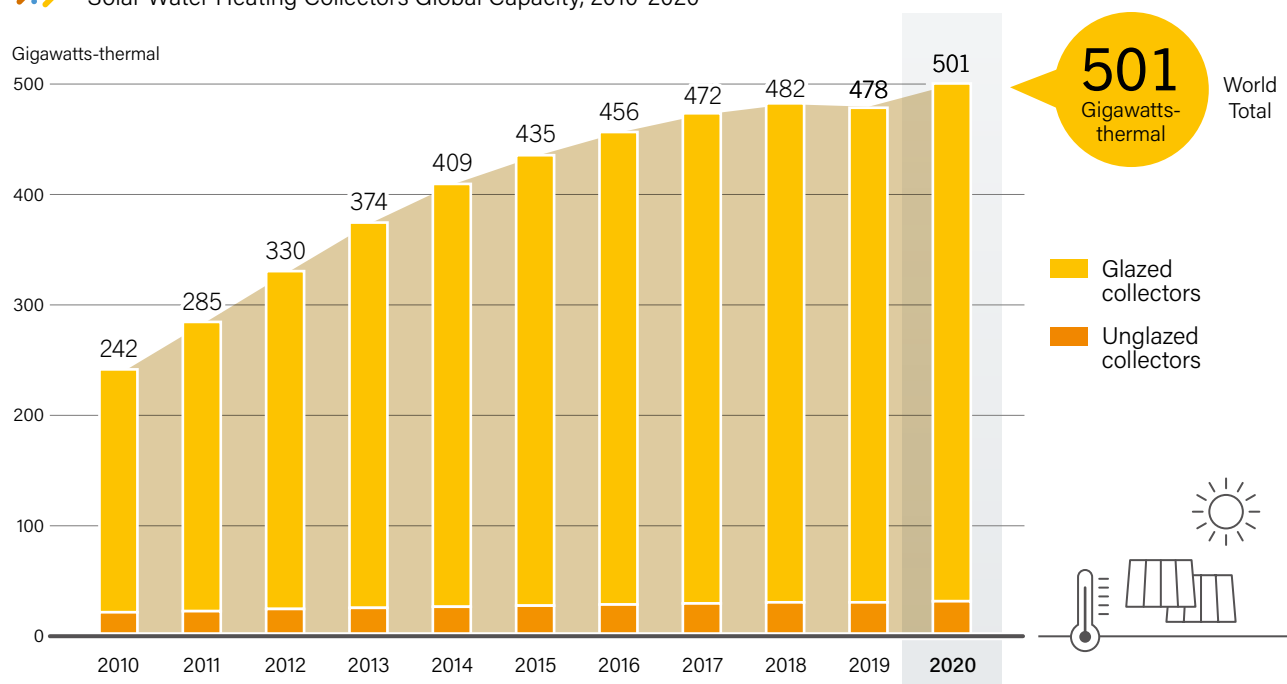
By the end of 2020, millions of residential, commercial and industrial clients in at least 134 countries were benefiting from solar heating and cooling systems.<sup>4</sup> The total operating capacity for glazed (flat plate and vacuum tube) and unglazed collectors (used mainly for heating swimming pools) reached an estimated 501 GW<sub>th</sub> by year's end, up 5% from 478 GW<sub>th</sub> in 2019<sup>ii,5</sup> (→ See Figure 31.) These collector types provided around 407 terawatt-hours (1,465 petajoules) of heat annually, equivalent to the energy content of 239 million barrels of oil.<sup>6</sup>



i Added capacity or new additions in this section are gross additions, whereas total capacity counts only net additions (replacement of decommissioned systems is not included).

ii Annual additions for China in 2019 were revised (see endnote 1 for this section), and the assumptions for estimating new solar thermal capacity additions beyond the largest 20 markets were adapted for 2019 and 2020 (see endnote 5 for this section), which also had an impact on estimates for total global capacity.

**FIGURE 31.**  
Solar Water Heating Collectors Global Capacity, 2010-2020



Note: Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors. The drop in 2019 was caused by revised annual additions for China in 2019 (see endnote 1 for this section) and new assumptions for projecting total capacity in operation for 2019 and 2020 (see endnote 5 for this section).

Source: IEA SHC. See endnote 5 for this section.

In addition to the three main types of collectors, 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. By the end of 2020, hybrid – or solar photovoltaic-thermal (PV-T) – technologies provided 635 MW<sub>th</sub> of thermal capacity (and 232 MW of electric power capacity) for space and water heating.<sup>7</sup> In addition, 566 MW<sub>th</sub> of concentrating solar thermal capacity provided hot water or steam for industrial and commercial customers at year's end.<sup>8</sup> Around 1 GW<sub>th</sub> of air collectors for drying and space heating was in operation in 2019 (latest data available).<sup>9</sup>

The leading countries for new glazed and unglazed installations in 2020 were again China, Turkey, India, Brazil, the United States, Germany and Australia.<sup>10</sup> (→ See Figure 32.) China dominated the market, accounting for 71% of new global sales, followed by Turkey and India (5% each).<sup>11</sup> Most of the top 20 countries for solar thermal installations (glazed and unglazed collectors) in 2019 remained on the list in 2020; the exceptions were Denmark, the State of Palestine and Switzerland, which were replaced in the rankings by the Netherlands, Morocco and Portugal.<sup>12</sup> The top 20 countries accounted for an estimated 96% of the global market in 2020.<sup>13</sup>

In China, the solar thermal market ended 2020 on a high note, with sales in the second half of the year nearly making up for the delays in construction activity related to COVID-19 during the first six months.<sup>14</sup> Installations in 2020 totalled 18 GW<sub>th</sub> (25.7 million square metres (m<sup>2</sup>) of collector area),

resulting in a decline of only 3% from 2019 (compared with a 21% drop in 2019 relative to 2018).<sup>15</sup> At year's end, China's operating capacity was 364 GW<sub>th</sub>, or 67% of the global capacity in operation.<sup>16</sup>

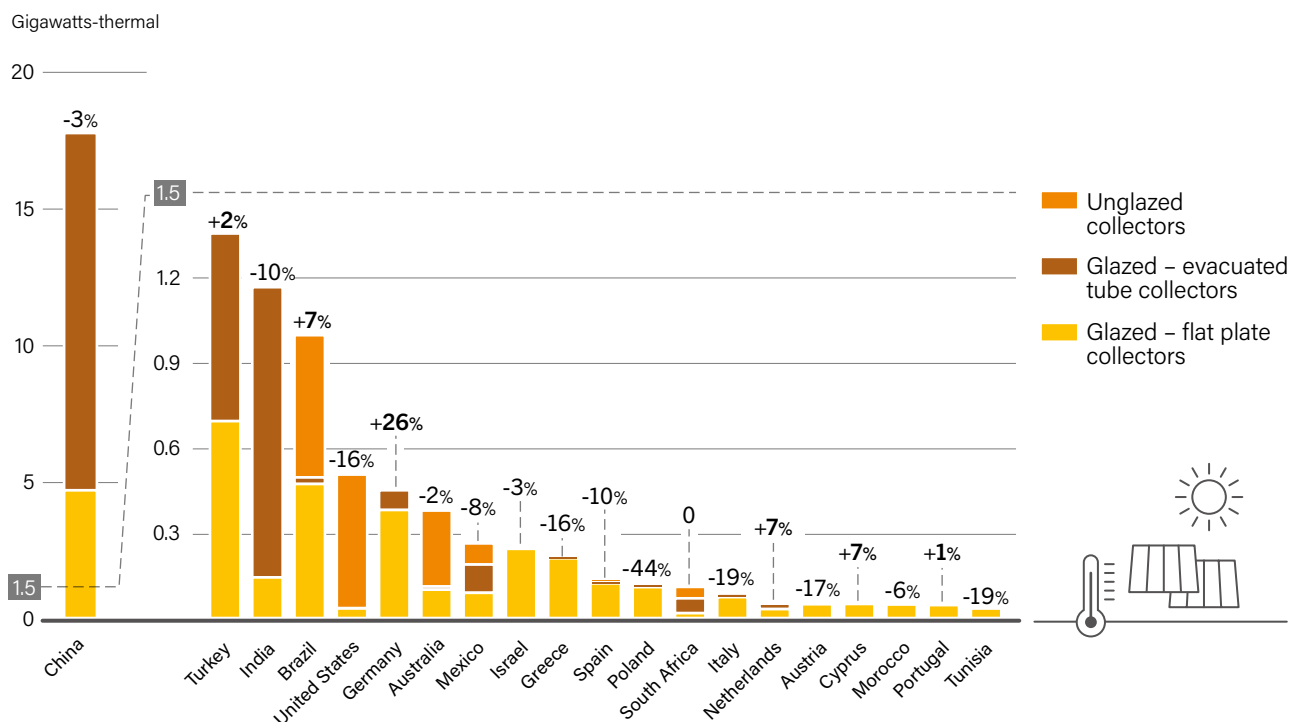
The large project market in China<sup>i</sup> – covering a wide range of customer groups including industry, large-scale residential projects, agriculture, and public institutions such as hospitals and schools – remained stable and contributed to nearly three-quarters (74%) of total sales in 2020, while the market for small retail solar water heaters made up the remaining 26%.<sup>17</sup> Within the large project market, the most dynamic growth was in the solar space heating segment, totalling 1.7 GW<sub>th</sub> of newly added capacity, or 10% of all new installations.<sup>18</sup> Prior to 2020, a total of only around 0.6 GW<sub>th</sub> of solar space heating projects was put online.<sup>19</sup>

### Germany's green heating policy

helped drive a 26% increase in sales in 2020.

i Chinese statistics differ between standardised small residential solar water heaters and "engineered" solar thermal solutions, which are called the "large project market" in the GSR and refer to larger systems used in, for example, industry, agriculture, public institutions and residential housing projects.

**FIGURE 32.** Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2020



Note: Additions represent gross capacity added. For the Netherlands, the shares of flat plate and vacuum tube collectors were estimated based on actual shares in 2019. For Morocco, the share of collector types was not available.

Source: See endnote 10 for this section.

Although vacuum tube collectors still accounted for 73% of China's newly installed capacity, the market continued to transition from vacuum tubes to flat plate systems.<sup>20</sup> China's market for new vacuum tube collectors contracted 6% in 2020 (to 13.1 GW<sub>th</sub>), while new flat plate collector area grew 6% (to 4.9 GW<sub>th</sub>).<sup>21</sup> Sales of flat plate collectors have been driven by building codes mandating the use of solar thermal systems (or heat pumps) in new construction and major renovations as a means to reduce local air pollution.<sup>22</sup> These regulations have increased the demand for both façade- and balcony-integrated applications, where flat plate collectors have been the preferred solution.<sup>23</sup>

Turkey's solar thermal market, the second largest for new sales worldwide, expanded slightly (up 2%) in 2020, following stagnating sales the previous year, resulting in 1.35 GW<sub>th</sub> of newly installed capacity.<sup>24</sup> The 18.4 GW<sub>th</sub> of solar thermal capacity in operation at year's end accounted for 4% of the global total.<sup>25</sup> The pandemic affected Turkey's market in two opposing ways. In the residential sector, sales of solar water heaters increased as Turkish residents moved away from urban areas and apartment buildings to villages and individual houses, boosting the renovation business and the prefabricated housing market and triggering solar thermal sales. Meanwhile, sales of solar thermal systems for hotels and resorts declined.<sup>26</sup>

India's demand for glazed collectors fell 10% in 2020 to 1.16 GW<sub>th</sub> (1.66 million m<sup>2</sup>) due to the restrictions on production, sales and installation during the country's full lockdowns in April and May and partial lockdowns over several months.<sup>27</sup> Even so, India again ranked

third for annual additions. As in Turkey, Indian solar thermal manufacturers reported opposing trends: for example, precautionary health measures, such as more frequent hot baths, increased the demand for solar water heaters, partly offsetting the negative impact of the pandemic.<sup>28</sup>

The market share of vacuum tube collectors in India grew to 88% of newly installed capacity in 2020 (up from 85% in 2019), mainly because flat plate collector sales declined more strongly (down 24%) due to higher prices resulting from rising material costs.<sup>29</sup> Furthermore, there was a decrease in the number of public tenders that mandated systems certified by the Bureau of Indian Standards, which so far can be fulfilled only by flat plate collectors.<sup>30</sup>

Demand from homeowners for solar water heaters increased in Turkey, India and Brazil during the pandemic.

Karnataka state again dominated capacity additions, representing nearly 65% of India's total market (up from 50% in 2019), followed by Gujarat and Maharashtra.<sup>31</sup> The driving force in Karnataka was again a strict policy mandating use of the systems, overseen by local electric utilities that deny grid access to households not equipped with a solar water heater.<sup>32</sup>

Brazil continued its growth trajectory, adding 992 MW<sub>th</sub> (up 7%) of solar thermal capacity in 2020 despite COVID-19 worries, following a 6% increase in 2019.<sup>33</sup> The pandemic caused demand to fall in the first six months of the year, as commercial clients put plans on hold and wholesalers closed their doors.<sup>34</sup> Sales then rose in the second half of the year, a development attributed in part to the recovery of the residential sector as people spent more time at home and invested in infrastructure improvements (such as solar pool heating and solar hot water systems); commercial clients also took advantage of the lower interest rates available for financing to identify energy-saving solutions that could give them a competitive edge.<sup>35</sup>

For the first time, Brazil's unglazed collector market, aimed mainly at swimming pool heating, pulled ahead of the US market, the long-term leader for this type of collector.<sup>36</sup> Brazil added 498 MW<sub>th</sub> of new unglazed capacity, followed by the United States (473 MW<sub>th</sub>) and Australia (266 MW<sub>th</sub>).<sup>37</sup>

Brazil's strong market in 2020 resulted almost solely from the competitiveness of domestically manufactured solar thermal systems compared to other water heating options, as well as the ongoing reduction in value-added tax (VAT), enjoyed by solar thermal products but not other water heating options.<sup>38</sup> Meanwhile, the implementation of two previously announced policy support programmes was temporarily postponed because of the pandemic.<sup>39</sup> The federal government delayed the launch of the new social housing programme Casa Verde e Amarela, which was to succeed Minha Casa Minha Vida, the main programme behind the increase in Brazil's solar thermal capacity between 2009 and 2014.<sup>40</sup> Law PL 107 from 2019, stipulating the use of solar energy in all municipal and federal government institutions in the city of São Paulo, also did not enter into force.<sup>41</sup>

The United States, the fifth largest market for the three main types of solar thermal collectors in 2020 (with 505 MW<sub>th</sub>), suffered a sharp decline (down 16%).<sup>42</sup> This resulted from a severe drop in sales of glazed collectors (down 71%) due to COVID-19 restrictions and to the end of a major support scheme, the California Solar Initiative, in July 2020.<sup>43</sup> Meanwhile, demand in the unglazed segment fell only 3%, which led its share in newly added capacity to increase to 94% (from 81% in 2019).<sup>44</sup> The United States continued to rank third globally for total operating capacity, with 18 GW<sub>th</sub> at the end of 2020.<sup>45</sup>

Australia ranked seventh, following Germany for solar thermal sales, adding 380 MW<sub>th</sub> of new capacity in 2020, down slightly from 2019.<sup>46</sup> The Australian solar thermal market has been dominated by unglazed collectors, which have fluctuated between 260 MW<sub>th</sub> and 280 MW<sub>th</sub> each year since 2013.<sup>47</sup>



Preliminary numbers for glazed collectors suggest a decline in 2020 (down 7%), with new installations totalling around 114 MW<sub>th</sub>.<sup>48</sup> Sales of glazed collectors contracted, while heat pumps gained a larger share of the residential new-build market; in addition, restrictions on the number of workers allowed at worksites during several months of the pandemic affected solar thermal sales.<sup>49</sup>

The European Union (EU-27) remained the second largest regional market after Asia in 2020.<sup>50</sup> However, additions (estimated at 1.4 GW<sub>th</sub>) were down 15% from 2019.<sup>51</sup> The total capacity in operation in Europe at the end of 2020 was an estimated 37.5 GW<sub>th</sub>, accounting for 7% of the global total.<sup>52</sup> The four leading countries in 2019 (Germany, Greece, Poland and Spain) saw mixed results in 2020, with strong growth in Germany and declines in Greece, Poland and Spain, resulting largely from changing policies and the impacts of the pandemic.<sup>53</sup>

Germany extended its leading position in Europe and reversed its decade-long market decline, ranking sixth globally for new installations. Annual sales were up 26% in 2020, to reach 450 MW<sub>th</sub>, or around 83,000 new solar thermal systems for the year.<sup>54</sup> A key driver of growth was the new national support scheme to accelerate decarbonisation of the heat sector, launched at the start of 2020, which covers 40% of the cost of replacing an outdated oil heater with a new solar-supported gas condensing boiler.<sup>55</sup>

A high volume of grant applications in the last quarter of 2020 helped fuel optimism for continued growth in 2021.<sup>56</sup> Germany reached 13.9 GW<sub>th</sub> in operation at the end of 2020, accounting for 3% of total global capacity.<sup>57</sup>

The solar thermal market in Greece, again the second largest for new additions in Europe, contracted significantly (16%) in 2020 (for the first time since 2013), with only 213 MW<sub>th</sub> installed.<sup>58</sup>

i The restrictions affected the glazed solar thermal market more than the unglazed market because the glazed market is aligned heavily with new home builds.



The drop was caused by reduced sales during lockdowns in the first half of the year, when shops were closed and internet sales were insufficient to offset the decline in direct sales.<sup>59</sup>

Spain came in third place in Europe in 2020, ahead of Poland (due to a large market decline in Poland, rather than to expansion in Spain). The Spanish solar thermal market fell 10% (adding 131 MW<sub>th</sub>), in line with the year's housing market decline, whereas Poland's market plunged 44%, with 113 MW<sub>th</sub> added.<sup>60</sup> The contraction in Poland was attributed to the pandemic and to a phasing out of the emission reduction programme, which aimed to improve local air quality by subsidising renewable heating systems purchased and distributed by municipal administrators.<sup>61</sup>

Although most solar thermal capacity continued to be installed for the purpose of water heating in individual buildings, the use of **solar thermal technology in district heating** expanded further during 2020, and in an increasing number of countries. The vast majority of new solar district heating capacity added was again (in descending order) in China, Germany and Denmark.

In China, the solar district heating market shifted in 2020 from being purely state-financed to being partly commercial, with large orders from the housing industry. Whereas in 2019, three publicly funded solar district heating systems were commissioned in Tibet (totalling 52 MW<sub>th</sub>), in 2020 only one such plant (7.9 MW<sub>th</sub>) was erected, at a college in Lhasa.<sup>62</sup> Across China, newly installed solar thermal capacity for space heating (for both district heating and heating of large buildings) increased by a significant 1.7 GW<sub>th</sub>, due to green heating policies aimed at replacing coal boilers in the country's north to improve air quality.<sup>63</sup> For this new capacity, the statistics do not differentiate between central space heating projects for blocks of flats or larger buildings (which would be considered solar district heating) and decentralised space heating units for rural, single-family houses.<sup>64</sup>

Germany passed Denmark for new installations of solar district heating by bringing online six new plants (totalling 22 MW<sub>th</sub>) in 2020, following the completion of five new systems (totalling 7.1 MW<sub>th</sub>) in 2019.<sup>65</sup> The 2020 additions included Germany's then-largest solar

district heating plant, in Ludwigsburg, with a solar capacity of 10.4 MW<sub>th</sub>.<sup>66</sup> By year's end, the country had 41 solar district heating plants in operation totalling 70 MW<sub>th</sub> of capacity.<sup>67</sup> Five additional plants, with a combined capacity of 22.5 MW<sub>th</sub>, were being planned or in the installation phase and were expected to come online in 2021; they included a 13.1 MW<sub>th</sub> system in Greifswald that, once operational, will overtake the Ludwigsburg plant to become the country's largest solar district heating plant.<sup>68</sup>

The strong market in Germany was driven by supportive framework conditions, including grants from two programmes: the Municipal Climate Change Showcase Programme and Heat Networks 4.0. The Municipal Showcase Programme has provided grants since January 2020 to cover up to 80% of the investment cost of municipal activity in the areas of greenhouse gas reduction, smart infrastructure and wastewater treatment.<sup>69</sup> Heat Networks 4.0 has provided support to utilities since mid-2017 for feasibility studies and the construction of fourth-generation district heat networks<sup>i</sup>, where at least half of the heat injected into the grid must come from renewables.<sup>70</sup> Thanks in part to these programmes, German utilities increasingly consider solar heat to be an economically feasible alternative, promising stable heat prices over a period of 25 years, compared to the volatile prices of natural gas and biomass.<sup>71</sup>

Denmark continued to lead globally for total district heating capacity, with more than 1 GW<sub>th</sub> in operation at the end of 2020.<sup>72</sup> However, the country brought online only one small solar district heating plant and three extensions during the year, increasing total capacity by 10 MW<sub>th</sub>.<sup>73</sup> This is down sharply from 2019, when 10 new district heating plants and 5 extensions were added for a total of 134 MW<sub>th</sub>.<sup>74</sup> The market contraction was due to increasing competition from heat pumps, driven by policy changes.<sup>75</sup> As of mid-June 2019, solar heat was no longer eligible to fulfil the energy savings mandates for utilities, whereas heat pumps were included in the mandate until the end of 2020.<sup>76</sup> At the beginning of 2020, the Danish Energy Agency also began providing grants for heat pumps, triggering additional demand.<sup>77</sup>



The top markets for  
**solar industrial  
heat**  
in 2020 were China,  
Mexico and Germany.

<sup>i</sup> Fourth-generation heat networks operate at lower temperatures of around 60 degrees Celsius (°C) to reduce heat losses, extend pipe lifetimes and create the best conditions for injecting heat produced with renewable sources.

Demand for new solar district heating systems increased in other existing European markets as well. In France, the market picked up in response to an attractive investment grant for large solar heat systems.<sup>78</sup> At the start of 2020, France had only a handful of solar district heating plants, with the largest commissioned in 2018 (1.6 MW<sub>th</sub>) in Châteaubriant; by the end of 2020, three additional systems were under construction with a combined capacity of 7.4 MW<sub>th</sub>, including a 4.2 MW<sub>th</sub> field in Narbonne that will be France's largest solar district heating plant when it comes online in 2021.<sup>79</sup>

Austria's subsidy scheme for large and innovative solar thermal projects again saw results in 2020, with the inauguration of three new solar district heating fields totalling a combined 4.7 MW<sub>th</sub>.<sup>80</sup> This represented a change from 2019, when no solar district heating plants were commissioned in Austria.<sup>81</sup> A much higher budget for the subsidy scheme, starting in April 2021, is expected to drive up demand for large-scale applications in the coming years.<sup>82</sup>

Sweden also had a new plant under construction at the end of 2020. Once completed in 2023, the 1.5 MW<sub>th</sub> solar district heating plant in Härnösand, north of Stockholm, will be the country's largest solar district heating field using concentrating collectors.<sup>83</sup>

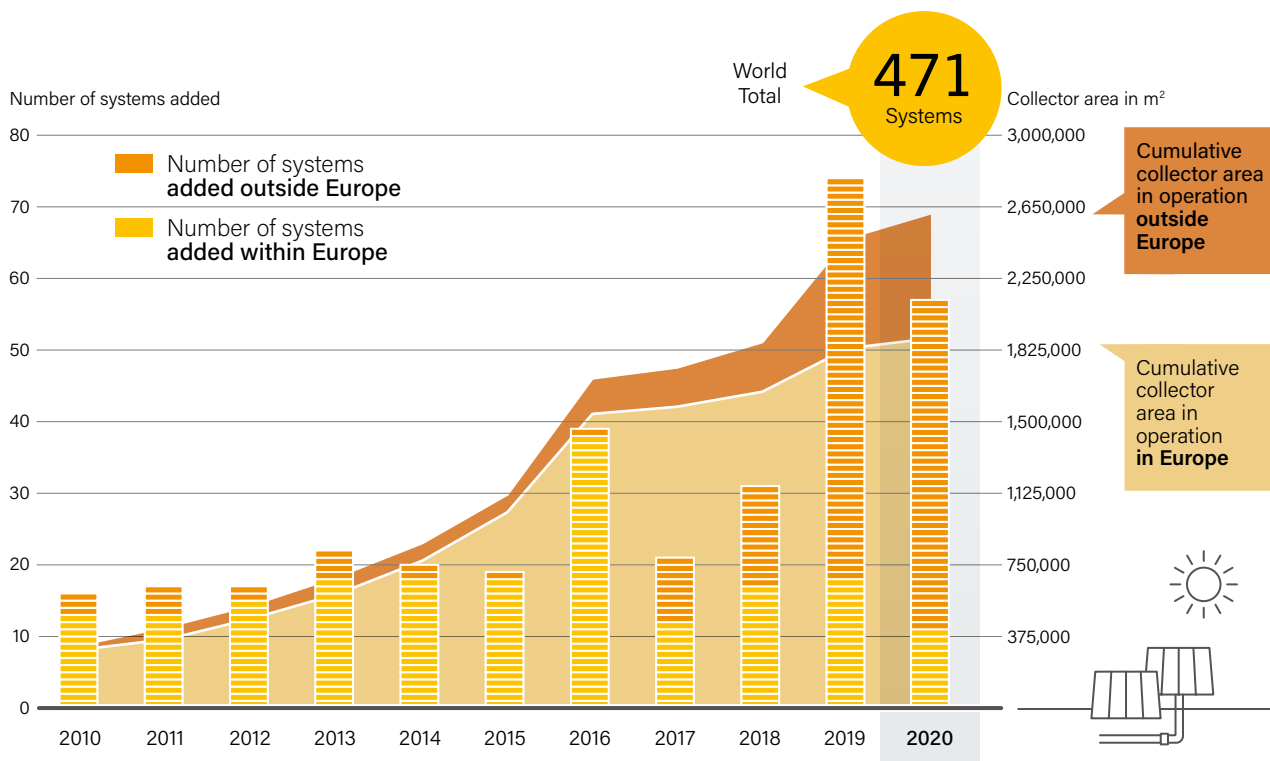
The global solar district heating market also diversified into new markets in both Europe (Croatia, Kosovo and Serbia) and Asia (Mongolia, driven by public funding for pre-feasibility and feasibility studies). In Mongolia, the European Bank for Reconstruction and Development (EBRD) funded a study

on 20 different renewable and energy efficiency options for decarbonising the district heating grid for over 1 million people in the capital city of Ulaanbaatar; among the options is a 49 MW<sub>th</sub> solar district heating plant.<sup>84</sup>

With support from the EU project KeepWarm, pre-feasibility studies for the integration of solar fields in district heating networks with a total capacity of 37.5 MW<sub>th</sub> were carried out in the Croatian cities of Samobor, Velika Gorica and Zaprešić.<sup>85</sup> Solar district heating also attracted more attention in Serbia and Kosovo during 2020 because of the continued support from the EBRD for (pre-) feasibility studies.<sup>86</sup> In early 2021, feasibility studies were under way in Pančevo (Serbia) and Priština (Kosovo) for at least 70 MW<sub>th</sub> of solar district heating plants.<sup>87</sup> The Serbian towns of Bor and Novi Sad had completed pre-feasibility studies, and Novi Sad's municipal council was proceeding with the next planning step.<sup>88</sup>

In addition to solar district heating, **central solar hot water systems** for large residential buildings, hospitals, sport clubs and prisons sold well in Brazil, China and Turkey during 2020. In total, at least 57 large solar thermal systems of at least 350 kilowatts-thermal (500 m<sup>2</sup>) each, used either for district heating or for central hot water, were added globally in 2020.<sup>89</sup> These capacity additions of 93 MW<sub>th</sub> brought the total number of large collector fields to at least 471 systems (1.8 GW<sub>th</sub>) by year's end (including glazed and concentrating solar thermal collectors).<sup>90</sup> (→ See Figure 33).

**FIGURE 33.** Solar District Heating, Global Annual Additions and Total Area in Operation, 2010-2020



Note: Includes large-scale solar thermal installations for residential, commercial and public buildings. Data are for solar water collectors and concentrating collectors.

Source: See endnote 90 for this section.



The additions in 2020 appear to represent a decline from the 74 large systems reported by technology suppliers as commissioned in 2019.<sup>91</sup> However, one large Chinese project developer, which was responsible for 36% of the plants completed in 2019, failed to report any large systems for 2020 despite completing several projects; this suggests that the world market remained more or less stable in 2020.<sup>92</sup>

Also during the year, several international organisations published a joint report emphasising the need to decarbonise industrial heat demand.<sup>93</sup> However, this urgent call for carbon-free heat solutions did not appear to stimulate demand for the use of new solar thermal systems to provide process heat for industry. Only 74 **solar heat for industrial processes (SHIP)** projects, with a total capacity of 92 MW<sub>th</sub>, came online in 2020, down from 86 projects and 251 MW<sub>th</sub> in 2019.<sup>94</sup> Multiple factors contributed to the relative decline: for example, the pandemic delayed the closing of contracts and the installation of ordered projects, and India's SHIP market declined in 2020 following the expiry in March of the national support programme for solar concentrating systems.<sup>95</sup> In the United States, Glasspoint, which was responsible for a large share of the global SHIP capacity added in 2019 (180 MW<sub>th</sub> of solar steam capacity commissioned in Oman), closed its doors in May 2020.<sup>96</sup>

By year's end, at least 891 SHIP systems totalling more than 792 MW<sub>th</sub> were supplying process heat to factories worldwide.<sup>97</sup> The top markets in 2020 were again China (30 new projects), Mexico (16) and Germany (10), followed distantly by India and Spain (3 each).<sup>98</sup> China's demand for solar industrial heat was triggered by government support policies to activate the economy after the pandemic, which helped drive an increase in the reported number of new projects from 26 in 2019 to 30 in 2020.<sup>99</sup>

Solar industrial heat plants in Mexico are cost competitive with fossil fuels such as liquefied petroleum gas (LPG), fuel oil and diesel, suggesting the potential for further market growth.<sup>100</sup> In many other countries, however, achieving competitiveness against oil and natural gas depends on investment support subsidies for SHIP systems or the elimination of fossil fuel

subsidies.<sup>101</sup> In Germany, continued funding since 2012 resulted in the commissioning of 10 new plants (totalling 1.5 MW<sub>th</sub>) in 2020.<sup>102</sup> Only one or two industrial solar heat systems were commissioned each in Austria, Belgium, Cyprus, Italy, Malaysia, Morocco, the Netherlands, Niger and Turkey.<sup>103</sup>

Although many solar technology suppliers reported delays in installation and construction, some megawatt-size plants were successfully commissioned in 2020. The top plants for new capacity demonstrated the variety of collector types typically used for SHIP plants globally. The largest new installation, at 10.5 MW<sub>th</sub>, used flat plate collectors to heat the greenhouses of a freesia farm in the Netherlands.<sup>104</sup> The largest plant with vacuum tube collectors (4.6 MW<sub>th</sub>) supplies heat in China to a factory in Sanya in Hainan province.<sup>105</sup> The largest SHIP plant with concentrating collectors (3.9 MW<sub>th</sub>), used for drying agricultural products, started operation in May 2020 in Ganzhou, Tibet (China).<sup>106</sup> Two 3.5 MW<sub>th</sub> plants also came online – one in Tibet with vacuum tube collectors for greenhouse heating, and one in Turkey with parabolic trough collectors providing heat to a packaging factory.<sup>107</sup>

**Hybrid or PV-T collectors**, which are solar thermal collectors mounted beneath solar PV modules to convert solar radiation into both electrical and thermal energy, have supplied only niche markets in recent years; thus, their capacity is not included in global and national capacity statistics. Since PV-T collectors have begun to gain popularity in a number of countries in recent years, market data are included in this report for the first time.<sup>108</sup> In 2020, 36 manufacturers globally reported PV-T capacity of at least 60.5 MW<sub>th</sub> (connected to 24 MW-electric), up strongly from 46.6 MW<sub>th</sub> in 2019.<sup>109</sup>

The largest markets in new PV-T additions in 2020 were, in order of capacity added, the Netherlands, China, France, Ghana and Germany.<sup>110</sup> Demand among residential and commercial clients in these countries has been driven by the ability to produce both heat and electricity from the same roof space, therefore generating a higher yield per area.<sup>111</sup> In the Netherlands, China and Germany, subsidy schemes also have played a role in triggering demand.<sup>112</sup>



### SOLAR THERMAL HEATING INDUSTRY

The global solar thermal industry experienced mixed results in 2020. Most large manufacturers reduced production volumes due to disruptions in the movement of labourers and goods during several months of the pandemic.<sup>113</sup> However, a small number of producers profited from growing demand triggered by new support policies (as in Germany) and from continuously high national demand from the construction industry and solar mandates in some provinces (as in China).<sup>114</sup>

China's solar thermal industry, which saw virtually no impact from COVID-19, continued two major trends from previous years: a high share of large systems for domestic commercial clients, and increasing domestic sales of flat plate collectors.<sup>115</sup> Consequently, Chinese companies again dominated the list of the world's largest manufacturers of flat plate collectors, holding the top six positions: in the lead was SunEast Group (including the Sunrain and Micoe brands), followed by Jinheng Solar (with its export brand BTE Solar), Haier (the majority owner of the Austrian company Greenonetec<sup>i</sup> until December 2020), Linuo Paradigma, Sangle and Fivestar.<sup>116</sup>

Excluding Greenonetec, which had no sales in China, the other six Chinese flat plate collector producers increased their combined sales volume 12% in 2020, growing faster than the domestic flat plate collector market overall (up 6%).<sup>117</sup> Industry consolidation in China continued, with only large solar equipment manufacturers implementing the rising number of solar space heating projects and responding to central procurement offers for solar water heating equipment for big construction projects.<sup>118</sup> Outside China, the combined sales volumes of the 14 largest flat plate collector manufacturers fell 9% on average in 2020, buffered slightly by strong sales growth in Germany.<sup>119</sup>

Global leaders in large solar heat project development also were affected by declines in the number of contracted projects and setbacks in project development in 2020. Arcon-Sunmark, the market leader in solar district heating from Denmark, closed its collector factory and stopped project development in mid-June, after several years of high fluctuations in turnover and low

margins in contracted projects.<sup>120</sup> The company continued to operate a small maintenance unit to fulfil its long-term service and warranty contracts with clients.<sup>121</sup>

Despite the demise of Arcon-Sunmark's manufacturing and development division, the company's know-how and assets remained partly available in the sector. Greenonetec (Austria) acquired the production line for large-scale collector panels, targeting the growing solar district heating market in Europe.<sup>122</sup> In addition, Viessmann (Germany) engaged a team of Arcon-Sunmark's planners and sales experts to strengthen its commercial solar heat project development unit, and Solareast Group (China) bought shares in the company's Asian business.<sup>123</sup>

US-based Glasspoint closed its doors as well in 2020, due in part to uncertainty resulting from the COVID-19 pandemic. In March, the company was forced into liquidation after existing shareholders from the oil industry decided to halt the additional funding that was required to keep it operational.<sup>124</sup> Glasspoint had been in charge of installing the world's largest solar steam-producing plant in Oman, which reached a capacity of 360 MW<sub>th</sub> in early 2020.<sup>125</sup> The company's difficulties started in 2019, when implementation of a 850 MW<sub>th</sub> solar steam-producing project in the Belridge oilfields of California was delayed due to a lack of financing; this was followed by a halt in the extension of the Oman project because the client did not approve the third phase at the beginning of 2020.<sup>126</sup>

Medium-sized European technology suppliers signed a number of new contracts during 2020 using improved business models that help to reduce the risk and the heat costs for clients investing in large-scale solar heat systems; these included solar heat contracts and sales of complete production lines. NewHeat (France) secured a bank loan of EUR 13 million (USD 16 million) in September for a pool of five large commercial solar heat systems in France, totalling 28 MW<sub>th</sub>.<sup>127</sup> As an energy service company, NewHeat offers solar heat contracts to two industrial sites and three district heating utilities.<sup>128</sup>



COVID-19 restrictions slowed installation work on solar industrial heat plants already under contract.

<sup>i</sup> In December 2020, Greenonetec founder re-acquired the 51% ownership stake that was sold to Chinese Haier in May 2017.



In April 2021, Kyotherm (France), which specialises in financing renewable heat projects, commissioned, together with its subcontractors (among others NewHeat, Savosolar of Finland and Sunoptimo of Belgium), Europe's largest solar industrial heat plant, a 10 MW<sub>th</sub> project for a malting facility in France.<sup>129</sup> Kyotherm, with its network of solar thermal project developers, continued contractual negotiations with commercial heat consumers in the United States and India, with the first contracts expected to be signed in 2021.<sup>130</sup>

In early 2021, Absolicon (Sweden) signed its 13<sup>th</sup> letter of interest thus far, with a potential buyer for its complete parabolic trough collector production line, which has a typical annual capacity of 100,000 m<sup>2</sup>.<sup>131</sup> The purchasers intend to invest in new production lines and are located around the globe, including in Ecuador, Ghana, India, Kenya, Mexico, Spain, Turkey and Uruguay.<sup>132</sup> With this strategy, Absolicon aims to reduce technology costs by enabling its buyers to produce solar collectors close to a large number of potential heat customers in sun-rich countries.<sup>133</sup>

Concentrating solar heat solutions are commonly used to produce temperatures above 100°C, even though other collector types, such as high-vacuum flat plate collectors, are able to reach temperatures up to 180°C.<sup>134</sup> Such systems use concentrating collector technologies with smaller dimensions (length and width) than for concentrating solar thermal power plants and provide heat for processing as well as for steam networks in hospitals or district heating. An increasing number of collector manufacturers have met the challenge of providing such high-temperature solutions. By the end of 2020, 23 solar industrial heat suppliers based in China, Europe, Mexico and North America were producing concentrating collectors, dominated by parabolic trough producers (14 companies) then Linear Fresnel (7) and concentrating dish (2) producers.<sup>135</sup>

A new generation of developers and manufacturers of innovative concentrating collector technologies established in recent years revealed their first demonstration or commercial projects in 2020. These technology providers rely on a wide range of concepts aimed at further lowering the cost of energy by reducing the quantity of material input per unit and by improving performance. The largest new producer, established in 2016, is WuCheng Energy based in Inner Mongolia, China, which signed contracts in 2021 to build a commercial 82 MW<sub>th</sub> district heating plant with parabolic trough collectors in the northern Chinese city of Handan, slated to start construction in summer 2021.<sup>136</sup>

Solarflux Energy Technologies (US) relies on a dish receiver that, as of early 2021, had been shipped to China, India, Mexico, Qatar and the United States to be used in demonstration projects (totalling 650 m<sup>2</sup>).<sup>137</sup> Four other start-ups – Skyven Technologies (US), True Solar Power (Spain), Umbral Energia (Mexico) and Heliac (Denmark) – were developing new solar collectors that consist of a heliostat array focusing on a receiver.<sup>138</sup> Concentrating collector companies in the technology prototype stage included Alto Solution (France), with a new parabolic trough unit, and Heliomis (Austria), which is developing a concentrator housed in an inflatable cylindrical foil-walled tunnel.<sup>139</sup>

Increasing awareness of solar thermal technologies by end-customers in the Russian Federation fuelled optimism in 2020 for investing in solar component factories. During the year, St. Petersburg saw the ramping up of two factories by privately owned Russian companies: the engineering firm Silagnis started producing heat pumps and solar collectors, and Solar Fox increased its manufacturing volume of solar air collector units.<sup>140</sup>

A strong and committed supply chain of around 80 turnkey SHIP suppliers offered solar heat solutions to industrial clients in 2020, despite the challenges of the pandemic.<sup>141</sup> Four out of five companies confirmed that the pandemic delayed the closing of SHIP contracts in 2020, because of economic uncertainty among potential customers.<sup>142</sup> Three out of four suppliers also confirmed that COVID-19 restrictions slowed installation work on plants already under contract.<sup>143</sup> Consequently, only 15 of the around 80 SHIP suppliers commissioned at least one project during the year, compared to 25 companies that put up at least one plant in 2019.<sup>144</sup>

Linuo Paradigma (China) was the 2020 market leader in both new projects and newly added SHIP capacity, reporting 22 projects totalling 58 MW<sub>th</sub> in 2020.<sup>145</sup> High demand in China was triggered by government support policies to activate the economy, which helped industrial clients invest in SHIP plants.<sup>146</sup> Modulo Solar (Mexico) realised the second largest number of SHIP plants, with 13 new small systems that totalled 0.8 MW<sub>th</sub>.<sup>147</sup> The second largest company for SHIP capacity in 2020 was SunEast Group (China), which reported the completion of five systems with a total of 8 MW<sub>th</sub>.<sup>148</sup>

Project developer Kyotherm had to postpone (to 2021) the commissioning of its 10 MW<sub>th</sub> SHIP plant at a malting factory in central France because of travel restrictions in Europe during the pandemic.<sup>149</sup> Similar restrictions affected other manufacturers, such as VSM Solar (India) and Absolicon (Sweden), which were unable to execute confirmed orders.<sup>150</sup> Although the number and capacity of new SHIP plants were down in 2020, the large number of delayed plants under contract fuels hope that the market will increase again in 2021.<sup>151</sup>



## KEY FACTS

- The world added a **record 93 GW of wind power capacity in 2020**, led by China and the United States. Both countries broke national records for new installations, driven in part by pending policy changes. The rest of the world commissioned about the same amount as in 2019, but several additional countries had record-breaking years.
- For the first time, global capital expenditures committed to **offshore wind power** in 2020 surpassed investments in offshore oil and gas.
- The industry continued to face perennial challenges exacerbated by the pandemic, but maintained **momentum in technology innovation** in continuous pursuit of an ever lower levelised cost of energy.
- Wind power accounted for a **substantial share of electricity generation** in several countries in 2020, including Denmark (over 58%), Uruguay (40.4%), Ireland (38%) and the United Kingdom (24.2%).

## WIND POWER

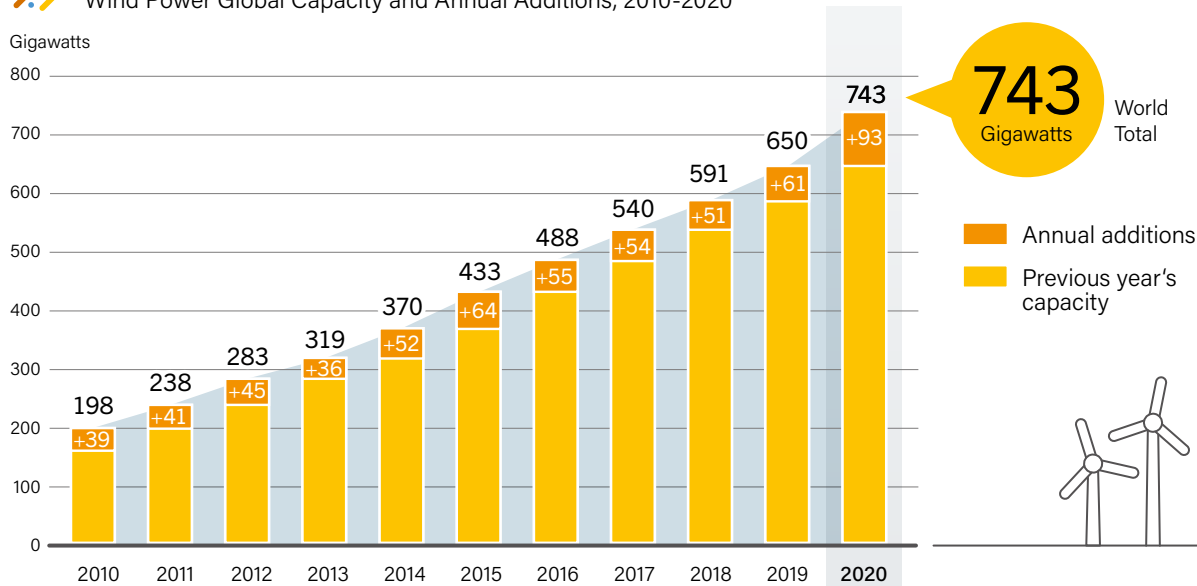


### WIND POWER MARKETS

An estimated 93 GW of wind power capacity was installed globally in 2020 – including more than 86.9 GW onshore, the highest yet, and nearly 6.1 GW offshore.<sup>1</sup> This record-breaking market was 45% above the previous high, in 2015 (63.8 GW), and represents an increase of nearly 53% relative to 2019 installations.<sup>2</sup> For several months of 2020, pandemic-related restrictions disrupted supply chains, rendered much of the wind energy workforce unavailable, resulted in postponed or cancelled auctions and delayed investments, and forced delays or cancellations to project construction in many countries, particularly in the onshore sector.<sup>3</sup> But even with the global health, economic and political challenges, by year's end total global wind power capacity was up 14% over 2019 and neared 743 GW (707.4 GW onshore and the rest offshore); this was double the capacity in operation worldwide only six years earlier, at the end of 2014.<sup>4</sup> (→ See Figure 34.)

The rapid growth in 2020 was due to a dramatic increase in China as well as to a jump in the United States in advance of policy changes; the rest of the world installed about the same amount of (net) additional capacity as it did in 2019.<sup>5</sup> The pandemic added to previously existing financing, infrastructure, policy and regulatory challenges in some countries, while other countries (in addition to China and the United States) saw record installations during 2020, including Argentina, Australia, Chile, Japan, Kazakhstan, Norway, the Russian Federation and Sri Lanka.<sup>6</sup> New wind farms reached full commercial operation in at least 49 countries, down from 55 countries in 2019, and at least one country, Tanzania, brought online its first commercial project.<sup>7</sup> By the end of 2020,

**FIGURE 34.** Wind Power Global Capacity and Annual Additions, 2010-2020



Note: Totals may not add up due to rounding.  
Source: GWEC. See endnote 4 for this section.

more than 100 countries had some level of commercial wind power capacity, and 37 countries – representing every region – had more than 1 GW in operation.<sup>8</sup>

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, often without financial support.<sup>9</sup> The economics of wind energy have become the primary driver for new installations.<sup>10</sup> Outside of China (which had a feed-in tariff, or FIT) and the United States (with tax credits and state renewable portfolio standards, or RPS), global demand for wind power in 2020 was driven largely by other policy mechanisms including auctions (or tendering).<sup>11</sup> Corporate power purchase agreements (PPAs) are playing a growing role in some markets, particularly in the United States and Europe but also increasingly in Latin America and Asia. In 2020, however, the capacity contracted globally through corporate PPAs was down 29% relative to 2019, to 6.5 GW.<sup>12</sup>

Wind power provides a substantial **share of electricity** in a growing number of countries. In 2020, wind energy generated enough to provide an estimated 15% of the annual electricity consumption in the EU-27, and much higher shares in at least five individual Member States.<sup>13</sup> Wind energy met an estimated 48% of Denmark's electricity demand in 2020 and accounted for nearly 58.6%<sup>i</sup> of the country's total generation.<sup>14</sup> Other European countries with wind generation shares of at least 20% for the year included Ireland (38%), the United

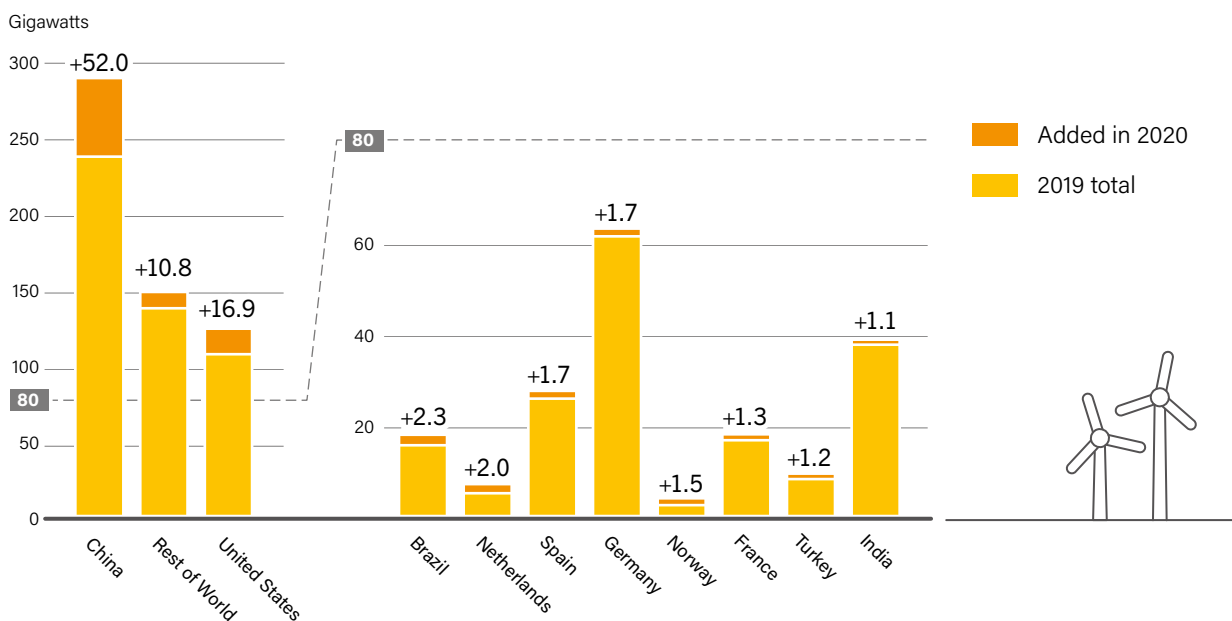
Kingdom (24.2%), Portugal (24%), Germany (23.2%) and Spain (21.9%).<sup>15</sup> Uruguay (40.4%) and Nicaragua (27.6%) also achieved high shares of generation from wind energy, and shares were high at the sub-national level in several countries.<sup>16</sup> Globally, wind power capacity in operation accounted for an estimated more than 6% of total electricity generation in 2020.<sup>17</sup>

For the 12th consecutive year, Asia was the largest **regional market**, representing nearly 60% of added capacity (up from 50% in 2019), with a total of nearly 348.7 GW by the end of 2020; almost 56% of new capacity was in China alone.<sup>18</sup> Most of the remaining installations were in North America (18.3%), Europe (14.8%) and Latin America and the Caribbean (5.0%).<sup>19</sup> The only regional markets that did not expand in 2020 were Europe, where the pandemic pushed many installations into 2021, and Africa and the Middle East, which remained stable.<sup>20</sup>

China widened its lead for new capacity (both onshore and offshore) and was followed distantly by the United States, which was well ahead of Brazil, the Netherlands and Spain; these five countries together accounted for just over 80% of annual installations, with China and the United States alone responsible for nearly 74%.<sup>21</sup> Other countries in the top 10 for total capacity additions were Germany, Norway, France, Turkey and India.<sup>22</sup> (→ See Figure 35 and **Reference Table R18** in *GSR 2021 Data Pack*.) Although the list of the biggest markets changed significantly relative to 2019, the top 10 countries<sup>ii</sup> for cumulative capacity were unchanged from those in both 2018 and 2019.<sup>23</sup>

- i The difference between generation (electricity produced within a country's borders) and consumption is due to imports and exports of electricity, as well as to transmission and distribution losses (which vary considerably across countries).
- ii The top countries by additions in 2019 were China, the United States, the United Kingdom, India, Spain, Germany, Sweden, France, Mexico and Argentina. The top 10 for cumulative capacity in the years 2018-2020 were China, the United States, Germany, India, Spain, the United Kingdom, France, Brazil, Canada and Italy.

**FIGURE 35.**  
Wind Power Capacity and Additions, Top 10 Countries for Capacity Added, 2020



Note: Numbers above bars are gross additions, but bar heights reflect year-end totals. Germany's net additions were slightly below those of Norway.  
Source: See endnote 22 for this section.

**China** had its biggest year yet for new installations, despite pandemic-related delays to grid connections early in the year.<sup>24</sup> The estimated 52 GW (48.9 GW onshore and 3.1 GW offshore) added in 2020 was about what the entire world installed in 2018, and almost double China's 2019 installations, and brought the country's total wind power capacity to an estimated 288.3 GW.<sup>25</sup> Around 72 GW (including 3.1 GW offshore) of wind power capacity was integrated into the national grid in 2020, with 281 GW<sup>i</sup> considered officially grid-connected by year's end.<sup>26</sup>

The Chinese market was driven primarily by a rush to install onshore projects that had to be grid-connected before the end of 2020 to receive the expiring national feed-in tariff.<sup>27</sup> The offshore market also faces a FIT qualification deadline (see discussion later in this section).<sup>28</sup> During the year, the central government reaffirmed plans for onshore wind power (and solar PV) to achieve grid parity by 2021.<sup>29</sup> The policy changes result from a mounting deficit in China's Renewable Energy Development Fund, which has caused a backlog of outstanding FIT payments for existing projects (only worsened by the pandemic), and from the central government's belief that wind (and solar) power is capable of competing without subsidies with coal-fired power.<sup>30</sup> In 2020, China accounted for 67% of the 33.7 GW onshore wind capacity awarded globally in auctions, and most of China's awarded capacity was based on the grid-parity scheme.<sup>31</sup>

The majority of China's wind power capacity continues to be in the north and west of the country, and at the end of 2020 wind power accounted for more than 20% of total capacity in several provinces in these regions.<sup>32</sup> However, deployment has continued to shift towards China's demand centres in the more populated regions in the central east and south, which together accounted for 40% of newly installed capacity in 2020.<sup>33</sup> The top regions and provinces for official grid-connected additions during the year were East Inner Mongolia (6.8 GW), Henan (6.6 GW), Shanxi (5.5 GW) and Hebei (5.2 GW).<sup>34</sup> As the main wind regions in China approach saturation, with ongoing curtailment and fewer sites available for deployment, the country's wind sector is increasingly looking to distributed options and in particular to offshore wind along China's extensive coastline, where economic activity is concentrated.<sup>35</sup>

Overall, an estimated 16.6 TWh of potential wind energy was curtailed in China during 2020 – an average of 3% for the year, down from 4% (16.9 TWh) in 2019, and below the national government's targeted cap (5%).<sup>36</sup> Curtailment remained concentrated mainly in Xinjiang, Gansu and Western Inner Mongolia, but all three regions continued to see reductions relative to previous years.<sup>37</sup> China's generation from wind energy was up 15% (to 466.5 TWh), and wind energy's share of total generation continued to rise steadily, reaching 6.1% in 2020 (up from 5.5% in 2019).<sup>38</sup>

**Elsewhere in Asia,** Turkey's annual installations nearly doubled relative to 2019, with 1.2 GW added for a total approaching 9.3 GW (all onshore).<sup>39</sup> For the first time since 2017, Turkey was among the top 10 countries globally for capacity added, ranking ninth.<sup>40</sup> Around 5 GW of new capacity was under construction as of early 2021.<sup>41</sup> Turkey is working to expand its renewable energy capacity to lessen the country's heavy reliance on imported energy, create jobs and reduce the national carbon footprint.<sup>42</sup> Wind energy accounted for 8.4% of Turkey's electricity generation in 2020.<sup>43</sup>

India fell from fourth to tenth place globally for additions, experiencing its lowest annual additions since at least 2006; however, it continued to rank fourth for total capacity at the end of 2020.<sup>44</sup> India added 1.1 GW for a year-end total of 38.6 GW, all operating onshore.<sup>45</sup> Installations peaked in 2017 (4.1 GW) and (aside from a slight uptick in 2019) have declined since auctions were introduced to the wind tendering process in 2017.<sup>46</sup> The number and diversity of local investors in India's wind power sector also have declined since the shift to auctions, while installations have become more concentrated geographically.<sup>47</sup>

At the end of 2020, the top Indian states for total capacity were Tamil Nadu (9.4 GW), Gujarat (8.2 GW) and Maharashtra (5 GW), which together accounted for nearly 59% of the country's total wind power capacity.<sup>48</sup> Across India, wind energy generated around 5% of all electricity during 2020; despite the increase in capacity, output fell 24% during the peak wind season (June to September) compared to 2019, due mainly to a significant and unusual drop in wind speeds, and it was down 5% for the year.<sup>49</sup>

The United States added more capacity in the final three months of 2020 than in any previous year except 2012.



<sup>i</sup> Statistics differ among Chinese organisations and agencies as a result of what they count and when. See endnote 26 for this section.



India's wind sector has faced challenges associated with grid connection and permitting, land acquisition and (during the pandemic) significant project construction delays.<sup>50</sup> By mid-year, a large amount of the capacity tendered in 2017-18 was not yet online, due to these challenges and to low winning tariffs that some developers have deemed unviable, making it difficult to obtain financing.<sup>51</sup> The Indian government announced plans to remove tariff caps from future wind (and solar) power tenders, eliminating a key limitation on investor interest; even so, in late 2020, two European companies stated that they would not participate in India's auctions, despite the country's large resource potential, due to low tariffs combined with land acquisition and grid connection problems.<sup>52</sup>

Japan placed fourth in Asia with record additions of almost 0.6 GW (double the country's 2019 installations) for a total of 4.4 GW.<sup>53</sup> The increase in projects under development both onshore and offshore was driven by the country's generous feed-in tariff.<sup>54</sup> Kazakhstan brought 0.3 GW online during the year, as the oil-rich country looks to green its energy mix and achieve 50% renewable electricity by 2050.<sup>55</sup> Other countries in the region that installed new wind power capacity in 2020 included Chinese Taipei (74 MW), Pakistan (48 MW added), the Republic of Korea (160 MW, including 60 MW offshore), Sri Lanka (88 MW) and Vietnam (125 MW), where the market was driven by a planned FIT expiration, a decline in the capital cost of wind turbines and rapid growth in electricity demand.<sup>56</sup>

The **Americas** added a record of nearly 22 GW (up 62% over 2019), with most (72%) installed in the United States.<sup>57</sup> The country commissioned 16.9 GW of new capacity in 2020, up 85% over 2019 installations.<sup>58</sup> US capacity brought online in the fourth quarter alone exceeded annual additions for every preceding year except 2012.<sup>59</sup> For the ninth year running, the oil and gas state of Texas was the leader in annual wind power installations (4.2 GW), followed by Iowa (1.5 GW), Wyoming (1.1 GW), Illinois (1.1 GW) and Missouri (1 GW).<sup>60</sup> At year's end, US total capacity reached 122.5 GW, enough to power more than 38 million average US homes.<sup>61</sup> Texas continued to lead for total capacity (33.1 GW), with 27% of the US total; if Texas were a country, it would rank fifth globally for cumulative installations.<sup>62</sup>

As in past years with record additions, the US market was propelled by the impending phase-out of the 100% federal production tax credit<sup>i</sup> (PTC) at year's end, which was granted a one-year extension in late 2019, and extended again at the end of 2020.<sup>63</sup> Demand from corporations also played a role, as did utilities (through direct ownership and, primarily, through PPAs) aiming to meet customer preferences, sustainability goals and mandates under state RPS laws.<sup>64</sup> US wind power PPAs for the year totalled 5.4 GW, down relative to the previous two years due at least in part to uncertainty caused by COVID-19.<sup>65</sup>

Wind energy accounted for 8.4% of US utility-scale electricity generation in 2020, up from 7.3% in 2019 and nearly four times the share a decade earlier.<sup>66</sup> In Texas, the country's largest electricity consumer by far, wind energy passed coal for the first time and accounted for nearly 20% of the state's utility-scale generation.<sup>67</sup> Wind energy saw higher shares for the year in at least 10 other states, including Iowa (58%), Kansas (43%), Oklahoma (35%) and North Dakota (31%).<sup>68</sup> The Southwest Power Pool (SPP), a regional transmission organisation, became the first US grid operator to see wind energy become the top source of electricity, surpassing both coal and natural gas.<sup>69</sup> The SPP, which covers some of the windiest states in the central plains corridor, has a robust transmission system and relies on accurate forecasting, a diverse mix of generators and an efficient wholesale market to manage high shares of variable renewable energy.<sup>70</sup> (→ See *Systems Integration* chapter.)

Despite the many advances across the United States, developers continued to report challenges related to raising tax equity<sup>ii</sup> for projects already in development due to economic uncertainty, limited tax equity supply and tight lending standards.<sup>71</sup> New projects increasingly are facing challenges related to project siting and resource availability, as well as grid congestion.<sup>72</sup> Many of the best areas for wind power projects in some states, such as California, have already been developed or have established prohibitions on new development, while grid congestion and related transmission upgrade costs have led to the cancellation of several wind (and solar) power projects – including many that had already secured PPAs – in nearly every region of the country.<sup>73</sup>



i The PTC gives wind energy generators a tax credit of roughly USD 0.02 per kilowatt-hour for electricity fed into the grid. Starting in 2021, the credit was scheduled to decline steadily and to end in 2025. In light of delays and supply chain issues caused by the pandemic, the commissioning deadline for projects that began construction in 2016 and 2017 was extended by one year; in December 2020, the PTC was legally extended for a further year at 60% of the full credit rate.

ii Essentially, trading the monetary value of the federal PTC (the future stream of tax credits to be received upon project completion) for upfront capital in order to develop a project.

Canada had a relatively slow year in 2020 (adding less than 0.2 GW), and most of the remaining installations in the Americas were in Latin America and the Caribbean.<sup>74</sup> Even as the region was hard-hit economically by the pandemic, a record 4.7 GW of new capacity came online, with Brazil ranking third globally for additions and eighth for total capacity.<sup>75</sup> Wind power has become the region's fastest growing power source, with around 33.9 GW of wind power capacity operating across at least 26 countries at year's end.<sup>76</sup>

Brazil added 2.3 GW, three times the country's 2019 installations, for a total of 17.7 GW.<sup>77</sup> The significant increase was thanks to capacity deployed through local PPAs, driven by wind energy's competitive prices in Brazil.<sup>78</sup> The government cancelled auctions in 2020 due to the pandemic but rescheduled them for 2021.<sup>79</sup> Wind energy accounted for 9.7% (56.5 TWh) of the country's total 2020 electricity generation.<sup>80</sup>

Argentina (1 GW) and Chile (0.7 GW) followed Brazil in the region, both with record years.<sup>81</sup> Mexico (0.6 MW), Panama (66 MW) and Peru (38 MW) also added capacity.<sup>82</sup> After two years of ranking among the world's top 10 installers, Mexico's market declined 45% in 2020 due to policy and regulatory changes undertaken since a new federal administration took office in late 2018 – including the cancellation in 2019 of government-led electricity auctions.<sup>83</sup> The changes have eroded the competitiveness of electricity from wind energy and other renewable sources, creating significant uncertainty for potential private investors and developers.<sup>84</sup> Social acceptance issues and limited grid connection availability also have hampered Mexico's wind energy development.<sup>85</sup> PPAs for corporate procurement in Mexico nearly dried up in 2020, whereas Brazil signed a record 1 GW of corporate renewable energy PPAs that year.<sup>86</sup>



**Europe** added 13.8 GW of new wind power capacity in 2020 (down nearly 7% relative to 2019), of which 21% is operating offshore, bringing the region's total to nearly 210.4 GW.<sup>87</sup> Onshore additions were below expectations due largely to commissioning delays resulting from COVID-19-related supply chain disruptions and restrictions on the movement of people and goods, as well as continued permitting delays in some countries (particularly Germany).<sup>88</sup> As in other regions, the diversity and number of investors has declined in recent years with the phase-out of FITs.<sup>89</sup> Even so, 2020 was Europe's third biggest year for new installations, after 2017 and 2019.<sup>90</sup>

Outside of the EU, annual additions were up the most in Norway and the Russian Federation, both with record installations. Norway added 1.5 GW of capacity onshore, for an onshore total of nearly 4 GW.<sup>91</sup> Europe's largest wind farm (1 GW Fosen) was completed in Norway, despite the country's low power prices and protests over the project's potential impacts on local reindeer herders.<sup>92</sup> The Russian Federation increased its capacity more than four-fold (adding 0.7 GW), as capacity awarded in a 2018 auction began to come online, for a year-end total of 0.9 GW.<sup>93</sup> Although the Russian Federation remained the world's only major economy just beginning to develop a domestic wind market and industry, the awarded capacity (3.3 GW in total) should continue to come online through 2024.<sup>94</sup>

In the United Kingdom, which just a year prior was the top installer in Europe and the third largest globally, additions fell 75% in 2020 to 0.6 GW, most of it added offshore, for a cumulative total of 24.2 GW.<sup>95</sup> After five years with no public support for onshore wind (or solar) power, the UK government announced in 2020 that the technology will again be allowed to participate in the Contracts for Difference scheme.<sup>96</sup> Wind generation rose 18% relative to 2019 due to increased capacity and even more so to favourable wind conditions, particularly offshore, where output increased 26% and exceeded onshore generation for the first time.<sup>97</sup> During the year, more than 100 wind farms across the United Kingdom were participating in a flexibility market trial, enabling them to provide balancing services; industry governance codes require new UK wind farms to provide "power available" signals.<sup>98</sup>

Most new capacity in Europe was installed in the EU-27, which brought online nearly 10.8 GW (8.4 GW onshore and 2.4 GW offshore), or net additions of 10.4 GW (accounting for decommissioning).<sup>99</sup> Across the 27 Member States, 16 added capacity during 2020, down from 18<sup>iii</sup> in 2019.<sup>100</sup> Annual additions were slightly below those in 2019, with installations down in all but a handful of countries.<sup>101</sup> The EU ended the year with a total of 179.3 GW<sup>iv</sup>, including 164.7 GW onshore and 14.6 offshore.<sup>102</sup>

i The Contracts for Difference (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 A power available signal is a live data feed available to engineers in the control room of the UK's National Grid ESO. The data provide engineers with the potential maximum power output of a generator (in this case a wind farm) at any given time, enabling control systems to calculate each generator's response and reserve capability; this in turn allows the generator to compete with other generators to provide real-time response and reserve services. See endnote 98 for this section.

iii This figure excludes the United Kingdom for the sake of comparison.

iv Note that the EU cumulative data are lower than those reported for end-2019 because they no longer include the United Kingdom, which ended 2020 with around 24.2 GW (13.7 GW onshore and 10.4 GW offshore).



The community structure of the Dutch Zeewolde project helped to **increase social acceptance**, easing permitting and reducing risk for potential financiers.

The EU's annual wind power market was again fairly concentrated, with the top five countries – the Netherlands (added 2 GW), Spain (1.7 GW), Germany (nearly 1.7 GW), France (1.3 GW) and Sweden (1 GW) – accounting for 70% of the total.<sup>103</sup> Although it was not among the top countries, Poland also saw a substantial jump over 2019 with 0.7 GW installed (up from 0.05 GW), helping to balance the decline in other countries.<sup>104</sup> The leading countries<sup>i</sup> for cumulative capacity at year's end were Germany, Spain, France, Italy and Sweden.<sup>105</sup>

The Netherlands was the top installer in Europe and ranked fourth globally, adding nearly 2 GW (up from 0.3 GW in 2019) for a cumulative total of 6.8 GW.<sup>106</sup> Most of the new capacity was offshore, with the country's largest offshore project fully commissioned in December.<sup>107</sup> Onshore in mid-2020, a cooperative of 200 local residents, farmers and other investors closed turbine supply contracts and financing for a repowering project near Amsterdam.<sup>108</sup> Once completed in 2021-2022, the 0.3 GW Zeewolde project is expected to be the largest onshore wind farm in the Netherlands and the largest community-owned wind power project in Europe.<sup>109</sup> The community structure helped increase social acceptance of the project, easing permitting and reducing risk for potential financiers.<sup>110</sup> The Dutch government aims to increase community ownership from only a small fraction of wind power capacity in 2020 to 50% of new wind (and solar) projects by 2030.<sup>111</sup>

Spain ranked second in the region and fifth globally for new capacity, adding more than 1.7 GW for a total of 27.4 GW.<sup>112</sup> While down from the 2.2 GW brought online in 2019, and below the government's target (set in 2020) of 2.2 GW per year to 2030, it is a significant increase over annual installations during the years 2009 through 2018.<sup>113</sup> In late 2020, Spain approved an order that regulates a new auction mechanism for wind and other renewable power capacity for the 2020-2025 period.<sup>114</sup> Wind energy accounted for 21.9% of Spain's electricity generation in 2020.<sup>115</sup>

Germany placed third in the EU (and all of Europe) and sixth globally for new capacity, but total additions were the country's lowest in a decade.<sup>116</sup> Germany added almost 1.7 GW (1.4 GW net) for a total of 62.6 GW (54.9 GW onshore and 7.7 GW offshore).<sup>117</sup> Offshore installations (0.2 GW) were down 80% relative to 2019; onshore additions increased nearly 33% after two years of decline following Germany's shift from a feed-in policy to tenders, but were at their second-lowest level since 2010.<sup>118</sup> Even so, wind output was up 4% and wind energy accounted for 23.6% (131 TWh) of national gross electricity consumption during 2020, exceeding brown coal (lignite) for the second consecutive year.<sup>119</sup>

In recent years, most of Germany's auctions for onshore capacity have been undersubscribed (including six of seven in 2020), and annual deployment has fallen significantly. Factors behind the drop include restrictive siting legislation in some states, complex planning procedures and a decline in local proponents as the number of local investors has fallen and projects increasingly are planned by a relatively limited number of participants (mostly larger-scale developers); these developments together have resulted in a lack of permitted projects eligible to compete in the tendering process.<sup>120</sup> As of mid-2020, the onshore wind permitting process took more than two years, compared to the historical average of 10 months.<sup>121</sup> Uncertainty about possible changes to setback distancing rules also has reduced investments in new onshore capacity; in mid-2020, the federal government gave states the final authority on distancing rules.<sup>ii,122</sup> Germany's New Renewable Energy Sources Act (EEG 2021), passed at the end of 2020, set a new target for a total of 71 GW of wind power onshore (and 20 GW offshore) by 2030.<sup>123</sup>

For the EU and the United Kingdom combined, wind energy generated an estimated 458 TWh in 2020 (up from 417 TWh in 2019) and met around 16.4% of total electricity demand (13.4% with onshore and 3% with offshore wind).<sup>124</sup> The 1.9 percentage point share increase relative to 2019 resulted from additional capacity, windy conditions early in the year and a drop in electricity demand due to COVID-related restrictions.<sup>125</sup>

i If the United Kingdom were still an EU member, the country would rank third in the EU for total capacity, and the top five list would remain unchanged from 2019.

ii New federal provisions allow states to set minimum distances between turbines and residential areas at 1,000 metres. See endnote 122 for this section.



In the **South Pacific**, Australia continued to account for the majority of new installations, while New Zealand added capacity (0.1 GW) for the first time since 2015.<sup>126</sup> For the second consecutive year, Australia saw records for both installations and output, with 1.1 GW brought online at 10 new wind farms for a total approaching 7.4 GW (all onshore).<sup>127</sup> Renewable capacity under corporate PPAs also achieved a new capacity record, with wind power accounting for 41% (the rest being solar PV) of the 1.3 GW contracted in 2020.<sup>128</sup> Community engagement also is playing a growing role in Australia, with the industry increasingly recognising the importance of benefit sharing with the local community for successful project development.<sup>129</sup>

Wind power again was Australia's largest renewable source of electricity, producing 22.6 TWh (up 16% over 2019), or 9.9% of the country's total generation.<sup>130</sup> Among the individual states, the highest local shares of generation occurred in Victoria (29.7%), South Australia (25.9%) and New South Wales (20.4%).<sup>131</sup> The rapid increase in the number and capacity of large wind (and solar) power projects and their output continued to challenge the grid, with ongoing connection and transmission issues; several state governments announced renewable energy zones that are expected to ease pressure on the grid.<sup>132</sup> (→ See *Solar PV section in this chapter*.)

**Africa and the Middle East** combined installed over 0.8 GW of wind power capacity, nearly the same amount as in 2019, despite the pandemic's impact on supply chains and project installation.<sup>133</sup> South Africa accounted for nearly 63% of these additions with more than 0.5 GW added, followed by Senegal (0.1 GW), which fully commissioned its first commercial wind farm, and Morocco (nearly 0.1 GW), where several additional projects were under construction.<sup>134</sup> Jordan, Iran, Egypt and Tanzania also added capacity, with Tanzania completing its first commercial wind project.<sup>135</sup> At year's end, 13 countries in Africa and 5 in the Middle East had a total of 7.3 GW of wind power capacity (all onshore), with most of it in South Africa (2.5 GW), Egypt (1.5 GW) and Morocco (1.3 GW).<sup>136</sup>

Countries in the region are installing wind (and solar) power to diversify their energy mix, lower per unit electricity costs while meeting rising demand, reduce reliance on imported electricity and fuels, and free up more of their own oil and gas for export.<sup>137</sup> For example, to eliminate its heavy reliance on imported electricity from Ethiopia, Djibouti was planning its first utility-scale wind project (59 MW) in 2020, and Ghana was planning for 1 GW of wind capacity to reduce reliance on fossil fuels and hydropower, which has seen output decline with reduced river flows.<sup>138</sup> However, both Africa and the Middle East continued to face challenges to further wind power deployment, including uncertain or unsupportive policy and power market frameworks, bottlenecks in transmission infrastructure and off-taker risk.<sup>139</sup>

In the **offshore wind power** segment, five countries in Europe and two in Asia, as well as the United States, connected nearly 6.1 GW in 2020, increasing cumulative global offshore capacity to more than 35.3 GW.<sup>140</sup> Wind turbines operating offshore accounted for 6.5% of all newly installed global wind power capacity in 2020 (down from 10% in 2019) and represented 4.7% of total capacity at year's end (down from 5% in 2019).<sup>141</sup> China led the sector for the second year running, accounting for just over half of new installations, and Europe installed most of the rest.<sup>142</sup>

China added a record 3.1 GW of offshore capacity, raising the total 44% to around 10 GW.<sup>143</sup> More capacity might have been commissioned in 2020, but progress was stalled by bottlenecks including supply chain issues and a lack of offshore turbine installation vessels.<sup>144</sup> Developers rushed to finalise projects before the end of 2021, when the national FIT for offshore wind power is scheduled to end.<sup>145</sup> Jiangsu, Fujian and Guangdong together were home to more than 80% of China's offshore capacity in operation at the end of 2020.<sup>146</sup> These and other coastal provinces have set offshore wind capacity targets totalling nearly 60 GW of capacity by 2030.<sup>147</sup>

Elsewhere in Asia, the Republic of Korea added 60 MW of offshore wind power capacity; Japan launched its first offshore wind auctions, including one for a floating wind farm; and Chinese Taipei had three projects under construction offshore with a total capacity of 0.7 GW.<sup>148</sup> The Republic of Korea aims for 12 GW of offshore capacity by 2030, and in December 2020 Japan released a vision document that calls for 10 GW of offshore capacity by 2030 and 30-45 GW by 2040.<sup>149</sup>

In July 2020, a PPA was signed for the entire output of a 0.9 GW wind project (the world's largest-ever renewable energy PPA at the time) off the west coast of Chinese Taipei that is due to begin construction in 2025.<sup>150</sup> To date, relatively few corporate deals have been signed globally for offshore wind energy, but corporate interest is increasing due to the large scale of generation, high capacity factors, fairly uniform generation profile and falling costs.<sup>151</sup> Six new offshore PPAs also were signed in Europe, for projects in Belgium, Germany and the United Kingdom, following the first six in 2018-19.<sup>152</sup> PPAs have become an increasingly important means for developers to guarantee revenue over the long term, especially in the case of exposure to wholesale market price (as with "zero-subsidy" bids at auction).<sup>153</sup>

Europe remained home to most of the world's offshore capacity. The region added 2.9 GW in 2020 (down 20% from 2019) in nine completed wind farms, bringing the regional total to 25 GW.<sup>154</sup> The Netherlands more than doubled its offshore capacity (adding 1.5 GW) and accounted for more than half of Europe's installations; it was followed by Belgium (0.7 GW), which had a record year, the United Kingdom (0.5 GW), Germany (0.2 GW) and Portugal (nearly 17 MW).<sup>155</sup> UK installations were the lowest since 2016, not because of faltering commitment but because of





a gap between government contracting rounds, and foundations were installed to prepare sites for enormous future wind farms.<sup>156</sup>

Germany saw its lowest numbers in nearly a decade, with no new offshore wind power projects under construction at year's end as all projects planned under tenders had been installed. However, under a new offshore wind energy law that entered into force in December 2020, Germany is set to increase offshore tender volumes significantly.<sup>157</sup> Portugal's additions of two floating turbines completed the Windfloat Atlantic wind farm.<sup>158</sup> Europe's total floating capacity reached 62 MW, and the pipeline for floating wind projects in the region for the next decade exceeds 7 GW.<sup>159</sup>

At year's end, five countries continued to host nearly all of Europe's offshore capacity: the United Kingdom (42%), Germany (31%), the Netherlands (10%), Belgium (9%) and Denmark (7%).<sup>160</sup> The year brought a record EUR 26.3 billion (USD 32.3 billion) of financing for 7.1 GW of future capacity (including transmission infrastructure) off the coasts of the United Kingdom, Germany and France; this is up from EUR 6 billion (USD 7.37 billion) in 2019.<sup>161</sup> In 2020, several countries increased their future targets for offshore wind power capacity, including the United Kingdom (boosted its 2030 target from 30 GW to 40 GW) and Germany (increased its 2030 target from 15 GW to 20 GW).<sup>162</sup> As of early 2021, total government commitments for offshore wind power by 2030 reached 111 GW.<sup>163</sup>

Targets also were increased in the United States, with six eastern states aiming to bring online a combined 28.1 GW of offshore wind power capacity by the 2030-2035 period.<sup>164</sup> By early 2020, state procurement commitments totalled 28.9 GW, and another

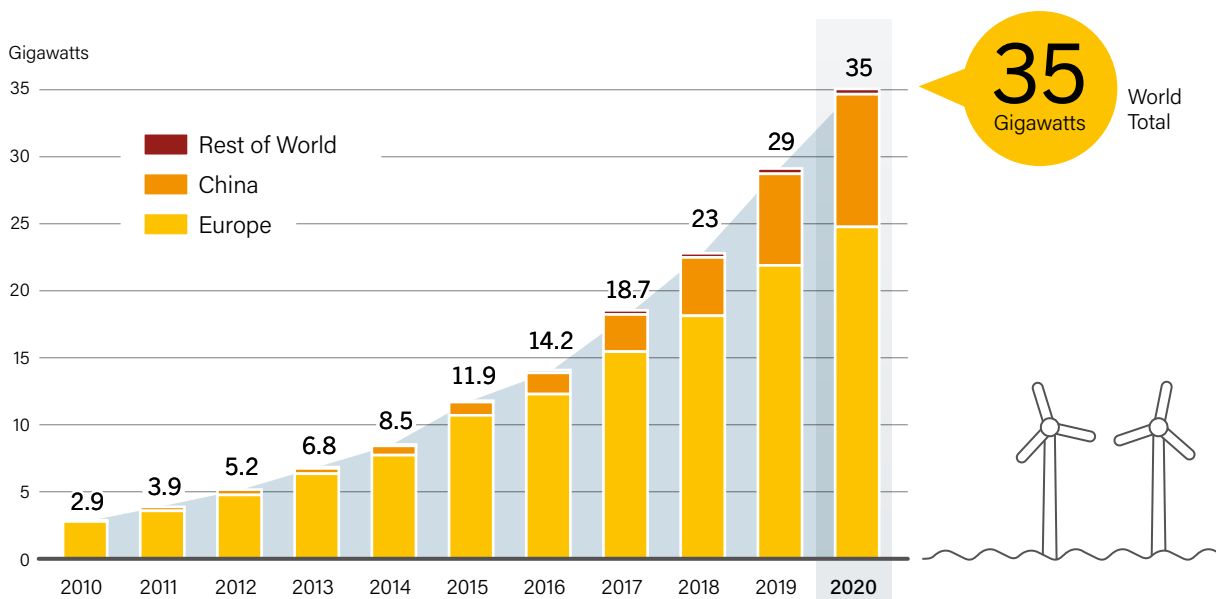
55.9 GW was in interconnection queues by mid-year.<sup>165</sup> Actual installations remained low, however. The country's first project installed in federal waters, a 12 MW pilot<sup>i</sup> off the coast of Virginia, was completed during 2020, bringing total US offshore capacity to 42 MW.<sup>166</sup>

Other US developments in 2020 included: New York state issued a second solicitation for 2.5 GW; Rhode Island announced a request for proposals for 0.6 GW; Massachusetts approved contracts for the 0.8 GW Mayflower Wind project; the Icebreaker project on Lake Erie moved forward after years of permitting battles; and Louisiana began investigating the potential for offshore wind in the Gulf of Mexico to create jobs and reduce greenhouse gas emissions.<sup>167</sup> In early 2021, the 0.8 GW Vineyard Wind project (Massachusetts) was granted final federal approval.<sup>168</sup>

By the end of 2020, 18 countries (12 in Europe, 5 in Asia and 1 in North America) had offshore wind capacity in operation, unchanged from 2019.<sup>169</sup> The United Kingdom maintained its lead for total capacity (10.4 GW), followed by China (10 GW), which overtook Germany (7.7 GW), the Netherlands (2.6 GW) and Belgium (2.3 GW), both of which overtook Denmark (1.7 GW) in 2020.<sup>170</sup> Europe was home to around 70% of global offshore capacity (down from 75% in 2019 and 79% in 2018), with Asia (mostly China) accounting for nearly all the rest.<sup>171</sup> (→ See Figure 36.) Around the world, an additional 82 GW of offshore capacity was under construction, had been approved through regulatory processes or had reached financial close.<sup>172</sup> Global capital expenditures committed to offshore wind power surpassed investments in offshore oil and gas for the first time in 2020.<sup>173</sup>

i This proof-of-concept project was a step towards development of a 2.6 GW project in the same area, scheduled to be brought online in phases between 2024 and 2026.

**FIGURE 36.**  
Wind Power Offshore Global Capacity by Region, 2010-2020



Note: Totals above 20 GW are rounded to nearest GW. Rest of World includes the rest of Asia as well as North America.

Source: See endnote 171 for this section.

The **decommissioning** of wind turbines that had reached the end of their service life, or were ripe for refurbishment on economic grounds, totalled an estimated 0.5 GW in 2020, across 10 countries.<sup>174</sup> In Europe, seven countries decommissioned almost 0.4 GW of capacity, all of it onshore, led by Germany (222 MW), Austria (64 MW) and Denmark (62 MW), with smaller amounts in Belgium, France, Luxembourg and the United Kingdom.<sup>175</sup> The United States decommissioned around 74 MW of capacity, with the remainder removed from operation in Japan and the Republic of Korea.<sup>176</sup> Decommissioning does not necessarily mean the end of a project, but can pave the way for repowering with more advanced and efficient technology; some of the decommissioned projects were repowered. (→ See *Industry section below*.)

The pandemic added to existing challenges, but **several developments fed hope** for the year to come.

## WIND POWER INDUSTRY

Even as the global market expanded and several countries had a strong year, the global wind industry continued to face perennial challenges that were exacerbated by the pandemic. Nonetheless, a number of developments fed hope for the year to come, including: remedial policy adjustments in several countries, ongoing technology development and innovations, growing attention to climate change mitigation and wind energy's potential role, and increasing interest among industry actors and governments in advancing floating wind technologies and green hydrogen.

Particularly early in the pandemic, the wind industry was affected by restrictions on movement of labourers and supplies.<sup>177</sup> Turbine assembly generally requires components produced in numerous countries around the globe, and lockdowns disrupted supply chains.<sup>178</sup> Restrictions also slowed project permitting and development (particularly onshore), which was especially challenging for developers racing to complete projects before support policies changed or expired at year's end, or before fixed commissioning deadlines.<sup>179</sup> Short-term declines in electricity demand and prices led asset owners to reduce operation and maintenance (O&M) budgets; these downward trends also adversely affected demand for turbines and new projects and curtailed access to financing for onshore wind, which slowed the signing of PPAs and investment in new onshore projects.<sup>180</sup> The result was reduced margins for turbine manufacturers (suppliers of both machines and, increasingly, O&M).<sup>181</sup>

These troubles all added to existing challenges, including: the lack of grid access and unreliable grid systems; poorly designed

tenders in some countries; and the lack of available land with good wind resources.<sup>182</sup> Permitting delays also have been prevalent, due in some cases to local opposition as the number of participants declines and the size of developers and the scale of projects increase; in 2020, delays worsened as government staff was reassigned to pandemic-related matters.<sup>183</sup> In another ongoing challenge, downward pressure on bid prices in some markets is affecting manufacturers and developers, even as a lack of investment and competition in other markets has driven bid prices up.<sup>184</sup>

In several countries, governments responded by extending deadlines to account for pandemic-related delays.<sup>185</sup> By the end of 2020, new policy commitments had helped stimulate record investments in new projects.<sup>186</sup> The year saw new entrants (including fossil fuel companies) to the wind power sector, and wind turbine manufacturers and developers expanded further into new sectors.<sup>187</sup> The industry continued to better integrate wind energy into existing electricity grids and to improve technologies to increase output and further reduce the cost of energy.<sup>188</sup>

By one estimate, from the second half of 2019 to the same period in 2020, the global benchmark **levelised cost of energy** (LCOE) from new wind power projects fell 17% onshore (to an average USD 41 per MWh) and 1% offshore (USD 79 per MWh).<sup>189</sup> Cost reductions are the result of several factors, including more powerful and efficient turbines that can capture more wind and economies of scale with larger projects, which reduce per unit costs of installation, operation and maintenance.<sup>190</sup>

**Auctioned capacity** in 2020 was down 26.5% relative to 2019 but reached the second highest level on record, with a global total of 35 GW<sup>ii</sup> (including 33.7 GW onshore).<sup>191</sup> Activity plummeted early in the year, due mainly to pandemic-related postponements in some key markets, but increased over the second half of 2020 relative to the same period in 2019.<sup>192</sup> China accounted for two-thirds of the total wind power capacity auctioned and awarded, with most of this for onshore projects to be built without direct government support.<sup>193</sup> Thirteen other countries or regions held wind-specific or renewable energy auctions, including several in Europe as well as Ecuador, India and the US state of New Jersey.<sup>194</sup>

Results<sup>iii</sup> from auctions vary widely depending on local conditions and costs, project scale and other factors.<sup>195</sup> For example, Europe's winning onshore bids during 2020 were in the range of EUR 42.4 to EUR 69.2 (USD 52 to USD 85) per MWh, compared with EUR 21 to EUR 67 (USD 25.8 to USD 82.3) per MWh in 2019.<sup>196</sup> While declining costs and fierce competition in auctions and tenders have driven down average bid prices in many markets, bids have been stable or even rising in others. Relative to earlier auctions, prices for onshore wind power in 2020 were down significantly in France and Greece.<sup>197</sup> In contrast, prices were up in Italy, where all three auctions for solar PV and wind power were undersubscribed, due in part to permitting challenges.<sup>198</sup>

i Note that energy costs vary widely according to wind resource, project and turbine size, regulatory and fiscal framework, the cost of capital, land and labour, exchange rates and other local influences.

ii 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.

iii Note that bid levels do not necessarily equate with costs. Bid levels differ from market to market due to varying auction designs, policies and risks, among other factors.

In Germany, winning bid levels for onshore capacity were fairly stable through the year, but remained higher than at auctions in 2017 and early 2018, and above the statutory tariffs under the country's previous Renewable Energy Act.<sup>199</sup>

In India, several wind tenders in recent years resulted in relatively low levels of competition, as policy, regulatory and market uncertainty have shifted the sector towards developers with greater risk-taking capacity.<sup>200</sup> The inconsistent regulatory environment and lack of suitable sites in most Indian states for wind power project development have contributed to the rise in wind tariffs since 2017 and helped to increase the relative attractiveness of solar PV.<sup>201</sup>

In the offshore sector, the Netherlands held its third 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.<sup>202</sup> The winning consortium of Shell and Eneco plans to build a 759 MW project that will include floating solar PV and battery storage, and to use the electricity generated to produce hydrogen.<sup>203</sup> Offshore wind tenders also were held in the US state of New Jersey (bid price pending as of early 2021) and France, where the winner of a tender for 1 GW off the coast of Normandy is expected to be announced in 2022.<sup>204</sup>

In some countries where auctions are putting growing price pressure on markets, **direct PPAs** are becoming increasingly important.<sup>205</sup> In Brazil, for example, returns to developers can be higher through PPAs than in national electricity auctions.<sup>206</sup>

PPA prices trended upwards in Europe through most of 2020 but generally declined in the fourth quarter.<sup>207</sup> In the United States, prices under PPAs for onshore wind power capacity rose throughout 2020, with steeper increases starting in the second quarter; the pandemic was among the factors driving up prices, in addition to grid connection delays, permitting challenges and the fact that the windiest sites with easy grid access have already been developed.<sup>208</sup> This increase followed a steady decline in US average PPA prices since 2009.<sup>209</sup> In the offshore segment, in early 2020 developers signed PPAs with six utilities in the US state of Massachusetts for electricity from the 0.8 GW Mayflower

Wind project, due for commissioning in 2025; the levelised price over 20 years was USD 58.47 per MWh<sup>i</sup> (13% below the levelised price of the relatively nearby Vineyard Wind project in 2018), setting a new benchmark for US offshore wind.<sup>210</sup>

The wind industry has seen more than 100 **turbine suppliers** over the years, with a peak of 63 suppliers reporting installations during 2013; the number has declined rapidly since 2015, with 33 in 2019, but might have climbed slightly in 2020, due to the rush of installations in China.<sup>211</sup> The six leading manufacturers captured 75% of the capacity installed in 2020 (up from 64% in 2017).<sup>212</sup>

The top six turbine suppliers in 2020 were Vestas (Denmark), GE Renewable Energy (GE, US), Goldwind, Envision (both China), Siemens Gamesa (Spain) and Mingyang (China), together accounting for more than 63 GW of installations.<sup>213</sup> Vestas stayed on top for the fifth consecutive year, GE delivered record global volumes and benefited from a strong home market – as did Goldwind (which also supplied more than 1 GW of turbines for overseas markets for the first time), Envision and Mingyang – and Siemens Gamesa dropped from third in 2019 to fifth in 2020, but led the offshore market.<sup>214</sup> Chinese manufacturers took 10 of the top 15 places, thanks to the dramatic increase in China's onshore installations; the role of most Chinese firms beyond the domestic market remains limited.<sup>215</sup>

Senvion (Germany) and Suzlon (India), both among the top 10 in 2017, and Germany's Enercon (eighth in 2019), all continued to struggle due to declining sales in their home markets.<sup>216</sup> Even top manufacturers suffered losses for the year, closed factories and laid off workers, despite selling more turbines (by capacity), as the highly competitive market combined with pandemic-related costs and delays to further squeeze profit margins.<sup>217</sup> Both Vestas and GE reported that their orders for new turbines had fallen slightly relative to 2019.<sup>218</sup> Legal battles among manufacturers escalated in 2020 and into 2021 over intellectual property as they sought to maintain or gain control over key markets.<sup>219</sup>

To further diversify their portfolios in key markets, wind power developers and turbine manufacturers continued expanding into new sectors during 2020.<sup>220</sup> Ørsted (Denmark), the largest



In some countries where auctions put growing price pressure on markets, **direct PPAs** are becoming increasingly important.

<sup>i</sup> The combined price for electricity and renewable energy credits under the Mayflower Wind project will come to USD 77.76 per MWh on a nominal levelised basis for the two phases of the project. See American Clean Power Association, *ACP Market Report – Fourth Quarter 2020* (Washington, DC: 2021), p. 16, <https://cleanpower.org/resources/american-clean-power-market-reportq4-2020>.

offshore wind developer and operator, took the final investment decision in late 2020 to develop a large solar PV project in the US state of Texas under a long-term PPA, bringing the company's solar portfolio to 1.1 GW under construction.<sup>221</sup> Chinese turbine manufacturers are turning to solar PV and other avenues to diversify their business as national subsidies are phased out. Mingyang, for example, has developed a solar and financing lease business, while Goldwind has expanded into water treatment, and Envision acquired Automotive Energy Supply Corporation (Japan) to move into energy storage and batteries.<sup>222</sup>

Manufacturers also focused on **technology innovation**, building largely on existing concepts.<sup>223</sup> The fact that nearly all major wind power markets are auction driven (including new, emerging markets) has pressured the industry to continuously reduce costs and achieve the lowest possible levelised cost of energy.<sup>224</sup> One ensuing trend in recent years has been a move to turbines with lower specific power (the ratio of capacity to rotor swept area). This results in less energy production per square metre of rotor area but offers several benefits that help reduce the LCOE, including lower generator costs and savings on other components, as well as higher capacity factor and reduced variability of output, which lowers balancing costs and can increase the value of the turbine's generation to the grid system.<sup>225</sup>

Turbines for use onshore and offshore continued to get **larger and taller** during 2020, enabling them to capture more energy from the wind to make wind-generated electricity economical in more locations.<sup>226</sup> Onshore turbines in the 5 to 6-plus MW range were introduced by GE, Nordex (Germany), Siemens Gamesa, and Vestas, and Mingyang launched a 6.25 MW machine.<sup>227</sup> Several companies also launched new smaller machines for low-wind sites, including those targeted to wind conditions in specific markets.<sup>228</sup> Goldwind was working on new turbines for low- and medium-wind speeds (both onshore and offshore) and new hybrid tower concepts to further reduce the LCOE as China's FITs come to an end.<sup>229</sup>

Taller turbine towers and longer blades have affected everything from design to manufacture, transport and installation (and related costs).<sup>230</sup> To address the challenges associated with transporting taller towers, Nordex launched a facility in Spain (the company's 12th such factory) based on a mobile concept that enables concrete towers to be produced and assembled locally, reducing logistics costs as well as transport distances. The facility can be dismantled and reassembled in new locations.<sup>231</sup> GE announced a partnership with a robotics firm and a building manufacturer to develop 3-D printed concrete bases for on-site production of turbine towers. The process

Larger, taller wind turbines are able to capture more energy, making wind-generated electricity **economical** in more locations.

should allow for larger bases and thus taller hub heights to capture stronger winds, while also reducing transport-related costs and challenges.<sup>232</sup>

The world's then-longest blade – LM Wind Power's 107 metre blade – was certified for use in November 2020.<sup>233</sup> The move towards ever-longer blades for use onshore and offshore has affected supply chain strategies, including the increasing outsourcing of production.<sup>234</sup> Even so, the number of blade suppliers declined by about one-third from 2016 to 2020 as small- and medium-sized manufacturers were unable to compete on R&D investment, costs and global presence.<sup>235</sup> In 2020, both GE and Siemens Gamesa closed blade manufacturing facilities to cut costs and because of the facilities' inability to handle larger blades and the falling demand for the smaller blades they produced.<sup>236</sup>

In 2020, the average size of turbines delivered to market was 2% larger than in 2019 (2.76 MW), at 2.81 MW (2.7 MW onshore and 6.0 MW offshore).<sup>237</sup> In late November, the last of 77 MHI Vestas<sup>i</sup> 9.5 MW turbines – the largest turbines installed thus far – was installed at a site off the Dutch coast.<sup>238</sup> Just one of these turbines has nearly as much power capacity as the combined total of the first two offshore wind farms, off the coast of Denmark.<sup>239</sup>

Turbines are set to get only larger as manufacturers race to build the biggest and most powerful units, especially for offshore use. In 2020, GE increased the power rating of its Haliade-X prototype to 13 MW, and later boosted it to 14 MW for use in the UK's Dogger Bank wind farm, with installation set to begin in 2025.<sup>240</sup> Siemens Gamesa released a 14 MW turbine that can be boosted to 15 MW and should be commercially available starting in 2024.<sup>241</sup> By mid-2020, several Chinese manufacturers had entered the fray, with Dongfang commissioning a 10 MW prototype and Mingyang announcing an 11 MW hybrid drive (the world's largest), which it expects will be commercially available in 2022.<sup>242</sup> Not to be left behind, Vestas became the first to launch a 15 MW turbine (upgradable to 17 MW) in early 2021.<sup>243</sup>



<sup>i</sup> Note that Vestas acquired Mitsubishi Heavy Industry's (MHI) shares in MHI Vestas in late 2020, and the company was integrated back into Vestas. See endnote 238 for this section.



**Offshore** developers are taking advantage of larger turbines as soon as they become available, with several orders placed for these mega-turbines during 2020.<sup>244</sup> Larger, higher-efficiency turbines mean that fewer turbines, 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, all particularly important for the offshore sector.<sup>245</sup>

Floating turbines 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.<sup>246</sup> Costs are about double those of fixed bottom turbines but continue to fall as technologies advance, and the sector is ready for full commercialisation.<sup>247</sup> In late 2020, an MHI Vestas (now Vestas) 9.5 MW turbine became the largest yet installed for use in a floating project, off the coast of Scotland.<sup>248</sup>

Throughout 2020, several major wind power developers – including Enel (Italy), Equinor (Norway), Ørsted, RWE (Germany) and Vattenfall (Sweden) – unveiled plans to produce hydrogen or methane with wind energy.<sup>249</sup> In addition, Siemens Gamesa and spin-off Siemens Energy were developing an offshore turbine with a fully integrated electrolyser to produce hydrogen directly.<sup>250</sup> Several **oil and gas companies** also announced plans or launched partnerships to develop hydrogen projects linked to offshore wind power.<sup>251</sup>

As offshore wind power has advanced (and particularly floating technologies), major oil companies have begun investing large and growing amounts of money into the sector, which is one of the areas (in addition to geothermal) where the skill and knowledge transfer from oil to renewable energy is most clear.<sup>252</sup> As of early 2021, oil majors accounted for only 5% of offshore capacity in operation, but from early 2019 to March 2021 they won about half of offshore wind power tenders awarded outside of China.<sup>253</sup> European oil majors' have a combined target of at least

125 GW of renewables capacity by 2030, with much of this being offshore wind power.<sup>254</sup>

Among developments in 2020, Total (France) made its first major investments in offshore wind power, acquiring stakes in projects in UK waters and announcing plans to develop a 2.3 GW floating project off the Republic of Korea, and Eni (Italy) also entered the UK market, acquiring 20% of the UK Dogger Bank project.<sup>255</sup> Both Equinor (Norway), a pioneer in floating wind technology, and Neoenergia (Spain) were looking at the possibility of developing offshore wind projects in Brazil, and Equinor and BP (UK) partnered to develop offshore wind capacity in the United States.<sup>256</sup> Shell (Netherlands) is partnering on several offshore projects, and (along with German utility Innogy) is a major backer of the Steisdal TetraSpar, a new floating foundation that promises easier assembly and installation, and thus lower costs.<sup>257</sup> Also, Australian oil and gas explorer Pilot Energy announced plans to undertake a feasibility study into a 1.1 GW project off the coast of Western Australia as part of its effort to diversify beyond fossil fuels.<sup>258</sup>

Several Asian and European utility companies have begun moving into offshore wind power technology and project development, especially in the floating sector.<sup>259</sup> In 2020, two of India's largest fossil fuel and electricity companies partnered to develop renewable energy projects, including offshore wind.<sup>260</sup>

Offshore wind is not without its **challenges**. There are concerns that the offshore sector is growing so quickly – in the number of projects and the scale of turbines – that it will outpace the number, size and ability of installation vessels to transport and lift large components.<sup>261</sup> As of late 2020, only four vessels were capable of handling the next generation of offshore turbines, such as GE's Haliade-X.<sup>262</sup> In addition, 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 grid infrastructure.<sup>263</sup> The United States, for example, had no offshore wind factories as of 2020; however, at least six states were competing during



i Excludes Shell, which did not have a stated target as of early 2021.

the year to host them, announcing plans to build manufacturing facilities and to transform ports and marine terminals into hubs for an offshore wind industry, and some states announced plans to start training workers.<sup>264</sup>

Around the world, and particularly onshore, major manufacturers are focused increasingly on the **repowering**<sup>i</sup> segment.<sup>265</sup> 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 (partial repowering).<sup>266</sup> Bigger blades, new rotors and improved mechanics all can boost efficiency and provide better monitoring of wind speed and direction, increasing output by 10% or more, and without the challenges of interconnection and permitting hurdles.<sup>267</sup>

In the United States, project owners partially repowered 2.9 GW at existing projects in 2020, slightly below 2019 levels but 130% above 2018 levels.<sup>268</sup> Repowering in the country was driven by the looming expiration of the federal PTC<sup>ii</sup> at year's end (later extended in December) and by the significant technology improvements of recent years.<sup>269</sup> Repowering increased somewhat in Europe (345 MW) through projects in Germany (339 MW) and smaller amounts in Greece, Luxembourg and the United Kingdom.<sup>270</sup> Repowering in China has been limited to date.<sup>271</sup>

As the earliest fleets of wind turbines reach retirement age, and components are replaced, concerns are increasing about what to do with turbines and components at the **end of their life**. Although most of a turbine can be used on another wind farm or recycled, blades are made of complex composite materials that are difficult and expensive to recycle.<sup>272</sup> Efforts have focused on repurposing old blades (e.g., as sound barriers) or developing

solutions for recycling and reusing their composite materials, and on developing blades with entirely different materials.<sup>273</sup>

Related developments in 2020 and early 2021 included: GE signed a contract with Veolia North America to use decommissioned blades as raw material in place of coal, sand and clay for cement production; the DecomBlades consortium (Denmark) launched to find sustainable recycling solutions for composite materials in blades; a consortium of 10 companies and technical centres launched the Zero wastE Blade ReseArch (ZEBRA) project in Europe to develop the world's first fully recyclable blade of thermoplastic resin; and US researchers validated the structural integrity of thermoplastic composite blades, determining that they could be more efficient and robust, manufactured on site, and the material could be melted and reused.<sup>274</sup>

An increasing number of manufacturers also are focused on making wind turbines sustainable in their production as well as at end of life, and trying to do so in a way that is cost effective in order to remain competitive.<sup>275</sup> After achieving its 2019 goal to become carbon-neutral in early 2020, Siemens Gamesa turned its attention to its international supply chain.<sup>276</sup> Also in 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.<sup>277</sup> Early in 2021, Envision committed to achieving carbon neutrality for its operations by 2022 and for its value chain by 2028.<sup>278</sup>

→ See Box 7 for developments in the small-scale wind power sector.<sup>279</sup> Also see Sidebar 6 on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.<sup>280</sup>



An increasing number of manufacturers are focused on **making wind turbines sustainable** in production as well as at end of life.

i Repowering refers to the process of replacing turbines within an existing wind farm with newer turbines. If the majority of components (including foundation) are replaced, a project is considered repowering; replacement of only specific components is considered partial repowering. See endnote 265 for this section.  
 ii Repowering a project enables owners to reset the clock on 10 years' worth of US federal tax credits, encouraging the replacement of parts of existing turbines well ahead of the end of their original life expectancies. Looming expiration of the tax credit drove increased activity. See endnote 269 for this section.

## BOX 7. Small-scale Wind Power

Small-scale<sup>i</sup> (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 2019 (latest data available) in response to onerous local permitting and planning laws, inconsistent policy support as well as unfavourable policy changes (e.g., introduction of market caps, removal of incentives), and ongoing competition from relatively low-cost solar PV.

By one estimate, 42.5 MW of new small-scale wind power capacity was installed in six countries during 2019, down from an estimated 47 MW in 2018 and 114 MW in 2017. Due to a lack of data, these estimates do not include off-grid systems even in large markets, or installations in additional countries. At the end of 2019, more than 1 million small-scale turbines (totalling at least 1.7 GW) were estimated to be in operation worldwide.

China continued to be the largest market with an estimated 23 MW installed in 2019, down from 30.7 MW in 2018. Japan added 17 MW, followed distantly by the United States with 1.4 MW, a 7% annual reduction that continued the country's downwards trend in small-scale turbines; much of the new US capacity was for retrofit projects. Other important markets included Germany (0.5 MW), the United Kingdom (0.4 MW) and Denmark (0.2 MW).

Markets declined during 2019 in all of these countries except Japan, where installations were up nearly 32% over the previous year. By June 2020, Japan had more than 5,000 projects (108 MW) approved under a new FIT system, and only a small portion of these was already in operation.

In response to shrinking domestic markets, the number of producers of small-scale wind turbines in China and the United States has declined sharply in recent years, with manufacturers relying heavily on export markets, which also have been in decline. US-manufactured exports, for example, fell below 0.5 MW in 2019, down from 2015 (21.4 MW), as

key export markets largely dried up due to reduced or discontinued feed-in tariff programmes. US domestic sales rose slightly in 2019 (from 1.1 MW in 2018 to 1.2 MW in 2019) as imports fell; but domestic small-scale turbine sales were well below their annual totals early in the decade.

At least in the United States, however, things were looking up in 2019 and early 2020 with evidence that a 2018 extension of the federal investment tax credit for small-scale wind power, combined with public research and development (R&D) funding to improve competitiveness, could enable small and distributed wind power to turn the corner in the country. US R&D efforts also were under way to make wind power technology a plug-and-play component in hybrid systems and microgrids, among other options.

Italy, which has been an important market in past years, also received a boost from a new FIT incentive that was enacted in mid-2019. Following a decline in total capacity due to decommissioning (8.2 MW in 2018 and 2.6 MW in 2019), an estimated 8 MW of new small-scale wind power capacity was installed in the first half of 2020.

Elsewhere, the small-scale wind sector is seeing the emergence of several start-up companies, including Diffuse Energy (Australia) and Alpha 311 Ltd (UK), which manufactures vertical-axis turbines that are attached to existing light posts located near roads or rail lines. New uses for small-scale turbines under consideration or development include mining, small microgrids and data centres.

<sup>i</sup> 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 around 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.

Source: See endnote 279 for this section.





## SIDEBAR 6. Renewable Electricity Generation Costs in 2020

Renewable power costs continued to decline in 2020, keeping with trends from the past decade. The mature technologies such as hydropower, bio-power and geothermal, typically are dispatchable and low-cost power sources, and are competitive in regions where unexploited resources exist. However, the decade was notable for the rapid improvements in the competitiveness of solar and wind power technologies.

The levelised cost of electricity (LCOE)<sup>i</sup> of utility-scale solar PV fell 85% between 2010 and 2020, from USD 0.381 per kWh to USD 0.057 per kWh. (→ See Figure 37.) Over the decade, utility-scale solar PV became competitive with the lowest-cost new fossil fuel-fired capacity<sup>ii</sup>. Cost declines were driven primarily by falling module prices and reductions in balance-of-system<sup>iii</sup> costs, which tumbled between 2010 and 2020 as module efficiency improved and manufacturing was scaled up and optimised. As a result, the total installed cost of utility-scale solar PV fell 81% over the decade.

The LCOE of onshore wind power fell 54% between 2010 and 2020, from USD 0.089 per kWh to USD 0.041 per kWh. The total installed cost of newly commissioned onshore wind projects fell from USD 1,970 per kW to USD 1,355 per kW during the decade.

Cost reductions for onshore wind were driven by declining turbine prices and by reductions in balance-of-plant costs and operation and maintenance costs. At the same time, costs have been reduced through continued improvements in wind turbine technology (e.g., larger turbines, higher hub heights and larger swept blade areas), wind farm siting and reliability that have led to an increase in average capacity factors, with the global weighted average rising from 27% in 2010 to 36% in 2020<sup>iv</sup>.

For offshore wind, the LCOE of newly commissioned projects fell 48% from USD 0.162 per kWh in 2010 to USD 0.084 per kWh in 2020. Annual values for the global weighted average total installed costs, capacity factors and LCOE are relatively volatile given the small number of projects added in some years<sup>v</sup>. From 2010 to 2020, total installed costs fell around 32%, while capacity factors increased from 38% in 2010 to 42% in 2019, before dropping back to 40% in 2020. The drop in the global weighted average capacity factor in 2020 was driven by new plants being commissioned mainly in China, where offshore wind farms still predominantly use smaller offshore wind turbine designs and are in areas with lower-quality wind resources (e.g., inter-tidal or near shore).



- i All references to LCOE and total installed costs in this sidebar are global weighted averages. 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 outlined in International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2020* (Abu Dhabi: 2021), which provides further details on the LCOE methodology.
- ii The fossil fuel-fired power generation cost range varies by country and fuel, but overall is estimated at between USD 0.055 per kWh and USD 0.148 per kWh. The lower bound represents new coal-fired plants in China.
- iii Balance-of-system and balance-of-plant costs encompass the full project costs, including labour, hardware, permitting, grid interconnection, etc.
- iv The global weighted average capacity factor for newly commissioned onshore wind projects in 2020 reported here is uncertain given that the geographic distribution of new capacity connected to the grid in China in 2020 was not available when the analysis was undertaken.
- v The growth in new markets in recent years, both within Europe (where offshore wind's first markets developed) and globally, have made year-on-year cost comparisons difficult.



The LCOE of concentrating solar thermal power (CSP) fell 68% from USD 0.340 per kWh to USD 0.108 per kWh between 2010 and 2020. These costs declined into the middle of the range of the cost of new capacity from fossil fuels despite only several projects being commissioned in recent years. Similar to solar PV, the decline in the cost of electricity from CSP has been driven by reductions in total installed costs. Yet, technology improvements that have spurred improved economics of thermal energy storage also have played a role in increasing capacity factors.

For bio-power, geothermal and hydropower, the installed costs and capacity factors tend to be project specific. This, coupled with different cost structures in different markets, results in considerable year-to-year variability in global weighted average values, particularly when deployment is relatively thin and the share of different countries or regions in new deployment varies significantly.

Between 2010 and 2020, the LCOE of bio-power projects was volatile. By the end of the decade, it had remained at around the same level as in 2010 at USD 0.076 per kWh – still at the lower end of the cost of electricity from new fossil fuel-fired projects.

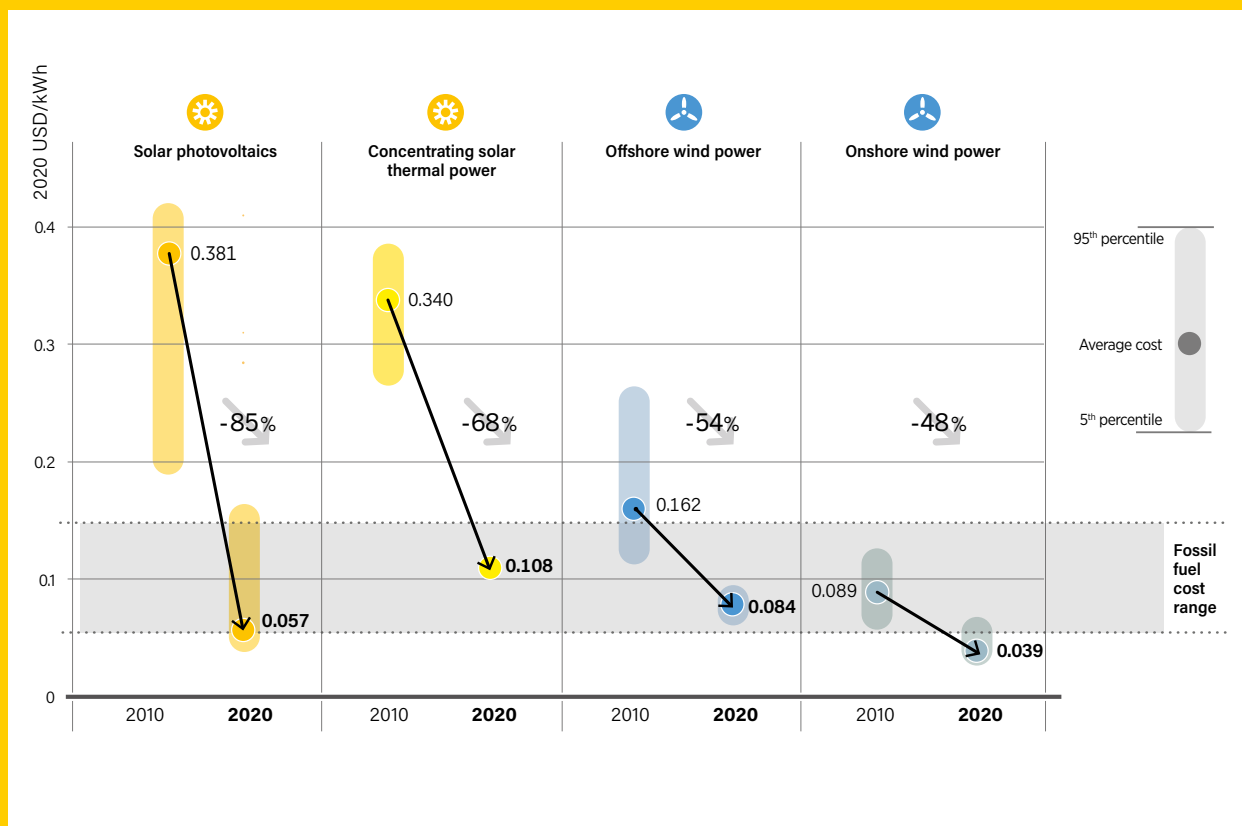
For the same period, the LCOE of hydropower rose 16%, from USD 0.038 per kWh to USD 0.044 per kWh. This was still lower than the cheapest new fossil fuel-fired electricity option, despite the 10% year-on-year increase in costs in 2020.

The global weighted average LCOE of geothermal has ranged between USD 0.071 per kWh and USD 0.075 per kWh since 2016. The LCOE of newly commissioned plants ended up at the lower end of this range in 2020 at USD 0.071 per kWh, having declined 4% year-on-year.



**FIGURE 37.**

Global Levelised Costs of Electricity from Newly Commissioned Utility-scale Renewable Power Generation Technologies, 2010 and 2020



Source: IRENA. See endnote 280 for this chapter.



**Oorja - a company working at the intersection between agriculture and clean energy - finances and installs distributed solar energy systems for farming purposes.**



04



# 04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

## KEY FACTS

- By the end of 2019, 90% of the global population had access to electricity, although **one-third still had to cook with polluting fuels**. Only 4% of people living in rural sub-Saharan Africa had access to clean cooking solutions.
- Sales of off-grid solar systems fell 22% in 2020, as **businesses were affected by the effects of the COVID-19 pandemic** such as lockdowns, supply chain issues and economic downturn. Sales improved in the second half of the year.
- Financing for off-grid solar companies increased slightly by around 1%, with a much larger **shift from equity finance to debt** and grant funding.
- While many mini-grid projects were delayed, in several countries new **solar mini-grids were commissioned specifically to power healthcare facilities** as an emergency response to COVID-19.
- Overall, clean cooking continues to attract only a fraction of the estimated funding needed to achieve universal access; however, 25 clean cooking companies were able to raise USD 70 million in 2019, a **63% increase** compared to the 32 companies that raised USD 43 million in 2018.

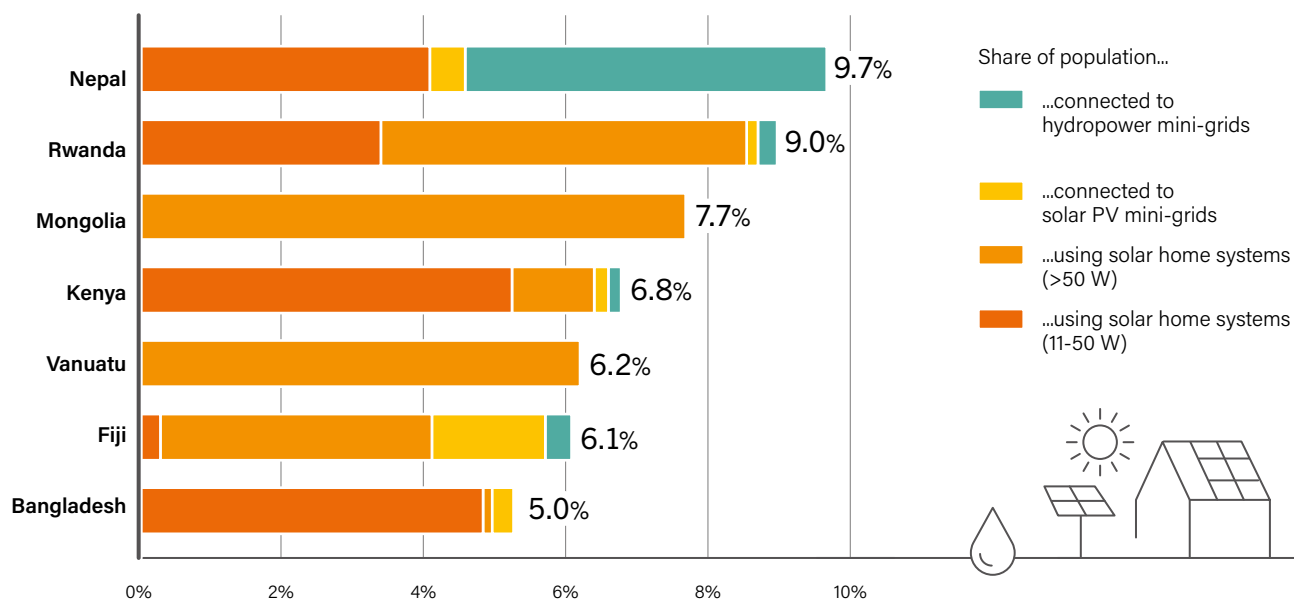
## INTRODUCTION

**D**istributed renewables for energy access<sup>i</sup> (DREA) play an increasingly important role in delivering energy access in developing countries, providing electricity to between 5% and 10% of the population in several countries.<sup>1</sup> (→ See Figure 38.) These systems deliver a wide range of services, including electricity for lighting, appliances, productive uses, cooling, irrigation and water pumping, as well as energy for cooking and heating.

**Renewables-based electric power systems** have proven valuable in rural and peri-urban communities that are difficult or costly to reach through grid electrification programmes. Distributed renewables can provide affordable electricity access that can be scaled up over time, powering not only households but also businesses and community services, such as health care and education. In recent years, solar photovoltaics (PV) has become the technology of choice for off-grid electricity access, but many other renewable access solutions are in place (for example, mini-grids based on mini-hydropower or small wind turbines to power households).

<sup>i</sup> See Sidebar 9 in GSR 2014 for more on the definition and conceptualisation of DREA. Note that since 2018 the GSR has used the terminology “distributed renewables for energy access” to distinguish from “distributed renewable energy” (DRE) that has no link to providing energy access.

**FIGURE 38.**  
Top 7 Countries with the Highest Electricity Access Rate from Distributed Renewable Energy Solutions, 2019



Note: Data in figure include solar home systems and mini-grids but exclude solar lights.  
Source: See endnote 1 for this chapter.

Providing **clean cooking**<sup>i</sup> remains the biggest energy access challenge and has seen the least progress in recent years. Many people in the developing world have little choice than to cook using traditional biomass systems, such as indoor open fires or inefficient cook stoves. This results in high levels of household air pollution with serious health impacts that fall disproportionately on women.<sup>2</sup> Clean cooking solutions exist but are not always available or affordable.<sup>3</sup> In off-grid settings, renewables such as biogas and improved biomass cook stoves can play a role,



whereas in urban areas, electricity, liquefied petroleum gas (LPG) and ethanol are most frequently used. While a switch to LPG has improved health outcomes in many countries, clean cooking ultimately needs to align with decarbonisation objectives.<sup>4</sup>

**Cooling** is a critical aspect of the provision of modern energy services. Without access to sustainable cooling<sup>ii</sup>, labour productivity often remains low, agricultural produce goes to waste, and health care is compromised (for example, vaccine storage is not possible).<sup>5</sup> In the rural areas of many developing countries, lack of electricity access is the main reason for the lack of cooling, whereas in urban areas the key factors are a poor standard of housing and the intermittency of electricity supply.<sup>6</sup> Distributed renewables can enable the use of cooling, especially when combined with efficient appliances.

The coronavirus pandemic has led to renewed focus on the importance of energy access. Evidence has emerged about the links between long-term exposure to particulate matter from air pollution and the risk of mortality from COVID-19.<sup>7</sup> As the crisis has progressed, the challenges of health care and vaccine roll-out in the absence of reliable access to electricity have become increasingly clear.<sup>8</sup> (→ See Box 8.) Renewables-based energy systems have been highlighted as offering solutions to these energy access problems, as well as providing economic opportunities during the recovery phase.<sup>9</sup>

i As per the guidelines of the World Health Organisation for indoor air quality linked to household fuel combustion, 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.  
ii Sustainable cooling includes efficient fans, air conditioners, refrigerators and other cold storage, ideally run on renewable electricity. In addition, it covers measures to reduce the need for cooling through insulation, shading, reflectivity or ventilation.



## BOX 8. Energy Access, Health and COVID-19

A lack of access to modern energy services has implications for health and the provision of medical services. Cooking with polluting fuels has been linked to 4 million premature deaths from illnesses such as chronic obstructive pulmonary disease, and people with these diseases also are at higher risk of severe cases of COVID-19. At the same time, a lack of electricity access greatly restricts the available treatment options for COVID-19 and other diseases. Crucial equipment such as ventilators and oxygen generators require constant electricity to function, but 60% of healthcare facilities in 46 middle- and low-income countries lack a reliable power supply. In rural areas of sub-Saharan Africa, there is often no electricity at all.

Reliable electricity is essential for vaccine storage, and all of the COVID-19 vaccines that are approved or under development require refrigeration, some as low as minus 70 degrees Celsius. Solar-powered vaccine refrigerators have been available since the 1980s but often fail due to short battery lifetimes or lack of regular maintenance. The global

vaccine alliance GAVI has been investing in solar direct-drive refrigerators, which can store vaccines at constant temperatures using ice banks instead of batteries. These refrigerators have already been transformative in remote and under-immunised areas. While they are not able to operate at the very low temperatures that some COVID-19 vaccines require, they are suitable for vaccines that only need to be stored at ordinary fridge temperatures. Cold storage during transport is also crucial, and innovations such as cool boxes with solar-powered batteries can provide a solution for transport to remote locations.

In response to the COVID-19 pandemic, many donor programmes have allocated funds to support the electrification of health services. For examples, Power Africa, funded by the US Agency for International Development (USAID), redirected programme funds to provide USD 2.6 million in grants to off-grid companies for electrification of rural and peri-urban health clinics.

Source: See endnote 8 for this chapter.

## OVERVIEW OF ENERGY ACCESS

Globally, billions of people continue to lack access to modern energy services. The biggest deficit is in clean cooking, with a third of the world's population, or 2.6 billion people, still relying on polluting fuels (mostly traditional use of biomass) in 2019.<sup>10</sup> The trend for electricity access has been more positive, with 90% of people globally having access to electricity in 2019, up from 80% in 2010.<sup>11</sup> However, modelling data for 2020 suggest that this trend may have reversed due to the pandemic; in Africa, 2% fewer people had access to electricity in 2020.<sup>12</sup>

Progress in **clean cooking** remains slow and is focused on relatively few countries. Although more than 1 billion people gained access to clean cooking between 2010 and 2018, most of this improvement was in Asia.<sup>13</sup> In China and India, more than 450 million people achieved clean cooking access, but these two countries still account for nearly half of the global population without access.<sup>14</sup> Many countries in Latin America and the Caribbean have high rates of access to clean cooking, but notable exceptions include Haiti (only 6% access), Guatemala (46%), Honduras and Nicaragua (both 55%).<sup>15</sup>

Sub-Saharan Africa continues to lag, with the number of people gaining access to clean cooking not keeping up with population growth.<sup>16</sup> Large differences exist between rural and urban areas: the average access rate in rural sub-Saharan Africa is only 4%, whereas in urban areas it reaches 31%.<sup>17</sup> Nigeria and Ethiopia have the largest populations in the region without access to clean cooking, a total of 275 million people in 2018.<sup>18</sup> In Ethiopia, the problem is primarily rural, whereas Nigeria has large urban and rural deficits, with only 21% of its urban population able to access

clean cooking options.<sup>19</sup>

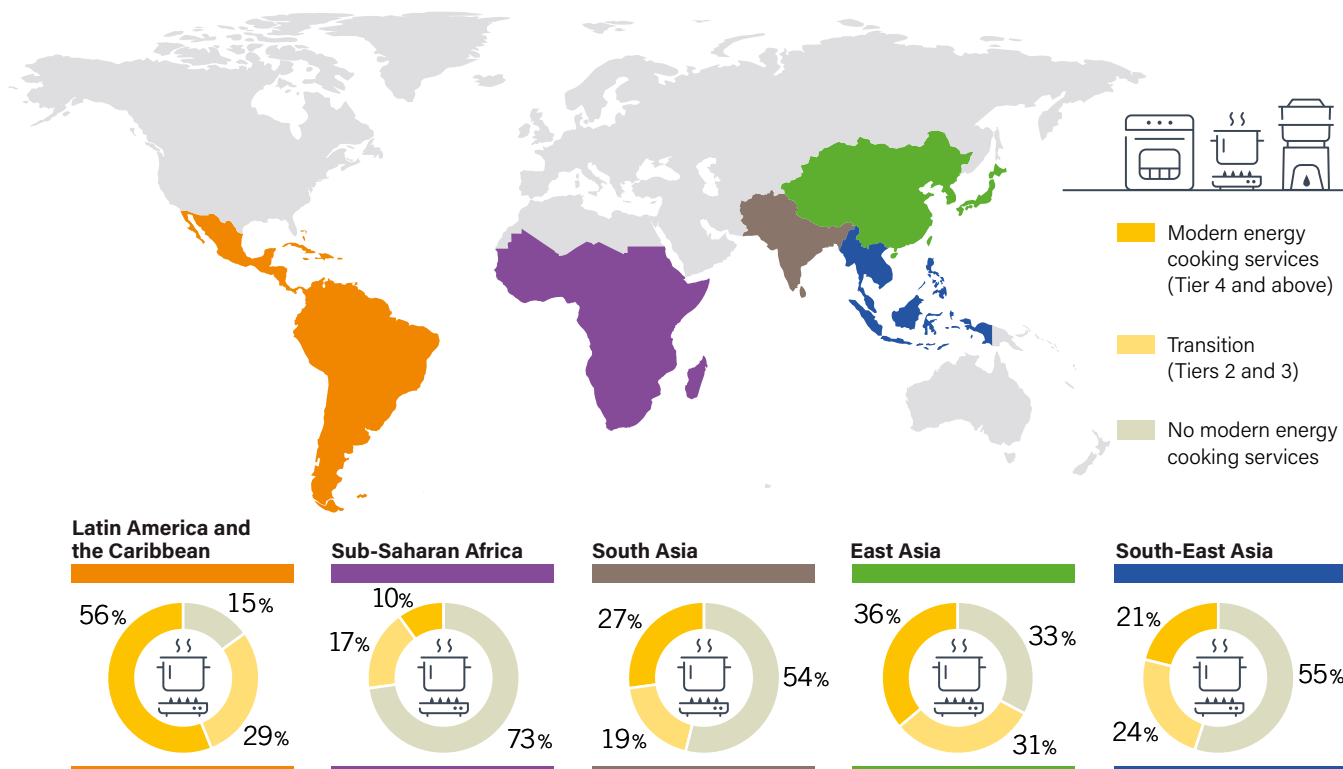
The assessment of clean cooking progress is constrained by data limitations.<sup>20</sup> In September 2020, new data on the state of access to modern energy cooking services provided a more granular assessment than was available previously.<sup>21</sup>

These data suggest an even higher deficit in access, with an estimated 4 billion people out of a sample of 5.3 billion people across 71 countries lacking access to modern energy cooking services in 2020.<sup>22</sup> Only 12% of rural households had access to such services, compared to 38% in urban areas.<sup>23</sup> Sub-Saharan Africa had the smallest share of the population with access, at 10%, whereas Latin America and the Caribbean and East Asia had the highest shares, at 56% and 36% respectively.<sup>24</sup> (→ See Figure 39.)

The **electricity access** deficit has improved for some years, with the number of people lacking access decreasing from 801 million in 2018 to 759 million in 2019.<sup>25</sup> However, large variations persist among and within regions. Sub-Saharan Africa lags the most, accounting for three-quarters (570 million) of people globally without electricity access.<sup>26</sup> Although access in urban areas of sub-Saharan Africa reached 78% by 2019, access in rural areas was only 25%.<sup>27</sup> In some African countries – such as Chad, Congo and Djibouti – rural electricity access rates are as low as 1%.<sup>28</sup>

After seven consecutive years of improvements, the number of people **without access** to electricity in Africa was estimated to have increased in 2020.

**FIGURE 39.** Population with Access to Modern Energy Cooking Services, by Region, 2020



Note: Data based on a 71-country sample of 5.3 billion people representing 90% of lower- and lower-middle-income countries. Modern energy cooking services refers to a household context that has met the standards of Tier 4 or higher across all six measurement attributes of the Multi-Tier Framework (MTF). The MTF for cooking includes six attributes: exposure, efficiency, convenience, safety, affordability and fuel availability. To measure progress, each attribute has six tiers, ranging from 0 to 5.

Source: ESMAP. See endnote 24 for this chapter.

In developing Asia, urban electricity access rates were 99% in 2019, with rural areas close behind at 94%.<sup>29</sup> The access rate in Cambodia increased the most, from 23% in 2010 to 75% in 2019.<sup>30</sup> India and Indonesia also made big improvements, with their rates rising from 67% (Indonesia) and 68% (India) in 2010 to near-universal access in 2019.<sup>31</sup> The People's Democratic Republic of Korea was the only country in the region with access rates below 50% (reaching only 26% in 2019).<sup>32</sup>

Central and South America reached very high average electricity access rates (97%) in 2019.<sup>33</sup> Haiti again was an exception, with only 39% access overall and a mere 12% in rural areas.<sup>34</sup> Bolivia, Honduras and Panama had rural access rates below 80%.<sup>35</sup>



In the Middle East, Yemen remained the only country with a significant electricity access deficit (53%) in 2019.<sup>36</sup>

In many countries, renewables (both on-grid and off-grid) have played an important role in enabling greater electricity access, especially in rural areas.<sup>37</sup> However, in several countries the recent successes have been based mostly on grid expansion using fossil fuels. Indonesia's move to universal energy access was accompanied by a 155% increase in coal consumption, whereas renewables have increased very little and contributed only 16% of national electricity generation in 2019, up slightly since 2010.<sup>38</sup> In India, electricity access rose from 68% to almost 100% during this period, while coal's share of electricity generation increased from 67% to 71%.<sup>39</sup> Bangladesh's electricity access improvement (from 46% to 83%) was accompanied by large increases in natural gas and oil generation.<sup>40</sup>

In Cambodia, on the other hand, hydropower has played a major role in the country's improved energy access. Electricity access jumped from 23% in 2010 to 75% in 2019, while at the same time hydropower generation increased from 32 gigawatt-hours (GWh) to 4,370 GWh.<sup>41</sup> Ethiopia's more than doubling in electricity access since 2010 also is based mostly on hydropower (with some additional wind generation in recent years), whereas in Kenya geothermal has played a big role.<sup>42</sup> Electricity access in Kenya increased from 18% in 2010 to 85% in 2019, and renewable energy generation doubled over the same period, with its share increasing from 69% to 82%.<sup>43</sup>

Although much of this renewables-focused expansion has been driven by larger-scale, grid-connected systems, distributed renewables increasingly play a role in providing electricity access. In 2019, solar home systems<sup>i</sup> supplied electricity to nearly 8 million people in Bangladesh, 4.4 million people in India and 3.4 million people in Kenya.<sup>44</sup>

Despite overall progress in electricity access, the trend is currently measured based on household consumption levels, which masks the ongoing lack of sufficient electricity for other activities, such as productive uses that can allow people to get out of poverty.<sup>45</sup> In addition, unreliable connections remain a significant problem. Across Africa, only two-thirds of people connected to the grid have electricity most of the time.<sup>46</sup>

Worldwide, the **provision of cooling** is affected by low, unreliable or unaffordable electricity supply. In 2021, more than 1 billion people – two-thirds of them in urban areas – were considered at “high risk” because of no access to electricity, low incomes, and other factors, with a lack of cooling threatening their health and safety.<sup>47</sup> In Asia, the highest risk populations are predominantly the urban poor, whereas in sub-Saharan Africa the rural poor are affected most.<sup>48</sup> This reflects both different population dynamics as well as varying levels of electricity access.<sup>49</sup>

Between 2020 and 2021, the number of people in rural areas at high risk from a lack of cooling is estimated to have increased faster than those at risk in urban areas, primarily due to the poverty impact of the COVID-19 pandemic.<sup>50</sup> India, Indonesia, Nigeria, Bangladesh and Pakistan were among the top 10 countries for both rural and urban poor at risk.<sup>51</sup> India saw the fastest rise (13%) in people at risk in rural areas, affecting an additional 14 million people.<sup>52</sup> China and India accounted for 36% of the growth in poor urban settings, with an additional 6.8 million people at risk.<sup>53</sup> In rural areas, distributed renewables can provide cooling needs, from simple fans connected to solar home systems to sophisticated refrigeration units based on solar PV.



## TECHNOLOGIES AND MARKETS

Renewables-based systems have enabled greater energy access in many countries and often represent the most cost-effective solution, especially when solar systems are used to provide electricity in low-density rural areas.<sup>54</sup> For access to clean cooking, renewable options such as improved biomass stoves, biogas, ethanol and solar cookers already make a contribution, and renewables-enabled electric cooking has begun to play a role as well.

Renewables deployment for energy access has grown strongly in recent years, although the COVID-19 pandemic had an impact in 2020.<sup>55</sup> As lockdowns spread across countries, energy access companies initially struggled to maintain operations, and the resulting economic crisis affected people’s ability to make payments for their existing power supply or to purchase new systems.<sup>56</sup> In August 2020, of 600 energy access companies surveyed in 44 countries, 70% reported significant disruptions from the pandemic, with 30% having to either pause all activity or cease operations entirely.<sup>57</sup> In several countries, however, the off-grid sector was recognised as providing essential services and was allowed some degree of continued operation.<sup>58</sup> Investment also picked up later in the year, and some sectors such as off-grid solar proved surprisingly resilient.<sup>59</sup>

### CLEAN COOKING

The global clean cooking market is dominated by **liquefied petroleum gas**, with almost 2 billion people cooking with LPG.<sup>60</sup> In the 71 countries with a clean cooking deficit in 2019, 37% of people overall used LPG as a cooking fuel; however, LPG shares exceeded 70% in urban areas of South Asia, South-East Asia and Latin America and the Caribbean.<sup>61</sup> Electricity also was used increasingly for cooking, with its share more than doubling from 4% in 2010 to 10% in 2019.<sup>62</sup>

Renewables-based clean cooking solutions include improved biomass cook stoves and more efficient fuels (for example, pellets and briquettes), biogas, ethanol, solar cookers and electric cooking linked to renewables-based electricity such as solar or hydropower mini-grids. These options are being promoted mostly through national and donor-funded programmes and tend to involve some form of performance-based incentive or

A lack of access to cooling threatens the **health and safety** of at least 1 billion people worldwide.

i Solar home systems are off-grid solar systems, rated at 11 watts (W) and above, that can be used for lighting and to power small electrical appliances.

subsidy.<sup>63</sup> Even where clean cooking solutions are prevalent, households commonly practice “fuel stacking” and continue to use some traditional cooking methods, often to meet socio-cultural expectations.<sup>64</sup>

With traditional uses of biomass still dominant in cooking in most of the developing world, **improved biomass cook stoves**<sup>i</sup> have been a focus of donor, non-governmental and government programmes for several decades.<sup>65</sup> Of the many types of improved cook stoves, very few meet World Health Organization guidelines for emissions.<sup>66</sup> However, no comprehensive data are available on distribution of the stoves, and data for 2020 are particularly scarce.

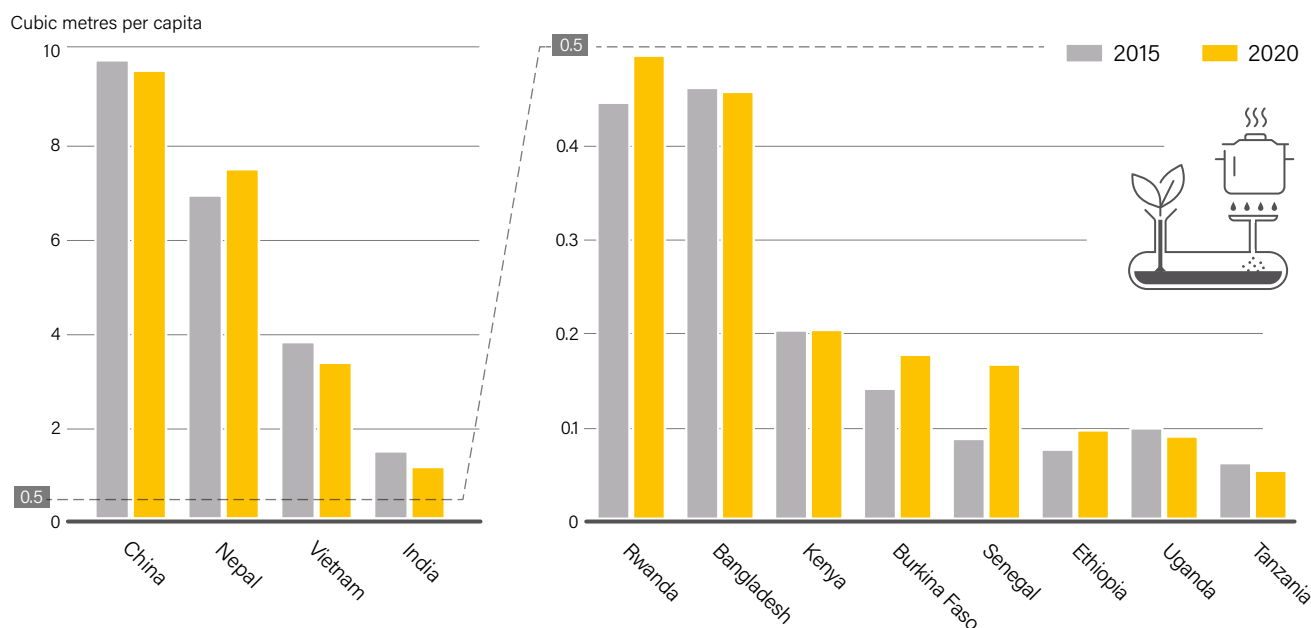
Recent programmes include the Bangladesh Improved Cookstove Programme, initiated jointly by Bangladesh’s Infrastructure Development Company Limited (IDCOL) and the World Bank in 2013; by the end of 2020, the programme had distributed 2.4 million improved cook stoves, with a target of 5 million by the end of 2023.<sup>67</sup> On a smaller scale, in Kenya, the Results-Based Finance programme of the Energising Development (EnDev) multi-donor partnership delivered around 80,000 improved biomass and ethanol cook stoves (as well as 21,000 LPG stoves) between 2016 and 2019, reaching half a million people.<sup>68</sup> A new phase starting in January 2020 aimed to deliver 40,000 additional highly performing cook stoves by March 2021.<sup>69</sup>



**Biogas** can be a solution in areas where agricultural residues, animal or human wastes are locally available.<sup>70</sup> An estimated 125 million people use biogas for cooking globally, a figure that has been broadly constant over the last decade.<sup>71</sup> Most people cooking with biogas live in Asia (99.7%), with the bulk of the production per capita occurring in China, Nepal, Vietnam, India and Bangladesh.<sup>72</sup> (→ See Figure 40.)

i An improved cook stove is a biomass stove that is more efficient and emits less emissions than a traditional stove or three-stone fire. An array of diverse technologies exist, which vary considerably in terms of efficiency and emissions.

**FIGURE 40.** Per Capita Production of Biogas for Cooking, Selected Countries, 2015 and 2020



Source: IRENA. See endnote 72 for this chapter.



While most of the 125 million people who cook with biogas live in Asia,

**African biogas** production has increased 28% in the last five years.

In Africa, production remains small but increased 28% between 2015 and 2020.<sup>73</sup> This occurred mostly in Rwanda, Senegal and the five countries covered by the Africa Biogas Partnership Programme (Burkina Faso, Ethiopia, Kenya, Tanzania and Uganda). More than

38,000 biogas digesters were installed during Phase II of the programme, implemented by Hivos and SNV between 2014 and 2019 with funding from EnDev and the Netherlands Directorate-General for International Cooperation.<sup>74</sup> Although well below the targeted 100,000 installations, the programme was successful in establishing markets for private sector biogas companies.<sup>75</sup> Funding was approved for a follow-up biogas programme funded by the Dutch government through EnDev, expected to start during 2021.<sup>76</sup>

**Electric cooking** is already cost effective for many people connected to national grids or off-grid small-scale hydropower, and battery-supported electric cooking linked to solar-hybrid mini-grids is expected to become cost effective by 2025.<sup>77</sup> To achieve this, the focus has been on linking renewables-based solutions to efficient cooking appliances such as electric pressure cookers (which greatly reduce the cost of electric cooking compared to traditional electric hotplates) and on reducing the demand on the system during peak times.<sup>78</sup> However, high upfront equipment costs remain a challenge, which could be addressed by "Pay-As-You-Go" (PAYGo) providers adding these cookers to the services they offer.<sup>79</sup>

The electric cooking market is in the early stages of development, especially for the direct current appliances required for off-grid settings.<sup>80</sup> In 2020, the Global LEAP Awards launched the first-ever competition for highly energy-efficient electric pressure cookers suitable for use in both off-grid and weak-grid settings.<sup>81</sup>

**Solar cookers** (such as parabolic cookers and solar ovens) offer another clean cooking solution. Globally, more than 4 million solar cookers had been distributed by early 2021, providing clean cooking solutions to an estimated 14.3 million people.<sup>82</sup>

## DISTRIBUTED RENEWABLES FOR ELECTRICITY ACCESS

**Pico solar**<sup>i</sup> and **solar home systems** have played a growing role in the provision of energy access, with more than 180 million units sold over the last decade.<sup>83</sup> Apart from bringing electricity to the homes of over 100 million people, these units allow some 2.6 million people to run a business.<sup>84</sup> During the COVID-19 pandemic, many countries officially designated off-grid solar companies as "essential services", enabling them to operate at least partly during lockdowns.<sup>85</sup>

The global market for off-grid solar systems grew a record 13% in 2019, the highest increase of the preceding five-year period.<sup>86</sup> Similar, if not higher, expansion had been expected by the industry in 2020, but the pandemic led to a significant slowdown.<sup>87</sup> Sales of affiliated<sup>ii</sup> systems fell 22% compared to 2019, with cash sales (especially of solar lanterns) experiencing the biggest reductions (30%), while PAYGo sales declined only 1.7%.<sup>88</sup> The business operations of off-grid solar companies were disrupted because of lockdown measures that restricted the movement of goods and sales staff, as well as supply chain issues.<sup>89</sup> While businesses were affected mainly during the early months of the crisis, two-thirds of off-grid companies still reported lower sales in the second half of 2020 compared to 2019.<sup>90</sup>

Around 6.6 million affiliated off-grid lighting products were sold during 2020.<sup>91</sup> Portable solar lanterns (up to 3 W) accounted for 64% of this, with another 18% of sales for larger light systems of up to 10 W.<sup>92</sup> In addition, 1.2 million solar home systems were sold, with all but 49,000 systems having an output smaller than 100 W.<sup>93</sup> Appliance sales linked to off-grid solar products also decreased, with a total of 946,000 appliances sold in 2020 compared to almost 1.2 million in 2020.<sup>94</sup> Television sales proved more resilient than fan sales, with decreases of 3% and 31%



i Pico solar systems/products refer to off-grid systems rated up to 10 W, used primarily for basic lighting and mobile phone charging.

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.

respectively.<sup>95</sup> Solar water pump sales plunged more than 60%, although this was due to at least in part to bulk procurement in 2019, which did not happen in 2020.<sup>96</sup>

Regionally, the biggest reduction in off-grid solar product sales in 2020 occurred in South Asia, with a 51% drop compared to 2019.<sup>97</sup> East Africa, which remained by far the largest market, saw a dip of 10% (mostly in cash sales), whereas sales in Central Africa and West Africa increased despite the pandemic, up 22% and 9% respectively.<sup>98</sup> West Africa experienced a small reduction (3.6%) in cash sales, but PAYGo sales increased 23%, while in Central Africa both segments increased (up 8% for cash sales and 71% for PAYGo sales).<sup>99</sup> (→ See Figure 41.)

Kenya, India, Ethiopia, Uganda and Nigeria were the top five off-grid solar markets globally by sales volumes.<sup>100</sup> The largest reductions occurred in India, where sales dropped 54% in 2020 (the country had already experienced a 31% reduction in 2019).<sup>101</sup> In Ethiopia, where off-grid solar sales had more than doubled in 2019 to just over 1 million products, sales dropped 40% in 2020.<sup>102</sup> Nigeria was the only one of the top five markets where sales increased in 2020, although by less than 1% (compared to a 5% increase in 2019).<sup>103</sup>

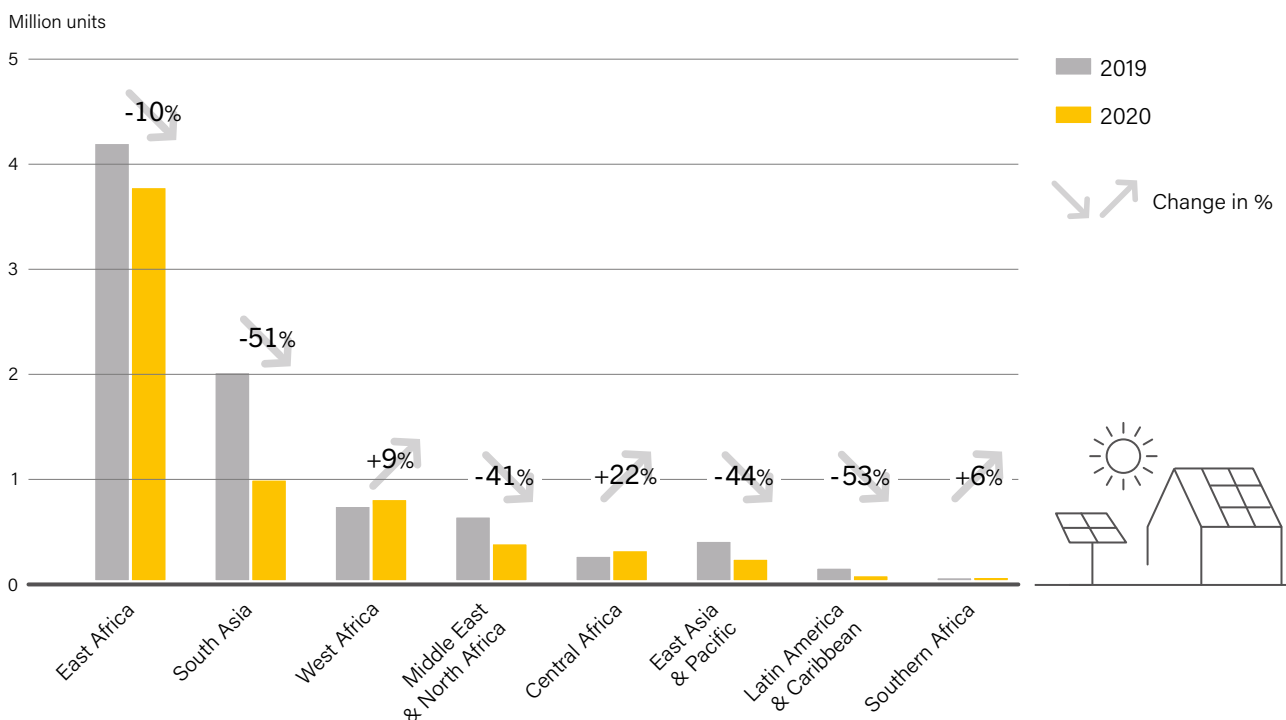
In addition to stand-alone solar systems, **renewables-based mini-grids** are recognised increasingly as an important facilitator

of energy access.<sup>104</sup> Of the identified 5,544 mini-grids operating in energy access settings in March 2020 (with a total capacity of 2.37 GW), 87% were renewables-based.<sup>105</sup> Solar PV has been the fastest growing mini-grid technology, incorporated into 55% of mini-grids in 2019 compared to only 10% in 2009.<sup>106</sup> (→ See Figure 42.)

Mini-grid development used to be driven by utilities and non-governmental organisations (NGOs), but in recent years private developers also have entered the space.<sup>107</sup> In 12 sub-Saharan African countries with high electricity access deficits, renewables-based mini-grid connections installed by private developers increased from just 2,000 in 2016 to more than 41,000 in 2019, mostly in East Africa.<sup>108</sup> Over 200,000 people, as well as businesses, schools and health facilities, have been connected through these mini-grids.<sup>109</sup> The rapid growth has been linked to policy and regulatory changes, as well as to donor programmes that have provided incentives to developers.<sup>110</sup>

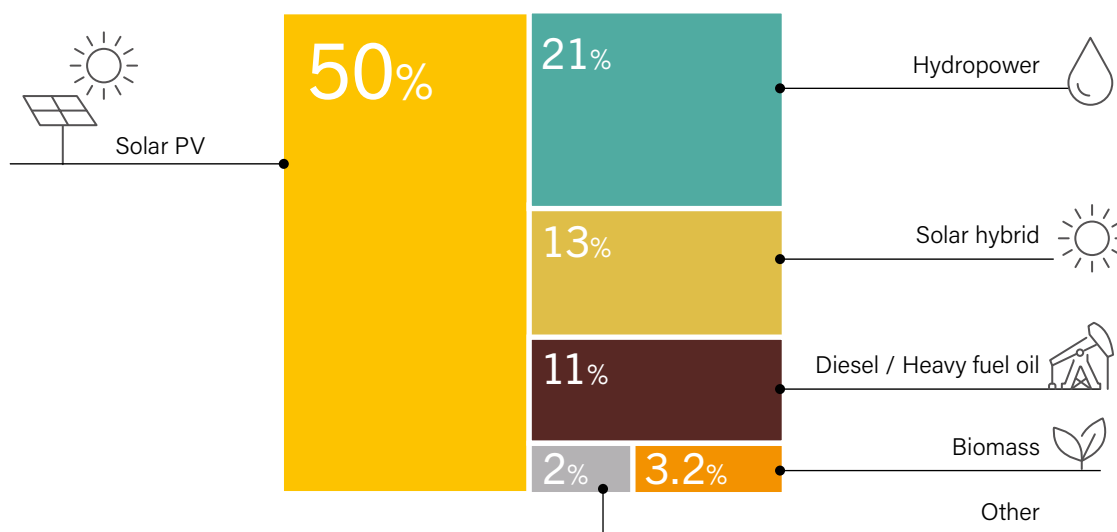
While most mini-grid developers are small-scale companies or start-ups, some are beginning to reach scale; in late 2020, Husk Power became the first company globally to install 100 community mini-grids, which also serve 5,000 business customers.<sup>111</sup> In recent years, large and international corporations such as EDF, Enel, ENGIE, Iberdrola, Shell and Tokyo Electric also have joined the mini-grid market, generally by taking over or investing in smaller

**FIGURE 41.** Sales Volumes of Affiliated Off-Grid Solar Systems, Selected Regions, 2019 and 2020



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: GOGLA. See endnote 99 for this chapter.

**FIGURE 42.**  
Shares of Installed Mini-Grids by Technology, March 2020



Note: Figure refers to currently operational (functioning) mini-grids in energy access settings. Solar hybrid mini-grids combine solar PV with other power sources such as hydropower or wind power but most frequently with diesel generators. Where totals do not add up, the difference is due to rounding.

Source: Mini-Grids Partnership. See endnote 106 for this chapter.

companies.<sup>112</sup> Although private sector interest in mini-grids has grown, most developers have relied on public funding such as grants or results-based financing from donors, although some form of subsidy is also common for grid-based electricity.<sup>113</sup>

In Africa, the COVID-19 pandemic impacted the mini-grid sector more than the rest of the solar industry in 2020 due to complex logistics and difficulty accessing remote areas.<sup>114</sup> Many projects under development or being tendered were slowed or put on hold.<sup>115</sup> However, some progress occurred. Nigeria, which has one of the largest mini-grid support programmes under its National Electrification Project, aims to electrify 300,000 households and 30,000 local enterprises through private sector-driven solar-hybrid mini-grids by 2023.<sup>116</sup> With funding from the World Bank and the African Development Bank, it offers minimum subsidy tenders and performance-based grants.<sup>117</sup> In 2020, Nigeria's Rural Electrification Authority (REA) commissioned several installations under the project, including two solar hybrid mini-grids with a combined capacity of 135 kW developed by Renewvia Energy and a 234 kW solar hybrid mini-grid installed by local developer GVE Projects Limited that will power nearly 2,000 households.<sup>118</sup>

Nigeria's REA also developed several solar mini-grids for use at hospitals and other healthcare facilities as an emergency response to COVID-19.<sup>119</sup> Health facilities were a focus of several other donor-driven mini-grid initiatives as well. Power Africa, funded by USAID, redirected USD 4.1 million in grants to off-grid companies in 2020 for rural and peri-urban health clinic electrification, including through mini-grids.<sup>120</sup> In Lesotho, OnePower together with SustainSolar aim to supply seven containerised solar mini-grids under Power Africa to electrify

several clinics.<sup>121</sup> Recent mini-grid activity has occurred in several countries of francophone West Africa. Benin in 2020 selected 11 companies to construct solar mini-grids serving 128 localities under its Off-Grid Clean Energy Facility.<sup>122</sup> In early 2021, Togo's Rural Electrification and Renewable Energy Agency announced the first 129 localities to be electrified by its mini-grid programme, and Senegal's Rural Electrification Agency launched a tender for the electrification of 117 villages through solar mini-grids.<sup>123</sup>

In East Africa, Kenya has been the most active mini-grid market with almost 200 sites in operation in 2019.<sup>124</sup> Renewvia Energy commissioned another three solar mini grids in 2020, with a total capacity of 87.6 kW in Kenya's Turkana and Marsabit counties, serving two communities and a refugee camp in an electrification project supported through the EnDev RBF facility.<sup>125</sup> Meanwhile Kenya Power launched a tendering process in early 2021 to hybridise 23 older diesel mini-grids, mostly with solar.<sup>126</sup> In Central Africa, a 1.3 MW solar-hybrid mini-grid installed by Nuru in the city of Goma, in the Democratic Republic of Congo, was put into service in February 2020.<sup>127</sup>

In Asia, Bangladesh's 170 kW BREL solar mini-grid project came online in early 2020, financed by IDCOL as part of its solar mini-grids initiative for islands and other remote areas.<sup>128</sup> This brought the total under this initiative to 27 projects, with a combined capacity of 5.6 MW.<sup>129</sup> In the Americas, in late 2020, the national Rural Electrification Program (PERMER) in Argentina's remote Rio Negro province repowered two mini-grids (22 kW and 40 kW), which previously ran on LPG, with solar PV and wind power as well as storage; this increased electricity access for 100 families from 16 to 24 hours.<sup>130</sup>

## BUSINESS MODEL INNOVATIONS

In most developing countries, grid-based electricity access is the domain of state-owned electric utilities. In contrast, off-grid renewables are much more reliant on the private sector and on innovative business models. Business models vary greatly among off-grid renewables providers. Over the last decade, PAYGo systems have enabled energy access for millions of off-grid consumers, mostly through solar home systems, although PAYGo also has made inroads into productive uses such as solar water pumping and even clean cooking. PAYGo companies typically provide either a “lease-to-own” or a “usage-based” payment model.<sup>131</sup>

In 2020, 84% of affiliated solar home systems were sold on a PAYGo basis.<sup>132</sup> Traditionally, many PAYGo companies providing solar home systems focused on basic services such as lighting and phone charging, or possibly a small television. Increasingly, companies have expanded their offerings to bigger systems that power a broader range of appliances, such as fans and refrigerators, as well as bundling in other services.

For example, the product range of M-Kopa, which operates in Kenya, Nigeria and Uganda, includes three sizes of solar home systems, solar fridges for small businesses and smartphones. For customers who have made reliable payments on a PAYGo product, the company also offers services such as clean biomass cook stoves, entertainment packages and even financial services such as loans (for example, for hospital stays).<sup>133</sup> Bboxx (UK) also has branched out into home entertainment and joined forces in 2020 with the French media company Canal+ to sell televisions and decoders with its solar home systems in Togo and the Democratic Republic of the Congo.<sup>134</sup>

While many companies have offered higher-value services for better-off customer segments, affordability remains a major problem for many communities, especially in more-remote rural areas with high levels of poverty. In August 2020, Bboxx launched a new product (bPower20) – a package of 20 W solar panels and new improved batteries – targeted specifically at low-income

rural households; with it, the company aims to reach a wider segment of the global market.<sup>135</sup> The initial target markets are the Democratic Republic of the Congo, Kenya, Rwanda and Togo, but Bboxx aims to expand into further markets in 2021.<sup>136</sup>

Pico solar and solar home systems remain the most common renewables-based electricity access solutions using PAYGo models, with 2.2 million affiliated systems sold worldwide in 2020.<sup>137</sup> In Rwanda, a new pilot PAYGo solution was launched in October 2020 when ENGIE Energy Access teamed up with OffGridBox to deploy containerised solar PAYGo.<sup>138</sup> This supplies clean drinking water, electricity for recharging and Wi-Fi from solar-powered containers equipped with electricity storage, water purification systems and a WI-FI hotspot.<sup>139</sup> Customers get a battery, LED (light-emitting diode) lights, phone chargers and a water canister and pay a small fee for recharging and refilling from the system.<sup>140</sup>

Beyond households, a number of PAYGo solutions exist in agriculture, particularly for solar irrigation. SunCulture, which already offered solar irrigation kits on a “pay-as-you-grow” basis in Kenya, announced a new partnership in December 2020 with Bboxx and EDF to bring solar irrigation to 5,000 farmers in Togo using the PAYGo model.<sup>141</sup> The government of Togo will provide a subsidy to halve the costs of the systems to make them more affordable for farmers.<sup>142</sup>

PAYGo also has advanced in the clean cooking sector, for example for ethanol, a renewable cooking fuel that is relatively easy to distribute.<sup>143</sup> The traditional model has been centralised bottling and bulk distribution, but in 2019 KOKO Networks launched a new **decentralised distribution model** with the fuel infrastructure company Vivo Energy in Nairobi, Kenya.<sup>144</sup> Customers pay digitally for the fuel, which is then dispensed by 700 ethanol vending machines (Koko Points) in corner shops across the city.<sup>145</sup> KOKO Networks also sells its own ethanol stoves, and by August 2020 it was serving 50,000 households.<sup>146</sup> In June 2020, the company was rewarded a results-based finance project for a further 250,000 connections under the Dutch SDG 7 programme.<sup>147</sup>





Most clean cooking PAYGo is dominated by small LPG start-ups – such as KopaGas and PayGo Energy – but in July 2020 ENGIE Africa, a major player, announced a new partnership with the PAYGo gas company PayGas in South Africa to support two new LPG refilling stations that can service 4,000 homes.<sup>148</sup> PayGas plans to scale its operations to other African countries.<sup>149</sup>

Similar to the solar irrigation sector, public funding is often needed to support private sector business models that operate in the clean cooking sector. To drive further innovation in clean cooking, in 2020 the Clean Cooking Alliance launched the Cooking Industry Catalyst, which aims to demonstrate new viable and scalable business models.<sup>150</sup>

Business models for mini-grids for rural electrification vary, with different combinations and approaches to ownership and operation, service delivery and billing. Many mini-grids are owned by national utilities, whereas others are under private, community or hybrid ownership.<sup>151</sup> There is no proven business model that works everywhere, and as of late 2020 no private mini-grid company was profitable.<sup>152</sup> In general, revenues per customer remain low, and low consumption is a systemic problem.<sup>153</sup> Expanding consumption is critical to the success of mini-grid business models, with many companies focusing on developing productive uses, which also are increasingly supported through donor funding.

In 2020, the Energy and Environment Partnership Trust Fund (EEP Africa) approved funding to support several innovative mini-grid business models that include productive uses. In Rwanda, EEP is supporting East African Power in developing a hydropower plant and mini-grid that will service not only households but also community buildings and an agricultural centre of excellence, as well as a women's aquaculture business to improve socio-economic development.<sup>154</sup> In Uganda, ENGIE Equatorial is receiving EEP support to deploy four solar-hybrid mini-grids, with an industrial park as an anchor client.<sup>155</sup> The project also includes an incubation programme that enables local women entrepreneurs to access asset financing for productive use appliances.<sup>156</sup>

Some companies involve communities to identify needs and how to grow demand. Miowna SA, a joint venture of PowerGen and Sunkofa Energy, won a competitive tender run by the Benin Off-Grid Clean Energy Facility in 2020 to electrify 40 villages in the country.<sup>157</sup> Miowna worked with communities and other local stakeholders to identify innovative value propositions through productive uses that will help increase local incomes and make the mini-grids viable.<sup>158</sup>

More than  
**2 million solar  
products**  
were sold on a pay-as-  
you-go basis in 2020.

## FINANCING FOR RENEWABLES-BASED ENERGY ACCESS

With less than a decade left before 2030, even prior to the COVID-19 pandemic the total investment in energy access was far below what has been estimated as needed to achieve SDG 7.<sup>159</sup> The energy access finance that was available mostly bypassed the countries with the greatest access deficit, and very little of the already small amount of finance was dedicated specifically to renewables-based energy access systems.<sup>160</sup>

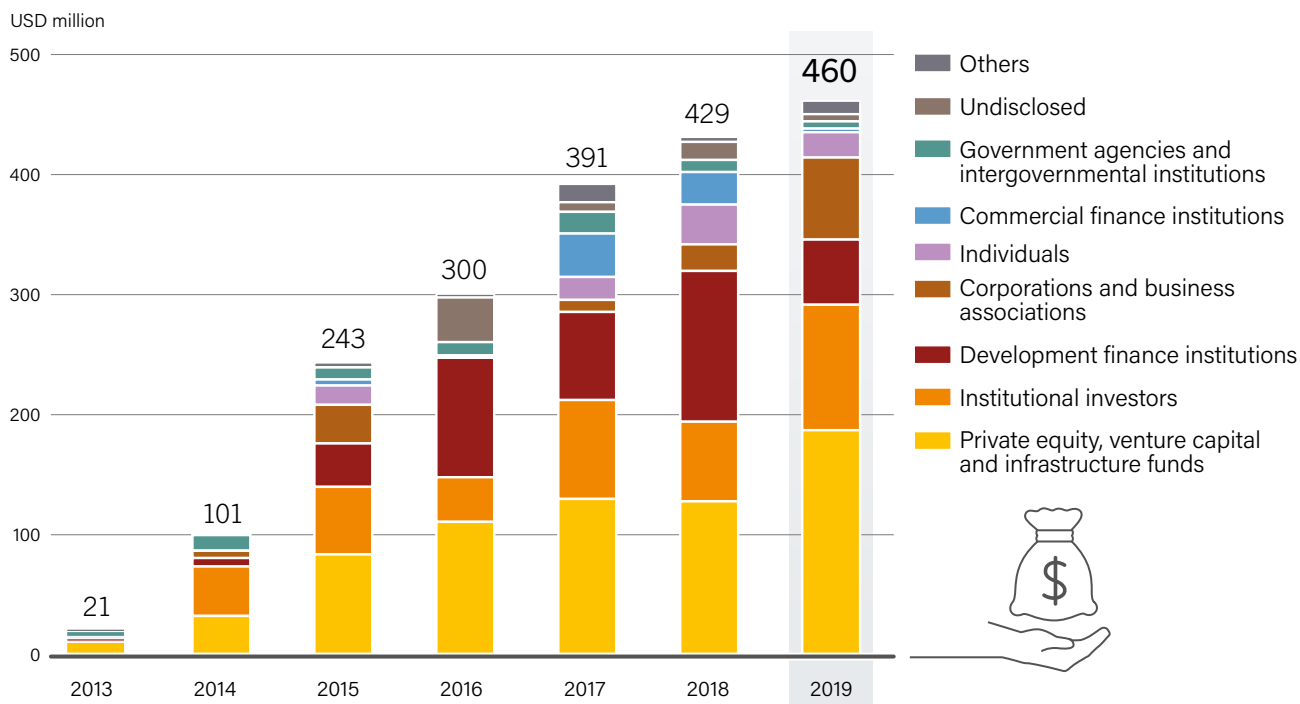
Clean cooking suffers from the largest investment gap overall and remains well below the estimated annual USD 4.5 billion required to achieve universal access by 2030.<sup>161</sup> However, positive developments have occurred, with overall finance for clean cooking tripling from USD 48 million in 2017 to USD 131 million in 2018 (most recent data available).<sup>162</sup> Most clean cooking funding comes from the public sector, with international donor and development finance institutions providing two-thirds of financing in 2018, nearly half of it as grants.<sup>163</sup> The public sector is also very active in the delivery of the funded activities, with 44% of the funding passing through public channels (compared to only 14% for electricity access).<sup>164</sup> Private finance plays a relatively small role, with just under one-quarter of funding in 2018, while carbon markets provided another 16%.<sup>165</sup>

Finance for electricity access in the 20 countries with the highest access deficit increased 25% between 2017 and 2018 to reach USD 43.6 billion.<sup>166</sup> In some countries, more than 95% of electricity finance went to grid-connected renewables, mini-grids and off-grid solutions; however, these accounted for only 14% of the total energy access funding in 2018, and, overall, renewables-based systems received only around 1.5% of the total.<sup>167</sup>

Unlike in clean cooking, private investment has been a key driver of off-grid electricity access, accounting for 78% of funding in 2019.<sup>168</sup> While public financing halved compared to the previous year, major increases in funding occurred from several types of private investors. Private equity, venture capital, infrastructure fund and institutional investors increased their off-grid funding from USD 193 million in 2018 to USD 290 million in 2019, while corporations more than tripled their investment during this period, from USD 22 million to USD 68 million.<sup>169</sup> The latter focused mostly on East Africa and South-East Asia.<sup>170</sup> (→ See Figure 43.)



**FIGURE 43.** Annual Commitments to Off-Grid Renewable Energy, by Type of Investor, 2013-2019



Source: IRENA and CPI. See endnote 170 for this chapter.

The COVID-19 pandemic affected finance flows to the energy access sector, particularly mini-grids.<sup>171</sup> Some attempts have been made to help companies struggling with these effects. The Energy Access Relief Fund was established with the aim of raising USD 100 million to provide unsecured, low-cost, subsidised loans, with funding from donors including the Green Climate Fund.<sup>172</sup> In late 2020, the African Development Bank launched the USD 50 million COVID-19 Off-Grid Recovery Platform to provide relief and recovery capital to energy access businesses.<sup>173</sup> Additionally, the Shine Campaign made available grants of between USD 3,000 and USD 10,000 to smaller players.<sup>174</sup>



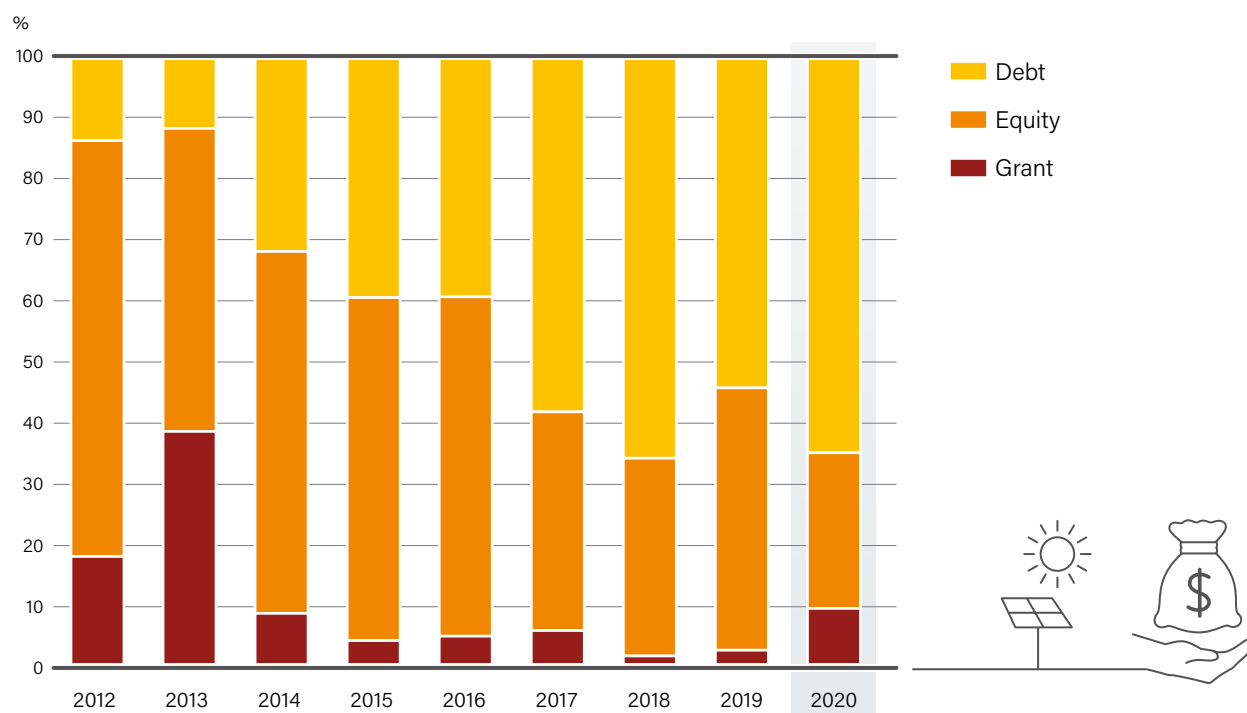
**CLEAN COOKING SECTOR FINANCING**

In 2019, 25 clean cooking companies were able to raise USD 70 million, a 63% increase compared to the 32 companies that raised USD 43 million in 2018.<sup>175</sup> Around three-quarters of the funding went to companies offering renewables-based solutions, with biomass stoves and biogas accounting for 25% and 19% respectively of the capital raised.<sup>176</sup>

In 2020 and early 2021, several renewables-focused clean cooking companies managed to raise new capital. Improved cook stove manufacturer BURN (Kenya) partnered with the crowdfunding platform Bettervest (Germany) in an attempt to raise more than EUR 1 million (USD 1.2 million) in working capital.<sup>177</sup> Bettervest also raised over EUR 300,000 (USD 360,000) for Kenyan biomass briquette company Sanergy in early 2021.<sup>178</sup> One of the companies involved in the African Biogas Partnership

Investment in the largest clean cooking companies increased 63% in 2019.

**FIGURE 44.**  
Shares of Off-Grid Solar Financing, by Type of Funding, 2012-2020



Note: The data cover financing for off-grid solar such as solar home systems, solar lanterns and solar-powered appliances (e.g., water pumps) but exclude solar mini-grids.

Source: GOGLA. See endnote 186 for this chapter.

Programme, Sistema.bio, received a USD 1.35 million loan facility from the Dutch Development Bank FMO in late 2020 to scale up its operations in Kenya.<sup>179</sup> In addition, Connected Energy, which offers a smart meter specifically for biogas systems, attracted USD 1.25 million in funding.<sup>180</sup>

Although sales revenues provided 80% of the total revenues of clean cooking companies in 2019, this was being supplemented by grants and results-based finance, as well as carbon offset revenues.<sup>181</sup> The latter experienced a five-fold increase between 2018 and 2019 to USD 5.2 million, with almost all of the carbon offset funding going to biomass stove manufacturers.<sup>182</sup>

### OFF-GRID ELECTRICITY ACCESS SECTOR FINANCING

The COVID-19 pandemic impacted financing for off-grid companies in 2020, but not to the extent that was initially feared. In the case of off-grid solar, the overall volume of funding for affiliated companies was up slightly at USD 316 million compared to USD 312 million in 2019.<sup>183</sup> The main impact has been a reduction in equity funding of 46%, due mainly to problems in carrying out on-the-ground diligence, which made it difficult to complete equity transactions.<sup>184</sup> Most of this reduction was due to strategic corporate deals falling from USD 76 million in 2019 to USD 8.5 million in 2020.<sup>185</sup> The reduction in equity funding was compensated by an increase in both debt and grant funding, mostly from governments and development finance institutions.<sup>186</sup> (→ See Figure 44.)

Much of the 2020 off-grid solar funding flowed to Africa. Lumos received USD 35 million in financing from the US International Development Finance Corporation to further expand in Nigeria.<sup>187</sup> Bboxx secured a USD 4 million loan from the Off-Grid Energy Access Fund of the Energy Inclusion Facility to expand in the Democratic Republic of the Congo.<sup>188</sup> Oolu closed a USD 8.5 million Series B investment round involving several impact investors to further develop its operations in West Africa.<sup>189</sup> UpOwa signed a EUR 3 million (USD 3.6 million) debt facility with EDFI Electrifi to enable expansion in Cameroon.<sup>190</sup> Easy Solar, which operates in Sierra Leone and Liberia, announced a USD 5 million round of funding including a USD 3 million Series A Equity led by global impact investor Acumen and Dutch development FMO, in addition to a USD 2 million debt facility from investment platform Trine.<sup>191</sup> Fenix International, a subsidiary of ENGIE, secured a USD 12.5 million loan from the European Investment Bank to support the deployment of 240,000 solar home systems in Uganda.<sup>192</sup>

Energy+, a less well-established Malian-owned and managed off-grid solar company, secured USD 1 million through a combination of debt, equity and grant financing from Venturebuilder, Cordaid and the US African Development Foundation.<sup>193</sup> Easy Solar, together with Altech of the Democratic Republic of the Congo and Deevabits of Kenya, also received unspecified loans from the newly established Sima Angaza Distributor Finance Fund, which aims to provide capital for the last-mile distribution sector.<sup>194</sup> In addition to the finance provided to companies

focused on household solar systems, solar-powered irrigation supplier SunCulture closed a Series A investment round of USD 14 million in late 2020; investors included Energy Access Ventures, Électricité de France, Acumen Capital Partners and Dream Project Incubators.<sup>195</sup>

Crowdfunding continued to play an important role for off-grid solar companies. In the first half of 2020, crowdfunding transactions were mostly refinancing of earlier loans.<sup>196</sup> For example, the initial response of UK crowdfunding platform Energise Africa to the pandemic focused on refinancing the existing debt of seven companies, raising just over GBP 1.5 million (USD 2.0 million).<sup>197</sup> By late 2020, the platform had not only resumed its normal lending activities but also launched its first funding campaigns both for solar projects in the small and medium-sized enterprise sector and outside of Africa, raising a total of GBP 1.9 million (USD 2.6 million) for Candi Solar to provide solar energy to such enterprises in South Africa and India.<sup>198</sup>

While funding for the off-grid solar sector has held up during the COVID crisis, funding for the mini-grid sector dropped by almost a third, with the biggest reduction occurring in equity finance.<sup>199</sup> However, by late 2020 some activity had resumed, with, for example, Dutch development bank FMO investing USD 5 million in Husk Power in October 2020.<sup>200</sup> Winch Energy in early 2021 mobilised USD 16 million for 49 mini-grids in Sierra Leone and Uganda through NEoT Off-grid Africa, a platform developed by Électricité de France, Mitsubishi and Meridiam.<sup>201</sup> The funding includes some grants through development aid from Germany, the European Union (EU) and the United Kingdom.<sup>202</sup> Also in early 2021, Nigerian start-up Havenhill Synergy obtained USD 4.6 million local currency funding for 22 solar mini-grids from the Chapel Hill Denham Nigeria Infrastructure Debt Fund.<sup>203</sup>

Funding in 2020 was not just limited to companies supplying renewables equipment but also those providing enabling services. For example, Angaza, which sells software for solar PAYGo solutions, raised USD 13.5 million from East African energy impact fund KawiSafi Ventures and Total Carbon Neutrality Ventures, the venture capital arm of energy company Total (France).<sup>204</sup> Total was also one of several investors providing USD 12 million Series A financing to SparkMeter, a provider of grid management services to hard-to-reach communities.<sup>205</sup> Acumen invested an unspecified amount in Solaris Offgrid, a social enterprise providing PAYGo software.<sup>206</sup>

A new innovative financing instrument was launched in early 2021 by South Pole and Positive.Capital Partners with the support of several foundations.<sup>207</sup>

The D-REC Initiative will provide funding for renewables-based energy access projects by selling third-party-certified renewable energy certificates to companies interested in going beyond their corporate renewables commitments.<sup>208</sup>

The Green Climate Fund committed **USD 300 million** to renewables-based energy access projects in 2020.

## PUBLIC FUNDING AND INITIATIVES

While the private sector has been driving much of electricity access funding, development finance institutions (DFIs), bilateral donors and other funders such as philanthropic foundations continue to commit funding to energy access. This funding takes various forms including grants, results-based finance, guarantees, loans and other debt facilities and can be used to support governments, development partners such as NGOs, or private sector companies in implementing energy access programmes.

Off-grid energy access funding by DFIs has consistently lagged behind funding for on-grid electrification.<sup>209</sup> In 2019, DFIs committed an estimated USD 1 billion – around 12% of their total energy funding commitments – to off-grid electricity access.<sup>210</sup> DFI funding for clean cooking, meanwhile, totalled only USD 78 million in 2018, even though the lack of access to clean cooking affects many more people than the lack of electricity access.<sup>211</sup> In 2020, most of the significant new energy access commitments from DFIs were again focused on electricity access, with a few exceptions as set out below.

The World Bank approved USD 150 million in financing to improve access to modern energy for households, enterprises and public institutions in Rwanda, both on- and off-grid.<sup>212</sup> Although the majority of the funding will go to electricity access, the project includes the Bank's largest clean cooking commitment in Africa, and the first project co-financed by the recently launched Clean Cooking Fund (CCF).<sup>213</sup> The CCF will provide USD 20 million for clean cooking, with USD 10 million as grants and USD 10 million as loans.<sup>214</sup> The project targets 2.15 million people, leveraging an additional USD 30 million in public and private sector investments.<sup>215</sup>

In Burundi, the World Bank agreed to provide USD 100 million in grants for the Solar Energy in Local Communities programme (SOLEIL), which will double the rate of electricity access in the country, with a focus on rural areas.<sup>216</sup> The World Bank also approved USD 52.9 million in financing for the Lesotho Renewable Energy and Energy Access Project, aimed at expanding electricity access in remote areas of the country.<sup>217</sup> In Haiti, the World Bank approved USD 6.9 million additional financing for the Haiti:





Renewable Energy for All project, specifically to provide renewable energy solutions for at least four priority healthcare facilities involved in the response to COVID-19.<sup>218</sup>

The African Development Bank (AfDB) made its first significant investment in clean cooking in late 2020 with a USD 5 million commitment to the SPARK+ Africa Fund, with another USD 10 million for the Fund coming from the European Commission.<sup>219</sup> SPARK+ Africa, which targets total investment of USD 50-70 million, is a new impact investment fund launched by Enabling Capital and the Clean Cooking Alliance to provide debt and equity financing to enterprises that manufacture, distribute and finance clean cooking solutions across sub-Saharan Africa.<sup>220</sup>

The AfDB, jointly with the European Commission, KfW, the Clean Technology Fund, Norfund and other investors, also committed a total of USD 160 million to the first close of the Facility for Energy Inclusion, a fund to improve electricity access across Africa through small-scale renewable energy and mini-grid projects.<sup>221</sup> To further support mini-grids, the AfDB approved a USD 7 million grant from the Sustainable Energy Fund for Africa (SEFA) for technical assistance.<sup>222</sup>

The European Union provided a EUR 62 million (USD 76 million) de-risking guarantee to COFIDES, the Spanish development finance institution, and AECID, the Spanish development agency, for their renewable energy support programme for rural sub-Saharan Africa.<sup>223</sup> The guarantee will help generate a total investment of more than EUR 800 million (USD 983 million) and is expected to provide electricity to at least 180,000 new people in rural areas.<sup>224</sup> A EUR 62 million (USD 76 million) guarantee agreement with France's Agence Française de Développement in partnership with Italy's Cassa di Risparmio di Venezia is expected to provide electricity access to another more than 1 million people.<sup>225</sup>

Sweden's Beyond the Grid Fund for Africa (BGFA) expanded to Uganda, with initial funding of EUR 11.8 million (USD 14.5 million) for a six-year programme.<sup>226</sup> The Fund now operates in five countries, with total funding of EUR 59 million (USD 73 million).<sup>227</sup> Sweden's SIDA together with the Nordic Environment Finance Corporation announced in September 2020 the allocation of SEK 5 million (USD 0.6 million) for a new Scaling of Clean Cooking Solutions programme in Zambia. The aim is to accelerate the use of higher-tier cooking solutions.<sup>228</sup>

**Climate finance** has become a significant funding source for energy access, and the Green Climate Fund (GCF) approved three projects in 2020 for just over USD 300 million.<sup>229</sup> Although the GCF provided funding in 2019 for clean cooking projects in Bangladesh, Kenya and Senegal, in 2020 the main energy access projects were focused on mini-grids. They included: a USD 45.7 million project to develop 22 community-scale solar plus battery storage micro-grids in southern Haiti to provide an alternative to diesel generators; a USD 235.5 million project in Senegal to mobilise private sector participation in solar-powered mini-grids for 1,000 remote villages; and USD 21.4 million to kickstart a renewable energy market in rural Afghanistan and lay the groundwork for developing a mini-grid sector (including three solar mini-grids).<sup>230</sup> In addition, the GCF approved USD 60 million for equity and co-financing of the Energy Access Relief Fund, open to both electricity and clean cooking enterprises.<sup>231</sup>



## PHILANTHROPIC AND INNOVATION FUNDING

Significant announcements in **philanthropic funding** in 2020 included the Rockefeller Foundation committing USD 1 billion over a three-year period to catalyse a green recovery from COVID-19, building on Rockefeller's existing work on mini-grids.<sup>232</sup> A key focal area is scaling distributed renewable energy across developing countries, in addition to equitable access to COVID-19 tests and vaccines.<sup>233</sup>

The IKEA Foundation, jointly with UK Aid, launched the Powering Renewable Energy Opportunities (PREO) programme in June 2020 to support productive use of energy projects in rural areas, with a focus on grants of up to EUR 300,000 (USD 368,473) for action learning and supply chain innovation.<sup>234</sup> The aim is to deliver a project portfolio of EUR 20 million (USD 24.6 million).<sup>235</sup>

Several foundations (Rockefeller Foundation, Shell Foundation and Good Energies) supported Sustainable Energy for All (SEforALL) in establishing the Universal Energy Facility to provide results-based finance. Other donors and partners include UK Aid, Power Africa, Carbon Trust and the Africa Minigrid Developers Association. In the first phase, USD 6 million in grant payments are available for mini-grid projects in Benin, Madagascar and Sierra Leone to deliver around 14,000 electricity connections.<sup>236</sup>

While renewables-based energy access solutions are already well developed and commercially available for many applications, funding also has been allocated to support **research and innovation**. In 2020, the Fair Cooling Fund, administered by Ashden and launched in November with USD 580,000 in funding from the philanthropic collaborative K-CEP, awarded grants of between USD 40,000 and USD 100,000 to seven innovators for the development of sustainable cooling options, including in off-grid areas.<sup>237</sup> Engineers Without Borders USA awarded seven grants in May 2020 of between USD 30,000 and USD 50,000 for its Chill Challenge to catalyse innovative solutions for off-grid refrigeration; projects included innovative solar chilling refrigeration and an icemaker powered by farm waste.<sup>238</sup>

To support innovation in clean cooking, the UK Aid-funded modern energy cooking services (MECS) programme awarded a total of GBP 826,000 (more than USD 1 million) to 14 community-scale pilots and market assessments to advance efficient electric cooking.<sup>239</sup> Renewables-focused pilots include funding for PowerCorner Zambia, which will explore powering rural electric cooking with solar mini-grids.<sup>240</sup>

## NATIONAL POLICY DEVELOPMENTS

The scale-up of renewables-based systems for energy access requires conducive policy, regulatory and fiscal environments. This means national targets and plans that include off-grid renewables, combined with a variety of specific measures to support renewables – such as fiscal incentives (for example, lower VAT rates, import duty exemptions) and subsidies, quality standards for solar systems and cook stoves, and tariff regulations for mini-grids.<sup>241</sup> (→ See Tables 7 and 8.)

While many countries had electricity access targets in 2020, out of 64 selected countries with electricity access deficits, just under half had renewables-focused energy access targets.<sup>242</sup> (→ See Table 7.) Several countries also have included off-grid renewables targets for electricity access in their Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.<sup>243</sup> Some countries have adopted new off-grid energy access targets linked to economic recovery plans in response to the COVID-19 pandemic. For example, Nigeria announced that it would support 5 million new solar home systems or mini-grid connections serving up to 25 million customers under the Solar Power Naija Initiative.<sup>244</sup> As part of the Nigerian Economic Stability Plan, the initiative also aims to create up to 250,000 jobs in the energy sector.<sup>245</sup>

Over the last decade, policy frameworks benefiting renewables for electricity access have made major advances, especially in

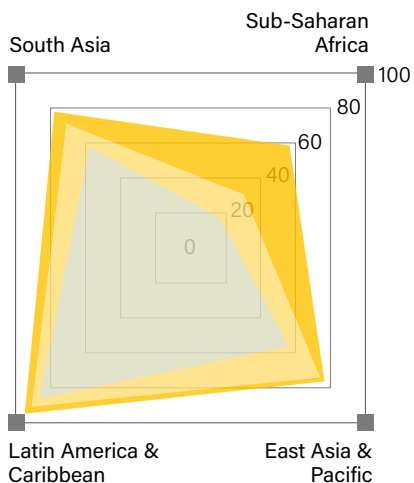
sub-Saharan Africa where most countries had few relevant policies in 2010 or even as recently as 2015.<sup>246</sup> By 2019, policies such as the inclusion of off-grid solutions in electricity planning, regulatory and fiscal frameworks to promote mini-grids and stand-alone renewables had been implemented in many more countries.<sup>247</sup> (→ See Figure 45.)

Developments in 2020 include the Ethiopian Energy Authority's new directive to establish procedures for mini-grid licencing and tariff regulations.<sup>248</sup> Benin and Mali introduced VAT and import duty exemptions for solar.<sup>249</sup> Kenya, on the other hand, removed a VAT exemption for solar and wind power, including batteries, in

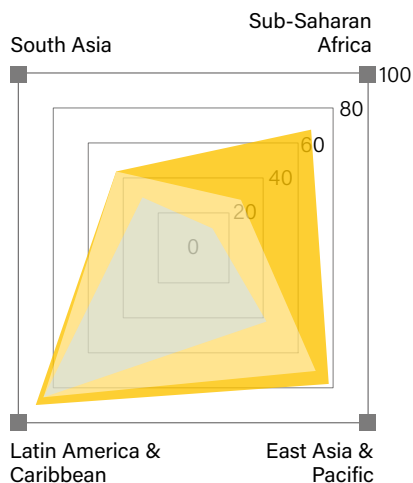


**FIGURE 45.** Key Improvements in RISE Indicators, Selected Regions, 2010, 2015 and 2019

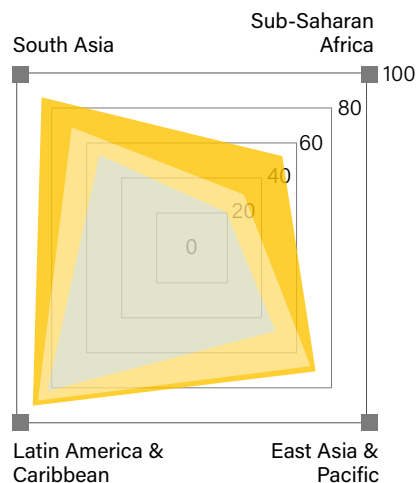
### Inclusion of off-grid solutions in electricity plan



### Framework for mini-grids



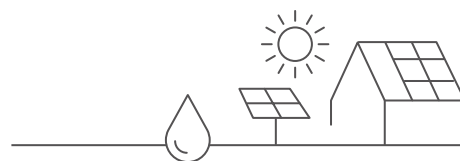
### Framework for stand-alone solutions



Legend: 2010 (light green), 2015 (yellow), 2019 (orange)

Note: RISE (Regulatory Indicators for Sustainable Energy) provides a set of indicators to help compare national policy and regulatory frameworks for sustainable energy. Indicators in the Figure assess average countries' policy and regulatory support for access to electricity across selected regions. RISE classifies countries into strong performers in the top third of the 0-100 score range, middle third performers, and weaker performers in the bottom third.

Source: ESMAP. See endnote 247 for this chapter.



its 2020 Finance Bill (although there were suggestions that this removal would be repealed in 2021),<sup>250</sup>

Solar irrigation received support in India, where the Kusun Yojana scheme offers farmers a 60% subsidy for installing solar pumps.<sup>251</sup> Togo announced that it would provide 50% subsidies for solar water pumps.<sup>252</sup>

Several donor programmes aim to further support off-grid renewables policy development, especially to improve the regulatory environment for mini-grids. In 2020, the Global Environment Facility, with the United Nations Development Programme as the lead agency, launched its new Africa Mini-grids Programme.<sup>253</sup> The programme focuses on policy de-risking to reduce costs and will initially support 11 African countries in addressing the key risks and underlying barriers holding back investment.<sup>254</sup>

**Clean cooking** tends to receive less attention from policy makers, as half of the population without access to clean cooking lives in countries that lack advanced policy frameworks (such as plans, standards and financial incentives) for clean cooking.<sup>255</sup> However, some countries have implemented these type of policy measures during the last decade, especially in Latin America, the Caribbean and South Asia.<sup>256</sup> In Africa, Benin, Kenya, Nigeria and Tanzania also have been catching up.<sup>257</sup> Clean cooking policies generally do not focus on renewables but support clean cooking solutions more broadly.

Several countries have covered clean cooking in their NDCs to address the significant climate impacts of deforestation from inefficient biomass cooking.<sup>258</sup> (→ See Table 8.) For example, the Nepalese government included new clean cooking targets in its second NDC submitted in December 2020.<sup>259</sup> In addition to 500,000 additional improved cook stoves and 200,000 household biogas systems, the NDC aims for 25% of households to cook with electricity by 2030, in tandem with targets to increase electricity generation from renewables.<sup>260</sup> To support a shift to electric cooking, the government decided in 2020 to waive the 15% customs duty for induction stoves and to introduce a 20% discount on electricity bills for induction stove users.<sup>261</sup>

India has supported major growth in clean cooking with LPG and in 2020 expanded the Pradhan Mantri Ujjwala Yojana scheme to provide subsidised LPG connections to 10 million additional poor households.<sup>262</sup> As part of the country's March 2020 COVID relief package, up to three free-of-cost LPG refills were provided to scheme recipients.<sup>263</sup> By contrast, in Kenya fiscal responses to the pandemic resulted in clean cook stoves and fuels losing the VAT exemption in place since 2016.<sup>264</sup> This was denounced by the clean cooking industry as a major setback in a country that had strongly supported growth in the sector.<sup>265</sup>



Half of the population without access to clean cooking lives in countries that lack policy frameworks for this.





**TABLE 7.**  
Distributed Renewables Policies for Electricity Access, Selected Countries, 2020

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 (connections codes, tariff, licencing, 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.)	
<b>Africa</b>										
▲ Angola	●		●	●	●	●	●	●		
Benin	●				●	○	●	●	★	
Botswana						●				
▲ Burkina Faso	●		●	●	●	●		●	●	
Burundi					●			★	●	
Cameroon		●	●		●		●	●	●	
Central African Republic					●		●	●		
▲ Chad									●	
Comoros									●	
▲ Congo, Democratic Republic of the	★		●		●				●	
Congo, 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		●		●	●		●	●	●	
<b>Asia</b>										
▲ Bangladesh		★	●	●	●	●	●	●	●	
Cambodia		●		●	●		●	●		
▲ India	●		●	●	●	○	●	●	●	
▲ Korea, Democratic People's Republic										
Mongolia	●				●					
▲ Myanmar	●	●	●		●	●	●	●	●	
Nepal	●	★		●	●	●	●	●	●	
▲ Pakistan		●					●		●	
Philippines			●		●			●		

Note: Please see key on the next page.





**TABLE 7.**  
Distributed Renewables Policies for Electricity Access, Selected Countries, 2020 (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, licencing, 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.)
<b>Central and South America</b>									
Guatemala			●						●
Haiti									
Honduras									●
Panama		★							
<b>Middle East</b>									
Syria									
▲ Yemen	●	●	●					●	

Note: The list includes only countries that have an electrification rate below 95% according to the IEA World Energy Outlook 2020 Electricity Access Database (except for India and the Philippines). The top 20 access-deficit countries are the 20 countries with the highest electricity access-deficit populations. These are Angola, Bangladesh, Burkina Faso, Chad, the Democratic Republic of the Congo, Ethiopia, India, Kenya, the Democratic People's Republic of Korea, Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, Pakistan, Sudan, Tanzania, Uganda and Yemen.

INDC and NDC refers to countries' (Intended) Nationally Determined Contributions towards reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: See endnote 241 for this chapter.

- Existing national policy or tender framework (could include sub-national)
- ★ New (one or more policies of this type)
- National tender held in 2020
- Removed
- ▲ Top 20 access-deficit countries



**TABLE 8.**  
Distributed Renewables Policies for Clean Cooking Access, Selected Countries, 2020

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.)
<b>Africa</b>								
▲ Ethiopia	●	●	●			●		
▲ Ghana			★			●		
▲ Kenya	●		●			●		□
Rwanda	●	●	●			●		●
▲ Uganda	●	●	●					●
<b>Asia</b>								
▲ Bangladesh	●	●	●			●		●
▲ China	●	●	●					
▲ India	●	●	●				★	
▲ Nepal	●	★	●			●	●	★
<b>Central and South America</b>								
Guatemala		●	●					

Note: The top 20 access-deficit countries are the 20 countries with the highest clean cooking access-deficit populations. These are Afghanistan, Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, Ghana, India, Indonesia, Kenya, the Democratic People's Republic of Korea, Madagascar, Mozambique, Myanmar, Nigeria, Pakistan, Philippines, Sudan, Uganda, Tanzania and Vietnam.

INDC and NDC refers to countries' (Intended) Nationally Determined Contributions towards reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: See endnote 241 for this chapter.

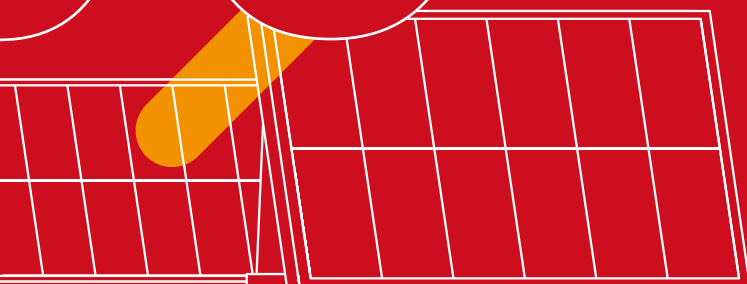
- Existing national policy or tender framework (could include sub-national)
- ★ New (one or more policies of this type)
- National tender held in 2020
- Removed
- ▲ Top 20 access-deficit countries



**In 2020, Banco do Brasil committed to expanding renewables in its energy matrix up to 90% by 2024 and inaugurated its first solar power plant in March.**



05



# 05 INVESTMENT FLOWS

## KEY FACTS

- Global investment in new renewable energy capacity totalled **USD 303.5 billion in 2020**, up 2% from 2019.
- **Developing and emerging economies surpassed developed countries** in renewable energy capacity investment for the sixth year running, although by a smaller margin than in previous years, reaching USD 153.4 billion.
- Recovery packages from January 2020 to April 2021 allocated at least USD 53.1 billion in direct support for renewable energy, **nearly six times less** than for fossil fuels.
- Renewable energy projects represented nearly **60% of all climate finance** during 2017 and 2018, averaging USD 337 billion.
- The divestment movement continued its upward trend in 2020, with more than 1,300 institutional investors and institutions worth **nearly USD 15 trillion committing to divesting** partially or fully from fossil fuel-related assets.

## INVESTMENT IN RENEWABLE ENERGY CAPACITY

**G**lobal investment in new renewable energy capacity (excluding large hydropower)<sup>i</sup> withstood the economic crisis triggered by the COVID-19 pandemic and totalled USD 303.5 billion<sup>ii</sup> in 2020.<sup>1</sup> This 2% increase over 2019 marks a significant rebound, particularly during the second half of the year.<sup>2</sup> With lockdowns and mobility restrictions affecting the entire renewables production and construction chain in the first half of 2020, new renewable capacity was expected to fall 10% for the year.<sup>3</sup> In the first quarter of 2020, final investment decisions<sup>iii</sup> on solar and wind projects dropped to their 2017 levels (USD 10 billion for solar and USD 23 billion for wind).<sup>4</sup>

However, government recovery packages increased the flow of renewable energy finance.<sup>5</sup> (→ See *Sidebar 3 in Policy Landscape chapter*, and *Figure 5 in Global Overview chapter*.) Private initiatives also contributed to the resilience of renewables, with continued development aimed at boosting investor interest in renewable energy – including through climate-related financial disclosure, green standards and taxonomies, and (to a certain extent) divestment campaigns. (→ See *Feature chapter*.)

i Renewable energy includes onshore and offshore wind, large- and small-scale solar, biofuels, biomass and waste, marine, geothermal and small hydropower.

ii These estimates are for capacity investment and exclude capital invested in companies and money spent on research, development and manufacturing.

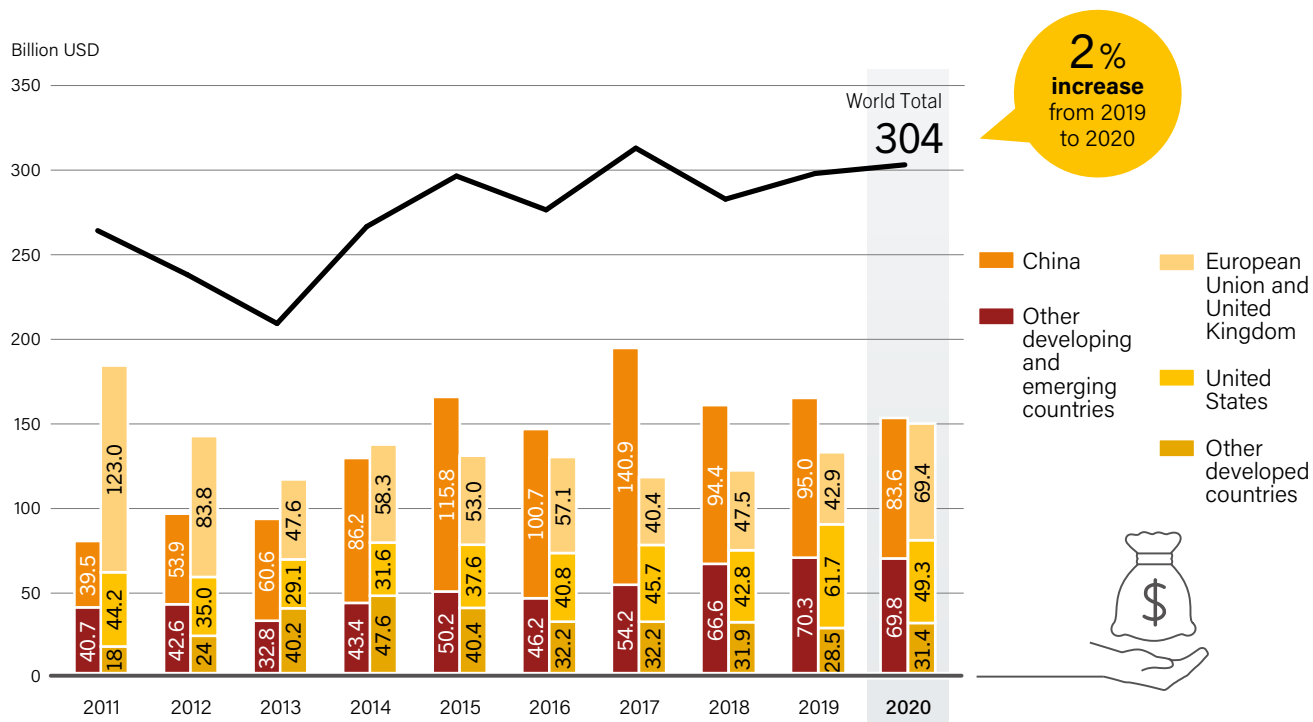
iii The final investment decision marks the point in the capital project planning process when the decision to make major financial commitments is taken. At that point, major equipment orders are placed and engineering, procurement and construction contracts are signed.

### INVESTMENT BY ECONOMY

For the sixth consecutive year, renewable energy capacity investments by developing and emerging countries (excluding hydropower projects larger than 50 megawatts, MW) exceeded those of developed countries, although by a smaller margin than in previous years, accounting for 50.5% of the 2020 total.<sup>6</sup> (→ See Figure 46.) Investments for the year rose 13% in developed countries and fell 7% in developing and emerging countries.<sup>7</sup>

The drop in developing countries was due mainly to declining capacity investment in China (down 12%), India (down 36%) and developing countries in the Americas (down 33%).<sup>8</sup> Investment also fell in Sub-Saharan Africa (down 14%), further diminishing the low investment in new renewable capacity in the region (USD 2.8 billion).<sup>9</sup> In contrast, investment growth continued for the seventh consecutive year in developing countries outside of those areas, including in Brazil (up 23%), the Middle East and North Africa (up 22%), and Asia and Oceania (up 13%).<sup>10</sup> (→ See Figure 47).

**FIGURE 46.** Global Investment in Renewable Power Capacity in Developed, Emerging and Developing Countries, 2010-2020



Note: Figure includes utility-scale renewable energy and small-scale solar projects and excludes large hydropower projects of more than 50 MW. Source: BloombergNEF. See endnote 6 for this chapter.



Renewable energy capacity investments in developing and emerging countries exceeded those in developed countries.



Although capacity investment in China fell 12% compared to 2019, the country continued to lead in overall renewable energy capacity investment, accounting for 27.5% of the global total.<sup>11</sup> The European Union (EU) was next, with 22.9%, followed by Asia-Oceania (16.9%, excluding China and India) and the United States (16.2%).<sup>12</sup> Africa and the Middle East accounted for 4.5%, non-EU Europe for 4.1%, the Americas (excluding Brazil and the United States) for 3%, Brazil for 2.9% and India for 2%.<sup>13</sup>

Overall capacity investment in China totalled USD 83.6 billion in 2020.<sup>14</sup> Around 65.5% of these investments were in the wind sector (onshore and offshore), followed by solar PV (30%), biomass and waste (4.2%) and small hydropower (0.5%).<sup>15</sup> In parallel, China's foreign investments in solar PV, wind power and hydropower represented for the first time more than half of the country's total overseas energy investments under the Belt and Road Initiative – China's main international co-operation and economic strategy – increasing from 38% in 2019 to 57% in 2020.<sup>16</sup> This was due mainly to the steady decline in coal investments since 2015 (although they resurged in 2020) and to the sharp decrease in natural gas investment, which represented only 2.4% of the total 2020 investment, compared with 23.7% in 2019.<sup>17</sup> The majority of renewable energy investment was in hydropower (35%), while solar and wind represented 23%.<sup>18</sup>

Qatar and Oman received 100% of the renewable energy investments from China in 2020.<sup>19</sup> However, most of the power plants financed<sup>i</sup> during the year by foreign direct investment from Chinese companies and China's two global policy banks<sup>ii</sup> were coal-fired plants (around 39% of the capacity), followed by hydropower (27%).<sup>20</sup> Wind and solar projects constituted a higher share of total projects than coal, gas and hydropower plants, but due to their smaller capacity they accounted for only 11% of Chinese investment overseas.<sup>21</sup>

After hitting a record high in 2019, US investment in renewable energy capacity fell 20% in 2020, to USD 49.3 billion.<sup>22</sup> Investments were mainly in solar PV (USD 31.3 billion, or 63.5% of the total) and onshore wind (USD 17.7 billion, 36%).<sup>23</sup> The EU was the main driver of increased renewable energy capacity investment in 2020, totalling USD 69.4 billion in 2020, led by the United Kingdom and the Netherlands (due to investments in large offshore wind projects), followed by Spain.<sup>24</sup>



i Chinese participation in these power plants includes foreign direct investment, mergers and acquisitions, greenfield investments and debt finance. See Global Development Policy Center, Boston University, "China's Global Power Database", <http://www.bu.edu/cgp>.

ii The China Development Bank and the Export-Import Bank of China.

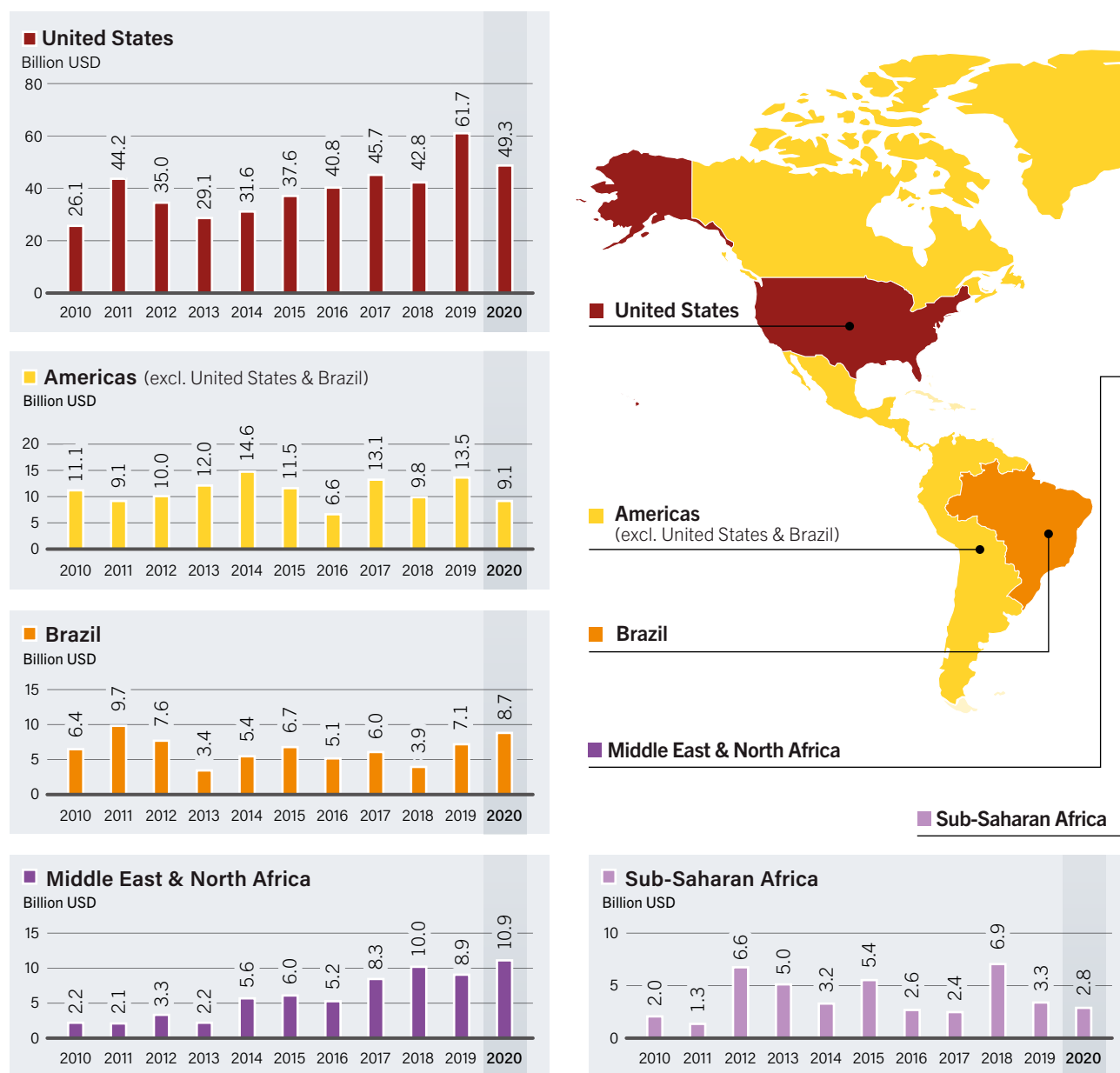
### INVESTMENT BY TECHNOLOGY

Solar power represented nearly half of global renewable energy capacity investment in 2020, at USD 148.6 billion.<sup>25</sup> It was the only renewable energy technology to increase for the year, up 12% from 2019.<sup>26</sup> Although wind power capacity installations grew during the year, investment

In 2020, solar power was the only renewable energy technology to experience an **increase in investments.**



**FIGURE 47.** Global Investment in Renewable Energy Capacity, by Country and Region, 2010-2020



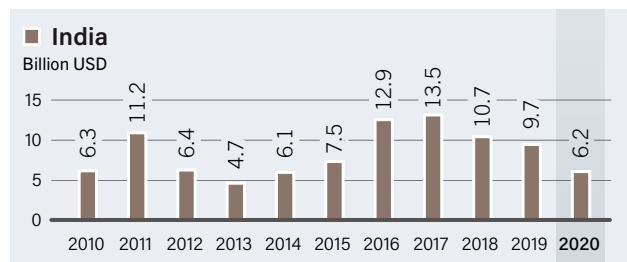
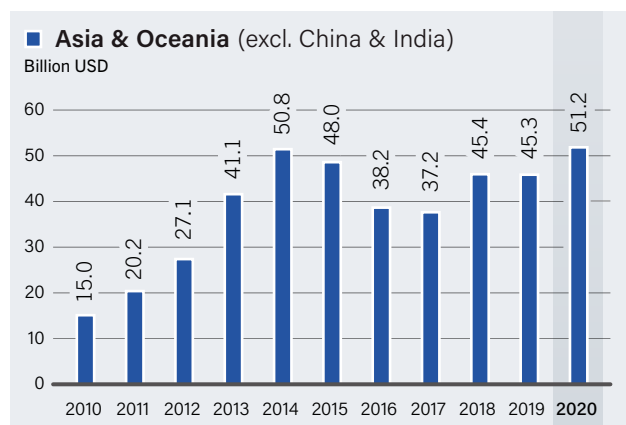
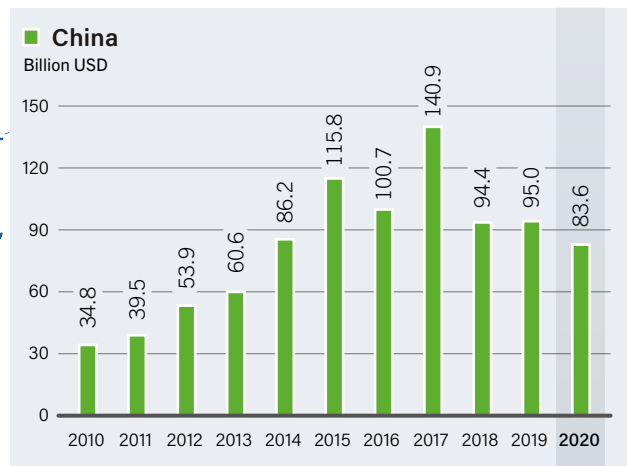
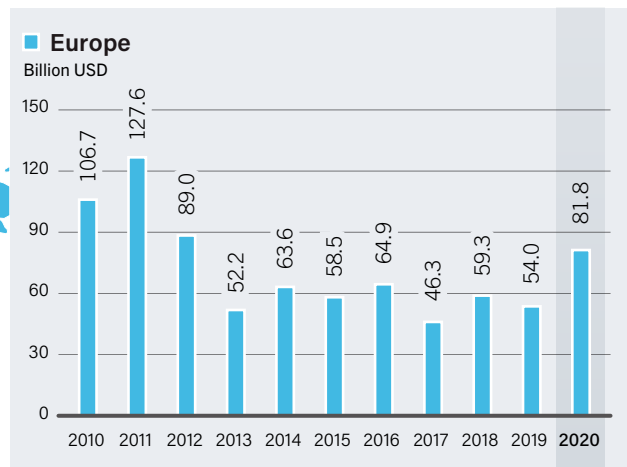
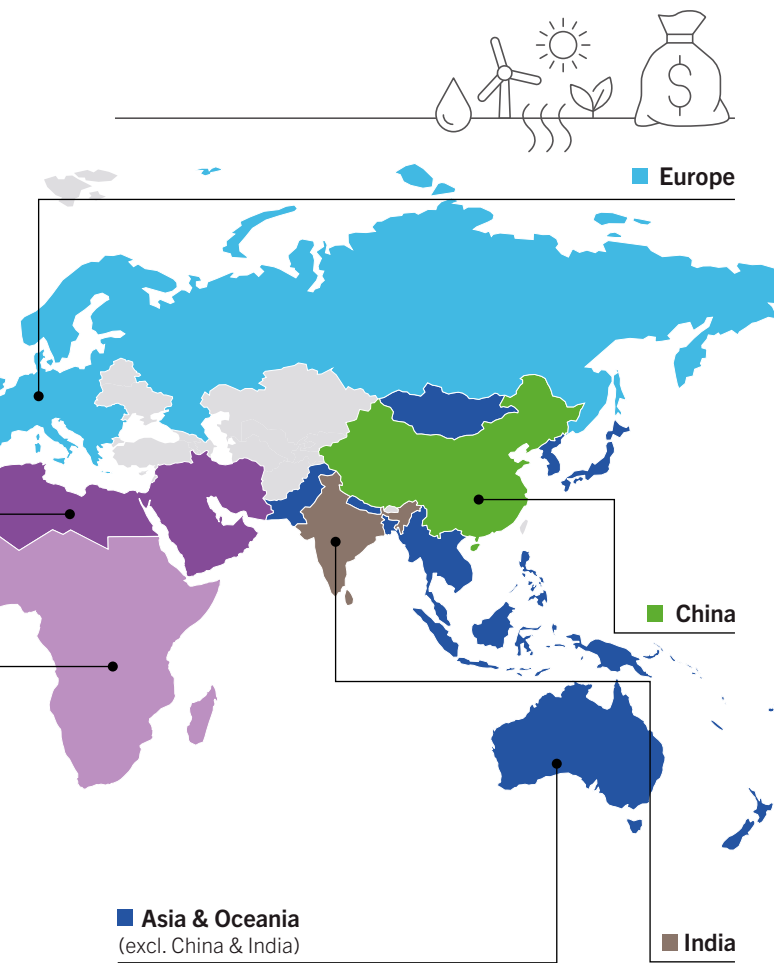
Note: Figures include utility-scale renewable energy and small-scale solar projects and exclude large hydropower projects of more than 50 MW. The regions in this chapter follow those presented in the BNEF *Energy Transition Investment 2021* report and differ from the regional definitions included elsewhere in the GSR. Source: BloombergNEF. See endnote 10 for this chapter.

in wind power fell 6% to USD 142.7 billion, representing 47% of the total.<sup>27</sup> (→ See Market and Industry chapter.)

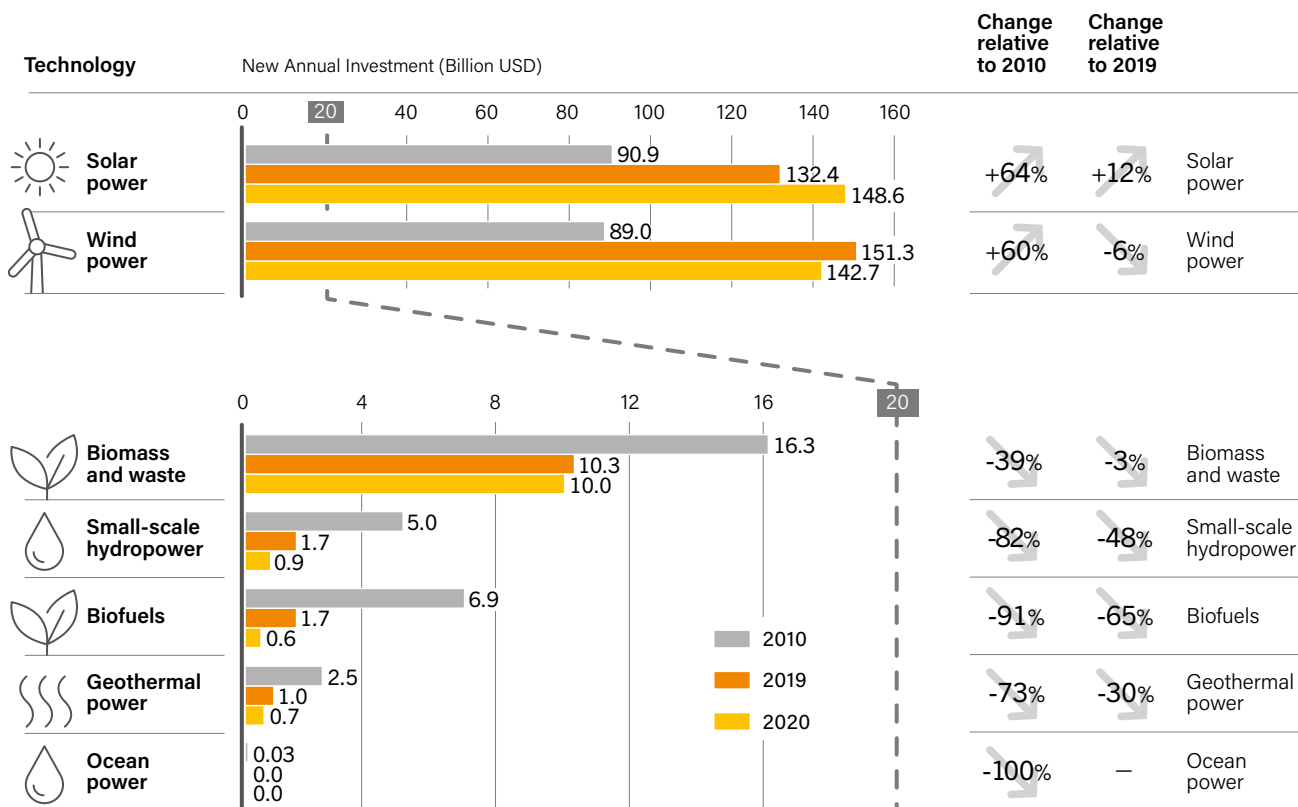
Biomass and waste-to-energy<sup>i</sup> investment was down 3% to USD 10 billion.<sup>28</sup> The remaining technologies continued their downward trend in 2020, with investment in small hydropower reaching USD 0.9, geothermal USD 0.7 billion and biofuels USD 0.6 billion – each dropping more than 70% since 2010.<sup>29</sup> (→ See Figure 48.)

The factors behind these trends vary by technology. Common barriers to investment in small hydropower projects include the high upfront cost, the lack of a regulatory framework encouraging deployment of the technology, and a high degree of risk and uncertainty in the different development stages.<sup>30</sup> For geothermal projects, high risks and expensive early-stage development (test drilling) have impeded further participation from private investors in the last two decades.<sup>31</sup>

i Although the energy produced from solid waste combustion is efficient, it cannot be considered entirely renewable as solid waste also contains inorganic material. Generally, around 50% of energy from municipal solid waste is classified as renewable. (→ See Glossary.)



**FIGURE 48.**  
Global Investment in Renewable Energy Capacity by Technology, 2010, 2019 and 2020



Note: Figure includes utility-scale renewable energy and small-scale solar projects and excludes large hydropower projects of more than 50 MW.  
Source: BloombergNEF. See endnote 29 for this chapter.

The declining investment in first-generation biofuels started in 2007, amid growing concern about the impacts of the fuels on food security and prices and on land use (also affecting greenhouse gas emissions).<sup>32</sup> In contrast, investment in second-generation biofuels<sup>i</sup> grew starting in 2007, but the growth lasted only until 2011.<sup>33</sup> The main barriers to further investment in the sector include the regulatory uncertainty regarding sustainability criteria (especially in Europe), low subsidy levels, high financing costs and doubts regarding technological readiness.<sup>34</sup>

Marine power received no capacity investment in 2020, mainly because of technology challenges and a lack of specific policy support in the key markets.<sup>35</sup>

Other investments that are relevant (indirectly) to the uptake of renewables include spending on electric vehicles (EVs), heat pumps and energy storage.<sup>36</sup> (→ See *Systems Integration chapter*.) In 2020, investment in EVs and associated charging infrastructure was up 28% to USD 139 billion, and investment in domestic installation of energy-efficient heat pumps was up 12% to USD 50.8 billion; meanwhile, investment in batteries and other energy storage technologies (excluding pumped hydropower,

compressed air and hydrogen) was unchanged from 2019, despite lower unit prices, for a total of USD 3.6 billion.<sup>37</sup> Hydrogen investment fell 20% in 2020, due to lower investment in fuel cell buses and commercial fuel cell vehicles, while investment in the electrolysis process rose 12.5% to USD 189 million due to the increased attractiveness of renewable hydrogen production.<sup>38</sup>



<sup>i</sup> Advanced biofuels, or second-generation biofuels, are made of "lignocellulosic feedstock such as corn stover, straw, wood waste, rapidly growing grasses and short-rotation trees, municipal waste, and waste oils, fats or algae, all of which have few non-energy uses, and some of which can be grown on less productive and degraded lands or in seawater (algae), thus involving a smaller impact in terms of land-use." See International Renewable Energy Agency, *Advanced Biofuels: What Holds Them Back?* (Abu Dhabi: 2019), <https://irena.org/publications/2019/Nov/Advanced-biofuels-What-holds-them-back>.



**COVID-19'S IMPACT ON INVESTMENT**

In addition to the resilience of renewable energy investments to the COVID-19 crisis, economic recovery packages in 2020 included significant spending to stimulate further investment in renewables, both to address climate change and to deploy specific renewable energy projects.

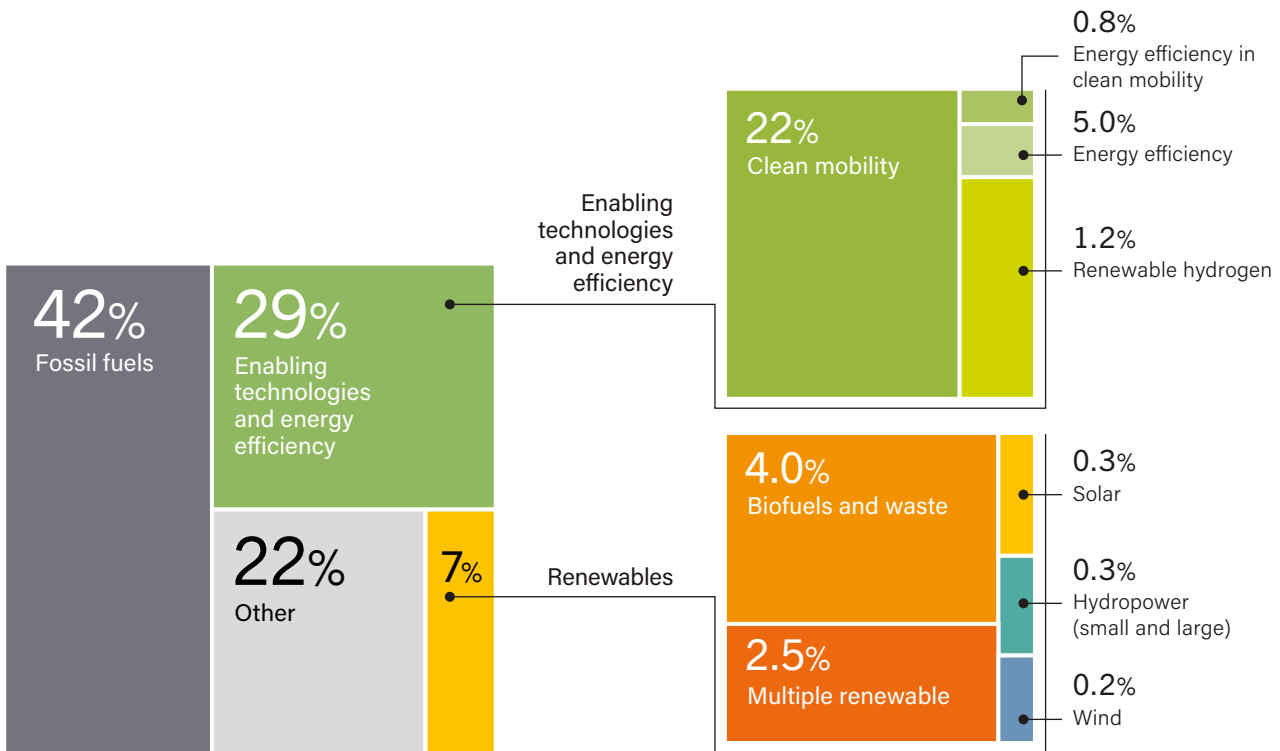
By September 2020, governments had announced USD 11.8 trillion in fiscal assistance in response to the pandemic-induced economic crisis, more than three times the amount spent to respond to the financial crisis of 2008.<sup>39</sup> While most of the funding prioritised supporting health and reducing unemployment, around 30% was allocated to sectors with an impact on the energy transition, with the aim of creating jobs and boosting economies.<sup>40</sup> Globally, investment in the solar PV sector in 2020 created an estimated 13 jobs per USD 1 million invested, or twice as many jobs as in the coal or gas industry.<sup>41</sup> Wind and hydropower projects generated as many jobs as nuclear power projects.<sup>42</sup>

As of April 2021, 31 governments had announced a combined USD 732.5 billion in spending to support all types of energy through new or amended policies.<sup>43</sup> Of this total, 42% (USD 309.9 billion) was allocated to fossil fuel-intensive sectors, 37% (USD 264.2 billion) to "clean energy"<sup>i</sup> and 21% (USD 152.9 billion) to other energy sources (including nuclear, first-generation biofuels, biomass and biogas, and hydrogen from unspecified sources).<sup>44</sup> (→ See Figure 49.)

Renewable energy investments in COVID-19 recovery packages were nearly **six times less** than those for fossil fuels.

i This refers to policies supporting the production or consumption of low-carbon energy and the energy transition, including: energy efficiency and renewable energy (solar, wind, small hydropower, rain, tides and geothermal heat, large hydropower); renewable hydrogen; active transport (cycling and walking), rail, public transport and EVs (electric cars, bicycles, scooters and boats) using multiple types of energy; smart grids and technologies that better integrate renewables; hydrogen in the case of mixed, but predominantly clean, sources (e.g., as under Germany's hydrogen strategy); and biofuels, biomass and biogas with a proven minimum negative impact on the environment. For details, see EnergyPolicyTracker.org, "Methodology", <https://www.energypolicytracker.org/methodology>.

**FIGURE 49.** Energy Investments in COVID-19 Recovery Packages of 31 Countries, January 2020 to April 2021



Note: Although the energy produced from solid waste combustion is efficient, it cannot be considered entirely renewable as solid waste also contains inorganic material. Generally, about 50% of energy from municipal solid waste is classified as renewable. (→ See Municipal solid waste in Glossary.). Multiple renewables include geothermal and ocean power. Enabling technologies include e-mobility and renewable hydrogen. The "Other" category refers to other types of energy-related policies including, among others, nuclear energy, incineration, hydrogen from unspecified sources, and multiple energy types (for example intertwined fossil fuels and clean energy). Where totals do not add up, the difference is due to rounding.

Source: EnergyPolicyTracker.org. See endnote 44 for this chapter.

Of the clean energy spending, around 20.1% (USD 53.1 billion) was allocated directly to policies to support the production or consumption of renewables (including solar and wind power, small and large hydropower, rain and tidal energy, geothermal heat, and biofuels and waste energy).<sup>45</sup> The amount for biofuels and waste energy covers mainly investments in India, where nearly USD 27 billion was allocated to set up 5,000 compressed biogas plants.<sup>46</sup> However, 67 of the 199 policies related to clean energy sources did not specify an amount, making the actual total allocation much higher.<sup>47</sup>

Investment in enabling technologies associated with renewable energy use (such as e-mobility and renewable hydrogen) and energy efficiency comprised an additional USD 204 billion in renewable energy-related stimulus.<sup>48</sup>

Regionally, the EU led in environmental investments as of April 2021, allocating 30% (around EUR 550 billion, or USD 660 billion) of its overall recovery package and its long-term 2021-2027 budget solely to climate-related projects.<sup>49</sup> These projects included scaling up renewable energy (mainly wind and solar), launching a European “clean hydrogen economy” and developing clean mobility (including EVs).<sup>50</sup> However, many of the clean energy policies that could strengthen the deployment of renewables had not yet been translated into legislation, and allocation amounts had not been determined as of April 2021.<sup>51</sup> Within the EU, the leaders in renewable energy measures and allocations were Germany (at least USD 12.6 billion) and France (at least USD 3.9 billion).<sup>52</sup>

By early 2021, the United States had pledged only around USD 459.5 million to support renewable energy and USD 26.8 billion to support mobility, including EVs; this was less than 40% of the amount that was allocated to fossil fuel energy, without establishing climate targets or additional pollution reduction requirements (at least USD 72 billion).<sup>53</sup> The administration’s proposed clean energy and sustainable infrastructure plan released in early 2021 favoured investment in renewable energy, although the US Congress still needed to pass legislation and allocate proper funding.<sup>54</sup>

Other economies that announced investments in renewables (as well as fossil fuels) included the Republic of Korea, which allocated USD 984 million for solar and offshore wind generation; China (at least USD 217 million in biofuels and waste and multiple renewables) and India (at least USD 30 billion, including USD 27 billion to biofuels and waste projects).<sup>55</sup> However, these economic recovery plans also include coal (USD 2.5 billion in the Republic of Korea, USD 1.07 billion in China and USD 15.5 billion in India).<sup>56</sup>

Several countries focused on electricity decarbonisation, with the Republic of Korea, France and Italy increasing their subsidies for rooftop solar PV.<sup>57</sup> Nigeria, Africa’s largest oil and gas producer,

aimed to use 10% of its stimulus funds (USD 620 million) to install solar systems for up to 5 million households.<sup>58</sup> Colombia allocated USD 4 billion to renewable energy and transmission projects, including wind (nine projects), solar (five), geothermal (three) and hydropower (one).<sup>59</sup>

With calls for a “green recovery” following the COVID recession, combined with the expectation that the new US administration would implement low-carbon measures, renewables became more attractive to investors, who increased investments in wind and solar power, batteries and EVs.<sup>60</sup> The decreasing cost of these technologies compared to fossil fuels also was key to their greater appeal.<sup>61</sup>

Several indices that track the performance of renewable energy companies surged in 2020. For example, the WilderHill New Energy Global Innovation Index (NEX)<sup>i</sup> gained 142% and the S&P Global Clean Energy Index<sup>ii</sup> gained 138%.<sup>62</sup> By contrast, the NYSE Arca Oil Index and the S&P 500 Energy Index – both of which follow the performance of fossil fuel-linked companies – fell 38% and 37%, respectively.<sup>63</sup> The solar equipment manufacturer Enphase Energy was among the three best performers on the NEX.<sup>64</sup>

Overall, the stock prices of solar power manufacturers and distributors rose sharply in 2020. For example, the company SunPower tripled its value, and the Invesco solar index increased 66% between January and September.<sup>65</sup> However, growth in these indices must be viewed with caution as market prices fluctuate widely: the S&P Global Clean Energy Index fell 30% between early January and mid-March 2021.<sup>66</sup>



i The term “clean hydrogen” refers to renewable and low-carbon hydrogen in the *Hydrogen Strategy for a Climate-neutral Europe* elaborated by the European Commission. See [https://ec.europa.eu/energy/sites/ener/files/hydrogen\\_strategy.pdf](https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf).

ii The WilderHill New Energy Global Innovation Index tracks the performance of around 100 companies focusing on clean energy, renewables, decarbonisation and efficiency worldwide.

iii The S&P Global Clean Energy Index is designed to measure the performance of 30 companies from around the world that are involved in clean energy-related businesses, comprising a diversified mix of clean energy production and clean energy equipment and technology companies.

## DEPLOYING RENEWABLE ENERGY THROUGH CLIMATE FINANCE

Climate finance is the finance channelled to support mitigation actions that seek to reduce greenhouse gas emissions – including developing renewable energy, implementing energy efficiency and promoting sustainable transport – as well as adaptation actions that address the impacts of climate change. The renewable energy capacity investment described earlier does not include all renewables-related spending channelled through climate finance, as the latter may include, for example, finance for renewable energy companies in addition to support for new renewable energy capacity.<sup>67</sup>

Preliminary data indicate that in 2019, climate finance totalled between USD 608 billion and USD 622 billion, or a 6% to 8% increase over the annual average in 2017 and 2018 (USD 574 billion per year).<sup>68</sup> The latest breakdown of climate finance (available only for those two years and updated at year-end 2020) shows that renewable energy projects received USD 337 billion on average, representing almost 60% of all climate finance.<sup>69</sup>

The investment picture for developing countries is different. The 2015 Paris Agreement underscored the importance of addressing those countries' needs, setting a USD 100 billion annual target to be met jointly by developed countries by 2020.<sup>70</sup> Climate finance from developed to developing countries rose from USD 52.2 billion in 2013, to USD 58.6 billion in 2016, to USD 78.9 billion in 2018.<sup>71</sup> Initial data indicate that this trend continued in 2019 but did not meet the USD 100 billion annual target in 2020.<sup>72</sup>

During the three years between 2016 and 2018, the energy sector received the largest share of total climate finance: USD 23.8 billion per year on average, representing 34% of total climate finance mobilised by developed countries.<sup>73</sup> Of that total, 53% (USD 12.5 billion) supported projects targeting energy generation from renewable sources, including solar (23%), hydropower (19%), wind (15%), geothermal (5%) and biofuels (4%), with the rest (34%) from multiple sources or unspecified.<sup>74</sup>

For developing countries, the sources of global climate finance are divided equally between private and public, whereas for developed countries public sources constituted more than 80%.<sup>75</sup> Public sources mobilised by developed countries include bilateral development agencies and institutions (the annual financial commitments from developed countries to developing country governments, non-governmental organisations (NGOs) and civil society, research institutes and the private sector), multilateral development banks and climate funds, and providers of climate-related export credits.<sup>76</sup> Export credits, which totalled USD 2.1 billion in 2018, covered mainly renewable energy projects, while the remaining USD 62.2 billion was allocated to a variety of mitigation and adaptation actions.<sup>77</sup>

### MULTILATERAL CLIMATE FUNDS AND DEVELOPMENT BANKS

The major multilateral climate funds include, in order of investment pledged, the Green Climate Fund (GCF), the Climate Investment Funds (CIF) and the Global Environment Facility (GEF).<sup>78</sup> Multilateral climate funds and multilateral development banks play an important role in providing direct support to developing countries, as they are the principal interface between the public and private sectors.<sup>79</sup>

Replenishing these funds is important for the future of climate finance; they are central to climate funding for developing countries and determine the amount of investment in addressing climate mitigation and adaptation challenges in these countries.<sup>80</sup>

As of year-end 2020, the GCF had received pledges totalling USD 10.3 billion from 49 countries and regions for the 2020-2023 period, thus succeeding in its first replenishment campaign.<sup>81</sup> Of that total, USD 8.3 billion was secured.<sup>82</sup> As of October 2020, 32% of the GCF's portfolio comprised energy generation and access projects, driven mainly by private funding (USD 1,422 million, compared to USD 589 million in public funding).<sup>83</sup> The energy area represented half of the funding for mitigation actions, although the amount fell 40% between 2019 and 2020.<sup>84</sup>

**60% of climate finance** is directed at renewable energy projects, reaching an average of USD 337 billion during 2017 and 2018.



i Latest data available. The estimation for 2020 was expected to be ready in 2022.

ii Climate-related export credits refer to government financial support to foreign buyers to help finance the purchase of goods from national exporters, such as direct financing, guarantees, insurance or interest rate support.

As of early 2021, the GEF had invested more than USD 1.1 billion in 249 stand-alone renewable energy projects, as well as USD 277 million in 54 mixed projects with renewable energy components in 160 developing and transition countries.<sup>85</sup>

The CIF and two of its programmes, the Clean Technology Fund (CTF) and the Scaling Up Renewable Energy Program, also pledged funding for renewable energy projects (respectively, USD 5.4 billion as of early 2020, including for renewable energy deployment projects, and USD 744 million).<sup>86</sup> Of the CTF portfolio, 68% was allocated to renewable energy projects in reporting year (RY) 2020, resulting in installed capacity of 7.9 gigawatts (GW).<sup>87</sup> All CIF projects are implemented by partner multilateral development banks.<sup>88</sup> For example, the Renewable Energy Financing Facility in Kazakhstan, implemented by the European Bank for Reconstruction and Development, accounted for the largest share of the CTF portfolio's new capacity (21% of the RY 2020 total), with 104 MW installed.<sup>89</sup>

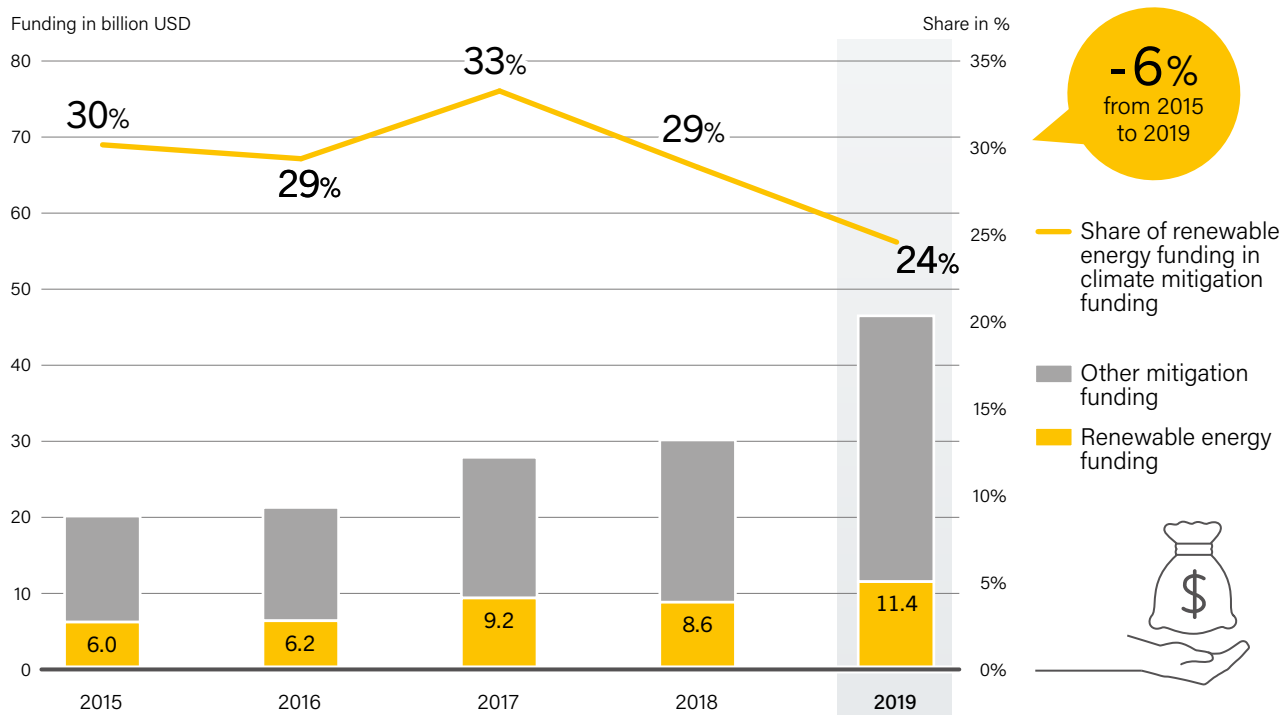
In 2019, multilateral development banks allocated USD 11.4 billion to renewable energy projects, including electricity generation, heat production and other applications, as well as measures to facilitate the integration of renewables into grids.<sup>90</sup> Of this total, 67% was allocated to low- and middle-income countries and 33% to high-income countries.<sup>91</sup> The regions that received most of the funding were the EU (30.2%), followed by Sub-Saharan Africa (16.4%), East Asia and the Pacific (9.9%), multi-regional (9.1%) and Latin America (8.8%).<sup>92</sup> Additional funding for renewables may have been allocated to research and development or policy support, but is tracked under other categories and thus is not included in the USD 11.4 total.<sup>93</sup>

Multilateral development bank investments in renewable energy projects have increased since 2014 (up 89% between 2015 and 2019).<sup>94</sup> However, their total investments (including non-renewable energy-specific funding) rose 132% over the same period.<sup>95</sup> Consequently, the share of renewable energy funding in total funding decreased during the five-year period, falling from 30% in 2015 to 24.4% in 2019.<sup>96</sup> (→ See Figure 50.)

**Multilateral development banks' investments in renewable energy projects have increased since 2014, reaching USD 11.4 billion in 2020.**



**FIGURE 50.** Share of Renewable Energy Funding in Climate Mitigation Finance from Multilateral Development Banks, 2015-2019





## CLIMATE FINANCE INSTRUMENTS

In 2018, loans and grants made up the key public finance instruments (84% and 13%, respectively) used in the energy sector overall.<sup>97</sup> Guarantees and equity investments also were used but represented only a very small share (3%).<sup>98</sup> Loans more than doubled from USD 19.8 billion in 2013 to USD 46.3 billion in 2018, increasing their share of total public finance from 52% to 74%.<sup>99</sup> Grants fluctuated between USD 10 billion and USD 12 billion, and their share fell from 27% to 20%.<sup>100</sup>

One loan instrument in particular contributed to this trend: **green bonds**, which are designed to fund projects with positive environmental or climate benefits.<sup>101</sup> Green bonds hit record levels for a second consecutive year, up 1.1% in 2020 to reach USD 269.5 billion.<sup>102</sup> Rebounding in the second half of the year amid the COVID-19 crisis, the green bonds market hit a milestone, exceeding a cumulative USD 1 trillion in issuance since this mechanism was created.<sup>103</sup>

Investment in the energy sector represented the largest share of green bonds in 2020, at USD 93.6 billion (34.7%).<sup>104</sup> More than half of this (USD 55.9 billion) was allocated to renewable energy projects.<sup>105</sup> The share of renewable energy bonds in total green bonds issued rose for the third straight year, from 17% in 2018 to 21% in 2020.<sup>106</sup> The United States was the leading issuer (20% of green bonds issued), followed by China (10%), Germany (9%), France (8%), the Netherlands (8%) and Spain (7%).<sup>107</sup>

In developing countries, particularly least-developed countries and small-island developing states, the market for green bonds remains small, due in part to these countries' lower credit ratings or lack of appropriate institutional arrangements.<sup>108</sup> Innovation in the securitising<sup>i</sup> green bonds, aggregating loans for small-scale low-carbon projects that, individually, are too small for the bond market, can help promote the issuance of green bonds in these countries.<sup>109</sup>

**Green securitisation** has grown in recent years, with more than USD 25 billion of the green bonds issued in 2019 estimated to be asset-backed securities, up from USD 1.9 billion in 2015.<sup>110</sup>

Growth in the renewable energy sector has led to the creation of **solar asset-backed securities**, which are securities backed by consumer receivables originated by solar energy companies, and used to finance PV systems.<sup>111</sup> While still an emerging sector, solar asset-backed security issuance grew to over USD 2 billion in 2018, with seven active issuers.<sup>112</sup>

## DIVESTMENT

The movement to pressure institutional investors to divest from financial assets related to fossil fuel companies has gained steam in recent years.<sup>113</sup> As of April 2021, more than 1,300 institutional investors and institutions worth nearly USD 15 trillion had committed to divest partially or fully from fossil fuel-related assets, up 36% from USD 11 trillion in 2019.<sup>114</sup> Faith organisations were the largest group of institutions divesting, accounting for almost 35% of the total number of commitments.<sup>115</sup> In 2020, 42 faith institutions from 14 countries announced the largest ever joint fossil fuel divestment by those institutions.<sup>116</sup> This commitment was echoed later by the Vatican's call for Catholics to divest from polluting industries and to shift to sustainable energy investments.<sup>117</sup>

Educational and philanthropic institutions accounted for another 30% of total commitments as of April 2021, while governments and pension funds represented 25% (large insurance companies and pension funds had contributed the highest share to divestments in 2019<sup>iii</sup>), and corporations and NGOs accounted for the remainder.<sup>118</sup> More than 58,000 individuals joined these institutions in the trend, divesting around USD 5.2 billion in 2020.<sup>119</sup>

The divestment movement focused initially on coal and expanded to include oil and natural gas. Since 2015, 135 banks and insurers with more than USD 10 billion in assets under management or loans have restricted their investments in coal (from mining to new coal-fired power plants), with 47 institutions joining in 2020 alone.<sup>120</sup> As of 2021, only 24 asset managers and owners with more than USD 50 billion in assets under management had done that, and more than half of those were announced in 2020.<sup>121</sup> The share of members from the 160 focus companies of Climate Action 100+<sup>iv</sup> – an investor-led initiative to address climate change – that are now planning a full phase-out of coal doubled between 2019 and 2020 (from 13% to 26%); meanwhile the share of companies with a partial phase-out plan rose from 35% to 48%, reflecting significant progress considering that those 160 companies represent over 80% of global industrial emissions.<sup>122</sup>

Investors have increasingly aligned their portfolios with the emission reduction goals of the Paris Agreement. Some, including the Bank of England, seek to reduce the financial risks of climate change, such as economic losses generated by extreme or chronic climate events, increased environmental regulations that negatively impact asset value, technological and demand changes, and litigation arising from inaction.<sup>123</sup> Global initiatives, including the Task Force on Climate-related Financial Disclosures, help the financial sector appropriately assess and price those climate-related risks and identify opportunities.<sup>124</sup>

i See Glossary for definition. The majority of the green bonds issued are green "use of proceeds" or asset-linked bonds. Proceeds from these bonds are earmarked for green projects but are backed by the issuer's entire balance sheet. To qualify for green bond status, they are often verified by a third party, such as the Climate Bond Standard Board, which certifies that the bond will fund projects that include benefits to the environment. See Socialfintech.org, "Capital markets and climate change: The green bond", <https://socialfintech.org/capital-markets-and-climate-change-the-green-bond>.

ii Securitisation is "the process whereby illiquid assets or rights are pooled and transformed into tradeable and interest-bearing financial instruments that are sold to capital market investors. These illiquid assets/claims may include bank or car loans, lease contracts, trade receivables, and insurance premiums, among others. Securitization acts not only as a means to raise cash on the capital markets, but also as a credit risk transfer tool." See Deloitte, *Securitization: Structured Finance Solutions* (Luxembourg: 2018), [https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/financialservices/lu\\_securitization-finance-solutions.pdf](https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/financialservices/lu_securitization-finance-solutions.pdf).

iii Data are not available for 2020; in 2019, the total amount divested was over USD 11 trillion. See Gofossilfree.org, "Commitments", <https://gofossilfree.org/divestment/commitments>.

iv Climate Action 100+ is now the largest ever investor engagement initiative on climate change. The numbers of focus companies, by sector, are: 39 oil and gas companies, 31 utility companies, 26 transport companies, 26 industrial companies, 23 mining and metals companies and 14 consumer products companies. See Climate Action 100+, "Companies", <https://www.climateaction100.org/whos-involved/companies>.

As of early 2021, 71 financial institutions had announced their divestment from oil and gas, particularly from oil sands extraction and Arctic drilling; 36 of these institutions joined the movement in 2020 alone.<sup>125</sup>

A survey of institutional investors representing USD 6.9 trillion under management showed that the COVID-19 economic crisis slowed planned divestments from fossil fuels, with investors divesting 4.5%, on average, of their overall portfolio in 2020, compared to 5.7% planned in the previous year's survey.<sup>126</sup> Respondents now expect to divest 5.2% over the next five years and 8.6% over 10 years, down from forecasts of 14.4% and 15.6%.<sup>127</sup>

### DOES DIVESTMENT REDUCE GLOBAL FOSSIL FUEL INVESTMENT?

Although divestment is growing, investment in fossil fuel-related companies among 35 private global banks has increased since the signing of the Paris Agreement, from USD 640 billion in 2016 to USD 736 billion in 2019.<sup>128</sup> This is because while some bank policies exclude financing for fossil fuel projects, they still allow lending to the corporate entity that engages in these projects.<sup>129</sup> Evidence also shows that other investors end up purchasing the divested stocks and that declining stock prices in fossil fuel company cannot be linked specifically to divestment.<sup>130</sup>

Divestment, per se, generally does not affect either the production costs of fossil fuel energy or consumers' willingness to buy.<sup>131</sup> Consequently, the profits of oil and gas company owners are not decreasing.<sup>132</sup> Furthermore, research has found that although increased oil and gas divestment pledges in a country are associated with lower capital flows to domestic oil and gas companies, this may not affect global investment, as national banks in countries with stricter exclusion policies seem to provide more funding to oil and gas companies abroad.<sup>133</sup>

However, some countries and some industry sectors have made progress in the sense that some companies now face new challenges in their development of fossil fuel projects.<sup>134</sup> In South Africa, the restrictive lending policies of two banks increased the cost of capital for fossil fuel projects.<sup>135</sup> Similarly, an estimated 85% of the banks in the global market have expressed unwillingness to invest in coal power plants.<sup>136</sup> As a result, 72% of the plants under construction outside of China have come to rely on Chinese financing.<sup>137</sup> As of July 2020, most public finance for coal worldwide came from China's financial institutions, which allocated USD 50 billion to 53,129 MW of installed capacity.<sup>138</sup>

When considering the impact on global greenhouse gas emissions, studies conclude that investment in innovative and environmentally friendly companies has a greater impact than divestment.<sup>139</sup>

### DOES DIVESTMENT ATTRACT INVESTMENT IN RENEWABLES?

In 2020, the estimated global investment in new renewable power and fuel capacity was more than twice that in coal, natural gas or nuclear power generating plants combined.<sup>140</sup> Nearly 70% of the estimated global investment was allocated to renewable energy power plants, while only 31% went to coal, gas and nuclear plants.<sup>141</sup> (→ See Figure 51.) Renewable energy projects have become more appealing, particularly in light of the COVID-19 crisis. A 2020 survey of institutional investors with USD 6.9 trillion under management found that investors planned to nearly double their allocation to renewable energy infrastructure in the near term, from 4.2% in 2020 to 10.8% in 2030.<sup>142</sup>

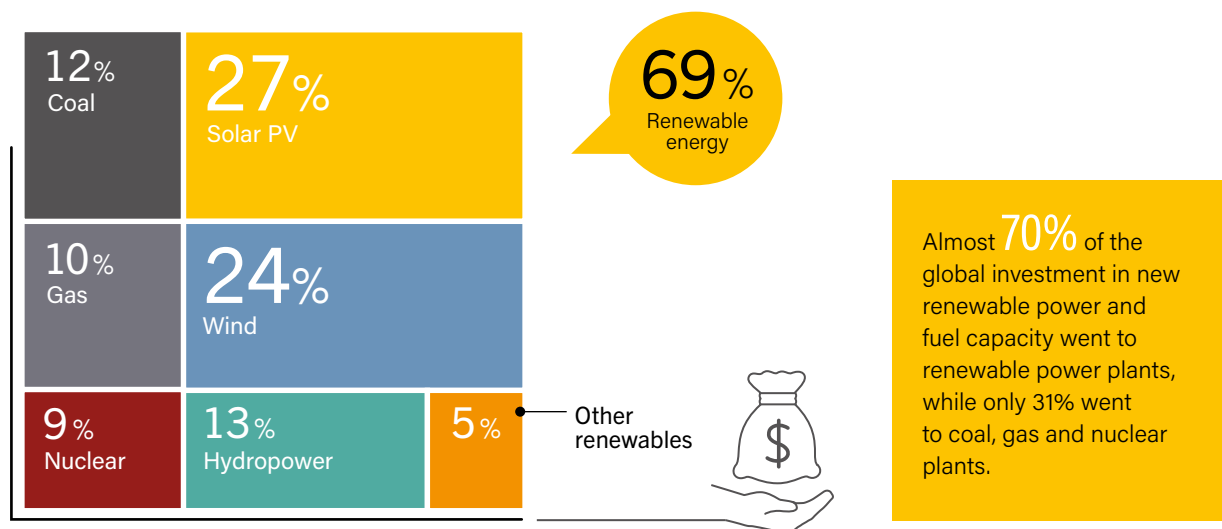
However, it is hard to establish a direct link between divesting from fossil fuels and investing in renewable energy. One study

**General guidance on reinvestment appears to be lacking for institutions and companies engaged in divestment.**



i Oil sands extraction is among the world's most carbon-intensive, large-scale crude oil operations. Carbon emissions are reported to be 31% higher than from conventional oil. Arctic drilling to extract natural gas and oil is more costly and technologically complicated than drilling for oil on land. Large amounts of water are consumed in the process, and the ability to respond to oil spills is highly limited. See Institute for Energy Economics and Financial Analysis, "Finance is leaving oil and gas," <https://ieefa.org/finance-exiting-oil-and-gas>.

**FIGURE 51.**  
Estimated Global Investment in New Power Capacity, by Type, 2020



Note: Hydropower includes pumped storage. Other renewables include bio-power, geothermal power, concentrating solar power (CSP) and ocean power.  
Source: IEA. See endnote 141 for this chapter.

suggests that between 2001 and 2018, more than half of energy utilities that prioritise growth in renewables over other technologies continued investing in natural gas and/or coal.<sup>143</sup> Of these utilities, 34% posted negative growth in coal and gas, and just 15% divested from both in their portfolios.<sup>144</sup> Two-thirds of the utilities prioritising renewable energy were located mainly in the United States and Europe (particularly Germany), while 10% were in China.<sup>145</sup>

A few concrete examples of “divest-invest” exist, including the pledge by 12 major cities<sup>i</sup> to divest from fossil fuel companies while investing in a “green and just recovery” from the COVID-19 crisis.<sup>146</sup> This commitment – “Divesting from Fossil Fuels, Investing in a Sustainable Future” – made by cities across three continents recognises the potential to create jobs, limit climate risk and facilitate the energy transition.<sup>147</sup> In another example, the Catholic Impact Investing Pledge represents 28 Catholic organisations with USD 40 billion in assets under management that have committed to invest in environmental and justice issues.<sup>148</sup>

In 2014, the Rockefeller Brothers Fund pledged to divest from fossil fuels. As of December 2020, the Fund’s total fossil fuel exposure was an estimated 0.3% of its total portfolio, down from 6.6% in April 2014.<sup>149</sup> The Fund also has set a target to allocate 20% of its portfolio to “impact” investments, prioritising investments in support of the United Nations Sustainable Development Goals, including clean energy development.<sup>150</sup>

The apparent impact of divestment campaigns lies in their ability to raise consciousness and change public attitudes

about the fossil fuel industry and investments in fossil fuels.<sup>151</sup> However, general guidance still appears to be lacking regarding reinvestment for institutions and companies engaged in divestment.<sup>152</sup>

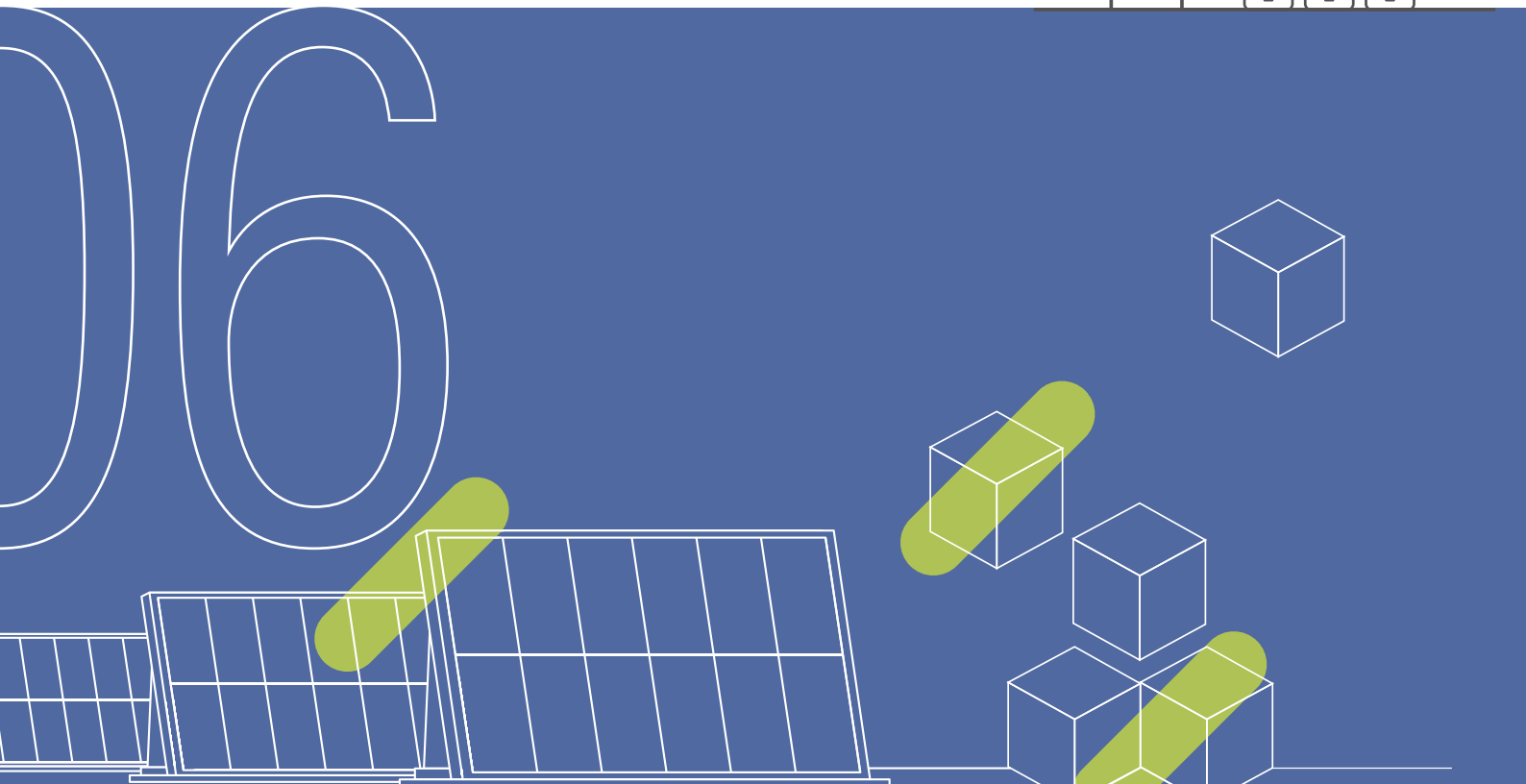


i The 12 cities are Berlin, Bristol, Cape Town, Durban, London, Los Angeles, Milan, New Orleans, New York City, Oslo, Pittsburgh and Vancouver.





**A new energy storage project marks the next frontier of Apple's efforts to become carbon neutral for its supply chain and products by 2030.**





# 06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

## KEY FACTS

- Several power systems saw record levels of **variable renewable electricity (VRE)** penetration in 2020.
- **Digital technologies** were used to modernise grid monitoring and control, improve forecasting, and optimise the flexibility and capacity of existing grid infrastructure.
- **Wholesale electricity market design** enabled more participation for VRE power plants, energy storage and flexible demand in certain markets.
- In 2020, the **heat pump** market was up in North America and Europe but slowed in the Asia-Pacific region. **Electric car** sales rose 41%, a significant increase considering that global car sales overall were down for the year. New **battery storage** projects increased 62% compared to 2019.

**E** Energy systems integration involves the co-ordinated design, implementation, operation, planning and adaptation of energy systems with the objective of delivering reliable, safe, cost-effective energy services with minimal environmental impact.<sup>1</sup> Here, it is addressed with a specific focus on the integration of higher levels of renewable energy in power grids, heating and cooling systems, and transport fuelling systems.

Renewable energy can lead to more sustainable and economical operation of energy systems.<sup>2</sup> However, as shares of renewable energy grow, the systems that have evolved or been designed around conventional<sup>i</sup> energy sources require adaptation efforts to maintain or improve the services that they deliver.<sup>3</sup> These efforts include top-down integration measures such as the planning and design of infrastructure, markets and regulatory frameworks, as well as the bottom-up development and advancement of supply- and demand-side technologies. To this end, governments, regulators, energy utilities, technology companies and energy consumers have been addressing barriers that may slow or halt the growth of renewables, working to expand existing end-uses of renewables, and creating new markets for renewable energy technologies and services.<sup>4</sup>

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 power – has occurred in many countries.<sup>5</sup> VRE achieved unprecedented penetration levels during 2020 due to cost reductions and

<sup>i</sup> The word “conventional” is used here to describe non-renewable energy resources or large hydropower. In the context of the power sector, the term “conventional generators” describes fossil fuel, nuclear and large hydropower generators.

subsequent demand.<sup>6</sup> In addition, COVID-19 containment measures that depressed electricity demand resulted in increased VRE shares due to preferential dispatch protocols and marginal cost advantages.<sup>7</sup>

Several power systems reached record-high instantaneous VRE shares in 2020, forcing grid operators to apply a range of new and existing measures to ensure ongoing service.<sup>8</sup> Some power systems, for example in South Australia, reached such high VRE penetration levels that electricity supply routinely exceeded demand.<sup>9</sup> During the year, consumption of electricity from renewable sources surpassed that from coal in the United States for the first time in 130 years, while the United Kingdom’s power system operated without coal power for 18 consecutive days – the longest period in nearly 140 years.<sup>10</sup>

At the end of 2020, renewables represented around 29% of global electricity generation, and more than 9% of the total generation was estimated to be from solar PV and wind power.<sup>11</sup> The penetration of modern renewables in transport and in the heating and cooling sector was much lower than this. (→ See *Global Overview chapter*.) Many examples of renewables integration in 2020 occurred in the power sector (or involved the electrification of end-uses in other sectors), particularly in countries and regions with supportive policy environments or energy markets such as Australia, China, Europe and North America. (→ See *Policy Landscape chapter*.)

In recent years, the growing shares of variable energy resources that require the use of power inverters<sup>i</sup>, and the corresponding decentralisation of power systems, have created new requirements for control and monitoring systems.<sup>12</sup> These shifts in turn have prompted the wider digitalisation of transmission and distribution grids, and of downstream or “behind-the-meter” systems that incorporate electricity generation, storage and demand.<sup>13</sup> As power grids continue to evolve, numerous examples have emerged of the digitalisation of key operating nodes (such as control rooms and sub-stations) in order to more effectively process and manage more complex flows of information.<sup>14</sup> Advanced digital technologies including artificial intelligence and machine learning have been applied to improve the accuracy of both generation and demand forecasting, and to enable the aggregation of distributed energy resources<sup>ii</sup> to improve power system flexibility.<sup>15</sup>

Several technologies have supported 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 enabling technologies are heat pumps, electric vehicles (EVs) and certain types of energy storage, such as batteries. Other technologies that were still emerging during 2020 but that may help to reach higher shares of renewables in all sectors include renewable hydrogen, non-lithium-ion batteries (such as flow batteries) and novel forms of mechanical storage.

Power systems are adapting to higher shares of generation capacity based on power inverters, such as **wind and solar.**



i Technologies such as solar panels, wind turbines and batteries use power inverters to convert direct current (DC) into alternating current (AC) to allow them to interface with AC-based power systems. Resources that require the use of inverters do not have the rotational characteristics of conventional gas, steam or hydro generators, and impose different stability requirements on power systems as they become more prevalent.  
 ii Distributed energy resources include generators such as solar PV and wind plants, energy storage facilities and sources of demand.

## INTEGRATION OF RENEWABLES IN THE POWER SECTOR

In numerous countries, the power sector has transformed rapidly in recent years, driven by the increased penetration of variable wind and solar power.<sup>16</sup> At least nine countries produced more than 20% of their electricity generation from VRE in 2020: Denmark, Uruguay, Ireland, Germany, Greece, Spain, the United Kingdom, Portugal and, for the first time, Australia.<sup>17</sup> (→ See Figure 52.)

Cost declines in wind, solar PV and battery technologies have profoundly impacted the rate of deployment of renewables in power systems. Solar PV and onshore wind have become the cheapest sources of new generation for around two-thirds of the world's population.<sup>18</sup> Battery storage has become the most cost-effective new-build technology for "peaking" services in natural gas-importing areas such as China, Europe, and Japan, and the ability of batteries to provide peak capacity has been found to improve as shares of solar electricity increase, due to a change in generation patterns.<sup>19</sup>

Declining costs have made renewables more accessible, prompting numerous major multinationals to commit to achieving

100% renewable energy supply over the coming decade. Many have been driving innovation in the procurement and application of renewable energy.<sup>20</sup> (→ See Feature chapter.)

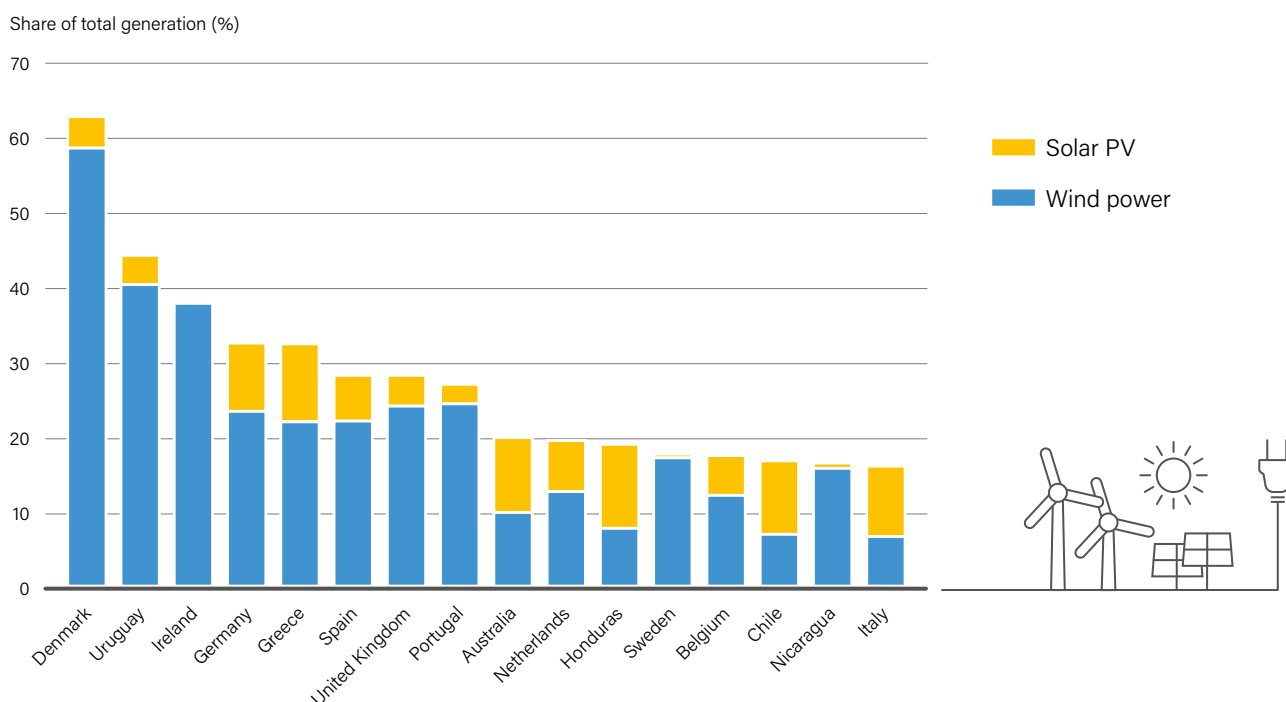
With the growth of VRE, the adaptation of power systems is occurring on several fronts. Many interventions have focused on maintaining or increasing system flexibility. As the grid evolves, flexibility is essential to ensuring safe and economical service delivery. Some of the key adaptations observed during 2020 involved:

- competitive wholesale market design to reward or promote flexibility and to allow for accurate pricing and remuneration of capacity and ancillary services from VRE and energy storage<sup>i</sup>;
- the wider integration of flexibility and ancillary services from sources of supply and demand, and from inverter-based energy resources;
- advances in the forecasting of electricity generation and demand, with the aid of advanced digital technologies; and
- enhanced grid interconnections and grid management systems to promote new linkages between VRE sources and demand centres, and to optimise the use of existing infrastructure.

i This change is colloquially known as the "duck curve" effect: increased shares of solar electricity can result in a generation surplus in the day and a deficit in the mornings and evenings when solar generation drops off. This can increase required generation ramp rates in the mornings and evenings and shorten peak demand periods to less than four hours, which in turn create conditions well suited to use of batteries for peak capacity supply. See endnote 19 for this chapter.

ii Electricity market design extends beyond wholesale markets. For brevity, the GSR covers key high-level developments at the wholesale level only.

**FIGURE 52.**  
Share of Electricity Generation from Variable Renewable Energy, Top Countries, 2020



Note: Figure shows countries among the top 15 according to the best available data at the time of publication. Several smaller countries with low total generation and/or high imports are excluded from this list.

Source: See endnote 17 for this chapter.

### COMPETITIVE WHOLESALE ELECTRICITY MARKET DESIGN

Many electricity markets source essential ancillary services – such as operating reserves, voltage support and “black start” capabilities – from conventional generators based on fossil gas, steam and hydro turbines. Market adaptations are required to enable the procurement of these and other services from VRE generators, energy storage systems and sources of flexible demand.<sup>21</sup> To this end, market rules were adapted in several electricity markets during 2020 to allow for the participation of ancillary services from distributed energy resources.

In the United States, the Federal Energy Regulatory Commission instituted market reforms that allow behind-the-meter VRE generators, EVs, batteries and flexible demand resources to participate in wholesale electricity markets in an aggregated manner.<sup>22</sup> At the state level, the California Public Utilities Commission set new interconnection policies for distributed resources (including EVs) and behind-the-meter solar and batteries, which may allow these resources to incorporate flexibility into the grid.<sup>23</sup> The UK system operator National Grid implemented several mechanisms to procure grid support from distributed energy resources, including communication and control signals that will allow wind farms to provide voltage and frequency response as well as generation reserves.<sup>24</sup>



### INTEGRATION OF FLEXIBILITY AND ANCILLARY SERVICES FROM SOURCES OF SUPPLY AND DEMAND

In conventional power systems with low VRE shares, the ability to balance generation and demand is obtained primarily from flexible or “dispatchable” conventional generators that adjust their output to follow demand.<sup>25</sup> With rising VRE shares in some power systems, the need for flexibility also has increased, with hour-to-hour ramping requirements growing in numerous major power systems including in China, the European Union (EU), India and the United States.<sup>26</sup>

In some cases, the flexibility of conventional generators has been enhanced in parallel with rising VRE shares. This has helped reduce the curtailment of both VRE and conventional generation, for example during periods of low demand and high VRE production, when conventional generators are increasingly required to ramp down production.<sup>27</sup> In parallel, flexibility and other ancillary services also have been recruited from VRE generators themselves, which have been continuously adapted to contribute essential reliability services to power grids, including frequency control and regulation, inertial response, voltage regulation, reactive power voltage support (also known as power factor correction) and even black start capabilities.<sup>28</sup> In Chile, for example, the National Electricity Coordinator approved during 2020 the provision of ancillary services from a 141 MW solar PV plant, including frequency management. During tests, the plant was shown to provide better performance for load response than equivalent gas-powered generators.<sup>29</sup>

A novel demonstration of ancillary service provision by VRE generators occurred when the UK energy utility ScottishPower used an offshore wind farm to restore part of the electricity grid after an outage, demonstrating the world’s first “black start” using VRE.<sup>30</sup> The ability of solar and wind inverters to provide this type of “grid-forming” service was the subject of US government-funded research and development (R&D) by GE, which aims to improve synchronisation between multiple grid-forming inverters and to improve the stability of power systems with high shares of variable renewables.<sup>31</sup>

Demand flexibility also is an 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 use of consumers.<sup>32</sup> In 2020, demand response technologies were supported by enabling policies in countries such as Japan and the United States, and in California demand response provided significant system support during heat waves that put severe pressure on the power system.<sup>33</sup> Nonetheless, while demand response capacity has grown in recent years, particularly in Australia, the United States and some European countries, global growth rates remain below those targeted by sustainable development plans such as the United Nations Sustainable Development Strategy.<sup>34</sup>

Energy storage in the form of pumped hydropower has long contributed to grid stability. More recently, however, other storage technologies including batteries have been used to provide both

i A “black start” is the process of restoring power in a power grid following a total or complete shutdown. Black starts have traditionally been supported by hydropower or non-renewable generators.



grid flexibility and ancillary services.<sup>35</sup> In some cases, batteries have started to compete in capacity markets, for example in the United Kingdom, where more than 100 megawatts (MW) of utility-scale battery assets secured demand-side response contracts in capacity auctions during 2020.<sup>36</sup>

Aggregators have extracted grid services from fleets of behind-the-meter batteries, along with other distributed energy resources, through the use of digital technologies that can control fleets of assets providing flexibility services. By late 2020, the system operator National Grid, which operates in both the United Kingdom and the United States, had enrolled 13 aggregators and 900 individual sites on a centralised demand management system across the US states of Massachusetts, New York and Rhode Island to provide more than 400 MW of flexible load capacity.<sup>37</sup> In the United Kingdom, the aggregation platform developed by GridBeyond, a company specialising in advanced demand response, enabled the participation of both batteries and sources of flexible demand in auctions for grid balancing services conducted by National Grid.<sup>38</sup> In Japan, Next Kraftwerke, a German operator of “virtual power plants”, partnered with Toshiba to aggregate privately owned VRE and energy storage resources to provide grid balancing services in the control reserve market, which will allow participation of these sources starting in April 2022.<sup>39</sup>

Fleets of EVs have been aggregated to provide grid balancing services in the Netherlands, Norway, and Sweden, and the provision of similar services is planned in Germany.<sup>40</sup> (→ See *Electric Vehicles* section in this chapter.)

### ADVANCES IN FORECASTING OF GENERATION AND DEMAND

Digital technologies have begun facilitating more accurate forecasting of both power system demand and VRE generation. This has allowed system operators to better anticipate VRE availability and to more cost-effectively balance generation and demand in short-term energy market scheduling. This can in turn reduce fuel costs, minimise curtailment of VRE and improve system flexibility and reliability.<sup>41</sup>

With the growing number of grid-connected, distributed VRE resources, generation forecasting has become increasingly complex and specialised.<sup>42</sup> Many grid operators have partnered with forecasting companies to more accurately predict VRE availability. For example, in Australia, the forecasting company Solcast started a demonstration project in 2020 for the South Australian grid, aimed at providing higher-resolution forecasts updated with greater frequency than pre-existing alternatives, that are designed specifically for the Australian energy market.<sup>43</sup>

Artificial intelligence has potential applications in increasing complex generation forecasting, and in managing and leveraging real-time supply and demand information produced by decentralising power systems.<sup>44</sup> In 2020, US federal funding was announced for 10 research projects that will use artificial intelligence and machine learning technologies to predict system

failures, schedule maintenance, address data quality issues and combine disparate datasets, with the aim of improving both forecasting and maintenance activities.<sup>45</sup>

Electricity demand forecasting has started to move away from traditional worst-case methodologies to probabilistic studies that involve intense computation processes.<sup>46</sup> Advances in computational power are allowing artificial intelligence and machine learning systems to more rapidly analyse data from energy users, bringing a bottom-up view to electricity demand forecasting and enabling more precise balancing of demand with available generation.<sup>47</sup>

### ENHANCED GRID INTERCONNECTIONS AND GRID MANAGEMENT SYSTEMS

Grid infrastructure can connect regions with strong wind and solar resources to 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 and efficiency.<sup>48</sup> Conversely, grid infrastructure constraints have become a significant bottleneck for the integration of VRE capacity.<sup>49</sup> In the United States, 245 clean energy projects at an advanced permitting stage were withdrawn between 2016 and 2020, due largely to limited transmission capacity.<sup>50</sup> Large transmission projects also have faced regulatory and developmental hurdles, notably in Australia, Germany and the United States, due to public opposition, environmental concerns, and the complexity of land-use agreements and approval processes.<sup>51</sup>

Despite these barriers, numerous major transmission projects were advanced in 2020, driven by demand for grid capacity from VRE generators.<sup>52</sup> (→ See *Figure 53*.) In the United States, around 225 kilometres of the planned 1,600 kilometre, USD 2.6 billion Gateway West line was completed, which will eventually connect wind farms in the state of Wyoming with electricity markets in other western states, via Idaho.<sup>53</sup> Other major transmission projects, including long-range high-voltage direct current (HVDC<sup>i</sup>) projects, were in planning across the country.<sup>54</sup> In India, seven new transmission projects were approved, which will allow the grid interconnection of new renewable energy parks in the country.<sup>55</sup>

South Africa’s public utility Eskom announced plans in 2020 to implement an SAR 118 billion (USD 8.4 billion) transmission expansion project to accommodate new generation targets, including 25 gigawatts (GW) of wind and solar by 2030.<sup>56</sup>

Digital technologies are increasing the usable capacity of existing transmission infrastructure, often a barrier to wider VRE deployment.

i Virtual power plants use digital technologies to co-ordinate and control energy demand, distributed generation and energy storage. See Glossary.

ii High-voltage direct current (HVDC) lines are used for high-efficiency, bulk transmission of power over large distances.

Several cross-border transmission projects were under construction or in planning during 2020. A new transmission line being built between the United Kingdom and France was one of several planned HVDC interconnections linking European electricity markets, with the objective of improving overall system flexibility and stability.<sup>57</sup> In Australia, an HVDC connection was proposed to connect solar generation in the country's Northern Territory with the city-state of Singapore.<sup>58</sup>

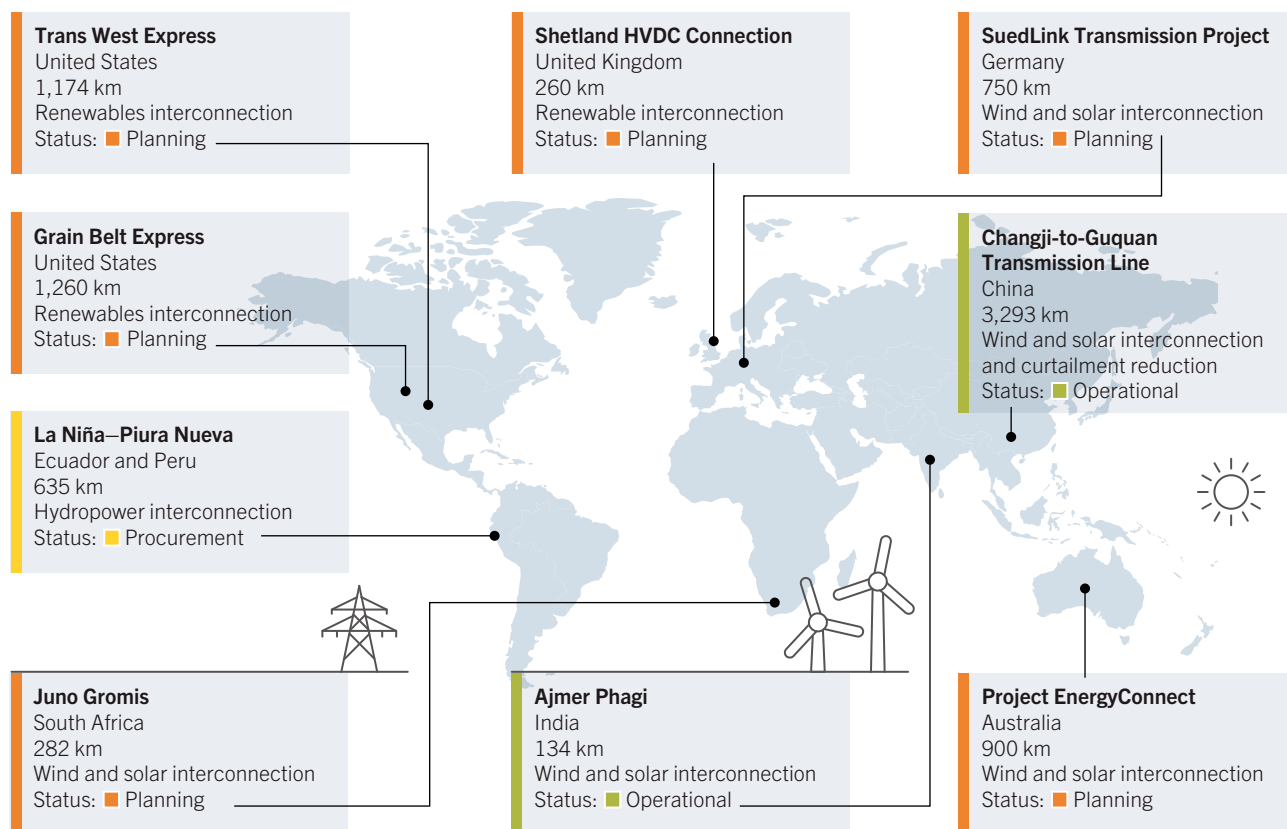
The digitalisation of power networks has helped to increase the efficiency and usable capacity of existing infrastructure. Digital technologies and methodologies – including power flow controls, dynamic line ratings and topology optimisation – can prioritise connections in the network that are below capacity in real time, reducing the need for infrastructure upgrades.<sup>59</sup> Several companies were developing technologies in these areas during 2020, including a number of start-ups.<sup>60</sup>

Many grid operators have expanded the digitalisation of grid control rooms, improved data management and communication technologies, built more robust security and enabled remote operations.<sup>61</sup> These efforts were accelerated in 2020 as lockdown measures related to COVID-19 forced many grid operations staff to work remotely.<sup>62</sup>

Changes also occurred at the level of the sub-station, where analogue communication and control systems were replaced with integrated digital solutions that enhance system visibility, operations and diagnostics; in India, for example, digital automation systems were retrofitted at more than 100 sub-stations over the past decade.<sup>63</sup> Improved data management capabilities at both the control room and sub-station levels of these network nodes supports the creation of “digital twins” – predictive grid simulations that promise to streamline maintenance.<sup>64</sup> Grid simulation systems, such as GE's Distribution Operations Training Simulator (DOTS), were used to train grid operations personnel and to run scenario analyses that cater to the growth of distributed energy resources.<sup>65</sup>

In some cases, digitalisation has prompted a shift of control away from centralised control rooms at the transmission level to smaller decentralised control points in the distribution system. WePower, a blockchain-based renewable energy financing and trading platform developed in Lithuania, was piloted in several markets, giving electricity distributors a more central role in the management of distributed energy resources and enabling the localised trade of electricity.<sup>66</sup>

**FIGURE 53.** Transmission Projects to Integrate Higher Shares of Renewables



Note: All projects are high-voltage direct current (HVDC).  
Source: See endnote 52 for this chapter.

## ADVANCES IN THE INTEGRATION OF RENEWABLES IN TRANSPORT AND HEATING

In contrast to the power sector, shares of renewables in global transport and heating systems remained low in 2020, accounting for less than 4% of total final energy consumption in transport and less than 11% in heating and cooling.<sup>67</sup> (→ See *Global Overview chapter*.)

Integrating renewables in both transport and heating systems requires planning and adaptation to enable or increase the blending or substitution of fossil energy with renewable alternatives such as direct solar thermal or geothermal heat, biofuels, biogas or renewable hydrogen. Alternatively, electrification of end-uses within these sectors can enable consumption of variable or other forms of renewable electricity. In many cases, these adaptations require wide-ranging changes to the infrastructure and technologies that both deliver and consume energy, such as the adaptation of gas pipelines to accommodate renewable hydrogen, the implementation of new safety standards, and the replacement or conversion of heating systems and vehicles.<sup>68</sup> Many of these efforts faced cost barriers in 2020 as oil prices plummeted on the back of reduced demand during COVID-19 lockdowns.<sup>69</sup>

Despite limited overall progress in transport, certain segments saw notable pre-commercial and commercial activities that supported the integration of renewables. Integration in road-based transport was advanced mainly through the electrification of vehicles (→ see *Electric Vehicles section in this chapter*). By contrast, efforts to use renewables in the aviation sector were focused mostly on the use of advanced biofuels, as well as the early-stage development of aircraft adapted to use renewable hydrogen. In September 2020, the world's largest aircraft manufacturer, Airbus (France), announced three concept designs for hydrogen aircraft, along with plans to bring the first emission-free passenger aircraft to market by 2035.<sup>70</sup> Smaller prototypes for electric and fuel cell passenger aeroplanes were tested in 2020 in both Canada and the United States.<sup>71</sup>

A range of renewable fuel types were either available or under development for shipping applications as of 2020. Of these, biodiesel, biofuel oil and bio-liquefied natural gas (LNG)<sup>i</sup> were commercially available.<sup>72</sup> (→ See *Bioenergy section in Market and Industry chapter*.) Others such as biomass-to-liquid and renewable hydrogen and ammonia remained pre-commercial.<sup>73</sup> In 2020, hydrogen ships were under development in Europe and Japan, while the world's first electric container ship, the *Yara Birkeland*, was launched in Norway.<sup>74</sup>

Efforts also were under way to integrate renewables into rail transport, which is already widely electrified and can directly access growing shares of VRE in a number of markets. Countries such as India and Scotland advanced plans in 2020 to decarbonise rail transport through wider electrification of diesel-based networks, and the parallel implementation of VRE capacity.<sup>75</sup> A train running on renewable hydrogen also was piloted in the United Kingdom during the year.<sup>76</sup>

Heat pumps are a mature and widely deployed technology and possess vast but largely untapped potential as an enabling technology for the use of renewable energy in the heating and cooling sectors. Along with other enabling technologies such as EVs and energy storage, heat pumps can contribute greatly to power system flexibility to support higher shares of VRE. (→ See *Heat Pumps section in this chapter*.)

The potential of heat pumps for integration of renewables was illustrated by the Dutch transmission system operator Tennet in early 2021, when it announced plans to use heat pumps with intelligent controls to create up to 1 GW of flexible demand while maximising the use of available wind and solar power.<sup>77</sup> The UK government announced plans to aggressively scale up the installation of heat pumps to decarbonise heating demand, as part of the prime minister's green industrial strategy.<sup>78</sup> Geothermal heat, solar thermal heat and various forms of bioenergy also were being used for heating and cooling. (→ See *Bioenergy, Geothermal and Solar Thermal sections in Market and Industry chapter*.)

Electrification efforts faced cost barriers in 2020 as

**oil prices plummeted**

on the back of reduced demand during COVID-19 lockdowns.



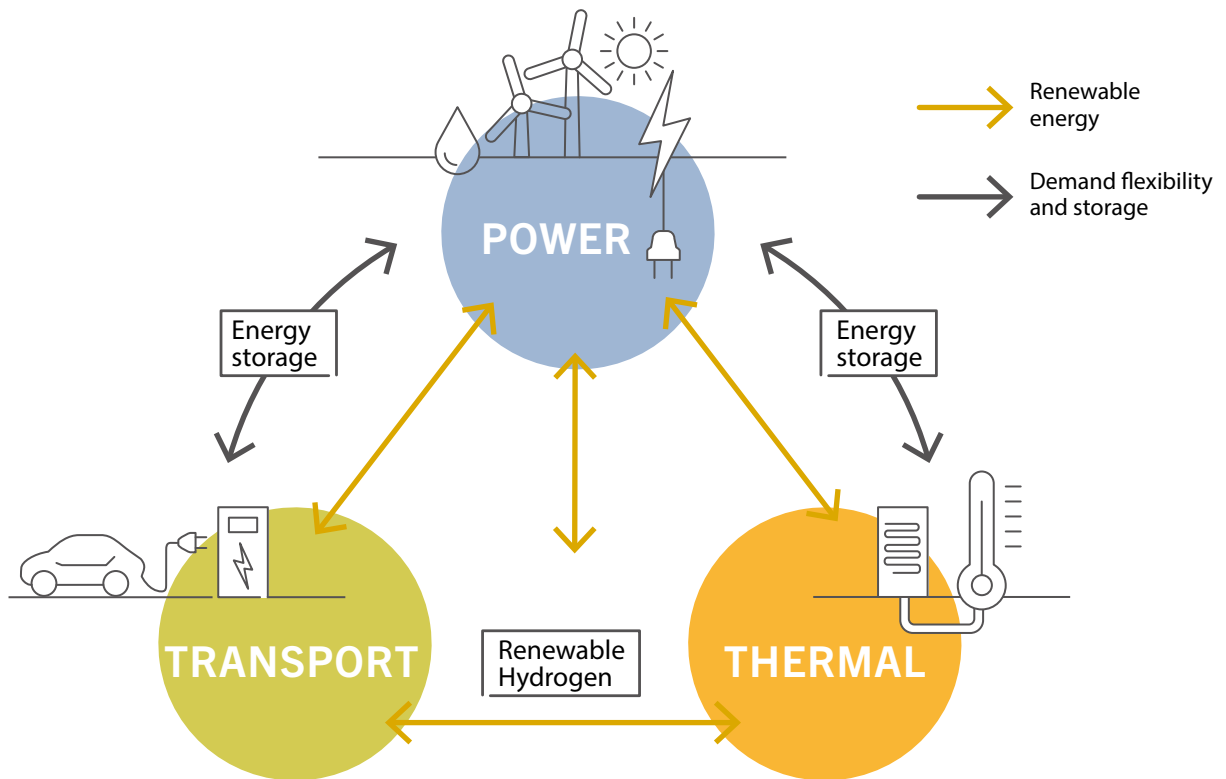
i Biofuel oil is a fuel oil produced through the pyrolysis of biomass or municipal solid waste. Bio-LNG is a renewable alternative to natural gas that is produced during the anaerobic digestion process of food or animal waste.

## ENABLING TECHNOLOGIES FOR SYSTEMS INTEGRATION

Heat pumps, electric vehicles and energy storage are important end-use technologies, supporting the integration of renewables and contributing to greater flexibility in power systems.<sup>79</sup> (→ See Figure 54.) All of these technologies experienced increased sales in 2020 despite the onset of the COVID-19 pandemic. While most of the technologies are well known, their level of uptake remains low relative to their potential. For example, heat pumps are widely present in new residential buildings in several countries, yet they still represent less than 5% of the global market for heating appliances.<sup>80</sup> EVs occupy only a small share of the vehicle market despite surging adoption in recent years. Meanwhile, the need for and interest in energy storage has increased with rising integration of VRE in power systems worldwide.



**FIGURE 54.**  
Coupling of the Power, Thermal and Transport Sectors



Source: See endnote 79 for this chapter.



## HEAT PUMPS



Heat pumps are commonly used to meet heating and cooling needs for residential, commercial and industrial applications – such as space heating and cooling, water heating, freezing and refrigeration – within a wide range of temperatures.<sup>81</sup> Heat pumps<sup>i</sup> typically are reversible units that can provide both heating and cooling functions by drawing on one of three main energy sources: the ground, ambient air and bodies of water.<sup>82</sup> During operation, these systems use an auxiliary source of energy (such as electricity or fossil gas) to transfer ambient energy from a low-temperature source to a higher-temperature sink in a refrigeration cycle.<sup>83</sup> Ambient heat sources include air, water, geothermal heat and different types of waste heat (such as from industrial processes and sewage treatment).<sup>84</sup>

Depending on the inherent efficiency of the heat pump itself, its external operating conditions and the system design, heat pumps that use varying ambient sources of energy differ in their installation costs and overall efficiency.<sup>85</sup> In general, heat pumps are highly efficient heating and cooling devices.

The most efficient systems, operating under optimal conditions, can deliver three to five units of thermal energy (either heating or cooling) for every one unit of external energy consumed.<sup>86</sup> The difference between the energy delivered and the energy consumed is considered the renewable portion of the heat pump output, regardless of the external energy source.<sup>87</sup> When the auxiliary energy used to drive the heat pump is renewable, so is 100% of the output of the heat pump.<sup>88</sup>

Electric heat pumps are among the most cost-effective solutions for decarbonising thermal energy, notably in buildings, and can be used in various environments, even in colder climates.<sup>89</sup> When used with appropriate control measures and thermal storage (e.g., thermal mass, hot water tanks, chilled water), they also can increase power system flexibility by using (surplus) solar and wind power, and coupling electricity generation with heating and cooling devices that have flexible demand characteristics. Adding large-scale heat pumps to district heating systems can increase flexibility through their inherent thermal storage capabilities.<sup>90</sup>

<sup>i</sup> In official statistics, heat pumps also can be recorded as “reversible air conditioners”, depending on the energy services they provide. Typically, if the appliance supplies energy only for cooling, it is considered an “air conditioner”, despite the fact that it is reversible. This chapter endeavours to report official statistics for heat pumps that are in use to provide energy for both heating and cooling.



When the energy used to drive a heat pump is renewable, so is  
**100% of its output.**



## HEAT PUMP MARKETS

Although heat pump technology is widely used in the residential and commercial sectors, limited availability of data related to this market remains a barrier to full assessment of global heat pump uptake.

Globally, air-source heat pumps accounted for the highest sales volumes of all heat pump technologies in recent years, followed by ground-source heat pumps.<sup>91</sup> Although heat pumps are the most common heating technology in new buildings in several countries, they met only 5% of global building heating demand in 2019.<sup>92</sup>

In the Asia-Pacific region, despite subsidies in Japan and northern China favouring heat pump adoption, uptake has slowed due to a decline in Chinese infrastructure investment and because natural gas boilers are favoured under China’s coal phase-out plan (as a less-expensive alternative to coal boilers in residential heating).<sup>93</sup> Additionally, because China does not classify heat pumps as a renewable technology at the national level, the devices cannot benefit from the clean heating subsidy offered in the country’s north.<sup>94</sup> Even so, more than 117 million<sup>i</sup> heat pumps were sold nationwide in 2020, virtually all (99%) of which were air-to-air heat pumps, with the rest being air-to-water devices.<sup>95</sup>

In Japan, air-source heat pumps dominated heat pump sales in 2020, although the total number sold fell 0.7% from the previous year (to 10.7 million in 2020, down from 10.8 million in 2019).<sup>96</sup> This drop was due to lower demand in the commercial sector (down 14.3%) and only minor growth in the residential sector (up 0.6%).<sup>97</sup> Japan also is a significant market for heat pumps for water heating, sales of which increased 30% since 2015 to more than 500,000 water heaters sold in 2020.<sup>98</sup>

The capability of heat pumps to provide both heating and cooling is a key factor behind their increased adoption in North America.<sup>99</sup> The US heat pump market continued to grow, with 3.4 million units sold in 2020, up nearly 10% from 2019.<sup>100</sup> The majority of demand comes from new buildings and the

replacement of oil and propane furnaces.<sup>101</sup> In Canada, more than 530,000 air-source heat pumps<sup>ii</sup> were sold in 2020, up 6% from 2019, thanks to an increase in residential installations (up 13%) that counterbalanced a decline in the commercial sector (down 21%).<sup>102</sup>

In Europe, despite facing shortages in the supply chain due to the COVID-19 crisis, 1.6 million heat pumps were installed in 2020, up 5% from the previous year.<sup>103</sup> France (394,000 units sold), Italy (233,000) and Germany (140,000) were the regional leaders, totalling 48% of all sales.<sup>104</sup> Spain, Sweden, Finland, Norway, Denmark, Poland and the Netherlands rounded out the top 10 countries.<sup>105</sup>

Germany experienced a 40% increase in heat pump installations, for a cumulative total of more than 1 million units by year’s end, entering the top three in Europe for the first time.<sup>106</sup> Uptake in the country was boosted by an aggressive new subsidy scheme that aims to accelerate heat pump deployment (subsidising 35% of the cost in new construction and renovations and up to 45% if the heat pump replaces an oil-fuelled boiler).<sup>107</sup> Similar support schemes exist in France – where the level of subsidy depends on household income – as well as in Italy.<sup>108</sup> The United Kingdom has proposed a target of 600,000 annual heat pump installations by 2028.<sup>109</sup>

In industrial processes, the growing application of heat pumps for temperatures below 100 degrees Celsius (°C) has demonstrated the reliability and efficiency of waste heat recovery for industrial processes, directly combining cooling and heating demands.<sup>110</sup> However, despite the technology’s availability and potential, heat pumps are still not widespread in the sector, even for new installed capacity where fossil fuel heating equipment remains the standard.<sup>111</sup> This is due, among others, to a lack of knowledge and awareness on the part of end-users and to a capital cost that remains high.<sup>112</sup>



Heat pump uptake slowed in Asia-Pacific in 2020, while **the market rose** 10% in the US, 6% in Canada, and 5% in Europe.

i Many of these units are used only for cooling, while heating demand is met via district heat or other sources.

ii Refers to residential and commercial units that are used for both heating and cooling. This number also includes ductless split units that are used for cooling only.

## HEAT PUMP INDUSTRY

The heat pump industry in 2020 was characterised by several trends, including company acquisitions, new solutions integrating heat pumps with other energy devices, and the development of components adapted to refrigerants with low global warming potentials, and those for ground-source heat pumps.

Several acquisitions of companies occurred throughout the year. NIBE (Sweden) completed six acquisitions, including of: water heater manufacturer TIKI Group (Serbia), the heat pump manufacturer Waterkotte GmbH (Germany), a 50% share in the Üntes group of companies (Turkey), a 51% share in Nathan Holding B.V. (Netherlands), a 60% share in VEÅ AB (Sweden) and an 87.5% share in the element company Termotech s.r.l. (Italy).<sup>113</sup> In addition, Legal & General Capital (UK) acquired a 36% stake in the ground-source heat pump firm Kensa (UK), with the aim of establishing a portfolio of companies decarbonising heat and transport.<sup>114</sup> Bosch Thermotechnology (Germany) acquired a controlling share in Electra Industries (Israel), a manufacturer of heat pumps based in Haifa.<sup>115</sup> After installing heat pumps in its own stores, the retailer IKEA (Sweden) decided to commercialise residential heat pumps in Switzerland as part of its “clean energy offer”.<sup>116</sup>

Both start-ups and well-established companies have begun offering or exploring energy solutions that integrate heat pumps with renewable or storage technologies. In 2020, the US Department of Energy explored existing European heat pump modular solutions that, by reducing the complexity of installation, could offer an effective solution to mass renovation of existing buildings in the United States and elsewhere.<sup>117</sup> LG Electronics (Republic of Korea) launched a hybrid system in early 2021 combining a heat pump, a solar PV system and battery storage to provide residential and small commercial buildings with heat and electricity.<sup>118</sup> The system also includes an energy management system, controlled by a software application, to maximise self-consumption.<sup>119</sup>



Factory Zero (Netherlands), Nilan (Denmark) and Drexel und Weiss (Germany) have proposed integrating a heat pump, hot water tank, ventilation system, solar PV system and monitoring equipment in a single “box”.<sup>120</sup> Such integrated systems, designed for use in nearly zero-energy buildings, have the potential to unlock the US retrofit market and to help the EU optimise the heating and cooling energy consumption of buildings through mass renovation.<sup>121</sup>

The heat pump market continues to be dominated by vapour compression technologies; however, opportunities exist for innovation to address overall efficiency of the system, operation in cold climates and digitalisation to improve integration with electricity grids.<sup>122</sup> Innovation in Europe was driven in part by the EU’s “F-gas” regulation, which gradually phases out the sale and manufacture of fluorinated gases – substances used mainly as refrigerants in air conditioning and other refrigeration systems with a high global warming potential – and encourages their replacement by alternatives with low global warming potential.<sup>123</sup> Heat pump manufacturers have focused on developing solutions to replace the refrigerants necessary for the exchange of heat within heat pump systems with HFO (hydrofluoro-olefin) and hydrocarbon refrigerants as well as carbon dioxide and ammonia – all of which have lower global warming potential.<sup>124</sup> Adapted components, such as compressors and heat exchangers, have been developed to accommodate the new refrigerants.<sup>125</sup>

Several notable ground-source heat pump pilot projects were approved, implemented or researched in 2020. The US state of Massachusetts approved two pilots for neighbourhood-wide deployment of the ground-source heat pump innovation concept GeoMicroDistrict, which uses the existing natural gas infrastructure to transfer thermal energy between a shared district water loop and a building’s heating and cooling distribution systems.<sup>126</sup> In the United Kingdom, a housing provider started installing a demonstration project in 300 homes to show how ground-source heat pumps with digitalised heating controls can reduce heating costs for residents and help balance the electricity grid.<sup>127</sup> A study in Mongolia, where temperatures can drop to minus 40°C, revealed that ground-source heat pumps were the most cost-effective and low-carbon solutions for heating.<sup>128</sup> Meanwhile, the US ground-source heat pump company Dandelion Energy raised USD 30 million to scale up its technology and develop its product further.<sup>129</sup>

For processes requiring temperatures above 100°C, current research, development and demonstration is focusing on the 100-200°C range.<sup>130</sup> The low priority of industrial heat pumps in the EU research programme Horizon 2020 limited the number of European projects.<sup>131</sup> However, some national projects focusing on the 100-200°C range exist in Scandinavia and the Netherlands and have shown that heat pumps can achieve significant energy savings and emission reductions.<sup>132</sup>

In recent years, innovation in digital technologies to integrate heat pumps and electric grids has begun allowing them to benefit from operational cost reductions using demand-side flexibility as well as enabling new business models.<sup>133</sup>



## ELECTRIC VEHICLES



Electric vehicles<sup>i</sup> are an important end-use for renewable energy, as they allow the displacement of fossil fuels in key transport modes, mainly in road and rail transport. On the demand side, EVs achieve a double benefit: not only are they more energy efficient than vehicles with internal combustion engines, but the required electricity can be supplied more readily from a wide variety of renewables. Allowing and interrupting the battery charging to coincide with renewable power generation could help integrate larger shares of VRE.<sup>134</sup> On the supply side, technology such as vehicle-to-grid can turn EVs into energy storage devices, allowing batteries to store energy from the electricity grid during off-peak periods and then to discharge it back to the network when it is most needed, increasing the overall flexibility of the grid.<sup>135</sup>

In 2020, key developments continued to focus on electric cars (passenger EVs), whereas electrification efforts for marine vehicles and aviation remained limited.<sup>136</sup> The rise in the number of EVs can be explained by the favourable support policy context (e.g., fiscal incentives, tightening of emission standards, support for charging infrastructure) and by the benefits such vehicles offer.<sup>137</sup> Consumers in Europe and the United States remained attracted, by order of importance, to the environmental benefit, the economic savings, the ease of driving and the novelty value of owning new technology.<sup>138</sup>

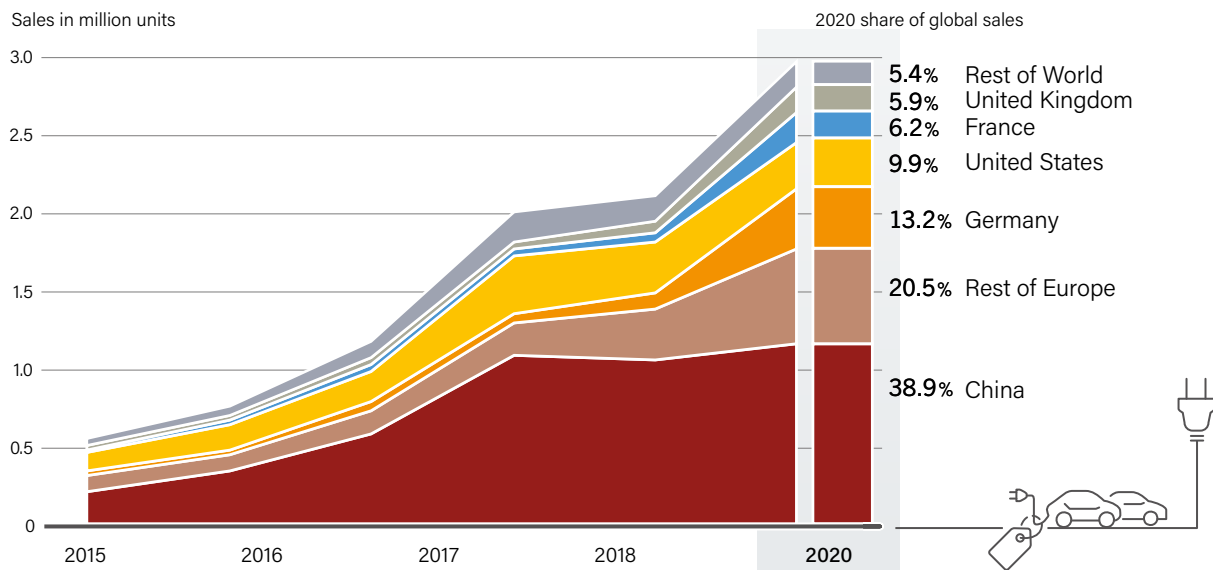
## ELECTRIC VEHICLE MARKETS

While global car sales decreased in 2020 – falling 14% from the previous year, according to preliminary market data – global sales of electric cars (including both battery electric vehicles and plug-in hybrids<sup>ii</sup>) resisted the COVID-19-induced downturn with 2.9 million units sold, up 41% from 2019.<sup>139</sup> Among other factors, this is attributed to favourable existing policies, lower battery costs and the fact that EV buyers are mainly from high-income households, which tended to be less affected by the crisis.<sup>140</sup> As a result, the market share of electric cars in new car sales reached 4.6% in 2020, surpassing the 2019 record of 2.7%, and the global stock of electric cars grew to exceed 10 million units.<sup>141</sup> (→ See Figure 55.)

Europe<sup>iii</sup> was the only market that did not experience lower **electric car** sales during the first half of 2020 – showing a 55% increase – whereas global EV sales were on average 15% lower due to lockdown measures that affected both the supply and demand.<sup>142</sup> For the full year, electric car sales in Europe were up 142% compared to 2019 (reaching almost 1.4 million units), surpassing China for the first time since 2015 (with 1.16 million units sold, only a 9% increase).<sup>143</sup> The United States occupied the third position with 296,000 units sold despite a 10% decrease compared to 2019.<sup>144</sup> Japan and Australia were the only major markets where the EV market declined more than overall car sales in 2020.<sup>145</sup> Norway remained the leading country in EV market share (75% in 2020), followed by Iceland (52%) and Sweden (32%).<sup>146</sup>

- 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 EVs. See Glossary.
- ii Fuel cell electric vehicles represent a small share of the total EV market, accounting for less than 0.5% of total sales in 2020.
- iii Including EU Member States and members of the European Free Trade Association (Iceland, Liechtenstein, Norway and Switzerland).

**FIGURE 55.** Electric Car Global Sales, Top Countries and Rest of World, 2015-2020



Note: Includes battery electric passenger vehicles and plug-in hybrid passenger electric vehicles.  
Source: IEA. See endnote 141 for this chapter.



The number of public charging stations totalled **1.3 million** in 2020, with most of the infrastructure built in China and Europe.

As of the end of 2020, around 290 million electric **two- and three-wheelers** were on the road globally.<sup>147</sup> Around one-third of all units sold during the year were electric, and 99% of new registrations were in China, with most of the rest also in Asia.<sup>148</sup> The Indian market fell 5.5%

in 2020, with more than 25,000 electric two-wheelers sold.<sup>149</sup> While still being a minor market, the European market grew rapidly (up 30%).<sup>150</sup> Electric micro-mobility (particularly e-bikes) increased greatly in the second half of 2020, benefiting from the implementation of new bike lanes and other mobility measures; in the United States, e-bike sales more than doubled for the year.<sup>151</sup>

China remained the main **electric bus** market in 2020 (up 9% in 2020) and accounted for 99% of global sales from 2016 to 2020; however, adoption of the buses increased worldwide, especially in Europe (up 7%).<sup>152</sup> Electric buses were the second largest category of EV spending (based on preliminary sales data and estimated vehicle prices) after private vehicles.<sup>153</sup> Still, annual spending in this sector continued its downward trend, totalling USD 11 billion in 2020 (down 48% since 2016).<sup>154</sup> This was due mainly to changing market dynamics in China, specifically a reduction in e-bus prices, combined with a decrease in purchase subsidies and market saturation in large cities, which slowed annual sales.<sup>155</sup>

Around 4,000 electric buses (including battery electric, plug-in hybrid, trolley buses<sup>i</sup> and fuel cell buses) were circulating in Europe, representing 1% of the total fleet.<sup>156</sup> Around 2,100 new electric buses were registered in 2020, up 22% from 2019.<sup>157</sup> Denmark led in the market share of new e-buses (78%), followed by Luxembourg (67%) and the Netherlands (65%).<sup>158</sup> In Latin America, 2,000 buses – less than 1% of the region's fleet – were electric in 2020, despite steady interest and the fact that Santiago, Chile has the largest number of electric buses of any city outside of China (400 added in 2020 for a total stock of more than 800).<sup>159</sup> Bogotá (Colombia) added 470 electric buses in 2020 and placed an order for 596 more.<sup>160</sup>

In North America, only 580 new electric buses were registered in 2020, down nearly 15% from 2019.<sup>161</sup> California leads in US deployment due to the state's commitment to buy only electric buses (battery electric or fuel cell) from 2019 onwards.<sup>162</sup> India increased electric bus registrations 34% to 600 in 2020.<sup>163</sup>

Alongside the increased adoption of EVs, **charging infrastructure** is expanding as well. Investment in EV charging infrastructure has surged since 2016 and constituted a small portion of the spending on new cars in 2020 (USD 4.1 billion in public charging and USD 2.1 billion in home charging).<sup>164</sup> The number of public charging stations installed globally totalled 1.3 million in 2020, up 45% from the previous year, with most of the infrastructure built in China and Europe.<sup>165</sup>

In China, an estimated 10,000 new public and private charging stations were installed monthly in 2020, due mainly to the government response to the COVID-19 crisis, which included high investments in charger installation to stimulate the economy.<sup>166</sup> China had a total of around 810,000 chargers as of 2020, followed by Europe with 288,000 chargers.<sup>167</sup> The United States had only around 100,000 total charging stations due to a lack of public support and incentives.<sup>168</sup> Canada allocated funds in its COVID-19 recovery plan towards deploying charging stations to accelerate EV use.<sup>169</sup>

Globally, all urban and high-speed **rail** networks are electric, and in 2019 around 75% of conventional (not high-speed) passenger rail activity used electricity.<sup>170</sup> The electrification of conventional rail continued in 2020: India announced its commitment to a 100% electrified railway network by 2023, and Russian Railways announced new electrification of freight routes in the country, despite the fact that 86% of cargo volumes in the Russian Federation are already served by electric trains.<sup>171</sup> The United Kingdom also continued the electrification of its railways, with 251 kilometres electrified between 2019 and 2020.<sup>172</sup>



## ELECTRIC VEHICLE INDUSTRY

In 2020, the leading manufacturers of passenger EVs globally were (by number of units produced) Tesla (US), Volkswagen (Germany), General Motors (US), R-N-M Alliance (France/Japan), Hyundai (Republic of Korea), BYD (China), BMW (Germany), Daimler AG (Germany), PSA (France) and Volvo (Sweden).<sup>173</sup> Tesla became the first automaker globally to produce 1 million electric cars, and its Model 3 became the all-time best selling EV, replacing the Nissan LEAF.<sup>174</sup>

In the European market, Renault (France) has a significant presence, with its Zoe model replacing Tesla's Model 3 as the best-selling battery electric car in Europe in 2020.<sup>175</sup> In China, three start-ups experienced a surge in sales in 2020: Nio (one of the best-performing US-listed Chinese companies in 2020) and Xpeng doubled their sales compared to 2019, while LiAuto saw a 150% increase.<sup>176</sup>

In 2020, traditional automakers continued announcing plans to shift production to EVs. Volvo started manufacturing its first fully electric car late in the year and said that half of the company's global sales would be fully electric by 2025.<sup>177</sup> General Motors announced plans for 40% of its models to be electric by 2025 and for all of its new light-duty vehicles to be zero-emission by 2035, while Jaguar (UK) committed to being a fully electric car manufacturer by 2025.<sup>178</sup>

i Instead of using an onboard battery, trolley buses draw power from overhead wires.

Both GM and Jaguar plan to include sport-utility vehicle (SUV) models in their electric transition (with the Hummer and Jaguar, respectively). Overall, nearly all major auto manufacturers – including Audi, Ford, Honda, Hyundai and Volkswagen – already have (or have announced) new electric SUVs in the coming years.<sup>179</sup> By 2020, 44% of EV models available worldwide were SUVs.<sup>180</sup> The increased offering of electric SUVs (100 models globally in 2019) compared to fossil-fuelled SUVs (180 models in 2019) is not yet reflected in sales, as the vast majority of SUVs sold (97%) are still fossil-fuelled.<sup>181</sup>

In total, 160 new EV models (battery electric and plug-in hybrid) were launched in 2020, mainly in China (77 models, 61 of them fully electric) and Europe (65 models, 30 of them fully electric).<sup>182</sup> Manufacturers in North America came in a distant third, launching only 15 new models.<sup>183</sup>

In 2020, seven truck manufacturers, including Daimler (Germany), Ford (US), Scania and Volvo (both Sweden), signed a pledge to stop selling diesel-fuelled trucks by 2040, a decade earlier than previously planned – focusing instead on the development of hydrogen battery and clean fuel technologies.<sup>184</sup> Meanwhile, Daimler's Mercedes-Benz abandoned its hydrogen car programme due to high costs and a lack of market interest.<sup>185</sup>

Several joint ventures were established in 2020, including Marathon Motor Engineering, a company created between Hyundai and Olympic champion Haile Gebrselassie, which began assembling the all-electric Hyundai Ioniq in Ethiopia.<sup>186</sup> Other joint ventures focused on the production of specific equipment for EVs. They included, among others: LG Electronics' association with the supplier Magna International to manufacture e-motors, inverters and onboard chargers; the launch of Automotive Cells Company, a battery manufacture created by Total and PSA (both France); and Volkswagen's acquisition of a more than 25% stake in Guoxuan High-tech Co Ltd, a Chinese battery manufacturer, in order to boost the German automaker's market penetration in China.<sup>187</sup> In Japan, seven companies established the e5 Consortium, aiming to develop zero-emission electric ships.<sup>188</sup>



Innovation in the EV battery industry, and in particular in lithium-ion batteries, was the main driver of technological progress in the electricity storage area.<sup>189</sup> Significant cost reductions were achieved due to an increase in manufacturing production, growth in battery EV sales and the introduction of new pack designs.<sup>190</sup> (→ See *Energy Storage Industry* section in this chapter.) With the sharp drop in battery costs (down 89% between 2010 and 2020) and depending on the automaker and location, EVs are nearing the cost (with the same margin for automakers) of comparable petrol-powered vehicles (cost parity is projected to occur by 2023).<sup>191</sup> Tesla announced its ambition to produce EV batteries using cobalt-free cathodes, since reducing the use of this costly material would make EVs more affordable.<sup>192</sup>

New charging technologies, crucial for mass adoption of EVs, also experienced significant developments. Wireless charging has been piloted in various cities – including in UK cities to charge taxis and in US cities to charge electric buses – and China announced a national standard for the technology.<sup>193</sup> Other charging innovations include pop-up pavement chargers<sup>i</sup> (an innovation of the start-up Urban Electric Networks, which concluded a successful trial period in 2020 and planned to start commercial production in 2021); electrified roads (transmitting energy directly to EVs); and lamp-post charging (such as London's "electric avenue", where 24 lamp-posts were converted by Siemens of Germany into charging units).<sup>194</sup>

In the United States, more than 35 utility-run managed charging demonstration projects were developed in 2019, in order to balance grid loads by changing customer behaviour or controlling charging time, scale and location.<sup>195</sup> Innovation also occurred in battery charging speeds, helping to reduce a key barrier for EV adoption; StoreDot (Israel) developed EV batteries that can be fully charged in just five minutes, using organic compounds combined with nano-materials.<sup>196</sup>

In 2020, around 80 vehicle-to-grid projects (mostly pilots) were in place mainly in Europe (51) and the United States (20), involving more than 6,700 EV chargers.<sup>197</sup> Only six projects were initiated during the year, involving 195 chargers, down from 9 projects started in 2019.<sup>198</sup>

Pilot projects for hydrogen-fuelled trains are under way in the United Kingdom and Scotland as a means to decarbonise the regional railway network.<sup>199</sup> Using hydrogen could be a less expensive option than electrifying the UK's rail system because existing diesel trains can be retrofitted to be hydrogen powered.<sup>200</sup> For shipping, Japan created an academic and corporate consortium to research integrating renewable hydrogen production systems in cargo ships to power them during low-wind periods.<sup>201</sup>

Electric aviation remains pre-commercial, with Rolls-Royce (UK) developing the fastest all-electric aircraft and Airbus (France) developing electric and hybrid-electric propulsion for commercial aircraft and partnering with Air Race E, the world's first all-electric aeroplane race.<sup>202</sup> Start-up Wisk continued to progress towards passenger trials of its autonomous air taxi service in New Zealand.<sup>203</sup>

i Pop-up pavement chargers are on-street devices that retract into the ground when not in use. EV owners can charge their cars using a standard cable and a mobile app to locate chargers around the city. See Urban Electric, <https://www.urbanelectric.london>.

## ENERGY STORAGE



Energy storage has been in use for decades. Batteries were invented in the 1800s, and the first pumped storage projects were implemented in the early 1900s.<sup>204</sup> More recently, storage has been increasing alongside the use of portable electronics, electrification of the transport sector and the growth of VRE (mainly wind and solar power), among others. The recent increase in VRE production requires more flexibility in the power grid, which can be supplied by energy storage by balancing demand and production.<sup>205</sup> By reducing curtailment and improving flexibility, storage technologies have the potential to increase the share of VRE in power systems. In buildings and industry, thermal energy facilitates temporal shifts in renewable electricity or thermal energy supply to meet heating and cooling demands, and can allow (surplus) renewable electricity to serve thermal loads.<sup>206</sup>

Forms of energy storage (and key technologies) include mechanical (pumped storage, flywheels), electrochemical (batteries, including lithium-ion and lead-acid), chemical (hydrogen) and thermal energy storage (molten salt storage and hot water tanks). Depending on the type of technology, storage duration can greatly vary: from less than 10 hours (e.g., some batteries) to seasonal storage (e.g., pumped storage). Battery energy storage systems were among the technologies with the most activity in 2020, as they are easy to deploy and benefit from cost reduction trends. Renewable hydrogen also experienced lower costs and a more favourable policy context.

## ENERGY STORAGE MARKETS

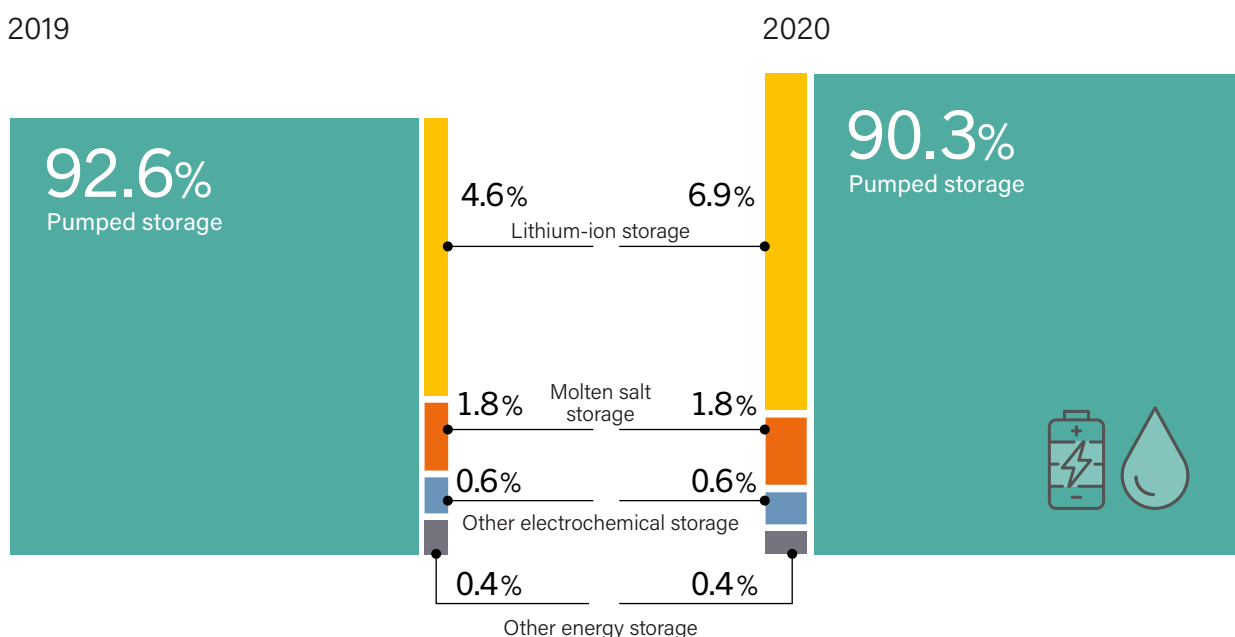
The COVID-19 crisis delayed the implementation of energy storage projects in 2020, as supply chains were disrupted and travel restrictions limited the ability to visit sites.<sup>207</sup> However, new electrochemical energy storage projects put into operation reached 4.73 GW in 2020, up 62% compared to 2019, when only 2.9 GW of capacity was added to electricity systems worldwide (nearly 30% less than in 2018).<sup>208</sup> The energy storage market also benefited from new opportunities in COVID stimulus packages that aim for a sustainable recovery and carbon-neutrality goals.<sup>209</sup>

Overall, the **global operational energy storage** capacity reached 191.1 GW in 2020, reflecting 3.4% growth year-on-year.<sup>210</sup> (→ See Figure 56.) The largest market was China (18.6% of the global total), which reached 35.6 GW by year's end, up 4.9% from 2019.<sup>211</sup> The United States added 1.5 GW due to a record fourth quarter in the deployment of front-of-the-meter storage, to reach an estimated 23.2 GW by year's end.<sup>212</sup> The European market grew 54%, adding 1.7 gigawatt-hours<sup>ii</sup> (GWh) of storage capacity for a cumulative capacity 5.4 GWh.<sup>213</sup> In addition, 4 GW was either announced or under construction across the region.<sup>214</sup>

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 Due to data limitations, Europe's storage capacity is reported in GWh.

**FIGURE 56.** Share of Global Energy Storage Installed Capacity, by Technology, 2019 and 2020



Source: See endnote 210 for this chapter.



**Pumped storage** continued to represent the majority of the installed capacity, with 90.3%, up 0.9% from 2019.<sup>215</sup> In China, pumped hydro capacity increased 4.9% for a total of 31.8 GW.<sup>216</sup> (→ See *Hydropower section in Market and Industry chapter*.)

**Batteries** continued their upward trend and constituted the second largest energy storage technology by capacity. In 2020, global battery storage capacity increased 1.7% to 14.2 GW (or 7.5% of total operating storage capacity).<sup>217</sup> Most of this battery capacity (92%) was lithium-ion batteries, with the rest being mainly sodium-sulphur (NAS) batteries (3.6%) and lead-acid batteries (3.4%).<sup>218</sup>

China surpassed 3 GW of battery capacity in 2020, up 91.2% from 2019, thanks notably to the addition of 1,083 MW of newly operational electrochemical storage, including the 200 MW / 200 MWh SPIC Huanghe New Energy Base project in Qinghai province.<sup>219</sup> The United States also experienced additions of large-scale batteries, surpassing the 1 GW mark in 2020 to reach 1.76 GW of overall capacity, up 72% from the previous year.<sup>220</sup> New installations totalled 734 MW and were located mainly in California, including the world's biggest batteries at the time of publication: Vistra Moss Landing (300 MW / 1,200 MWh) and the Getaway project (250 MW / 250 MWh).<sup>221</sup> Mega-battery projects also were added in nine other US states, mainly in Massachusetts and Texas.<sup>222</sup>

The residential behind-the meter battery sector grew strongly in the United States, with 90.1 MW deployed just in the fourth quarter of 2020, due mainly to rising interest among homeowners in California.<sup>223</sup> Germany also experienced a high increase in residential energy storage – from 185,000 installed units in 2019 to 285,000 in 2020 – for a combined 1.21 MW of capacity by year's end.<sup>224</sup> This was driven by the growing number of homeowners purchasing solar PV systems (which doubled compared to 2019), combined with the fact that half

of them also invested in batteries.<sup>225</sup> In Australia, small-scale battery storage increased from around 1,500 units in 2016 to more than 9,000 in 2020.<sup>226</sup>

Thanks to a decline in battery prices and an increase in wind and solar generation, interest in renewables-plus-storage projects – which combine wind and/or solar power capacity with on-site batteries, creating a hybrid power plant – grew in recent years to become a significant driver of battery storage implementation.<sup>227</sup> In the United States, the number of hybrid sites doubled between 2016 and 2019, with solar PV-plus-storage more common than wind-plus-storage.<sup>228</sup> In 2020, China announced several hybrid projects of more than 1 GW of capacity, many of which opted for wind energy as the basis of generation, combined with solar or thermal energy.<sup>229</sup> In Japan, a 6 MW utility-scale solar-plus-storage project became commercially operational at year's end.<sup>230</sup>

**Thermal energy storage (TES)**, mainly in the form of molten salts, represented 1.5% of the global operational energy storage capacity in 2020 (around 2.9 GW).<sup>231</sup> Due to its advanced technological readiness, molten salt storage is commonly deployed in concentrating solar thermal power (CSP) plants.<sup>232</sup> As of the end of 2020, the top five countries in installed molten salt storage capacity in CSP plants were Spain, the United States, South Africa, China and Morocco.<sup>233</sup>

Thermal energy also is commonly stored as water in tanks, large pits, boreholes, underground, or in a phase change material, which can be frozen and melted, thus storing and releasing heat.<sup>234</sup> The largest application of TES is in district heating and cooling networks, including those that generate heat from solar energy.<sup>235</sup> In these systems, TES can decouple the demand for district heating and cooling with available electricity generation, enabling seasonal storage of variable renewable energy sources.<sup>236</sup> In early 2021, five large-scale thermal storage pits<sup>i</sup> were in operation in Denmark connected to the local district



<sup>i</sup> In pit storages, water is stored in a pit with an insulated cover on top. See State of Green, "Large-scale thermal storage pit", <https://stateofgreen.com/en/partners/ramboll/solutions/large-scale-thermal-pit-storage>.



heating network.<sup>237</sup> District energy systems with thermal energy storage are present in Denmark, France, Germany, and Sweden, countries that make up more than 60% of total thermal storage capacity for district heating.<sup>238</sup> Use of TES in district heating also is rising in China, supported by the country's 13th Renewable Energy Development Five-Year Plan.<sup>239</sup>

**Renewable hydrogen** is an energy storage solution that can be produced by using renewable electricity to power an electrolyser that splits the hydrogen from water molecules.<sup>240</sup> Hydrogen also is produced directly from fossil fuels by using steam methane reforming or coal gasification.<sup>241</sup> More than 99% of global hydrogen production is currently based on fossil fuels (mainly natural gas).<sup>242</sup>

Interest in renewable hydrogen gained momentum in 2020, due in part to low electricity prices for VRE and to reductions in the cost of electrolysis equipment (leading to declines in production costs); in addition, several countries announced national hydrogen strategies and hydrogen energy frameworks (including Chile, Norway, the Russian Federation and some European countries).<sup>243</sup> At the time of publication, 8 countries and the EU had national strategies in place to support renewable hydrogen development, and several had hydrogen roadmaps or draft renewable hydrogen strategies in the pipeline.<sup>244</sup> China and India also have shown interest in ramping up their renewable hydrogen economies.<sup>245</sup> (→ See Table 5 in Policy Landscape chapter.)

By the end of 2020, the global operating capacity for hydrogen electrolysers was an estimated 82 MW (including all types of hydrogen) – or less than 0.05% of the global energy storage capacity.<sup>246</sup> The largest renewable hydrogen production site as of April 2021 was located in Quebec, Canada, offering 20 MW capacity of hydrogen produced with hydropower, doubling within a year the previous record set by Japan's 10 MW solar-powered hydrogen production facility.<sup>247</sup> As of the end 2020, additional renewable hydrogen projects of more than 130 GW were either

announced, planned or under construction (most of them gigawatt-sized projects).<sup>248</sup>

Europe and Australia dominate the renewable hydrogen pipeline, with 11 proposed projects of 1 GW electrolyser capacity or more.<sup>249</sup> The largest is being developed by a consortium of European companies that plans to use 95 GW of solar capacity to power 67 GW of electrolysers across multiple locations in Europe by 2030.<sup>250</sup> The next largest project is the Asian Renewable Energy Hub in Pilbara, Australia, where 16 GW of onshore wind and 10 GW of solar capacity will be used to supply 14 GW of electrolyser capacity.<sup>251</sup> These are followed by projects in the Netherlands and Germany (10 GW capacity, combined with offshore wind power capacity), China (5 GW), Saudi Arabia (4 GW), Chile (1.6 GW), Denmark (1.3 GW) and Portugal (1 GW).<sup>252</sup> At a smaller scale, the European Marine Energy Centre announced in 2020 its plan to combine tidal power and battery technology to generate renewable hydrogen at a pilot project in Scotland.<sup>253</sup>

**Other developments** related to energy storage markets included the release in California of the first major procurement targeting long-duration storage projects (more than eight hours storage).<sup>254</sup> Companies answering this tender covered a range of technologies, including pumped storage, gravity-based, compressed air, and flow batteries, as well as the current market leader lithium-ion batteries.<sup>255</sup>

A total of 130 GW of  
**renewable  
hydrogen**  
projects were either  
announced, planned  
or under construction  
in 2020.



## ENERGY STORAGE INDUSTRY

During 2020, the energy storage industry saw significant cost reductions and innovation in battery technologies, and an increased number of collaborations to produce renewable hydrogen.

Innovation has been particularly dynamic in the electricity storage sector, where inventions (estimated based on the number of international patent families<sup>i</sup>) increased 14% annually on average between 2005 and 2018, four times faster than for all technology fields.<sup>256</sup> This was driven mainly by **battery** innovation, particularly lithium-ion batteries used in consumer electronic devices and EVs.<sup>257</sup> (→ See *Electric Vehicles* section in this chapter.) Lithium-ion battery costs have fallen sharply, with prices dipping below USD 100 per kWh for the first time in 2020, and a market average of USD 137 per kWh.<sup>258</sup>

Battery R&D during the year included research on a long-duration solar flow battery that would benefit from a 20% efficiency record, and solid-state batteries that could be safer and contain more energy than traditional lithium-ion batteries (for example the lithium-metal battery of the start-up QuantumScap).<sup>259</sup> A power plant in the US state of Minnesota announced a pilot deployment of the “aqueous air” battery system, developed by the long-duration battery start-up Form Energy, which can discharge power capacity for up to 150 hours.<sup>260</sup> Among other investments, the state of California allocated USD 16.8 million for energy storage technologies beyond lithium-ion (employing mainly zinc), and Form Energy raised USD 70 million prior to its first

commercial deployments.<sup>261</sup> Eos, the developer of an aqueous zinc battery, entered the stock exchange market in 2020.<sup>262</sup>

Environmental and social concerns related to the increased mining of lithium for battery production prompted development in new extraction technologies from geothermal waters, with the aim of producing “green lithium” with a reduced environmental footprint.<sup>263</sup>

Because battery technologies are driven mainly by the EV industry, most cannot provide the type of long-duration storage suitable to countries that have harsh climatic conditions and low capacity for operation and maintenance.<sup>264</sup> Moreover, the high cost of battery technology has prohibited batteries from being widely deployed in large-scale projects in developing countries, even though these areas may have the greatest deployment potential.<sup>265</sup> To remedy this, the World Bank convened a global partnership in 2019 fostering R&D, policies, and regulations, and in 2020 the Bank highlighted the importance of warranties for battery storage systems to mitigate the technical and operational risks of projects for buyers and investors.<sup>266</sup>

In the area of renewables-plus-storage, two collaborations emerged in the United Kingdom. The first is a joint venture between Macquarie’s Green Investment Group and renewable energy developer Enso Energy to develop 1 GW of unsubsidised solar-plus-storage capacity.<sup>267</sup> In addition, the French electricity provider EDF partnered with the UK renewable energy developer Octo Energy to build 200 MW of solar-plus-storage capacity in England and Wales.<sup>268</sup>



<sup>i</sup> Each international patent family (IPF) represents “a unique invention and includes patent applications filed and published in at least two countries. IPFs are a reliable and neutral proxy for inventive activity because they provide a degree of control for patent quality and value by only representing inventions deemed important enough by the inventor to seek protection internationally”. See International Energy Agency, *Innovation in Batteries and Electricity Storage* (Paris: 2020), <https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage>.

**Thermal energy storage** technologies outside of molten salt storage include the commercially viable thermal tanks (using water) and solid-state (using rocks, concrete and ceramic bricks) and liquid air variants – which made significant strides towards commercial viability in the near term.<sup>269</sup> A UK-based company started developing large-scale plants whose mechanism stores energy by supercooling air in pressurised above-ground tanks.<sup>270</sup> Solid-state thermal storage using concrete is being developed in China as part of a deployment of CSP demonstration projects, and a US research programme progressed in 2020 with the design of a pilot-scale facility, with testing expected in late 2021.<sup>271</sup>

Malta Inc. (US), a company developing pumped heat energy storage – a long-duration energy storage technology converting electricity to be stored as thermal energy – raised USD 50 million in funding in 2020.<sup>272</sup>

**Renewable hydrogen** was a key focus of international collaboration in 2020, with some of the world's largest energy companies including Enel (Italy), ENGIE (France), Equinor (Norway), Ørsted (Denmark), Shell (Netherlands), BP (UK) and Siemens (Germany) proposing projects, investments and partnerships in low-carbon hydrogen.<sup>273</sup> The United Nations' Green Hydrogen Catapult aims to scale up hydrogen production by 2026 and was initiated by, among others, IPP ACWA Power (Saudi Arabia), wind turbine manufacturer OEM Envision (China), offshore wind developer Ørsted (Denmark) and gas grid firm Snam (Italy).<sup>274</sup>

Several countries agreed to join efforts on hydrogen development, such as the United States and the Netherlands, which are collaborating on collecting, analysing and sharing information on hydrogen production and infrastructure technologies; Germany and Niger, which established a hydrogen exploration partnership that will expand to West Africa; and the Netherlands and Portugal, which signed an agreement to facilitate the transport of renewable hydrogen between the two countries.<sup>275</sup> Additionally, the 21 countries participating in the Clean Energy Ministerial Hydrogen Initiative (CEM H2I) will collaborate on policies,

programmes and projects across all sectors of the economy to accelerate the commercial implementation of hydrogen and fuel cell technologies.<sup>276</sup>

With this rising interest, the cost of producing hydrogen from electricity has declined, falling 40% on average between 2015 and 2020.<sup>277</sup> However, the cost of producing renewable hydrogen in 2020 remained around twice as expensive as producing hydrogen using carbon capture.<sup>278</sup>

Boosted by cost declines and by national plans promoting investment in hydrogen production (as in France, Germany and Portugal), Europe has been centre stage for numerous new consortia.<sup>279</sup> In Portugal, the electric utility EDP, grid manager REN, and industrial group Martifer, together with Danish wind turbine manufacturer Vestas and other European partners, announced their intention to evaluate the viability of the H2Sines renewable hydrogen project.<sup>280</sup> In the Netherlands, NorthH2, a consortium comprising Shell, the gas grid operator Gasunie and the Port of Groningen, planned to develop a "Hydrogen Valley" linking offshore wind generation to renewable hydrogen production.<sup>281</sup>

Major electricity groups – including EDP, Enel, Iberdrola (Spain) and Ørsted – also created the joint initiative Choose Renewable Hydrogen to highlight hydrogen's role and to ensure its integration into EU COVID-19 recovery plans.<sup>282</sup> In early 2021, Sinopec, the Chinese oil giant and the world's largest producer of hydrogen, announced plans to move away from fossil-based hydrogen production and towards renewable hydrogen; it also entered a partnership with the world's largest solar PV manufacturer, Longi Green Energy Technology.<sup>283</sup>

In the United States, the hydrogen-specialised company Plug Power raised USD 1 billion to build a gigafactory that would produce both fuel cells and electrolyzers.<sup>284</sup> Additionally, major energy player Xcel Energy targeted wind and solar investment in the state of Minnesota to plan a renewable hydrogen production pilot as well as energy storage and EV charging.<sup>285</sup>



The cost of producing renewable hydrogen in 2020 remained around **twice as expensive** as producing hydrogen using carbon capture.





**In 2020, United Airlines pledged to reduce its greenhouse gas emissions by 100% by 2050, including the usage of sustainable aviation fuel.**





# 07 ENERGY EFFICIENCY, RENEWABLES AND DECARBONISATION

## KEY FACTS

- **Global carbon intensity has improved** due in part to an increase in renewable electricity production, but even more so due to greater energy efficiency, despite a recent decline in efficiency improvements.
- Increased penetration of renewables, along with rising electrification of key end-uses such as household appliances and industrial processes, have contributed greatly to **improving the carbon intensity of end-use sectors** such as buildings, industry and transport.
- Despite improvements in energy intensity, **total emissions have increased**, driven by rising energy demand (particularly electricity demand in buildings) in developing economies and by a growing trend towards energy-intensive transport.

## RENEWABLE ENERGY AND CARBON INTENSITY

**R**enewable energy and energy efficiency have long been known to provide multiple benefits to society, such as lowering energy costs, improving air quality and public health, and boosting jobs and economic growth. Increasingly, renewables and efficiency are viewed as crucial for reducing carbon emissions. Energy production and use account for more than two-thirds of global greenhouse gas emissions, and together renewables and energy efficiency have made significant contributions to limiting the rise in carbon dioxide (CO<sub>2</sub>) emissions.<sup>1</sup>

This is reflected by the growing number of countries pledging to achieve net zero emissions and making emission reduction commitments in their Nationally Determined Contributions (NDCs) under the Paris Agreement – providing a key driver for greater implementation of both renewables and efficiency. As of the end of 2020, 190 parties to the Paris Agreement mentioned renewable energy in their NDCs, while 144 parties mentioned energy efficiency, and 142 mentioned both.<sup>2</sup>

Previous editions of the *Renewables Global Status Report* have tracked the combined benefit of renewables and energy efficiency through trends in the share of renewable energy and in energy intensity. **Energy intensity** can be assessed both as primary energy supply per unit of gross domestic product (GDP), and as final energy consumption in an end-use sector relative to a sector-specific metric (for example, energy use per square metre in buildings).<sup>3</sup> Between 2015 and 2019, the annual rate of improvements in energy intensity slowed.<sup>4</sup>

However, energy intensity is an imperfect indicator for measuring the transition to more efficient and cleaner energy production and use. Trends in **carbon intensity**<sup>i</sup> – measured here as energy-based CO<sub>2</sub> emissions per unit of GDP – help to better understand the full impact of both energy efficiency and renewables. Unlike overall emissions, which until 2015 increased in parallel with GDP growth, carbon intensity of GDP reflects the technical or structural improvements that occur in various sectors.<sup>5</sup> As with changes in energy intensity, changes in carbon intensity result from a combination of factors beyond energy efficiency measures and the deployment of renewables alone, such as increased production from non-renewable energy sources and the growth of more carbon-intensive industries.<sup>6</sup>

Carbon intensity of GDP can be expressed as the product of the energy intensity of GDP and the *carbon intensity of energy* (that is, the CO<sub>2</sub> emissions associated with energy production and use).<sup>7</sup> Energy efficiency measures and the deployment of renewables can bring about improvements in both of these variables.

Renewable energy can improve the energy intensity of GDP by reducing the losses that occur in energy transformation and thus decreasing the amount of primary energy input that is needed to meet existing demand. Energy efficiency, in turn, can lower both the overall primary energy supply needed as well as the capacity and cost of the low-carbon energy systems needed to meet demand, thereby growing the share of renewables in the energy mix.<sup>8</sup>

Carbon intensity can be analysed both from the perspective of the energy sector as a whole, and with respect to the carbon intensity of specific end-use sectors, namely buildings, industry and transport. Some measures in these sectors – such as energy codes for buildings or the deployment of distributed renewables, heat pumps and other technologies for electrification – impact carbon intensity as they can have both an energy efficiency and a renewable energy component. Other energy efficiency measures can play a role in each sector, including digitalisation in the buildings and industry sectors, and fuels and vehicle emission standards in the transport sector. In 2020, the COVID-19 pandemic impacted the energy efficiency of all three end-use sectors.<sup>9</sup> (→ See *Sidebar 7*)

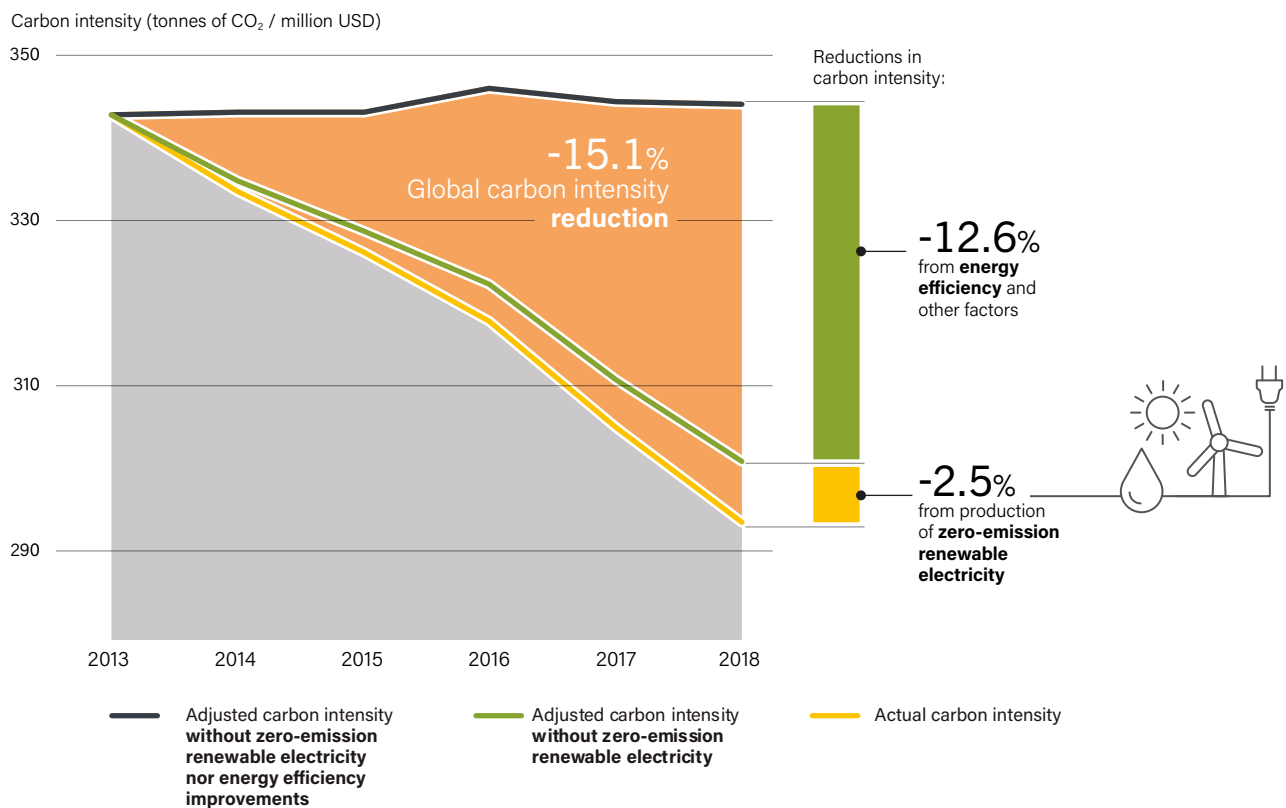
Energy production is associated with various sources of CO<sub>2</sub> emissions. These include, among others, oil and gas extraction and refining, fugitive emissions from mining and biofuels production, and the combustion of fossil fuels both for electricity production and for direct use in end-use sectors.<sup>10</sup>

Between 2013 and 2018, global energy-related CO<sub>2</sub> emissions grew 1.9% (0.4% per year on average), to nearly 38 gigatonnes (Gt).<sup>11</sup> The increase took place during a period of economic growth – global GDP grew 23% during the five-year period – but was slowed by improvements in the overall carbon intensity of GDP.<sup>12</sup> In other words, there was an overall decoupling of global economic growth and CO<sub>2</sub> emissions.<sup>13</sup> These improvements in carbon intensity were due in part to increased renewable electricity production and, to a greater extent, to improved energy efficiency.<sup>14</sup> (→ See *Figure 57*) This was despite a decline in energy efficiency improvements that began in 2015 and has been reinforced by the COVID-19 crisis and low energy prices.<sup>15</sup>

i A “complete” accounting of the carbon intensity of GDP includes all greenhouse gas emissions from both energy and non-energy uses. However, considering that CO<sub>2</sub> is the main greenhouse gas emitted by the energy sector, this chapter focuses on the carbon intensity of GDP due to CO<sub>2</sub> emissions from energy use and refers to this concept as “carbon intensity of GDP”.



**FIGURE 57.** Estimated Impact of Renewables and Energy Efficiency on Global Carbon Intensity, 2013-2018



Note: This figure estimates the additional primary energy input that would have been required in the absence of renewable electricity uptake since 2013, all else being equal. The estimation accounts for the difference in transformation losses between conventional and renewable electricity generation. However, it 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. Sources of renewable energy in this figure include those that emit no CO<sub>2</sub> in production of electricity. Dollars are at constant purchasing power parities.

Source: See endnote 14 for this chapter.

Renewable energy and energy efficiency together help lower carbon emissions per unit of GDP.



## SIDEBAR 7. COVID-19 and Energy Demand in Buildings, Industry and Transport

Throughout 2020, the COVID-19 pandemic affected most aspects of daily life across the globe, forcing individuals and communities to pivot quickly to new routines to prevent the spread of infection. Changes in energy use accompanied this major shift in societal behaviours.

Full lockdown measures reduced electricity demand 20% on average, depending on the country, with smaller effects for partial lockdowns. As a result, renewables claimed a greater share of global electricity generation (around 29% in 2020, up from 27% the previous year); this was in part because the output of renewables is often less directly influenced by electricity demand. (→ See *Global Overview chapter*.)

In **buildings**, remote working caused a shift in energy demand from commercial to residential buildings. In the first half of 2020, electricity use in residential buildings in some countries grew 20-30%, while it fell around 10% in commercial buildings. Depending on home size, heating or cooling needs, and the efficiency of computers and other information technology equipment and appliances used at home, a single day of teleworking can increase daily household energy consumption 7-23%, compared with a day working at the office. In some countries, consumers bought additional appliances (entertainment devices, teleworking equipment, etc.), which, coupled with the fact that people were spending more time at home, increased total appliance energy use. However, purchases of new, efficient appliances and replacement of old, inefficient models improve the energy intensity of the global appliances stock.

Most commercial buildings, even when offices remain unoccupied, continue to consume energy to maintain heating, ventilation and air conditioning systems and to power computing servers. The energy intensity of commercial buildings reportedly increased as the share of energy use from more energy-intensive essential sub-sectors grew. For example, food sales outlets, which largely continued to operate during the pandemic, were more than twice as energy intensive as the average office. Additionally, pre-COVID, around 30% of a building's energy was dissipated in ventilation and exfiltration of air; as more people returned to workplaces later in 2020, demands for higher ventilation rates (for health reasons) increased the energy intensity of commercial buildings.

Restrictions on the ability of professional contractors to access residential properties delayed efficiency upgrades. At the start of the COVID crisis, global construction activity slowed an estimated 24%, along with a 12% decrease in on-site work at buildings, but as the sector rebounded the overall slowdown in construction activity fell to 10% by the end of 2020. In some markets, increased rates of do-it-yourself renovations may have led to improved technical efficiency. For example, sales of insulation in Australia were 20% to 40% higher in the first half of 2020 than a year earlier, and sales at US home improvement chains increased compared to 2019.

In **industry**, reduced production and consumer demand lowered energy demand across all manufacturing sectors. Energy-intensive sub-sectors (such as iron and steel, and cement) saw a lower decline in their activity than less energy-intensive industrial sub-sectors (such as textiles, machinery and equipment). For example, the share of automotive manufacturing in the industry sector decreased 30% in the first half of 2020 relative to the previous year, whereas basic metals manufacturing fell only 15%. As a result, upstream energy-intensive industries made up a larger share of industry activity, thus increasing energy and carbon intensity.

In **transport**, the major trends emerging from the crisis in 2020 were related to the impact of travel restrictions and remote working measures on both urban transport and the aviation sector. Long-distance passenger load factors<sup>i</sup> in aviation fell dramatically, with the demand for commercial air travel dropping around 60% and rail demand declining 30%. This led to increased energy use per passenger and per kilometre travelled, despite the decline in overall energy use. A shift from aviation to rail can reduce energy intensity, whereas a shift from rail to road vehicles can increase it.

For those commuting by car, teleworking is estimated to reduce total energy consumption and emissions. However, for commuters who normally make only short trips by car (under 6 kilometres in the United States and under 3 kilometres in the European Union (EU)), as well as commuters who mainly take public transport, teleworking is estimated to produce a small net increase in total energy demand and emissions. This is even before accounting for the fact that smaller numbers of bus and train passengers during 2020 increased the energy and carbon intensity of these modes of transport, per passenger-kilometre travelled. Due to social distancing efforts, people turned instead to private vehicles and active modes of transport, such as walking and cycling. Temporary bike lanes were installed in Paris (France) and Toronto (Canada), among many other cities, and some of these lanes have been converted into permanent infrastructure. Consequently, energy efficiency (per passenger-kilometre) of buses and trains decreased in tandem with lower passenger volumes.

Globally, as sales of new cars declined in 2020, the vehicle stock became relatively older and less efficient. However, this was partially offset by the fact that the relative share of electric vehicles (EVs) in new car sales rose, impacting the average efficiency of new road vehicles.

<sup>i</sup> Passenger load factors measure the capacity utilisation of an aircraft (i.e., how many of its seats are filled).

Source: See endnote 9 for this chapter.



## DECARBONISATION OF END-USE SECTORS

Total final energy consumption (TFEC) – the energy remaining after losses during transformation, energy sector own-use, transmission and distribution – amounted to 378 exajoules in 2018, up 2% from the previous year.<sup>16</sup> This energy is consumed primarily in the three end-use sectors: buildings (residential and commercial), industry and transport.<sup>17</sup>

CO<sub>2</sub> emissions from final energy use reached 24 Gt in 2018.<sup>18</sup> Around 63% of this total was direct emissions, or emissions from sources that are directly controlled by a sector or entity (for example, emissions from combusting fossil gas in a boiler). The remainder was indirect emissions: these are released as a consequence of activities within a sector or entity (such as buildings), but they occur at sources owned or controlled by another sector (for example, emissions from producing the electricity that is later consumed in a building). Most indirect emissions come from electricity production.<sup>19</sup>

Reducing indirect emissions, as well as addressing direct emissions by improving the carbon intensity of final energy use, are key ways to decarbonise the entire energy sector. Between 2008 and 2018, the global carbon intensity of final energy decreased 2%.<sup>20</sup> At the same time, the global share of modern renewables in TFEC grew 38%.<sup>21</sup> (→ See Figure 58.)

Parts of the developed world showed a similar trend over the decade: that is, improvements in the carbon intensity of energy were accompanied by an increase in the share of renewables.

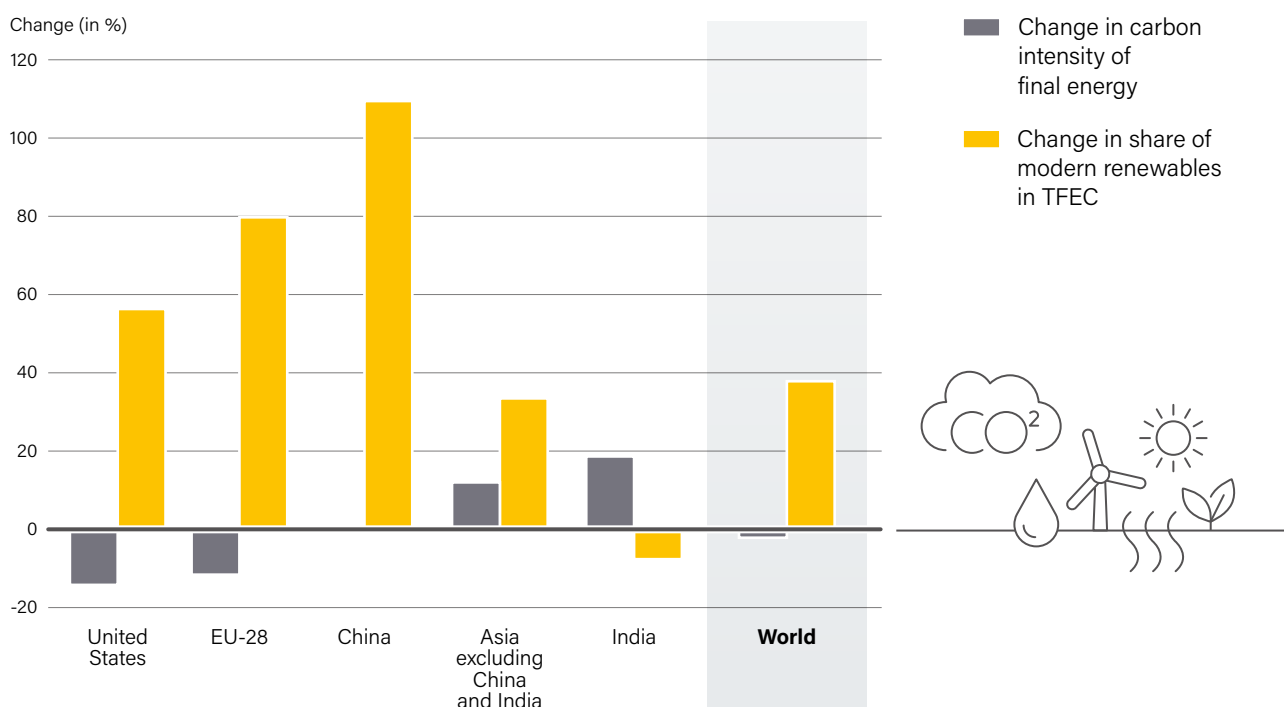
The United States and the EU-28 (two of the top-five emitting regions) experienced total decreases in their carbon intensities of 14% and 12%, respectively, during 2008-2018, together with respective increases in the share of modern renewables in TFEC of 56% and 80%.<sup>22</sup>

However, in certain developing and emerging countries, the rising share of renewables in TFEC did not necessarily coincide with an improvement in the carbon intensity of final energy. Despite a 109% increase in renewable energy uptake during 2008-2018 (4.4% annually), China's carbon intensity of final energy stayed relatively constant, for a total increase of 1% (0.05% annually).<sup>23</sup> In all Asian countries excluding China, the smaller increase in renewables – 29% over the decade – was not enough to halt the rise in carbon intensity, which grew 14%.<sup>24</sup>

Although the impact of increased renewable energy penetration varies depending on local circumstances, the rising share of renewables, together with increased electrification of key end-uses, has contributed greatly to improving the carbon intensity of end-use sectors.<sup>25</sup> (→ See Sidebar 8.) This highlights the importance of other decisions (for example, phasing out coal) that influence the energy mix, in addition to renewable energy uptake.

Additional decarbonisation can be achieved through a combination of direct deployment of renewables and energy efficiency measures in the end-use sectors. By reducing overall energy demand, or limiting its growth, energy efficiency in end-use sectors impacts both direct and indirect CO<sub>2</sub> emissions.

**FIGURE 58.** Change in Carbon Intensity of Final Energy Consumption and Share of Modern Renewables, Selected Countries, 2008-2018



Source: Based on IEA data. See endnote 21 for this chapter.

## SIDEBAR 8. Decarbonisation Through Monitoring, Reporting and Verification Systems

Accurate data and regular monitoring are key in tracking progress towards meeting the objectives of Sustainable Development Goal 7 (SDG 7), which calls for “affordable, reliable, sustainable and modern energy for all” by 2030. One such monitoring tool is RISE<sup>1</sup> (Regulatory Indicators for Sustainable Energy), a set of indicators used to compare countries’ policies and regulatory frameworks towards achieving SDG 7. In particular, RISE can help indicate the readiness of policy makers to track the carbon intensity of end-use sectors such as power, buildings, industry and transport.

The RISE Carbon Pricing and Monitoring indicator measures two important aspects of regulating carbon emissions: 1) monitoring, reporting and verification (MRV) of emissions and 2) assigning an appropriate price to emissions. Carbon pricing is seen as an efficient way to account for the external costs associated with energy-related CO<sub>2</sub> emissions. Whether or not it is economically or politically feasible for a country to price carbon emissions, an MRV system can be a first step towards adopting low-carbon policies. Implementing an MRV system for emissions can help standardise data and support decision making on policies or investments related to carbon intensity.

Policy makers can implement an MRV system to monitor carbon emissions on a regular basis, particularly for the most energy-intensive sectors of the economy. A monitoring system not only provides key data to better inform policy decision making, but also builds institutional capacity and knowledge for regulators to oversee economic activity transparently and effectively. In complex economies with diverse economic sectors, an effective approach to reporting carbon emissions is a bottom-up system whereby individual entities report their own emissions in order to comply with an enforced mandate, which is then verified by a regulatory agency.

In January 2021, the Republic of Korea entered the third phase of a bottom-up monitoring programme for its emission trading scheme. This phase involves monitoring emissions from heat and electricity generation, industry, buildings, transport, water and public buildings. The programme requires an independent third-party verifier (selected by the government) to approve the emission reports submitted by each entity. Based on the approved data, the Korean Greenhouse Gas Inventory and Research Center regularly releases evaluation reports that include key emission statistics, market performance indicators and survey results from these entities. The information verified by regulators can provide a foundation to monitor and quantify the mitigation impact of investment in renewable energy technologies and energy efficiency measures. This, in turn, can help attract international private or public finance targeting the deployment of renewable energy technologies.

Another bottom-up example is the Emissions Trading Scheme (ETS) used by the European Union (along with Iceland, Liechtenstein and Norway) since 2005, which sets a limit (or cap)

on the total amount of certain greenhouse gases that can be emitted by covered sectors. Within the cap, companies receive or buy emission allowances, which they can trade with one another as needed. This regional cap-and-trade system limits emissions from more than 10,000 heavy energy users within Europe, including power stations, industrial plants, and airlines, covering nearly half of the EU’s greenhouse gas emissions. As the MRV system improved following the EU ETS’ launch trial period (2005–2007), policy makers have used historic data to reform the programme by adjusting the limits on the total number of allowances via phased reforms over the past decade. This helped the programme overcome market failures due to volatility in the market price for allowances.

Top-down approaches, in contrast, require monitoring and verification of an entity’s emissions by public regulators or approved third parties. Because this kind of system has much higher public sector staffing costs, it may be more appropriate for use in economic sectors that have a homogenous group of emitters, such as specialized industrial sectors. For example, China launched the first phase of its national emission trading scheme in January 2021<sup>ii</sup> through a federal pilot to monitor only coal- and gas-fired power plants. Assigning federal regulators to each power plant will help determine appropriate emission baselines to inform not only the scheme’s design, but also energy conservation standards for other sectors, long-term plans for capacity retirements and China’s contributions for reducing emissions under the Paris Agreement. However, it may not be feasible to assign this same level of oversight to entities in all economic sectors, especially in developing countries that have more limited public resources.



By the beginning of 2020, only 60 out of the 138 countries covered by RISE had established a mandated system for emissions MRV from different end-use sectors. However, uptake of MRV has nearly doubled since 2010, when only 27 countries had such regulations. Of the 60 countries with MRV regulations in early 2020, 44 countries also had in place a carbon pricing scheme (carbon tax and/or emissions trading), and more than a third of these countries were in Europe (with only four countries located in Africa). However, Africa has experienced the largest increase in uptake of MRV regulations (eight additional countries since 2010) followed by the Middle East (seven additional countries). In 2019, Europe had the largest share of countries with MRV policies for emissions in place (27%), followed by the Middle East (15%) and Africa (14%). (→ See Figure 59.)

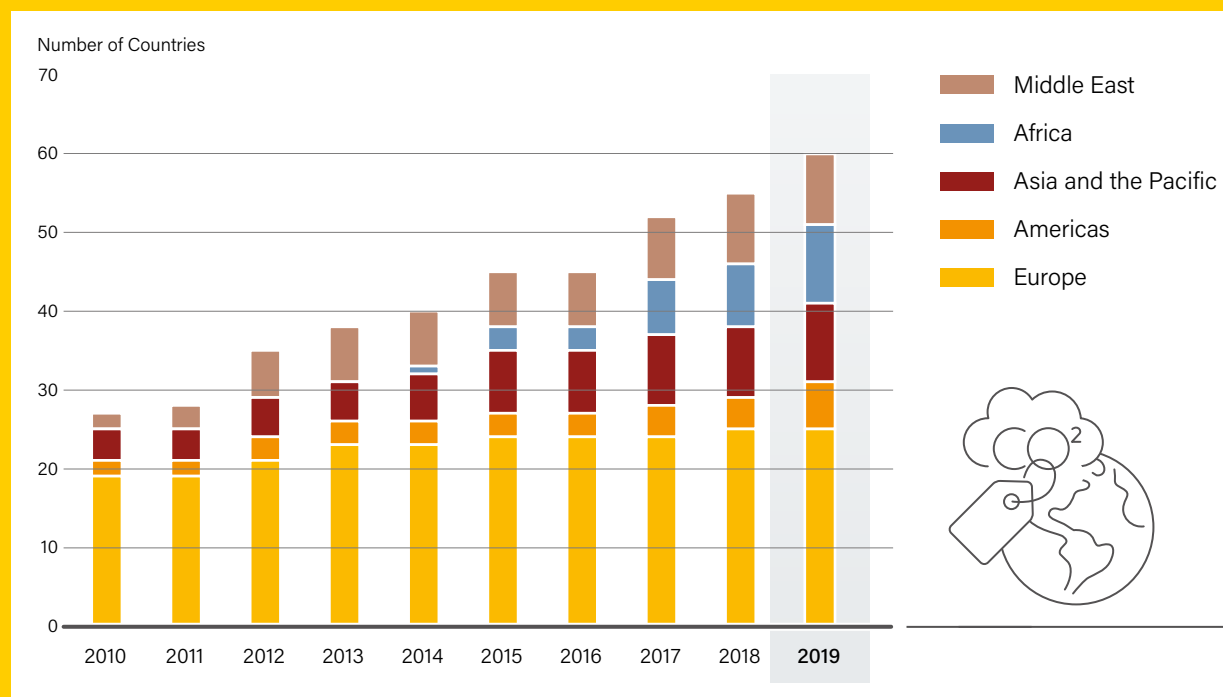
Within Africa, Malawi and South Africa are the only countries implementing both types of regulations (emissions MRV and carbon pricing). Malawi implemented its MRV programme in 2019 targeting emissions from oil and diesel generators and the transport sector, and the resulting tax revenues collected exceeded the country's expectations. In India, although there is no explicit carbon tax in place,

the MRV system implemented for the coal industry in 2010 has informed the efficient fuel-switching programme for electricity generators, as policy makers have been able to set appropriate benchmarks for emission limits based on the verified emission data. Subsequently, between 2010 and 2015, the Indian government introduced coal emission limits and corresponding excise duty penalties in a transparent step-phase approach. The limits and penalties are adjusted yearly based on historic data from the MRV system, giving emitters the ability to plan operations accordingly.

- i The 2020 edition of RISE includes 31 indicators distributed among four pillars (access to electricity, access to clean cooking, renewable energy and energy efficiency), measured across 138 countries globally and covering more than 95% of the world's population. By providing empirical evidence of the support provided by policy frameworks, the RISE database helps countries attract investments in their sustainable energy sectors. Private investors and developers also use RISE to carry out due diligence related to new projects, products and services. RISE indicators can help policy makers benchmark their own national energy framework against those of regional and global peers. See <https://rise.esmap.org>.
- ii China's Emission Trading Scheme was designed by the National Development and Reform Commission beginning in 2018 but was not officially implemented until the first phase began in January 2021.

Source: See endnote 25 for this chapter.

**FIGURE 59.** Number of Countries with Carbon Emission Monitoring, Reporting and Verification Policies, by Region, 2010-2019



Source: World Bank Group. See endnote 25 for this chapter.

## BUILDINGS



The buildings sector accounted for around 33% of TFEC in 2018, a share that has risen about 1% annually since 2008.<sup>26</sup> Residential buildings consumed nearly three-quarters of this energy, while the remainder was used in commercial and public buildings.<sup>27</sup> Total energy-related CO<sub>2</sub> emissions from buildings increased to a record 10 Gt in 2019, only 3.1 Gt of which were direct emissions.<sup>28</sup> Indirect emissions thus are highly relevant within the buildings sector, due notably to its dominant share of global electricity consumption (around 55% in 2019).<sup>29</sup>

Between 2013 and 2016, carbon intensity improvements in the power sector were sufficient to cause CO<sub>2</sub> emissions to level off in buildings, illustrating the general effectiveness of rising electrification in buildings, combined with the decarbonisation of electricity generation itself.<sup>30</sup> Electricity can power various services efficiently in buildings through the use of appliances and equipment (some of which are typically fossil fuel-powered) that are already widespread, such as fans, refrigerators, water boilers, cook stoves and heat pumps.<sup>31</sup> Additionally, electric appliances tend to be more efficient than the equipment they replace.<sup>32</sup> On a final energy basis, heat pumps can be three to five times more energy efficient than their natural gas counterparts.<sup>33</sup>

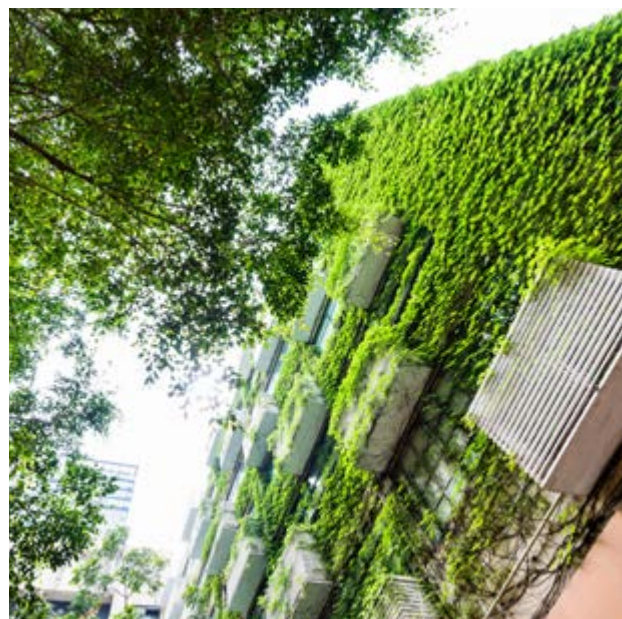
However, between 2000 and 2019, electricity use in buildings grew five times faster than improvements in the carbon intensity of electricity generation.<sup>34</sup> This is due in part to changes in rapidly developing countries (where electricity remains carbon intensive) – including rising electricity demand for space cooling and appliances, increased access to modern energy services, and changing consumer behaviour<sup>i</sup>, such as purchases of less-expensive but inefficient air conditioners.<sup>35</sup>

In developed countries, however, energy efficiency improvements largely offset increased electricity demand from increasing digitalisation<sup>ii</sup> and electrification.<sup>36</sup> Between 2008 and 2018, the carbon intensity of buildings in member countries of the Organisation for Economic Co-operation and Development (OECD) improved 2.7% annually in the residential sector (from an average of 4.6 tonnes of CO<sub>2</sub> per dwelling in 2008 to 3.5 tonnes in 2018), and it improved 3.6% annually in the commercial sector (from 3.8 tonnes of CO<sub>2</sub> per employee to 2.6 tonnes over the decade).<sup>37</sup>

In parallel, efforts in energy efficiency have progressed due to increasing digitalisation in building operations.<sup>38</sup> Digital solutions for building operations serve three essential functions: monitoring energy consumption (for example, via “smart meters”); identifying potential energy savings; and reducing energy consumption through intelligent controls.<sup>39</sup> Smart technologies range from

## Carbon intensity

in buildings is driven by indirect emissions (around 70%), notably by electricity generation.



applications that measure and optimise the use of energy or guide users' behaviour, to software for professional facility management.<sup>40</sup> Digital technologies can reduce building energy use nearly 20% in several types of commercial buildings, including offices, retail, hotels and hospitals.<sup>41</sup> Digital energy management devices are increasingly prevalent as well. Smart thermostats are the second most common smart home device (following audio speakers) in UK households, with 6% penetration, followed by smart lighting (5%).<sup>42</sup>

In addition to the energy savings realised by electrification measures and digital technologies, improved building performance – that is, energy usage per square metre – is critical. Improving energy performance is generally simpler in new buildings than in existing buildings, as efficiency improvements can be integrated into the design stage.

The EU's Energy Performance of Buildings Directive requires all new buildings from 2021 onward to be nearly zero-energy buildings (NZEBs).<sup>43</sup> However, since the directive does not provide a specific accounting method, tracking the market penetration of NZEBs can be challenging.<sup>44</sup> For example, the uptake of NZEBs in France appeared rapid because the country's NZEB accounting method matches the current thermal regulation (hence all new buildings are considered NZEBs), whereas in Italy the uptake seemed slower as the national accounting method is stricter compared to the building code requirements.<sup>45</sup>

In the United States and Canada, the number of zero-energy projects has increased steadily, reaching 27,965 in 2019, although the yearly rate of increase has declined from previous years (falling from 59% in 2018 to 26% in 2019).<sup>46</sup> Meanwhile, such standards often are lacking in developing countries that have rapidly growing urban populations (especially in Asia and Africa); in many of these countries, building codes either do not exist or do not apply to all building energy use.<sup>47</sup>

i For example, opting for larger homes or increasing the building floor area and appliance ownership per household, although these trends are not exclusive to developing countries.

ii In buildings, this refers to the data collection, representation, observation and control of physical systems by digital means, often called digital or “smart” technologies/solutions.



In developed countries, lower rates of new construction mean that decarbonising the existing building stock – a much greater challenge – is more critical to decarbonising the sector as a whole.<sup>48</sup> In the EU, however, only around 1% of existing buildings are renovated for energy efficiency improvements annually, compared to a required 3% in order to meet the region's 2030 emissions target.<sup>49</sup> In some OECD countries, energy-efficient renovations, including improving building insulation and installing more efficient heating systems, contributed to carbon intensity improvements for space heating.<sup>50</sup> In Finland, France and New Zealand, the carbon intensity of space heating was reduced more than 30% between 2008 and 2018.<sup>51</sup>

Integrating renewable energy solutions in buildings – such as solar water heaters, heat pumps and renewables-based district heating and cooling – can help reduce carbon emissions and is more effective in terms of implementation when planned in conjunction with building renovations or design.<sup>52</sup> The Energiesprong renovation programme, which began in the Netherlands and now operates in France, Germany, Italy, the United Kingdom and the US state of New York, can provide a framework to increase the uptake of NZEBs through a combination of standardisation, prefabricated building components and third-party finance.<sup>53</sup> Some buildings financed by Energiesprong have produced more energy than they consumed by combining energy efficiency technologies with renewables, using insulated rooftops with solar panels, and installing ventilation and cooling systems.<sup>54</sup>

## INDUSTRY



The industrial sector accounted for 34% of TFE in 2018, and its direct emissions totalled 7.9 Gt of CO<sub>2</sub><sup>i</sup> – representing 33% of direct greenhouse gas emissions from final energy use.<sup>55</sup> Global industrial direct CO<sub>2</sub> emissions due to energy consumption increased 13% between 2008 and 2018.<sup>56</sup>

A combination of factors influences changes in carbon intensity in the industrial sector – including the fuel mix of electricity generation, technological improvements and structural changes in the share of carbon-intensive industries in the economy. Nonetheless, it is noteworthy that, in a selection of OECD countries<sup>ii</sup>, carbon intensity in industry improved 25% between 2008 and 2018, as the share of electrification increased to 13%.<sup>57</sup> (→ See Figure 60.)

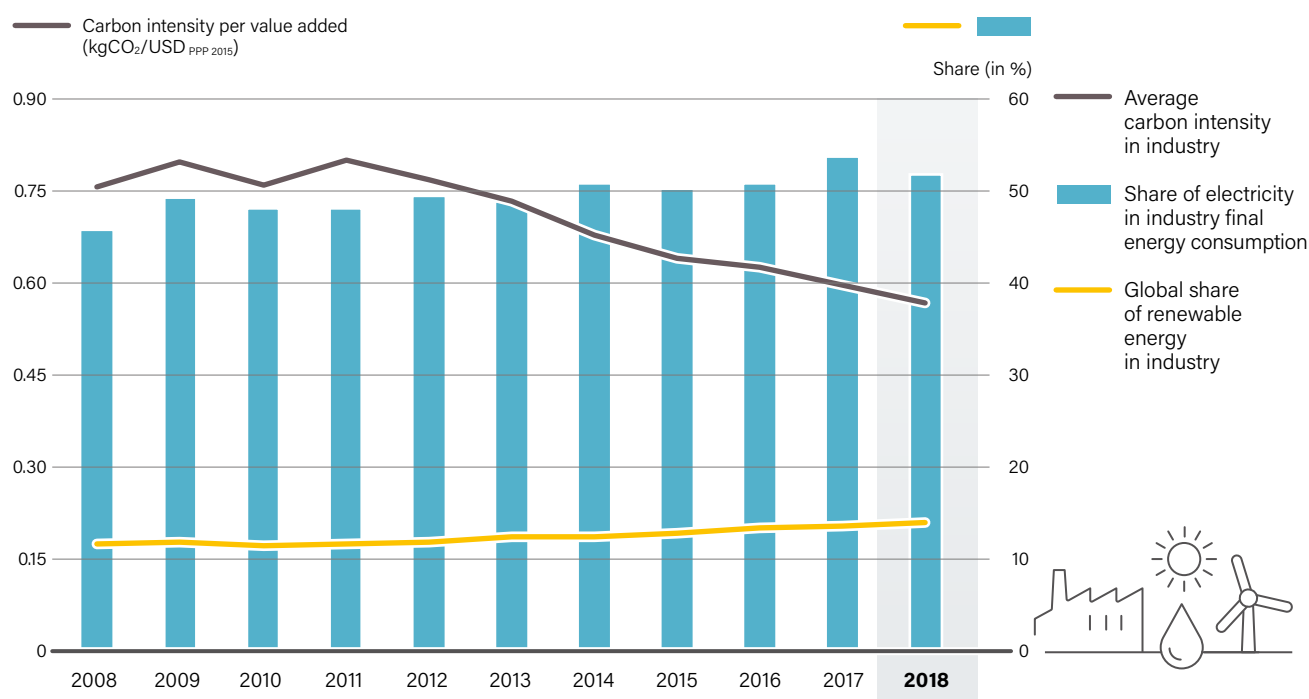
As with electric appliances in the buildings sector, electrically driven technologies in the industry sector are, in general, more energy efficient than conventional ones.<sup>58</sup> From a technical point of view, all energy required to generate heat for industrial processes up to around 1,000 degrees Celsius could be replaced by electricity.<sup>59</sup> However, the technologies involved can be more expensive than the conventional options, and policy support is needed to promote their uptake in industrial processes.<sup>60</sup> (→ See Policy Landscape chapter.)

Another effective strategy for achieving significant carbon intensity improvements is to implement heat recovery technologies.

i Data for indirect emissions were not available for the industry sector, and direct emissions data were provided only up to 2018.

ii Due to data availability, the analysis includes the following countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Portugal, the Republic of Korea, the Slovak Republic, Spain, Switzerland, the United Kingdom and the United States.

**FIGURE 60.**  
Carbon Intensity and Share of Electricity in Industry, Selected Countries, 2008-2018



Note: The countries included are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Portugal, the Republic of Korea, the Slovak Republic, Spain, Switzerland, the United Kingdom and the United States.

Source: See endnote 57 for this chapter.

These tap into waste energy streams and reuse them for various purposes within a facility (e.g., space heating or cooling) or within the process itself (e.g., pre-heating air and boiler make-up water). Active<sup>i</sup> heat recovery equipment, such as heat pumps, make it possible to increase the temperature of a waste heat stream to a higher, more-useful temperature.<sup>61</sup> Consequently, heat pumps can facilitate energy savings beyond those achieved by conventional passive heat recovery.<sup>62</sup> (→ See *Systems Integration chapter*.)

Industry-wide, low-temperature waste heat streams have the greatest potential to use waste heat recovery. However, barriers – such as the variability in temperature, availability and contaminating content of low-grade heat sources – continue to impede significant uptake.<sup>63</sup> While the deployment of heat pumps in industry is still low, a number of applications do exist, mainly in heating and drying applications.<sup>64</sup>

In recent years, the uptake of renewables in industrial processes (mainly bioenergy, as well as geothermal and solar heat) has helped improve industrial carbon intensity.<sup>65</sup> Although solar thermal has not yet been widely adopted in the sector, some 479 gigawatts-thermal of capacity was in operation in industrial processes at the end of 2020.<sup>66</sup> (→ See *Market and Industry chapter*.)

Finally, digitalisation has allowed industrial sites to more comprehensively analyse energy use and to continuously improve energy performance.<sup>67</sup> Modern digitally driven energy management systems, as well as standards such as ISO 50001, help industries identify opportunities to adopt and improve cost-saving technologies, including those that do not necessarily require high capital investment (whether energy efficiency technologies, renewables or both).<sup>68</sup> Additionally, by collecting data and simplifying monitoring, energy management systems ensure better performance, thereby improving the bankability of company projects and encouraging investments to improve carbon emissions.<sup>69</sup>



## TRANSPORT



The transport sector accounted for 33% of TFEC in 2018.<sup>70</sup> Road transport represented the bulk of the transport sector's energy demand (75%), followed by aviation (12%), marine transport (10%) and rail (2%).<sup>71</sup> (→ See *Global Overview chapter*.)

Direct CO<sub>2</sub> emissions from transport totalled 8.1 Gt in 2018, which represented 34% of direct<sup>ii</sup> greenhouse gas emissions from final energy use.<sup>72</sup> Emissions from transport grew 19% between 2008 and 2018, at an average annual rate of 1.8%.<sup>73</sup> This upward trend reflects the increase in the size and number of, as well as distances travelled by, road vehicles and to a lesser extent aviation.<sup>74</sup> It also underlines the increasing prevalence of sport utility vehicles (SUVs), which are larger and less fuel efficient than other passenger cars.<sup>75</sup> Total emissions from road transport in SUVs tripled globally between 2010 and 2020.<sup>76</sup>

In OECD countries, even as the demand for transport increased between 2008 and 2017 – with vehicle-kilometres travelled rising 0.73% annually during this period – the carbon intensity of transport (i.e., the CO<sub>2</sub> emitted per vehicle-kilometre for cars and light trucks) improved at an annual rate of 0.64%.<sup>77</sup> (→ See *Figure 61*.) In general, this carbon intensity improvement was due partly to the implementation of fuel economy and greenhouse gas emission standards for light-duty vehicles.

As of 2017, 10 out of the top 15 vehicle markets worldwide (including China, the EU, India and the United States) had established fuel economy and/or emission standards for light-duty vehicles.<sup>78</sup> This is significant considering that at the end of 2007, only four governments had mandatory standards of either kind.<sup>79</sup> In total, as of 2017, nearly 80% of new light-duty vehicles sold globally were subject to some kind of fuel economy or emission standards.<sup>80</sup> (→ See *Policy Landscape chapter*.)

However, challenges remain to determine the full impact of such regulations on global transport carbon intensity, as regulations in some countries became stricter (for example, in Japan and the Republic of Korea), while others were less binding (for example, in India).<sup>81</sup>

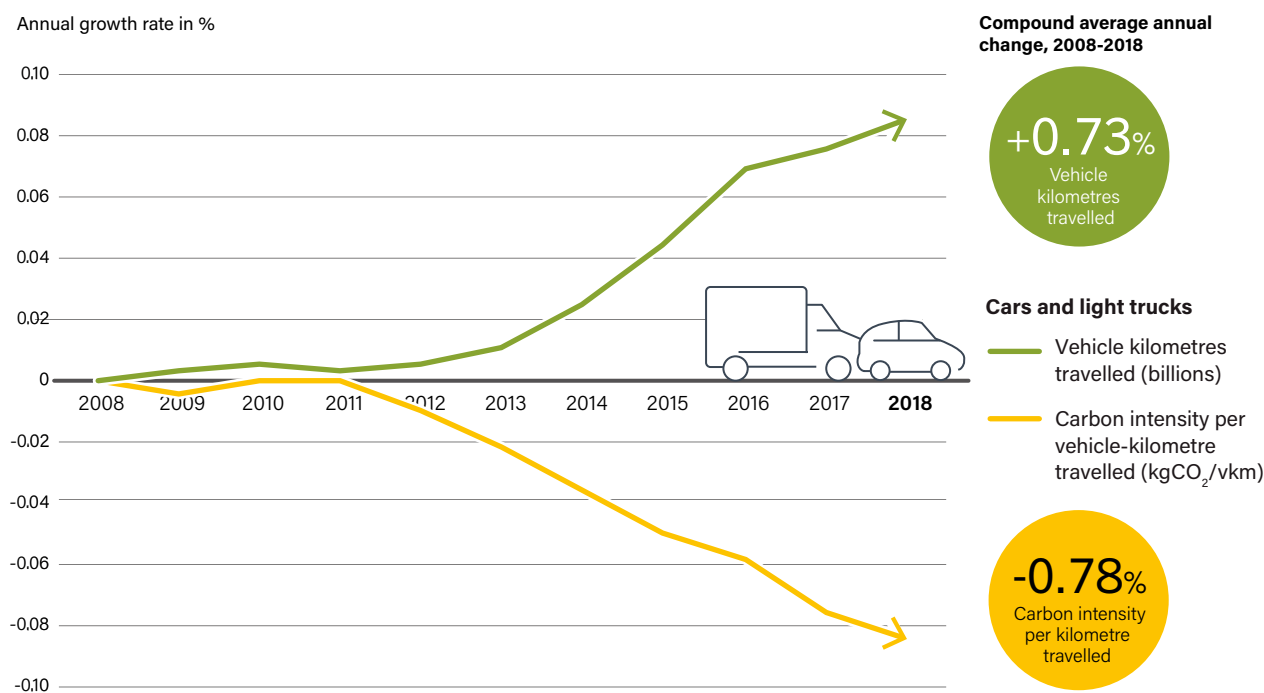
In developing countries, the carbon intensity of road transport is determined largely by the used vehicle market: 70% of the world's used exported light-duty vehicles are shipped to Africa (the largest importer at 40%), Eastern Europe (24%), Asia-Pacific (15%), the Middle East (12%) and Latin America (9%).<sup>82</sup> While import and export regulations tend to lower carbon emissions, such measures often are lacking in importing countries.<sup>83</sup> For example, Kenya imposes an age limit for imported cars of 8 years, whereas neighbouring Uganda has a limit of 15 years, and Rwanda has no age limit for imports.<sup>84</sup> All three of these countries import used vehicles from Japan, but because Kenya has a stricter import policy, the average fuel consumption and CO<sub>2</sub> emissions of its fleet are around 25% lower than those of its neighbours.<sup>85</sup>

The energy efficiency (kilometres travelled per unit of energy) of electric vehicles is higher than that of internal combustion

i Contrary to passive heat recovery, active heat-recovery equipment requires an external energy source to operate.

ii Data for indirect emissions were not available for the transport sector, and direct emissions data were provided only up to 2018.

**FIGURE 61.** Indexed Carbon Intensity and Kilometres Travelled, Passenger Vehicles in Selected Countries, 2008-2018



Note: The countries included are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Portugal, the Republic of Korea, the Slovak Republic, Spain, Switzerland, the United Kingdom and the United States.

Source: See endnote 77 for this chapter.



engine vehicles, and EVs produce zero direct CO<sub>2</sub> emissions.<sup>86</sup> EVs also can have a positive impact on the carbon efficiency of the global vehicle fleet, particularly when the share of renewable energy in the electricity mix is high.<sup>87</sup> While the CO<sub>2</sub> emissions benefit of EVs is somewhat less significant when considering indirect emissions during production and disposal of the vehicle and battery system, as well as the electricity generation necessary, the life-cycle emissions of EVs are typically much lower than those of internal combustion engine vehicles.<sup>88</sup>

Boosted by national and local government decisions to phase out petrol and diesel vehicles, sales of electric cars topped 3.2 million globally in 2020, surpassing the record year of 2019.<sup>89</sup>

The life-cycle emissions of EVs are typically **much lower** than those of internal combustion engine vehicles.

(→ See *Systems Integration chapter*.) However, the current overall impact of EVs on the carbon efficiency of the transport sector is minimal, as the share of electricity in TFC of transport remains low, around 1.1%, of which less than 30% is from renewables.<sup>90</sup>

Furthermore, few countries

explicitly link EV targets with renewable electricity targets. (→ See *Policy Landscape chapter*.)

Mobility systems focusing on shared transport, or mobility as a service, also improve energy and carbon efficiency per passenger.<sup>91</sup> While mobility innovations such as e-scooters have increased greatly in recent years and may have the potential to replace personal car use, their impact on improving energy intensity and carbon intensity remains anecdotal and is undetermined globally.<sup>92</sup>

During 2020, the COVID-19 crisis impacted existing mobility trends, with a growing tendency towards individual transport modes, thus decreasing public transport's energy efficiency and increasing its carbon intensity.<sup>93</sup> (→ See *Sidebar 7*.) Restrictive measures encouraging remote working also impacted energy consumption in the sector.<sup>94</sup>





**IKEA has invested heavily in wind and solar power over the past decade alongside other sustainability initiatives, such as sourcing all of its cotton from sustainable agriculture.**





## 08

# FEATURE: BUSINESS DEMAND FOR RENEWABLES

## KEY FACTS

- **Businesses are increasing their uptake of renewables** across power, heating and cooling, and transport needs. Company membership in business coalitions promoting renewable energy procurement surged across sectors.
- Despite a challenging business year, the **new renewable energy capacity** that businesses sourced through power purchase agreements increased 18% in 2020.
- Corporations increasingly sourced **low-temperature renewable energy for heating and cooling** from solar thermal heat, geothermal heat and bioenergy, as well as renewables-based electrification.
- Businesses source **renewable energy for their transport needs** mainly from biofuels, renewables-based electricity and renewable hydrogen across the road, rail, maritime and aviation sectors.

**B**usiness has a significant role to play in renewable energy deployment. Companies worldwide are contributing in various ways, including through manufacturing and production, research and development, installation, project financing and energy infrastructure, as well as by procuring their energy from renewable sources. Despite the impacts of the COVID-19 pandemic and related recession, corporate sourcing of renewable electricity through power purchase agreements (PPAs) rose 18% in 2020.<sup>1</sup> Businesses also increased their use of renewables for heat and transport, although to a far lesser extent.<sup>2</sup>



Firms and industries have different energy needs, and uneven patterns of business demand for renewables exist depending on the sector, technology and geography. Whereas corporate sourcing of renewable electricity is advancing quickly, the use of renewable energy in industrial heat and transport is not.<sup>3</sup> However, innovations in markets, financing mechanisms, policies and technologies (such as renewable hydrogen) are helping to close gaps and facilitate greater demand.

## DRIVERS OF BUSINESS DEMAND FOR RENEWABLE ENERGY

A combination of factors is contributing to growing business demand for renewables across all sectors. These include environmental and ethical considerations, cost savings, competitiveness, risk mitigation, and business coalitions and collaboration. Government policy also continues to play a key role in incentivising business demand for renewable energy on various fronts. (→ See *Policy Landscape chapter*.)

Renewables are central to companies' efforts to achieve their zero-emission or other ambitious **emission reduction goals**. For some companies, the drive to increase the use of renewable energy is part of larger environmental goals and, often, a fundamental element of a broader sustainability strategy.<sup>4</sup> Stakeholders such as customers, workers, local communities, suppliers and shareholders increasingly expect companies to play their part in climate action and to become more accountable as well as more publicly transparent about their sustainability practices.<sup>5</sup>

Renewable energy is a core area of business sustainability reporting (for example, providing updates on current use of renewables and on targets set for future use); this has become more standardised worldwide through the efforts of the Global Reporting Initiative, the Carbon Disclosure Project (CDP) and similar entities.<sup>6</sup> Investor and shareholder interest in renewable energy companies also is burgeoning. Investment in sustainability-related funds surged around 300% in 2020, and share prices in renewables and other clean energy firms<sup>i</sup> rose 142%; meanwhile, share prices for oil and gas companies fell 38%.<sup>7</sup>

**Cost savings and competitiveness** are another key driver of business demand for renewables. Renewable electricity in particular has become increasingly attractive commercially compared to new and existing fossil fuels, and has been cost competitive compared to nuclear power for some time.<sup>8</sup> In some cases, it can be less expensive for companies to source their own renewable electricity directly from suppliers or to produce it themselves than to buy it from the grid.<sup>9</sup> In electricity generation, renewables now offer more attractive cost options for at least two-thirds of the global population.<sup>10</sup> (→ See *Sidebar 6 in Market and Industry chapter*.)

**Risk mitigation** objectives also drive companies to adopt renewables, as these energy sources can help reduce energy supply risks, price risks and reputational risks as environmental values take deeper root in global society.<sup>11</sup> In addition, renewables can reduce policy and regulatory risks arising from potential future changes, such as carbon taxes and the market transition towards a low-carbon economy. Firms have come under growing pressure to disclose and address climate-related financial risk, particularly for credit rating agency assessments.<sup>12</sup>

**Business coalitions** promoting greater demand for renewables have grown quickly. The RE100 group of companies, committed to achieving 100% renewable electricity, nearly doubled its membership in just over two years, from 155 members in January 2019 to 309 members by May 2021.<sup>13</sup> Membership in EV100 – a group of companies committed to transitioning their vehicle fleets to electric vehicles (although without a direct link to renewables) – grew similarly.<sup>14</sup> Other organisations are providing leadership and support frameworks to help leverage business demand for renewables.<sup>15</sup> (→ See *Box 9*.)

Renewables are central to companies' efforts to achieve **emission reduction goals**.



<sup>i</sup> Clean energy firms refer here to those with activities in renewable energy, energy efficiency, emission abatement or other technology-based decarbonisation sectors.

## RENEWABLE ELECTRICITY



Business demand for renewable energy is most common in the electricity sector. The four main categories of such “corporate sourcing” of renewable electricity are:

- *Self-generation and consumption:* Companies develop their own renewable energy projects and use the electricity generated. These installations may be on site (for example, rooftop solar) or off site (such as a wind power project built relatively near the firm’s facilities).
- *Power purchase agreements (PPAs):* Companies sign long-term contracts (typically 10 years) with an independent power producer or utility that commits them to procure a specific amount of renewable energy at a fixed price for a specified duration. Virtual PPAs are more popular in larger markets due to their flexibility, as buyers and sellers do not need to be connected to the same grid provider. One advantage that corporate PPAs offer is “aggregation”, where smaller purchasing companies form a consortium and aggregate their demand to secure more competitively priced deals and reduce financial risk.<sup>16</sup>
- *Utility green procurement:* Companies buy renewable electricity through green premium products (green label-certified and -priced) or bespoke contract arrangements, such as green tariffs (special rates). Energy utilities offer both options, allowing their business customers to buy renewable energy directly through billing and without requiring a long-term contractual commitment. However, the trade-off is a less competitive price than that offered by PPAs.<sup>17</sup>
- *Environmental attribute certificates (EACs):* Companies purchase EACs from energy suppliers or brokers, effectively buying ownership rights to a specified amount of renewable electricity. The certificates are primarily “unbundled”, meaning that they are bought and sold separately from the associated electricity generated.<sup>18</sup> These certificates, referred to as renewable energy certificates (RECs) in North America and Guarantees of Origin (GOs) in Europe, are the most common corporate sourcing method.<sup>19</sup>

By the end of 2020, the only available global-level aggregated data on corporate sourcing covered PPAs. Despite a challenging business environment during the year, the capacity of new renewable corporate PPAs sourced by businesses worldwide increased 18% in 2020, reaching 23.7 gigawatts (GW) of additional renewable power capacity that year.<sup>20</sup> This compares to added capacity of just 0.1 GW in 2010 and 4.7 GW in 2015.<sup>21</sup> (→ See Figure 62.) The fourth quarter of 2020 alone saw a record 7.3 GW of contracts signed globally.<sup>22</sup>

North America continued to dominate the corporate PPA market in 2020, accounting for 57% (13.6 GW) of the global total, although this share fell from 81% (16.3 GW) in 2019.<sup>23</sup> Renewable capacity procured in 2020 nearly tripled in countries across Europe, the Middle East and Africa, surging from 2.6 GW to 7.2 GW.<sup>24</sup> Procurement in the Asia-Pacific region grew from 1.2 GW to 2.9 GW.<sup>25</sup>

### BOX 9. Organisations Leveraging Business Demand for Renewables

The Renewable Energy Buyers Alliance is an association of energy buyers seeking to procure renewable energy across the United States. Its goal is to reach 60 GW of new renewable energy projects by 2025 by unlocking procurement options for large-scale energy buyers. The Alliance counts more than 200 members, including stakeholders from energy companies, commercial and industrial businesses, and nonprofit organisations.

The RE-Source Platform is a global alliance of stakeholders representing clean energy buyers and suppliers. It co-ordinates activities to promote a better framework for corporate renewable energy sourcing in the European Union (EU) and at national levels. Its goal is to increase the number of active corporates using renewable energy sourcing from 100 to 100,000.

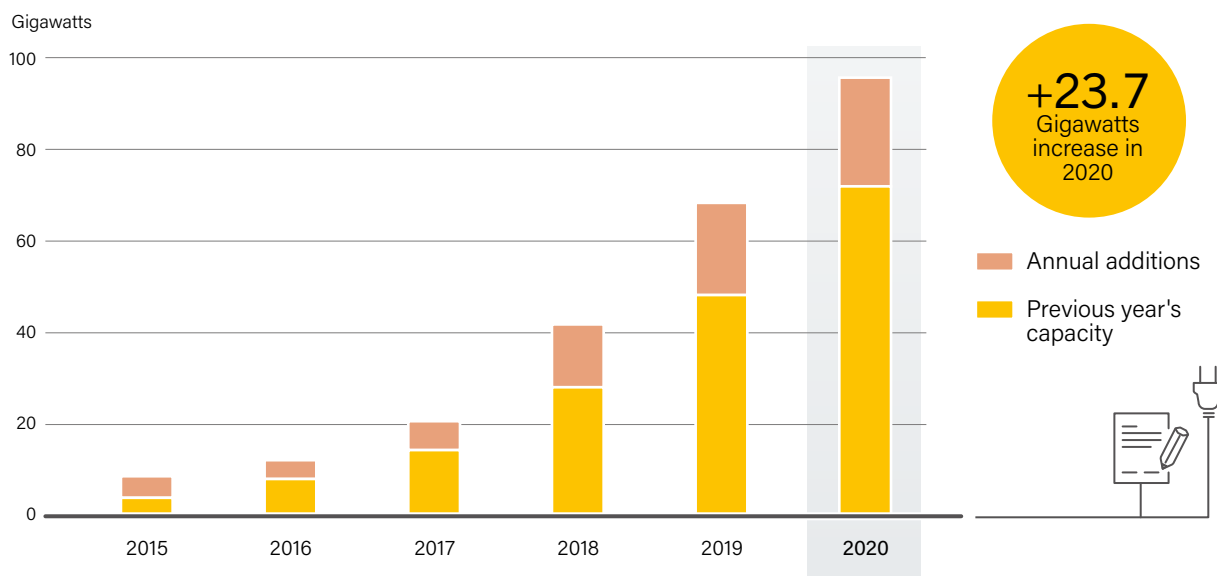
The Renewable Thermal Collaborative is a global coalition of companies, institutions and governments committed to scaling up renewable heating and cooling at their facilities. Its members identify market barriers and aim to use their collective purchasing power to reduce costs and scale deployment of these technologies.

Additional organisations leveraging business demand for renewables include:

- We Mean Business, a global non-profit coalition working with businesses to set science-based emission reduction targets, to identify and prioritise government policies, and to organise public-private partnerships;
- the Mission Possible Partnership, which aims to decarbonise some of the highest-emitting sectors by convening coalitions such as Clean Skies for Tomorrow (aviation), the Getting to Zero Coalition (shipping), the Clean Cement and Concrete Coalition, the Net-Zero Steel Initiative and more;
- the RE-Users platform in Japan, which allows corporate energy users to share information and best practices to accelerate renewable procurement in the country and also organises annual summits; and
- four initiatives by The Climate Group – RE100, EV100, EP100 and SteelZero – that aim to source renewable electricity, buy electric vehicles, improve energy productivity and create demand for low-carbon steel.

Source: See endnote 15 for this chapter.

**FIGURE 62.** Corporate Renewable Energy PPAs, Global Capacity and Annual Additions, 2015-2020



Note: Data are provided in direct current (DC) and do not include on-site power purchase agreements (PPAs).  
 Source: BloombergNEF. See endnote 21 for this chapter.

Trends in corporate sourcing markets that began two or three years ago continued in 2020.<sup>26</sup> Companies had already started to seek more flexible terms in PPA contracts to account for potential changes in technology, policy and new generating capacity that could affect market prices over the lifespan of the agreement. In addition, buyers began demanding that energy providers offer contracts for a shorter term than the standard 10-year agreement.<sup>27</sup>

An increasing number of companies began adopting a “24/7 consumption matching” approach, where the supply of electricity matches real-time demand.<sup>28</sup> This load balancing depends on the smart management of wind and solar energy supported by energy storage.<sup>29</sup> Deals in 2020 included agreements between Microsoft (US) and Swedish energy provider Vattenfall, and between Daimler (Germany) and Norwegian energy company Statkraft.<sup>30</sup> Also during the year, Google announced a goal to source its power on a 24/7 basis and introduced a new computing system, shifting data centre tasks to optimal times for wind and solar power generation.<sup>31</sup>

Companies also have started attempting to decarbonise their **supply chains**, addressing emissions for which they are indirectly responsible. Corporate sourcing previously had focused mainly on emissions generated directly by a company, as well as emissions from energy producers that supply the company’s energy needs. However, a growing number of large companies are requiring their supply chain partners, both upstream and downstream, to power their operations with renewable energy.<sup>32</sup>

As of early 2021, more than 40 of Apple’s major suppliers had signed on to the company’s Supplier Clean Energy Programme, which covered 4 GW of power capacity in 2020.<sup>33</sup> For smaller supplier companies, however, securing PPAs on the same

favourable terms as large companies has been a challenge, due to a lack of resources and market leverage.<sup>34</sup> Aggregation deals involving the major company itself have provided one solution.<sup>35</sup>

Regionally, national energy regulators across the EU further harmonised their rules to enable the use of cross-border PPAs, with the aim of creating a unified large market similar to that in the United States.<sup>36</sup> In Europe, corporate buyers and energy suppliers are often in different countries, and they face different national regulations that may be incompatible; they also may be hindered by the lack of cross-border grid connections.<sup>37</sup> To address some of these challenges, a single European market for cross-border PPAs was under development at the end of 2020, spurred by the EU’s new Renewable Energy Directive and by the European Green Deal.<sup>38</sup>

Challenges remain to corporate sourcing in regions beyond the leading markets of the United States and Europe. While the Asia-Pacific region reported the largest increase in RE100 membership in both 2019 and 2020, companies in the region identified regulatory and market barriers, including the relatively high costs of renewable power technologies as a result of unfavourable policy frameworks.<sup>39</sup> Elsewhere, a major challenge has been limited or no availability of corporate sourcing mechanisms, such as in Argentina, China, Chinese Taipei, New Zealand, the Republic of Korea, the Russian Federation and Singapore.<sup>40</sup>

Capacity of new renewable corporate PPAs increased 18% in 2020.



## COMPANY EXAMPLES AND BUSINESS GROUPS

Corporate sourcing of renewable electricity increased in 2020, particularly among larger firms. Many are part of the RE100 group, whose membership grew by more than 60 companies in 2020.<sup>41</sup> Amazon was the leading corporate PPA buyer in 2020 with 5.1 GW (3.1 GW of solar photovoltaic (PV) power and 2.0 GW of wind power) (→ see *Box 10*), followed by Total (3.0 GW) and Taiwan Semiconductor Manufacturing Company (TSMC, 1.2 GW).<sup>42</sup> TSMC signed the world's largest PPA on record



(920 megawatts, MW) with the Danish energy provider Ørsted for an offshore wind power project to be built off the coast of Chinese Taipei.<sup>43</sup>

On a cumulative basis, Amazon moved into first place during the year with 7.5 GW of corporate PPAs, ahead of Google (6.6 GW) and Facebook (5.9 GW).<sup>44</sup> Also notable was an aggregation PPA involving Honda, AT&T, McDonald's, Google and several other firms for 1.3 GW of solar power from the US developer Invenery.<sup>45</sup>

Information and communication technology (ICT) companies have accounted for around half of the global corporate sourcing of renewables in recent years.<sup>46</sup> The burgeoning growth in their data centres and data transmission networks has created a rapidly expanding demand for electricity, accounting for around 1% of global electricity consumption in 2020.<sup>47</sup> The ICT sector has become a focus of both corporate sourcing activity and innovation. For example, in 2020, Microsoft experimented with using renewable hydrogen<sup>i</sup> to power fuel cells at some of its data centres, and plans to use it instead of diesel generators to provide back-up power capacity.<sup>48</sup>

i Renewable hydrogen refers to hydrogen produced through water electrolysis using renewable electricity. (→ See *Systems Integration* chapter.)

### BOX 10. Amazon's Sourcing of Renewable Electricity

Amazon (US) became the world's leading corporate sourcing firm in 2020, completing 26 new projects across eight countries and four continents during the year, for a total of 127 projects worldwide. The largest deal signed in 2020 (and the largest offshore wind corporate PPA in Europe to date) was a 10-year PPA for 250 MW from Ørsted's planned 900 MW Borkum Riffgrund 3 offshore wind farm in Germany<sup>i</sup>. Amazon also signed PPAs for 650 MW of solar PV from French utility ENGIE. In February 2021, Amazon's largest single renewable energy investment to date was a PPA with the Shell-HKN Offshore Wind project for 380 MW (half the project's total capacity) in the Netherlands, expected to come online in 2024.

Amazon's stated objective is to power all of its offices and distribution and data centres with renewables by 2030 and to become net zero in its energy needs by 2040. In 2019, the company co-founded The Climate Pledge, a coalition of more than 50 large firms (as of early 2021) that are committed to becoming net zero carbon emission businesses by 2040. This includes meeting requirements for regular reporting on progress, decarbonisation strategies in line with the Paris Agreement (including renewable energy use across all sectors), and additional and quantifiable offsets. The initiative also includes a USD 2 billion fund to bring to market new renewable energy and energy efficiency technologies.

i The project is expected to be operational by 2025. In 2020, Ørsted also signed a large offshore wind PPA with TSMC.

Source: See endnote 42 for this chapter.



## RENEWABLE HEATING AND COOLING IN INDUSTRY



Several key industries use heating and cooling (thermal energy) processes, mainly for transforming raw material inputs into products. These include iron and steel, chemicals, cement, aluminium, paper and pulp, and food and tobacco. Renewables have made only limited inroads into many of these industrial sectors, representing around 10% of the total industrial thermal energy demand; of this renewable share, 90% comes from bioenergy sources.<sup>49</sup>

In 2020, industry accounted for 34% of total final energy consumption; of this, around three-quarters is in the form of direct thermal demand, with the rest in the form of electricity (some of it used to produce thermal energy).<sup>50</sup> Virtually all cooling in industry is done with electricity.<sup>51</sup> (→ See *Industry section in Global Overview chapter.*)

A range of renewable energy technologies exist for meeting industrial heating and cooling needs; they include renewables-

Environmental attribute certificate markets expanded to include thermal energy during 2020.

based electrification, renewable gases, and direct-use applications through geothermal heat, solar thermal heat and modern bioenergy.<sup>52</sup> Commercially and technically viable options for bioenergy use already exist in the food and tobacco and pulp and



paper industries, thanks to the availability of organic waste by-products and the lower process temperatures required.<sup>53</sup> In the aluminium and non-ferrous metals industry, both the use of electric arc furnaces and “sector coupling” opportunities for utilising renewable electricity are growing.<sup>54</sup>

However, the most energy-intensive industry sectors, such as steel, chemicals and cement, currently do not rely significantly on renewable heat. Each has its own specific thermal energy needs. Those with the highest temperature requirements generally have tended to rely heavily on fossil fuels, which have reached shares exceeding 80% in each of these three sectors.<sup>ii, 55</sup>

The business dynamics of industrial thermal energy are notably different from power generation, due mainly to the inherently high levels of self-consumption in industry.<sup>56</sup> Firms in the heating and cooling sector often operate in local markets, and energy often is produced directly at the point of demand.<sup>57</sup> As such, industrial energy users simultaneously produce and consume the thermal energy they need for heating and cooling on-site, without having to procure it from the market. Self-generation is thus the norm for thermal energy.

In thermal processes, procurement mechanisms for renewables that are similar to corporate sourcing of renewable electricity are rare, although some developments have emerged. Most projects for industrial renewable heat have involved the use of bioenergy and solar thermal heat. For example, in 2020 Elpitiya Plantations (Sri Lanka) met 87% of its heat demand using locally sourced modern bioenergy and third-party suppliers (→ see *Box 11*), and Goess Brewery (Austria) met 42% of its heat demand using renewables, including from solar thermal installations.<sup>58</sup> Worldwide, nearly 900 solar thermal systems totalling more than 792 megawatts-thermal were supplying industrial process heat by the end of 2020, with new projects concentrated in China, Mexico and Germany. (→ See *Solar Thermal section in Market and Industry chapter.*)

Another option for industry sectors that have lower-temperature heat requirements is to procure renewable thermal energy from district heating providers.<sup>59</sup> In 2020, Denmark’s largest industrial company, Danfoss, sourced 11% of the industrial thermal demand for its production processes from renewable district heating and recovery.<sup>60</sup> The company procures renewable thermal energy for many of its factories that manufacture energy efficiency technology and other products, with the aim of becoming carbon neutral in its heating and cooling needs globally by 2030.<sup>61</sup>

In 2020, the EU announced that its GO certificate system would extend beyond renewable electricity as of mid-2021 to include renewable heating and cooling, in line with the region’s Renewable Energy Directive and the European Green Deal.<sup>62</sup> In North America, a REC market for industrial thermal energy using biomethane and other “low-carbon fuels” was under development in 2020.<sup>63</sup> The market’s Green-e certified fuel certificate standard was being trialled on a small pilot basis in the region.<sup>64</sup>

i See Glossary.

ii The costs of converting these high-temperature processes to renewables are a major barrier, as the predominant energy source has been low-cost coal and coke, which are much less expensive than, for example, pelletised biomass fuels. The very large scale is also a barrier; for example, a large steel plant uses more energy than a large power station. (→ See *Industry section in Global Overview chapter.*)

### BOX 11. Elpitiya Plantations' Sourcing of Renewable Heat

Elpitiya Plantations PLC (EPP) is a Sri Lankan plantation firm operating across 13 estates and focused primarily on manufacturing tea and crepe rubber. EPP's main thermal energy need is heated air to wither and dry tea leaves. Operating temperatures for these processes range between 50 degrees Celsius (°C) and 100 °C. In rubber production, process heat is used to evaporate the surface moisture from the material.

EPP has developed a sustainability strategy formulated around six relevant United Nations Sustainable Development Goals, including Goal 7 on affordable and clean energy. EPP's target is to source 100% of its thermal energy consumption from self-produced sustainable biomass feedstocks by 2030. In 2020, EPP's annual biomass use for thermal applications represented 88% of the company's total energy consumption. EPP sourced 23% of this from its own biomass material – mainly uprooted rubber and eucalyptus trees – and procured the rest from other sustainable biomass suppliers.

EPP aims to increase reliance on its own biomass fuelwood through its Forestry Management Plan. By 2020, nearly 400 hectares of tree species had been grown for this purpose. However, given space constraints and the need to use the company's existing land to grow its commercial crops, EPP, like many plantation firms with similar renewable thermal energy goals, will still have to purchase significant biomass feedstocks from other suppliers.

Source: See endnote 58 for this chapter.



### COMPANY EXAMPLES AND BUSINESS GROUPS

The highest renewable energy shares in process heat are found in industries with lower temperature needs. However, some energy-intensive sectors that require high-temperature heat have launched initiatives to increase the use of renewables in some markets. Actions in the aluminium industry as of early 2021 included a commitment by BMW (Germany) to source aluminium produced using solar power, and the announcement by Norsk Hydro (Norway), an aluminium and renewable energy company, that it was exploring the development and use of renewable hydrogen for some of its aluminium plants.<sup>65</sup>

Projects to produce steel from renewable hydrogen were under development in Germany and Sweden, among other countries. In early 2021, German steel producer Salzgitter began operations using hydrogen produced from wind energy.<sup>66</sup> In Sweden, the HYBRIT demonstration plant is scheduled to start producing steel based on the direct reduced iron process using renewable hydrogen in 2026.<sup>67</sup> The commercial venture received strong state backing when it was launched in 2016 and is a 20-year, USD 46 billion collaboration among steel maker SSAB, the state-owned iron ore producer LKAB and the utility company Vattenfall.<sup>68</sup> In early 2021, Swedish firm H2 Green Steel announced that it also would produce steel using renewable hydrogen, beginning in 2024.<sup>69</sup>

i See Glossary.

A few business coalitions exist to support the use of renewables in industry. The Renewable Thermal Collaborative (RTC) commits members from both the public and private sectors to procure renewable thermal heat from suppliers, as well as to help promote the RTC's work in developing corporate sourcing markets and mechanisms for renewable heat.<sup>70</sup> In December 2020, Stanley Black and Decker (US) became the RTC's 21st member company.<sup>71</sup>

Also in December, The Climate Group, in partnership with the Responsible Steel initiative, launched SteelZero, the first business coalition of its kind in the industrial thermal energy sector.<sup>72</sup> SteelZero comprises firms that have committed to procure 100% net zero<sup>i</sup> steel by 2050 and that have made an intermediate commitment to procuring, specifying or stocking 50% of their net zero steel requirement by 2030.<sup>73</sup> SteelZero began with eight steel-buying company members, from sectors including construction, real estate and property development, steel production and renewable energy development.<sup>74</sup> While it aims primarily to drive business on the demand side, it also is lobbying for greater investment in renewable technologies and policies to facilitate the steel industry's transition to zero carbon.<sup>75</sup>



## RENEWABLES IN TRANSPORT



Energy use for transport comprises four main sectors: road, rail, maritime shipping and aviation. Although these sectors use varying amounts of renewable energy and face unique challenges, business demand for renewables generally increased across all sectors in 2020. (→ See *Transport section in Global Overview chapter, and Reference Table R19 in GSR 2021 Data Pack.*)

### ROAD TRANSPORT

Business demand for renewables in road transport mainly involves company vehicle fleets, including company cars, rental vehicles, short-haul or “last-mile” delivery vans, heavy-duty vehicles (such as long-haul freight trucks and refuse trucks), buses, taxis and special purpose vehicles. Fleet vehicles contribute half of all emissions from road transport worldwide, despite accounting for only 20% of global vehicle sales.<sup>76</sup>

Renewable energy can fuel road vehicles through the combustion of biofuels or renewable hydrogen in an internal engine, or by powering the vehicles with renewable-based electricity. Most business demand during 2020 was for electric vehicles (EVs), with many companies scaling up their fleets and committing to a shift to 100% EVs (although this was not necessarily linked directly to renewable electricity).<sup>77</sup> Demand from businesses seeking to use biofuels in commercial fleets also grew in certain markets, and bioenergy remained the largest renewable energy contributor in the transport sector.

In Europe, 6 out of 10 cars sold are company cars, but less than 4% of these were EVs in 2020.<sup>78</sup> By early 2021, fleet vehicles represented 59% of the EVs on European roads, but very few of these were electric heavy-duty vehicles, due mainly to a lack of such models in the market.<sup>79</sup> However, in early 2021 a range of new electric heavy-duty vehicles were scheduled for launch, including the Tesla Semi.<sup>80</sup> Uptake of liquefied biogas in

heavy-duty vehicles also increased in 2020, as infrastructure and investment in the technology grew, particularly in Scandinavia.<sup>81</sup>

Where companies have shown interest in electrifying their fleets, they have tended to first electrify a small share of vehicles to test driver sentiment and comfort, vehicle suitability, and depot charging capabilities (including the availability of charging station infrastructure). They also consider factors such as vehicle costs (especially relative to petrol/diesel fuel alternatives) and the total cost of ownership, as well as vehicle range, the operational considerations of integrating EVs into their fleets and financing models best suited to vehicle procurement.<sup>82</sup>

Emission standards also have helped to accelerate fleet electrification, especially among companies operating in the more than 300 “zero-emission zones” in cities worldwide.<sup>83</sup> Such standards and restrictions have influenced business decisions to invest in biogas for trucks as well in many regions.<sup>84</sup>

Company vehicle fleets have certain unique characteristics that make scaling up electrification particularly advantageous. These include the predictability of journeys, the constancy of distances travelled, fixed destinations and stopovers that support electric charging management. Given the high use rates for corporate fleet vehicles, their transition to electric also can make long-term economic sense because of the reduced servicing, maintenance and fuel costs associated with EVs.<sup>85</sup>

For hydrogen fuel cell vehicles, the business demand has been mainly for buses. As of early 2020, nearly all of the hydrogen produced worldwide was based on fossil fuels. However, some countries have begun adopting targets and policies to support renewable hydrogen specifically. (→ See *Systems Integration chapter, and Table 5 in Policy chapter.*) Investment in hydrogen fell 20% in 2020, to an estimated USD 1.5 billion.<sup>86</sup> This was driven by a COVID-induced slump in demand for hydrogen fuel cell buses, with investment falling from USD 865 million to USD 400 million.<sup>87</sup>





### Company Examples and Business Groups

Some companies took action to increase their direct use of renewables in road transport. In 2020, "MY Renewable Diesel", produced by Neste (Finland) from waste and residue raw materials, became available to businesses and private consumers at more than 500 fuelling stations across Europe and in the US states of California and Oregon.<sup>88</sup> IKEA Finland partnered with Neste to begin using MY Renewable Diesel as part of its broader strategy to achieve emission-free deliveries by 2025.<sup>89</sup> McDonald's Netherlands and the logistics company HAVI (Germany) also partnered with Neste to supply used cooking oil from McDonald's to make MY Renewable Diesel for HAVI's delivery trucks.<sup>90</sup> In addition, companies expanded their use of biogas: for example, Lidl partnered with IVECO, LC3 and Edison in early 2020 to introduce five biomethane-fuelled vehicles for use in Lidl's Italian fleet.<sup>91</sup>

Many companies also were using electric fleet vehicles based on renewable electricity. As of 2020, Deutsche Post DHL operated the largest EV fleet in Germany, and in early 2021 the company announced that it would power its entire delivery fleet of more than 80,000 vehicles with renewable electricity by 2030.<sup>92</sup> In the United States, a joint venture among First Student, First Transit and NextEra Energy Resources announced a plan in January 2021 to transition more than 55,000 buses across North America to renewably powered EVs.<sup>93</sup>

Business coalitions and collaborations have emerged to support decarbonised and electrified transport. As of early 2021, more than 100 companies had committed through EV100 to switching their fleets to electric and/or installing charging infrastructure by 2030.<sup>94</sup> The Transport Decarbonisation Alliance targets emission reductions in the road freight sector, which accounts for more than 60% of freight transport emissions; due to rising freight demand, these emissions are on track to double by 2050.<sup>95</sup> In the United States, the Drive to Zero programme works with buyer companies, energy providers and government agencies at the city, regional and national levels to promote business demand for zero-emission and near-zero-emission trucks, buses and other vehicles.<sup>96</sup>



### RAIL TRANSPORT

The rail transport industry comprises a mix of state-owned enterprises and private sector companies that develop and provide rail network infrastructure, manufacture trains and provide both passenger and freight services.<sup>97</sup> Rail is the most electrified transport sector globally, with around 75% of passenger rail and 50% of rail freight running on electric power as of 2019.<sup>98</sup> More than one-quarter of rail electricity worldwide is estimated to be renewable.<sup>99</sup> Business demand for renewables in rail transport has focused almost entirely on the direct use of biofuels and on renewable electricity, but developments also have occurred in renewable hydrogen.<sup>100</sup> At least two companies set targets for net zero carbon emissions during 2020: Indian Railways by 2030 and UK-based Network Rail by 2050.<sup>101</sup>

### Company Examples and Business Groups

Direct use of renewables in trains has been under way for some time. In 2007, Virgin Group (UK) launched Europe's first regular biofuel-powered passenger train service in the United Kingdom, and trains in parts of India have been running on biodiesel since at least 2015.<sup>102</sup> Florida Power and Light (US) began supplying biodiesel for high-speed inter-city rail service in 2017.<sup>103</sup> Also that year, Arriva (France) won a contract to provide 18 new biodiesel trains to the Netherlands starting in 2020, and successful trials were completed in July 2020.<sup>104</sup>

Rail freight companies that seek to decarbonise using renewable electricity can opt to procure electric-power trains from manufacturers; however, if they wish to source their electricity from renewables, they may have to depend on network infrastructure providers. In some cases, companies have invested directly in renewable power capacity to provide electricity for their activities. In early 2020, Amp Energy (India) partnered with Hyderabad Metro Rail to install a 7.8 MW solar PV plant to power the railway's operations.<sup>105</sup> Japan's largest railway company, East Japan Railway, began investing in solar power in 2013 for operational use, and in early 2021 the company announced plans to increase its share of renewable power in order to reach its target of zero carbon dioxide emissions by 2050.<sup>106</sup>

A growing number of rail companies have experimented with green hydrogen. Between February and March 2020, testing advanced on the world's first renewable hydrogen passenger train, as a group of French and Dutch companies<sup>i</sup> was able to successfully refuel the train in Groningen (Netherlands).<sup>107</sup> Energy company ENGIE (France) continued working with Gasunie (Netherlands) to develop a large-scale renewable hydrogen plant in Groningen, as a part of a long-term push to shift passenger trains in the northern Netherlands from diesel to green hydrogen.<sup>108</sup> In Italy, Enel Green Power and the transport firm FNM formed a joint venture in early 2021 to develop green hydrogen options for the rail network of Lombardy, as part of the H2lseO project to create a Hydrogen Valley in the province.<sup>109</sup>

<sup>i</sup> ENGIE refuelled the train, working alongside French train manufacturer Alstom, French rail services company Arriva, Dutch railway infrastructure agency ProRail and the independent testing organisation DEKRA.

## MARITIME SHIPPING

Business demand for renewables in maritime shipping has focused primarily on biofuels, with interest also growing in renewable hydrogen and ammonia.<sup>110</sup> In 2020, biofuels accounted for around 0.1% of the total global demand for shipping fuel.<sup>111</sup> Although biofuels have been more expensive compared to fossil-based options, cost differentials continued to narrow, leading them to be considered both a commercially and technically viable alternative.<sup>112</sup>

### Company Examples and Business Groups

A growing number of shipping companies have shown interest in increasing their use of renewable fuels, and some have completed successful voyages with them. In June 2020, a dredging vessel operated by Jan De Nul Group (Belgium) was the first to sail 2,000 hours on 100% renewable fuels, in collaboration with MAN Energy Solutions (Germany) and GoodFuels (Netherlands), marking the longest continuous use of 100% renewable fuels in the sector.<sup>113</sup> In March 2021, a Höegh Autoliners (Norway) vessel completed its first nearly carbon-neutral voyage between South Africa and Europe using advanced biofuels – reducing carbon emissions around 90% – and the company announced plans to scale up its procurement of shipping biofuels.<sup>114</sup>

Other companies were in the testing phase during 2020. The cargo firm Stena Bulk (Sweden) conducted a test voyage on a medium-range tanker ship using 100% biofuel (MR1-100) – based on waste cooking oil supplied by GoodFuels – and was able to reduce overall carbon emissions more than 80%.<sup>115</sup> Eastern Pacific Shipping (Singapore) also contracted with GoodFuels to supply biofuel bunkers for a medium-range tanker, with the

aim of trialling biofuels in other classes of ships in the near future.<sup>116</sup> Under the GoodShipping programme, automaker BMW (Germany) partnered with the shipping firm UECC (Norway) to test marine biofuel on UECC ships carrying BMW cars, with the goal of reducing emissions 80-90%.<sup>117</sup> Also in 2020, the Finnish firms SSAB Raahe, Gasum and ESL Shipping began testing the use of liquefied biogas in shipping, following agreements signed in 2019 by several Scandinavian shipping companies, including Preem (Sweden) and Hurtigruten (Norway), to use the fuel.<sup>118</sup>

Interest and activity in renewable hydrogen and ammonia also increased in the maritime sector.<sup>119</sup> In 2020, the HySHIP consortium, led by Norwegian shipping company Wilhelmsen, obtained EUR 8 million (USD 9.8 million) in EU funding to build a prototype ship powered by renewable hydrogen.<sup>120</sup> In addition, the ShipFC consortium of 14 European companies and institutions received EUR 10 million (USD 12.3 million) in EU funding to retrofit (in 2024) an offshore vessel with the world's first fuel cell powered by green ammonia.<sup>121</sup>

Maritime ports are working with shipping companies (and each other) to promote increased demand for renewable fuels. The World Ports Climate Action Programme, a coalition of 12 leading ports, aims to reduce carbon emissions from shipping and ports through the accelerated development of commercially viable "low-carbon fuels", among other steps.<sup>122</sup> In a different approach, 26 global shipping banks and top industry players from Asia, Europe and North America developed the Poseidon Principles to encourage more sustainable shipping practices, including greater use of renewables, in alignment with the International Maritime Organization's emission reduction goals.<sup>123</sup>



i Members include: Antwerp, Barcelona, Gothenburg, Hamburg, Le Havre, Long Beach, Los Angeles, New York and New Jersey, Rotterdam, Valencia, Vancouver and Yokohama.

ii In 2018, the International Maritime Organization, the international shipping regulatory body, set a goal of reducing greenhouse gas emissions in the sector 50% by 2050 (compared to 2008 levels), with carbon intensity reduction targets also set for 2030 and 2050.

## AVIATION

Business demand for renewable energy in aviation comes mainly from airline and airport companies. Sustainable aviation fuels (SAF)<sup>i</sup> have been developed primarily from bioenergy sources and technology, and e-fuels are produced from synthesising carbon dioxide (such as synthetic paraffinic kerosene, or SPK) and renewable hydrogen. The latter also can be used in fuel cells to power aviation systems based on electric propulsion.

The first flight using aviation biofuel was made in 2008, and by the end of 2020 more than 40 airlines had used SAF.<sup>124</sup> Since 2011, more than 315,000 commercial flights have flown on a blend of SAF, and 6 billion litres of the fuels have been purchased through forward purchase agreements.<sup>125</sup> However, SAF accounted for less than 0.1% of total aviation fuel demand in 2020.<sup>126</sup>

Biofuels used in aviation typically must be combined with fossil-based jet kerosene to achieve certain blend rates.<sup>127</sup> These blends could potentially reach 50% but in practice tend to be less than 1%, due to the relatively high cost of SAF (some of the fuels can cost five times their kerosene equivalent) and to the limited availability of even the most commercially viable aviation biofuels.<sup>128</sup> By the end of 2020, most SAF demand was in Europe and California (US), where dedicated policy incentives exist for SAF and other "low-carbon fuels".<sup>129</sup> Five airports worldwide – in Bergen, Brisbane, Los Angeles, Oslo and Stockholm – had facilities that regularly distributed SAF, while others offered semi-regular supply.<sup>130</sup>

Interest in the electrification of aviation has increased. As of May 2021, mostly just drones or small planes had been developed, although some companies were planning fully electric airliners to carry more than 120 passengers.<sup>131</sup> Others are aiming for hydrogen-powered electric planes.<sup>132</sup> So far, none of these ventures has had a direct link to renewable energy.

## Company Examples and Business Groups

Some airlines are boosting their sustainable aviation ambitions. In 2020, Scandinavian Airlines committed to running all domestic flights (representing less than 20% of the company's total fuel demand) on SAF by 2030.<sup>133</sup> KLM (Netherlands) is working with Amsterdam's Schiphol airport and fuel producer Neste to develop SAF supply facilities by 2022.<sup>134</sup> In 2020, British Airways, FinnAir, Lufthansa (Germany) and Virgin (UK) pledged to scale up their demand for aviation biofuel, as have air cargo carriers Amazon Air, FedEx and UPS (all US).<sup>135</sup> In addition, a few countries have conditioned their allocation of COVID-19 bailout funds to the aviation industry on a stronger commitment to renewable fuels. (→ See Sidebar 3 in Policy chapter.)

Companies also continued to develop electric and hydrogen aircraft, although in most cases these efforts do not specify the use of renewable energy. In 2020, Wright Electric announced the launch of an electric propulsion programme to develop a 186-seat aircraft for the carrier EasyJet.<sup>136</sup>

The business-based coalition Clean Skies for Tomorrow (CST) is committed to achieving broad adoption of SAF by 2030 and includes nearly 90 aviation companies, among them Airbus, Boeing, KLM Royal Dutch Airlines, Amsterdam's Schiphol Airport, London's Heathrow Airport, Shell, SkyNRG and SpiceJet.<sup>137</sup> CST is part of the broader Mission Possible Partnership developed by the World Economic Forum, the We Mean Business coalition, RMI and the Energy Transitions Commission. Its plan includes developing a mechanism to aggregate airline demand for aviation biofuel, similar to an aggregated corporate PPA for renewable electricity.<sup>138</sup>



Business demand for  
renewables  
in aviation and  
shipping

continued to advance at a  
slow pace.

FEATURE: BUSINESS  
DEMAND FOR RENEWABLES

i SAF are produced from renewable sustainable feedstocks from bioenergy sources.

ii These are customised contracts between two parties to buy or sell an asset at a specified price on a future date.



## ENERGY UNITS AND CONVERSION FACTORS

### METRIC PREFIXES

kilo	(k)	=	10 <sup>3</sup>
mega	(M)	=	10 <sup>6</sup>
giga	(G)	=	10 <sup>9</sup>
tera	(T)	=	10 <sup>12</sup>
peta	(P)	=	10 <sup>15</sup>
exa	(E)	=	10 <sup>18</sup>

### VOLUME

1 m <sup>3</sup>	=	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 m<sup>2</sup> = 0.7 GW<sub>th</sub>

Used where solar thermal heat data have been converted from square metres (m<sup>2</sup>) into gigawatts thermal (GW<sub>th</sub>), 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](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 five 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 annual developments for renewable energy technologies, market trends, policy developments and local perspectives. The questionnaire also collects data related to energy access from respondents with a focus on developing and emerging countries, covering the status of electrification and clean cooking, as well as policies and programmes for energy access and markets for distributed renewables. 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. 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.

- 3. 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.
- 4. 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.
- 5. 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 2021 report is the 16th 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 2020 data 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 2018 from IEA, *World Energy Balances*, 2020 edition (Paris: 2020).

**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 2018 from IEA, *World Energy Balances*, 2020 edition (Paris: 2020).

### NOTES ON RENEWABLE ENERGY IN TOTAL FINAL ENERGY CONSUMPTION, BY ENERGY USE

GSR 2021 presents an illustration of the share of renewable energy in total final energy consumption (TFEC) by sector in 2018. (→ See *Figure 4 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:

#### 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 4, 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 was intended to strengthen the accuracy of the representation. In total, the final energy consumption of all electrical energy accounted for 25.6% of TFEC in 2018.

## 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 2018, all electricity for heating and cooling met 7.8% of final energy demand in the sector (2.1% renewable and 5.7% 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 was

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, the GSR strives to provide the best and latest data available regarding bioenergy 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 Data<sup>i</sup>

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 1.6<sup>ii</sup>.

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 or pilot facilities and facilities of 5 MW or less are excluded. 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.

Revised gross additions for 2019 included in this GSR (26.1 GW<sub>th</sub>) are significantly lower than those published in GSR 2020 (31.3 GW<sub>th</sub>) for two reasons: First, the Chinese Solar Thermal Industry Federation (CSTIF) adjusted downwards its number for China's new additions in 2019, from 22.75 GW<sub>th</sub> (a preliminary figure, available as of early 2020) to 20 GW<sub>th</sub>. Second, data for new additions in China are based on produced collector area, rather than on annual installations in China; as a result, export volumes have been included in China's national statistics for 2020 and earlier years. In past editions of the GSR, this has resulted in a double counting of some collector area because the majority of coated vacuum tubes installed worldwide are purchased from China. For more details, see endnotes 1 and 5 in the Solar Thermal Heating section of the Market and Industry chapter.

### OTHER NOTES

Editorial content of this report closed by 31 May 2021 for technology data, and by 15 May 2021 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 2020 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.

<sup>i</sup> See Solar PV section of the Market and Industry chapter for sources on capacity data.

<sup>ii</sup> 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.** See Net zero emissions.

**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 emissions.** Can refer to all greenhouse gas emissions or only carbon emissions, and involves emissions declining to zero. Carbon neutral refers to the balancing of carbon emissions caused by an entity with funding an equivalent amount of carbon savings elsewhere. Although carbon neutrality is sometimes considered to be a synonym for net zero carbon emissions, carbon neutrality can be achieved at the domestic level by using offsets from other jurisdictions, whereas net zero does not necessarily include this feature.

**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 and energy efficiency improvements that can be repaid through increases on property taxes. It was originally conceived of in the United States but has been expanding worldwide.

**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.** 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 thermosyphon 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 (MWe) is used to refer to electric power, whereas a megawatt-thermal (MW<sub>th</sub>) 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	M&A	Mergers and acquisitions
AfDB	African Development Bank	m <sup>2</sup>	Square metre
AUD	Australian dollar	m <sup>3</sup>	Cubic metre
BEV	Battery electric vehicle	MENA	Middle East and North Africa
BloombergNEF	Bloomberg New Energy Finance	MJ	Megajoule
CCA	Community choice aggregation	MSW	Municipal solid waste
CHP	Combined heat and power	Mtoe	Megatonne of oil equivalent
CNY	Chinese yuan	MW/MWh	Megawatt/megawatt-hour
CO <sub>2</sub>	Carbon dioxide	MW <sub>th</sub>	Megawatt-thermal
COP	Conference of the Parties	NDC	Nationally Determined Contribution
CSP	Concentrating solar thermal power	O&M	Operations and maintenance
DC	Direct current	OECD	Organisation for Economic Co-operation and Development
DFI	Development finance institution	OTEC	Ocean thermal energy conversion
DHC	District heating and cooling	P2G	Power-to-gas
DOE	US Department of Energy	PACE	Property Assessed Clean Energy
DRE	Distributed renewable energy	PAYGo	Pay-as-you-go
DREA	Distributed renewables for energy access	PERC	Passivated Emitter Rear Cell
EC	European Commission	PHEV	Plug-in hybrid electric vehicle
ECOWAS	Economic Community of West African States	PJ	Petajoule
EGS	Enhanced (or engineered) geothermal systems	PPA	Power purchase agreement
EIA	Environmental impact assessment	PPP	Purchasing power parity
EJ	Exajoule	PTC	Production Tax Credit
ESCO	Energy service company	PV	Photovoltaic
EU	European Union (specifically the EU-27)	R&D	Research and development
EUR	Euro	REC	Renewable electricity certificate
EV	Electric vehicle	RED	EU Renewable Energy Directive
FAME	Fatty acid methyl esters	RFS	US Renewable Fuel Standard
FCEV	Fuel cell electric vehicle	RNG	Renewable natural gas
FIT	Feed-in tariff	RPS	Renewable portfolio standard
FS	Frankfurt School	SDG	Sustainable Development Goal
G20	Group of Twenty	SEforALL	Sustainable Energy for All
GDP	Gross domestic product	SEK	Swedish krona
GO	Guarantee of origin	SHC	Solar heating and cooling
GOGLA	Global association for the off-grid solar energy industry	SHIP	Solar heat for industrial processes
GNI	Gross national income	SUV	Sport utility vehicle
GSR	Global Status Report	TES	Thermal energy storage
GW/GWh	Gigawatt/gigawatt-hour	TFC	Total final consumption
GW <sub>th</sub>	Gigawatt-thermal	TFEC	Total final energy consumption
GWEC	Global Wind Energy Council	Toe	Tonne of oil equivalent
HEFA	Hydrotreated esters and fatty acids	TW/TWh	Terawatt/terawatt-hour
HJT	Heterojunction cell technology	UAE	United Arab Emirates
HVAC	Heating, ventilation, and air-conditioning	UN	United Nations
HVO	Hydrotreated vegetable oil	UNDP	United Nations Development Programme
ICAO	International Civil Aviation Organization	UNEP	United Nations Environment Programme
ICE	Internal combustion engine	UNFCCC	United Nations Framework Convention on Climate Change
IDCOL	Infrastructure Development Company Limited	dUSD	United States dollar
IEC	International Electrotechnical Commission	V2G	Vehicle-to-grid
IEA	International Energy Agency	VAT	Value-added tax
IEA PVPS	IEA Photovoltaic Power Systems Programme	VNM	Virtual net metering
IEA SHC	IEA Solar Heating and Cooling Programme	VRE	Variable renewable electricity
IFC	International Finance Corporation	W/Wh	Watt/watt-hour
IHA	International Hydropower Association	Yieldco	Yield company
IPP	Independent power producer	ZEV	Zero emission vehicle
ISCC	Integrated solar combined-cycle	USD	United States dollar
IRENA	International Renewable Energy Agency	V2G	Vehicle-to-grid
ITC	Investment Tax Credit	VAT	Value-added tax
ktoe	Kilotonne of oil equivalent	VC/PE	Venture capital and private equity
kW/kWh	Kilowatt/kilowatt-hour	VNM	Virtual net metering
kW <sub>th</sub>	kilowatt-thermal	VRE	Variable renewable electricity
LBG	Liquefied biogas	W/Wh	Watt/watt-hour
LCOE	Levelised cost of energy (or electricity)	WTO	World Trade Organization
LPG	Liquefied petroleum gas	ZEV	Zero emission vehicle
LNG	Liquefied natural gas		

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## GLOBAL OVERVIEW

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Of the companies represented in the figure, Eni was the only one that provided this number, under "Business of increasing renewable installed capacity" for 2020. Equinor's spending was calculated based on its self-reported 4% share of "Renewables and low carbon solutions" in its gross capital expenditure. ExxonMobil and Chevron reported on "Environmental capital expenditures" without clarifying what is included in this spending category. BP's renewables spending was reported under "non-oil and gas expenditure", which may conflate a range of spending categories including electric mobility. Shell reported on "Renewables and energy solutions", which includes power generation, trading and supply; hydrogen; and nature-based solutions. 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## POLICY LANDSCAPE

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## BIOENERGY

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## SOLAR PV

- 1 At least 139.4 gigawatts direct current (GW<sub>DC</sub>) was installed and commissioned globally for a year-end total of at least 760.4 GW<sub>DC</sub>, preliminary data from International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global PV Markets 2021* (Paris: April 2021), p. 6, [https://iea-pvps.org/wp-content/uploads/2021/04/IEA\\_PVPS\\_Snapshot\\_2021-V3.pdf](https://iea-pvps.org/wp-content/uploads/2021/04/IEA_PVPS_Snapshot_2021-V3.pdf), and confirmed by G. Masson, Becquerel Institute and IEA PVPS, Brussels, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 25 May 2021. Estimated 139.4 GW<sub>DC</sub> of capacity was installed and commissioned globally in 2020 (counting 136 GW of official or industry reported data for 60 countries plus an additional estimated 3.3 GW in the rest of the world) for a year-end global total of an estimated 760.4 GW<sub>DC</sub> (counting 745 GW of official or industry reported data for 69 countries plus an additional estimated and reported 15.2 GW in rest of world), based on preliminary reported data, from IEA PVPS and Becquerel Institute, Brussels, personal communication with REN21, March to May 2021. By contrast, global additions in 2019 totalled 111,585 MW<sub>DC</sub>, from IEA PVPS, *Trends in Photovoltaic Applications 2020* (Paris: 2020), p. 85, [https://iea-pvps.org/wp-content/uploads/2020/11/IEA\\_PVPS\\_Trends\\_Report\\_2020-1.pdf](https://iea-pvps.org/wp-content/uploads/2020/11/IEA_PVPS_Trends_Report_2020-1.pdf). Note that capacity data are uncertain due to several factors, including: a lack of good data in many countries, particularly with regard to small distributed systems, both on and off the grid; lack of information about the amount of capacity that has been decommissioned or is inoperable; large discrepancies between data available in alternating current (AC) and direct current (DC). With regard to the AC/DC issue, reported capacity data often do not specify if numbers are in AC or DC and, even where AC or DC is specified, the conversion rate is generally not published, all from Masson, op. cit. this note. Data from other sources include: additions of 135 GW in 2020 from BloombergNEF, *1Q 2021 Global PV Market Outlook*, cited in E. Bellini, "BloombergNEF expects up to 209 GW of new solar for this year", pv magazine, 23 February 2021, <https://www.pv-magazine.com/2021/02/23/bloombergnef-expects-up-to-209-gw-of-new-solar-for-this-year/>; market expanded 23% with almost 135 GW installed in 2020, from IEA, "Renewable electricity", in *Renewable Energy Market Update 2021* (Paris: 2021), <https://www.iea.org/reports/renewable-energy-market-update-2021/renewable-electricity>; net additions of 126,735 MW, including a mix of AC and DC, based on a total of 707,495 MW at the end of 2020 and 580,760 MW at the end of 2019, from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2021* (Abu Dhabi: March 2021), <https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021>; global installations were up 10% to 142 GW in 2020, from IHS Markit, cited in Reuters, "Solar installations on pace for biggest growth in five years, IHS Markit says", *Economic Times*, 30 March 2021, <https://energy.economictimes.indiatimes.com/news/renewable/solar-installations-on-pace-for-biggest-growth-in-five-years-ih-markit-says/81755484>; approximately 129.2-GW<sub>peak</sub> (DC) added for a global total of 722 GW<sub>p</sub>, based on shipments during 2020 and supply- and demand-side inventory, and considering losses due to poor quality and breakage in transport and installation, from P. Mints, SPV Market Research, San Francisco, CA, personal communication with REN21, 6 May 2021. Note that cumulative shipments from 1975 through 2020 totalled 722.8 GW direct current (or peak), from P. Mints, *Photovoltaic Manufacturer Capacity, Shipments, Price & Revenues 2020/2021* (San Francisco: SPV Market Research, April 2021), p. 15. The numbers published by IEA PVPS include all installations (both on-grid and off-grid) when reported, and 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. Further, while recycling numbers might also be helpful for determining capacity decommissioned, recycling programmes remain uncommon and data are extremely limited. 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 2021*, op. cit. this note, p. 13. Several countries report data officially in AC (i.e., Canada, Chile, Greece, India, Japan, Malaysia, Singapore, Spain, Sweden and the United States); these data were converted to DC by IEA PVPS, Becquerel Institute and other sources 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 60%, and most utility-scale solar PV plants built in 2020 have an AC-DC ratio between 1.1 and 1.6, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. this note, p. 11. MW<sub>peak</sub> or MW<sub>DC</sub> is the rated direct current of a solar system under solar standard test conditions; MW<sub>AC</sub>, measured in terms of alternating current, is the output a system is designed to deliver to the grid. Losses occur between the solar array and output to the grid, so capacity in AC will always be lower than peak capacity in DC. 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 (LBNL), December 2019), p. ii, [https://eta-publications.lbl.gov/sites/default/files/lbnl\\_utility\\_scale\\_solar\\_2019\\_edition\\_final.pdf](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: 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 across all solar PV capacity, and because the AC capacity of most countries is not available, GSR 2021 attempts to report all solar PV data in DC units; in addition, the GSR aims to report only capacity that has entered into operation by year's end.
- 2 See, for example, "Coronavirus cuts PV demand; lower loads lift operators' share", Reuters Events, 1 April 2020, <https://analysis.newenergyupdate.com/pv-insider/coronavirus-cuts-pv-demand-lower-loads-lift-operators-share/>; N. T. Prasad, "Indian solar industry confronts coronavirus crisis", Mercom India, 27 March 2020, <https://mercomindia.com/indian-solar-industry-coronavirus-crisis/>; IEA, "2020 and 2021 forecast overview", in *Renewable Energy Market Update: Outlook for 2020 and 2021* (Paris: May 2020), <https://www.iea.org/reports/renewable-energy-market-update/2020-and-2021-forecast-overview>.
- 3 See, for example, "Coronavirus cuts PV demand", op. cit. note 2; Prasad, op. cit. note 2; IEA, op. cit. note 2.
- 4 Below expectations in, for example, Europe, from SolarPower Europe, *EU Market Outlook for Solar Power 2020-2024* (Brussels: December 2020), p. 3, <https://www.solarpowereurope.org/european-market-outlook-for-solar-power-2020-2024/>; Israel, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 15. Largest increases in capacity based on data for 2020, as noted above, and historical data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85.
- 5 BloombergNEF, "Household solar demand surges through the roof in 2020", 23 October 2020, <https://about.bnef.com/blog/household-solar-demand-surges-through-the-roof-in-2020/>; "Solar power capacity in the U.S. will jump 43 percent this year", *New York Times*, 15 December 2020, <https://www.nytimes.com/live/2020/12/15/business/us-economy-coronavirus#solar-power-capacity-in-the-us-will-jump-43-percent-this-year>. See also country-specific information and sources below. The rooftop market grew particularly in Vietnam, as well as in Australia, Germany and the United States, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 12. Distributed definition in footnote from IEA PVPS, *Trends in Photovoltaic Applications 2019* (Paris: 2019), p. 9, [https://iea-pvps.org/trends\\_reports/2019-edition](https://iea-pvps.org/trends_reports/2019-edition).
- 6 Top three markets from various sources cited throughout this section, including IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1. Examples of other countries with noteworthy expansion include Australia, Brazil, Germany, Japan, the



- Netherlands, Poland, the Republic of Korea and the Russian Federation; see information and sources throughout this section. **Figure 25** based on historical data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 84–85, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 7 See, for example, IEA, *World Energy Outlook 2020, Executive Summary* (Paris: 2020), p. 18, [https://iea.blob.core.windows.net/assets/80d64d90-dc17-4a52-b41f-b14c9be1b995/WEO2020\\_ES.PDF](https://iea.blob.core.windows.net/assets/80d64d90-dc17-4a52-b41f-b14c9be1b995/WEO2020_ES.PDF). According to the IEA, “solar PV is consistently cheaper than new coal- or gas-fired power plants in most countries”, from idem. See also, for example, SolarPower Europe, *Global Market Outlook for Solar Power, 2019–2023* (Brussels: 2019), pp. 9, 13, <https://www.solarpowereurope.org/global-market-outlook-2019-2023>; 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](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>; 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-slowng-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>.
  - 8 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>.
  - 9 Figure of 20 in 2020 from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 7; up from 18 countries (Australia, Brazil, China, Chinese Taipei, Egypt, Germany, India, Japan, the Republic of Korea, Mexico, the Netherlands, Pakistan, South Africa, Spain, Ukraine, the United Arab Emirates, the United States and Vietnam) in 2019 based on preliminary estimates from IEA PVPS, *Snapshot of Global PV Markets 2020* (Paris: April 2020), p. 4, [https://iea-pvps.org/wp-content/uploads/2020/04/IEA\\_PVPS\\_Snapshot\\_2020.pdf](https://iea-pvps.org/wp-content/uploads/2020/04/IEA_PVPS_Snapshot_2020.pdf), and on data from Becquerel Institute, op. cit. note 1, 10 April 2020. Note that 16 countries added over 1 GW in 2019, up from 11 in 2018 and 9 in 2017, from SolarPower Europe, *Global Market Outlook for Solar Power 2020–2024* (Brussels: 2020), p. 5, <https://www.solarpowereurope.org/global-market-outlook-2020-2024>; up from 10 countries in 2018 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 9; 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](http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/2018_iea-pvps_report_2018.pdf); seven countries in 2016 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>.
  - 10 Figure of 42 countries at end of 2020 based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. This was up from 40 countries in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 4. As of the end of 2020, an estimated 95 countries had at least 10 MW of solar PV capacity installed, from F. Jackson, “Solar soars as emerging markets renewables investment hits record high”, *Forbes*, 9 December 2020, <https://www.forbes.com/sites/felicajackson/2020/12/09/solar-soars-as-emerging-markets-renewables-investment-hits-record-high>.
  - 11 IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 16. Based on cumulative capacity in operation at end-2019 and assumes close to optimum siting, orientation and long-term average weather conditions, from idem.
  - 12 **Honduras** sourced 11.2% of its net electricity generation from solar PV, based on data from Empresa Nacional de Energía Eléctrica, p. 7, *Boletín Estadístico – Diciembre 2020* (Tegucigalpa: 2020), <http://www.enee.hn/planificacion/2021/12%20diciembre.pdf>. **Germany’s** share of electricity production was 10.5% in 2020 (up from 9% in 2019), from Fraunhofer ISE, “Annual solar share of electricity production in Germany”, Energy-Charts, [https://energy-charts.info/charts/renewable\\_share/chart.htm?en&c=DE&share=solar\\_share&interval=year](https://energy-charts.info/charts/renewable_share/chart.htm?en&c=DE&share=solar_share&interval=year), updated 24 April 2021; solar PV generation accounted for 9.2% of Germany’s gross electricity consumption in 2020 (up from 8.0% in 2019), 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 2021) (Dessa-Roßlau: February 2021), pp. 45, 46, [https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare\\_Energien\\_in\\_Zahlen/Zeitreihen/zeitreihen.html](https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html). **Greece** based on 4,392 GWh of solar PV generation (including 494 GWh from rooftop systems) and 42,230 GWh of total electricity generation, from multiple original sources, all in Greek (including Manager of Renewable Energy Sources and Guarantees of Origin (DAPEEP SA), Μηνιαίο Δελτίο Ειδικού Λογαριασμού ΑΠΕ & ΣΗΘΥΑ, 2021, p. 15, [https://www.dapeep.gr/wp-content/uploads/ELAPE/2020/08\\_DEC\\_2020\\_DELTIO\\_ELAPE\\_v1.0\\_21.03.2021.pdf](https://www.dapeep.gr/wp-content/uploads/ELAPE/2020/08_DEC_2020_DELTIO_ELAPE_v1.0_21.03.2021.pdf), and total generation, based on data from the Greek Independent Power Transmission Operator (ADMIE), ΜΗΝΙΑΙΟ ΔΕΛΤΙΟ ΕΝΕΡΓΕΙΑΣ, 2021, pp. 3, 12, 13, 24, 35, [https://www.admie.gr/sites/default/files/attached-files/type-file/2021/03/Energy\\_Report\\_202012\\_v2.pdf](https://www.admie.gr/sites/default/files/attached-files/type-file/2021/03/Energy_Report_202012_v2.pdf), and provided by I. Tsiouridis, REDPro Consultants, Athens, personal communication with REN21, April 2021. **Australia** from Clean Energy Council, *Clean Energy Australia Report 2021* (Melbourne: April 2021), p. 9, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf>. **Chile** share of generation from Asociación Chilena de Energías Renovables y Almacenamiento AG. (ACERA), *Estadísticas Sector de Generación de Energía Eléctrica Renovable* (December 2020), p. 1, <https://acera.cl/wp-content/uploads/2021/01/2020-12-Bolet%C3%ADN-Estad%C3%ADsticas-ACERA.pdf>. **Italy** generated 25,549 GWh of electricity with solar PV in 2020, and total net production in the system was 273,108 GWh, for a solar PV share of 9.35%, from Terna, *Rapporto mensile sul Sistema Elettrico December 2020* (Rome: 2020), p. 9, [https://download.terna.it/terna/Rapporto\\_Mensile\\_Dicembre%202020\\_8d8b615dca4d4fe.pdf](https://download.terna.it/terna/Rapporto_Mensile_Dicembre%202020_8d8b615dca4d4fe.pdf). **Japan** from Institute for Sustainable Energy Policies (ISEP), “Share of electricity generated from renewable energy in 2020 (preliminary report)”, 12 April 2021, <https://www.isep.or.jp/en/1075>.
  - 13 Spain and United Kingdom from J. Parnell, “Clean air, clear skies and fresh megawatts cause Europe’s solar records to tumble”, Greentech Media, 22 April 2020, <https://www.greentechmedia.com/articles/read/clean-air-clear-skies-and-fresh-megawatts-see-europes-solar-records-tumble>; T. Barrett, “Less air pollution helps UK solar break generation record”, Air Quality News, 23 April 2020, <https://airqualitynews.com/2020/04/23/less-air-pollution-helps-uk-solar-generation-break-generation-record>; S. Vorrath, “Solar generation in Delhi ‘clearly’ boosted by clear skies of Covid lockdown”, RenewEconomy, 29 June 2020, <https://reneweconomy.com.au/solar-generation-in-delhi-clearly-boosted-by-clear-skies-of-covid-lockdown-22289>; United Arab Emirates from Middle East Solar Industry Association (MESIA), *Solar Outlook Report 2021* (Dubai: January 2021), p. 14, <https://mesia.com/information-center/research-papers-reports>. Note that sources also mention Germany, from J. Parnell, op. cit. this note, and from S. Hanley, “Clear skies over Germany lead to record amount of solar energy”, CleanTechnica, 22 April 2020, <https://cleantechnica.com/2020/04/22/clear-skies-over-germany-lead-to-record-amount-of-solar-energy>, but it appears that additional capacity was the main driver, along with generally sunny skies throughout the year, because output and capacity both increased by about the same percentage, from S. Hermann, German Environment Agency, Germany, personal communication with REN21, 13 April 2021. Also note that solar output declined in the United Kingdom for all of 2020, down 0.9% relative to 2019, from UK Department for Business, Energy & Industrial Strategy



- (BEIS), *Energy Trends – UK, October to December 2020 and 2020* (London: 25 March 2021), p. 17, [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/972790/Energy\\_Trends\\_March\\_2021.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972790/Energy_Trends_March_2021.pdf).
- 14 California output from E. F. Merchant, "California's wildfires hampered solar energy production in September", Greentech Media, 1 October 2020, <https://www.greentechmedia.com/articles/read/wildfires-in-california-undercut-solar-production-in-september>, and from S. York, "Smoke from California wildfires decreases solar generation in CAISO", Today in Energy, US EIA, 30 September 2020, <https://www.eia.gov/todayinenergy/detail.php?id=45336>. California variability and forecasting from California Independent System Operator (CAISO), cited in Merchant, op. cit. this note. In California, generation from large-scale solar projects (including concentrating solar power output) in the service territory of CAISO (which covers 90% of the state's utility solar capacity) in the first two weeks of September fell almost 30% below the July average, and 13% year-over-year, despite increased capacity, due to the increase in airborne particulate matter during wildfires, from Merchant, op. cit. this note, and York, op. cit. this note. Australia from Solar Trust Centre Team, "Understanding bushfires and their effect on solar output", Solar Trust Centre, 9 January 2020, <https://solartrustcentre.com.au/understanding-bushfires-and-their-effect-on-solar-output>.
- 15 SolarPower Europe, op. cit. note 4; IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, p. 91; grid infrastructure from IEA PVPS and Becquerel Institute, op. cit. note 1, 20 February 2020, from P. Mints, SPV Market Research, *The Solar Flare*, no. 4 (31 August 2019), pp. 8, 10, and from information and sources throughout this section. Financial and bankability challenges are issues of concern particularly in sub-Saharan Africa, from J. Nyokabi, Green Energy, Kenya, personal communication with REN21, 2 April 2021.
- 16 IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 34-35.
- 17 Lower than a decade ago but challenges remain, fossil and nuclear, from Masson, op. cit. note 1, 20 February 2020, 4 May 2020 and 9 March 2021; IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 17. Regarding utilities, in Brazil, for example, utilities have restricted approval and authorization of solar PV systems, saying that they lack the capacity to make grid connections, 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 India, distribution companies have pressured policy makers to remove net metering policies and adopt grid usage charges, from Bridge to India, "Bridge to India webinar – India rooftop solar policy round up", email received 2 December 2020. In Australia, the energy market operator has largely prevented attempts by electricity network operators to discriminate against and financially penalise solar customers, but in past years 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](https://iea-pvps.org/wp-content/uploads/2020/01/NSR_Australia_2018.pdf).
- 18 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 5.
- 19 IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 27, 56; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, pp. 48-56; Masson, op. cit. note 1, 9 March and 25 May 2021.
- 20 IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 28. US tax credits continued to play an important role, from Masson, op. cit. note 1, 9 March 2021.
- 21 IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 17, and information and sources throughout this section.
- 22 Masson, op. cit. note 1, 9 March 2021. In 2020, perhaps 20-30% of the market was installed without direct government incentives, although this does include some tenders that do not provide direct subsidies, from idem. Overall, about 5% of the market volume in 2019 was independent of government support schemes or "adequate regulatory framework", from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 28.
- 23 Eighth consecutive year based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, and from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1; Asia's share of additions and share without China, based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 24 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 25 Market and manufacturing from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 7, p. 89; share of additions in 2020 based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; share of additions in 2019 based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. China's share was 44% in 2018 (and 52% in 2017) from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 7, 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.
- 26 Top 10 countries, share of top 5 in 2020 and less concentrated based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; share in 2019 based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 12, 85. The share represented by the top 5 in 2018 was about 75%, 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](http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_T1_35_Snapshot2019-Report.pdf). The share represented by the top 5 in 2017 was 84%, based on global additions of at least 98 GW<sub>bc</sub>, 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](http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA_PVPS-A_Snapshot_of_Global_PV-1992-2017.pdf).
- 27 Figure for 2020 based on data of top 10 countries provided throughout this section. The figure for 2019 was 3.1 GW, based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. 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 26, p. 7, and from 954 MW in 2017, 683 MW in 2016, and 675 MW in 2015, all based on data from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 9, p. 13.
- 28 Leading countries for total capacity based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; leaders for capacity per inhabitant from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 7. **Figure 26** based on global and country-specific historical data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, and based on country-specific 2020 data and sources provided throughout this section for China, India, Japan and the United States. EU data for all years from Becquerel Institute, op. cit. note 1, 26 May 2021. India data from the following: data for 2010 and 2011 from European Photovoltaic Industry Association (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](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), [http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/PVPS\\_report\\_-\\_A\\_Snapshot\\_of\\_Global\\_PV\\_-\\_1992-2012\\_-\\_FINAL\\_4.pdf](http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/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), [http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/PVPS\\_report\\_-\\_A\\_Snapshot\\_of\\_Global\\_PV\\_-\\_1992-2013\\_-\\_final\\_3.pdf](http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/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), [http://www.iea-pvps.org/fileadmin/dam/public/report/national/Trends\\_2016\\_-\\_mr.pdf](http://www.iea-pvps.org/fileadmin/dam/public/report/national/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 IEA PVPS and Becquerel Institute, op. cit. note 1, 3 June 2019 and 4 May 2020; and data for 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 10.
- 29 China added 48.2 GW for a total of 253.4 GW, from China National Energy Administration (NEA), "National Energy Administration releases 2020 national power industry statistics", 20 January 2021, [http://www.nea.gov.cn/2021-01/20/c\\_139683739.htm](http://www.nea.gov.cn/2021-01/20/c_139683739.htm) (using Google Translate); added 48.2 GW (including 32.68 GW in centralised power stations and 15.52 GW in distributed systems) in 2020 for a year-end total of 253 GW, from National Energy Board, cited in NEA, "Transcript of the online press conference of the National Energy Administration in the first quarter of 2021", 30 January 2021, [http://www.nea.gov.cn/2021-01/30/c\\_139708580.htm](http://www.nea.gov.cn/2021-01/30/c_139708580.htm) (using Google Translate); and added 48.2 GW for a total of 253.4 GW from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Second only to 2017 based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. Distributed solar PV in China description in footnote based on the following: F. Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 22 April 2019; AECEA, "Briefing Paper – China Solar PV Development", September 2017 (provided by Haugwitz, AECEA); AECEA, "China 2017 – what a year with 53 GW of added solar PV! What's in for 2018!" Briefing Paper – China Solar PV Development, January 2018 (provided by Haugwitz, AECEA); A. Rajeshwari, "China's solar PV installations reach almost 10 GW in Q1 of 2018", Mercom India, 26 April 2018, <https://mercomindia.com/china-solar-10gw-q1-2018>.
  - 30 Increase of 60% based on 48.2 GW added in 2020 and on 30.1 GW added in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1. Two years of contraction based on additions 52.86 GW in 2017, followed by annual additions of 44.26 GW in 2018 and 30.1 GW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. Delays and disruptions, from EurObserv'ER, *Photovoltaic Barometer* (Paris: April 2020), p. 4, <https://www.eurobserv-er.org/category/all-photovoltaic-barometers>. China's solar PV market contracted in 2018 and 2019 because the government temporarily halted subsidy allocations and announced (in 2018) a transition to auctions. In 2020, projects awarded under competitive auctions in mid-2019 and mid-2020 (when almost 26 GW was awarded) were coming online before the phase-out of subsidies for all but residential applications at end of 2020. Residential systems are to receive financial support through the end of 2021, from IEA, "Solar PV", in *Renewables 2020* (Paris: 2020), <https://www.iea.org/reports/renewables-2020/solar-pv>.
  - 31 National Energy Board, op. cit. note 29.
  - 32 "Multi-pictures: Overview of the details of photovoltaic and wind power installed capacity and power generation in various provinces across the country", 360doc.com, 17 February 2021, [http://www.360doc.com/content/21/0217/07/73752269\\_962367138.shtml](http://www.360doc.com/content/21/0217/07/73752269_962367138.shtml) (using Google Translate).
  - 33 Year-end total of 253.4 GW, from China NEA, op. cit. note 29, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; total of 253 GW, from National Energy Board, op. cit. note 29. Total grid-connected capacity increased from 204,180 MW in 2019 to 253,430 MW at end-2020, a net increase of 49,250 MW, from official data and based on 204,180 MW of grid-connected capacity in operation at end of 2019 and 253,430 MW in operation at end of 2020, from China Electricity Council (CEC), cited in China Energy Portal, "2020 electricity & other energy statistics (preliminary)", 22 January 2021, <https://chinaenergyportal.org/en/2020-electricity-other-energy-statistics-preliminary>. Note that data are preliminary and based on grid-connected capacity; in addition, "Due to differences in statistical standards, confirmation of moment of grid connection, and other reasons, there are certain discrepancies in data on total and newly installed generation capacity", from CEC, cited in idem. Target for 2020 from Haugwitz, op. cit. note 29, 4 January 2021.
  - 34 IEA, op. cit. note 30.
  - 35 Deficit and backlog from Everchem, "Chinese wind subsidies to end in December China's renewable power price and subsidy: 'new' design in 2020?" 28 October 2020/29 January 2020, <https://everchem.com/chinese-wind-subsidies-to-end-in-december>; worsened by pandemic and subsidy free from G. Baiyu, "Despite coronavirus, China aims for renewables grid parity", China Dialogue, 2 June 2020, <https://chinadialogue.net/en/energy/despite-coronavirus-china-aims-for-renewables-grid-parity>. The cumulative deficit for all renewables amounted to the equivalent of USD 50 billion at the end of 2020, from Credit Suisse, cited in J. Wong, "China's green-power funding is blowing in the wind", *Wall Street Journal*, 21 April 2021, <https://www.wsj.com/articles/chinas-green-power-funding-is-blowing-in-the-wind-11619003815>. One source notes that wind and solar power projects benefit from lower technology costs, but other costs – such as curtailment, taxes on land, financing and initial development – remain high (accounting for 20% or more of wind and solar power project costs) and are barriers to grid parity, from Baiyu, op. cit. this note.
  - 36 Based on additions of 32.7 GW in 2020, from China NEA, provided by Haugwitz, op. cit. note 29, 25 February 2021, and on additions of 17.9 GW in 2019, from China NEA, "PV grid-connected operation in 2019", 28 February 2020, [http://www.nea.gov.cn/2020-02/28/c\\_138827923.htm](http://www.nea.gov.cn/2020-02/28/c_138827923.htm) (using Google Translate).
  - 37 "China's great energy shift sets mega hybrid plants in motion", Bloomberg, 12 May 2020, <https://www.bloomberg.com/news/articles/2020-05-12/china-s-great-energy-shift-sets-mega-hybrid-projects-in-motion>.
  - 38 Z. Shahan, "China's largest solar-plus-storage project goes online", CleanTechnica, 1 October 2020, <https://cleantechnica.com/2020/10/01/chinas-largest-solar-plus-storage-project-goes-online>; E. Bellini, "World's largest solar plant goes online in China – 2.2 GW", pv magazine, 2 October 2020, <https://pv-magazine-usa.com/2020/10/02/worlds-largest-solar-plant-goes-online-in-china>; G. Wilson, "Sungrow connects China's largest solar-plus-storage project", Business Chief, 30 September 2020, <https://medium.com/business-chief/sungrow-connects-chinas-largest-solar-plus-storage-project-565f73faf3bc>.
  - 39 Based on additions of 15.5 GW in 2020 (10.1 GW residential and 5.4 GW commercial and industrial), from China NEA, provided by Haugwitz, op. cit. note 29, 25 February 2021, and on additions of 12.2 GW in 2019 (5.3 GW residential and 6.9 GW commercial and industrial), from China NEA, "PV grid-connected operation in 2019", op. cit. note 36.
  - 40 Haugwitz, op. cit. note 29, 4 January 2021.
  - 41 Figure of 2% national average curtailment in 2020, from China NEA, provided by Haugwitz, op. cit. note 29; unchanged from 2019 from China NEA, "PV grid-connected operation in 2019", op. cit. note 36; national electricity consumption was down 6.5% in the first quarter of 2020, with curtailment reaching 2.8% in January and 5.6% in February, from Haugwitz, op. cit. note 29, 14 June 2020.
  - 42 National Energy Board, op. cit. note 29. Curtailment in Xinjiang fell 4.6% relative to 2019, down 2.8 percentage points, and in Gansu it fell 2.2%, down 2.0 percentage points, and across the entire region it declined to 4.8%, a year-on-year decrease of 1.1%, from idem.
  - 43 Haugwitz, op. cit. note 29, 14 June 2020.
  - 44 Based on total power production of 7,623,600 GWh and total solar production of 261,100 GWh (grid-connected capacity) in 2020, for a share of 3.4%, from CEC, cited in China Energy Portal, op. cit. note 33. This was up from just over 3% in 2019, based on total annual generation of 7,326,900 GWh and solar PV generation of 224,000 GWh, from idem. Note that, "Due to differences in statistical standards, confirmation of moment of grid connection, and other reasons, there are certain discrepancies in data on total and newly installed generation capacity", from CEC, cited in idem. Generation from solar PV was 260.5 TWh in 2020, from National Energy Board, op. cit. note 29. Also, note that China's solar data likely includes some generation from concentrating solar thermal power projects, but that is relatively small compared to solar PV. See CSP section in this chapter.
  - 45 Central government from China NEA guidance, provided by Haugwitz, op. cit. note 29, 25 February 2021. Governments at all levels from Haugwitz, op. cit. note 29, 7 September 2020. For example, Shaanxi province was offering subsidies for solar PV combined with electrical energy storage, from Haugwitz, op. cit. note 29, 25 February 2021.
  - 46 Haugwitz, op. cit. note 29, 14 November 2020. Provincial and local governments also strengthened existing policies and introduced new ones to support solar PV, particularly distributed systems. In January 2020 alone, 18 solar PV support policies were released

- across 14 provinces, with most of these related to distributed solar; in March, several provincial governments released solar PV policies and targets, all from Haugwitz, op. cit. note 29, 1 April 2020. In late 2020, several Chinese cities – including Beijing, Shanghai, Guangzhou and Xian – enacted policies to support solar PV; all of these except Beijing adopted feed-in tariffs, and Beijing began offering investment subsidies, from Haugwitz, op. cit. note 29, 25 February 2021.
- 47 Vietnam added 4.8 GW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1; Vietnam's additions in 2018 and 2017 from 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>; estimated total additions in 2020 of 11.1 GW for a total of 16.4 GW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; third and eighth place based on data and sources provided throughout this section. Vietnam installed 4,898 MW in 2019 and 11.5 GW in 2020, with rooftop solar PV accounting for about 9 GW, from T. Ha, "Renewables are booming in Vietnam. Will the upswing last?" Eco-Business, 13 April 2021, <https://www.eco-business.com/news/renewables-are-booming-in-vietnam-will-the-upswing-last/>; and Vietnam had 4,898 MW in operation at the end of 2019 and an estimated 16,504 MW at the end of 2020, from IRENA, op. cit. note 1. **Figure 27** based on historical global and country-specific data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; and on country-specific data and sources provided throughout this section.
- 48 Information for 2019 from, for example: E. A. Gunther, "Vietnam rooftop solar records major boom as more than 9GW installed in 2020", PV-Tech, 6 January 2021, <https://www.pv-tech.org/vietnam-rooftop-solar-records-major-boom-as-more-than-9gw-installed-in-2020>; GlobalData Energy, "Vietnam's solar drive", Power Technology, 30 July 2019, <https://www.power-technology.com/comment/vietnam-solar-drive>; S. Djunic, "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>; Maisch, op. cit. note 47; 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>; developments in 2020 from Vietnam Electricity (EVN) and the Viet Nam Energy Partnership Group, cited in Gunther, op. cit. this note. The rooftop market accelerated throughout 2020 and saw a sharp rise in December to qualify for the FIT2 tariff (USD 0.0838/kWh over 20 years for rooftop systems) before it expired at year's end, from idem.
- 49 Number of rooftop systems added in 2020 (82,900) and year-end rooftop solar PV capacity of 9.7 GW, from EVN / National Load Dispatch Centre of Vietnam (NLDC), provided by H. T. Tran, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Hanoi, personal communication with REN21, 11 April 2021; rooftop installations increased from a base of 378 MW<sub>DC</sub> at the end of 2019 to 9,583 MW at end of 2020, with 6,708 GW connected in December alone; at year's end, total operating capacity was 16,449 GW<sub>DC</sub> (13,160 GWAC), all from Vietnam Ministry of Industry and Trade, notice dated 31 December 2020, cited in Gunther, op. cit. note 48. Vietnam had installed a total of more than 101,939 rooftop systems with capacity of 9.3 GW as of 4 January 2021, from Electricity of Vietnam, "Vietnam to be the world's top 3 PV market with installed capacity exceeding 10GW", Nangluon Vietnam, 18 March 2021, <http://nangluongvietnam.vn/news/en/nuclear-renewable/vietnam-to-be-the-worlds-top-3-pv-market-with-installed-capacity-exceeding-10gw.html>. Note that total capacity at end-2020 was 19,400 MW<sub>DC</sub>, from EVN, "Rooftop solar power boom is underway with a total installed capacity reaching nearly 9,300 MWp", press release (Hanoi: 1 January 2021), <https://en.evn.com.vn/d6/news/Rooftop-solar-power-boom-is-underway-with-a-total-installed-capacity-reaching-nearly-9300-MWp-66-142-2169.aspx>; was 18.5 GW at the end of 2020, from EVN/NLDC and provided by Tran, op. cit. this note, and increased from 106 MW<sub>DC</sub> in 2018 to 19.4 GW<sub>DC</sub> at the end of 2020, from L. Stoker, "Unravelling the past, present and future of solar policy in Vietnam", PV-Tech, 17 March 2021, <https://www.pv-tech.org/unravelling-the-past-present-and-future-of-solar-policy-in-vietnam>.
- 50 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 48; ensure energy security and reduce carbon emissions from Ha, op. cit. note 47.
- 51 Ha, op. cit. note 47.
- 52 Rankings based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Japan had its best year since 2015, when the country added 10,811 MW, based on data from IEA PVPS, *Trends in Photovoltaic Applications 2021*, p. 85.
- 53 Four years of contraction based on data from IEA PVPS, *Trends in Photovoltaic Applications 2021*, p. 85, and 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; additions in 2020 and year-end total from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; increase based on 2019 additions from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. Figure of 8.2 GW<sub>DC</sub> (6.3 GWAC) also from RTS Corporation, cited in A. Bhambhani, "RTS Corporation says in 2020, Japan grew annual solar PV capacity by 17% to around 8.2 GW<sub>DC</sub> reaching cumulative of 71.7 GW<sub>DC</sub>", TaiyangNews, 20 January 2021, <http://taiyangnews.info/markets/japan-installed-8-gw-dc-new-solar-capacity-in-2020>.
- 54 M. Hall, "Japan's struggle to drive down renewables costs", pv magazine, 20 August 2020, <https://www.pv-magazine.com/2020/08/20/japans-struggle-to-drive-down-renewables-costs>; SolarPower Europe, op. cit. note 9, p. 80.
- 55 I. Kaizuka, "Agricultural PV emerges as Japan's next opportunity", pv magazine, 2 June 2020, <https://www.pv-magazine.com/2020/06/02/agricultural-pv-emerges-as-japans-next-opportunity>.
- 56 ISEP, op. cit. note 12. Shares include self-consumption.
- 57 Half of 2019 additions based on 10 GW added in 2019 from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1; lowest in five years from U. Gupta, "Tracking rooftop solar trends in India", pv magazine, 5 January 2021, <https://www.pv-magazine.com/2021/01/05/tracking-rooftop-solar-trends-in-india>. Investments fell 66% relative to 2019, to USD 2.8 billion (nearly USD 1.19 billion for utility-scale and USD 356 million for rooftop), from R. Ranjan, "Investments in the Indian solar sector declined by 66% in 2020", Mercom India, 1 March 2021, <https://mercomindia.com/investments-indian-solar-declined-2020>.
- 58 IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 10.
- 59 Based on preliminary data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. IEA PVPS and Becquerel Institute use official estimates (in AC) for ground-mounted capacity with a multiplier of 1.3 for conversion of centralised capacity to DC; rooftop and off-grid capacity are assumed to be in DC, from IEA PVPS and Becquerel Institute, op. cit. note 1, 23 April 2020. India added 3,865.48 MW in 2020 based on end-2019 capacity of 34,675.75MW and end-2020 capacity of 38,541.23 MW (all a mix of AC and DC), from Government of India, MNRE, "Physical progress – programme/scheme wise physical progress in 2019-20 & cumulative upto Dec, 2019", <https://mnre.gov.in/physical-progress-achievements>, viewed 9 January 2020, and data at end 2020 from Government of India, MNRE, "Physical progress – programme/scheme wise physical progress in 2020-21 & cumulative upto Dec, 2020", <https://mnre.gov.in/physical-progress-achievements>, viewed 3 February 2021. India's year-end solar power capacity was 37,464.6 MW (probably all in AC, although this is not specified), from Government of India, Ministry of Power, Central Electricity Authority (CEA), "All India installed capacity (in MW) of power stations (as on 31.12.2020) (utilities)", [https://cea.nic.in/wp-content/uploads/installed/2020/12/installed\\_capacity.pdf](https://cea.nic.in/wp-content/uploads/installed/2020/12/installed_capacity.pdf). Totals from MNRE and CEA are for all solar power, including off-grid solar PV, and also 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). The top states for total capacity at end-2020 were Karnataka (7.3 GW), Rajasthan (5.4 GW) and Tamil Nadu (4.3 GW) (probably all in AC),



- from Government of India, MNRE, "State-wise installed capacity of grid interactive renewable power as on 31.12.2020", [https://mnre.gov.in/img/documents/uploads/file\\_s-1612163907504.xlsx](https://mnre.gov.in/img/documents/uploads/file_s-1612163907504.xlsx), viewed 3 February 2021. India added 3.2 GW of solar PV capacity in 2020, from N. T. Prasad, "Solar generation in Q4 2020 9% higher from previous quarter, up 26% annually", Mercom India, 8 February 2021, <https://mercomindia.com/solar-generation-up-26-percent-annually>. (Mercom India data were confirmed to be provided in AC by S. Prateek, Mercom India, New Delhi, personal communication with REN21, May 2019.)
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- 63 Prasad, "Cost of large-scale and rooftop solar projects rose slightly in Q3 2020", op. cit. note 62; Prasad, "Top developments that influenced the rooftop solar segment in 2020", op. cit. note 62; Shukla, op. cit. note 62; Ranjan, op. cit. note 61. See also Ranjan, "Committee on Energy skeptical about India's chances of meeting its 2022 solar target", op. cit. note 60.
- 64 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, provided by A. Detollenaere, Brussels, personal communication with REN21, 22 March and 20 April 2021. As of September 2020, several projects ranging in size from 5 MW to 61 MW had secured licences in the Philippines, from E. Bellini, "Three 1.2 GW solar projects under development in the Philippines", pv magazine, 4 September 2020, <https://www.pv-magazine.com/2020/09/04/three-1-2-gw-solar-projects-under-development-in-the-philippines>; by end-2020, more than 1 GW of solar projects under PPAs were planned for installation in 2021 by a single developer, from E. Bellini, "Philippines to host 1 GW of solar under PPAs", pv magazine, 9 December 2020, <https://www.pv-magazine.com/2020/12/09/philippines-to-host-1-gw-of-solar-under-ppas>.
- 65 Based on data for 2020 from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; rankings for 2019 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 9, and from Becquerel Institute, op. cit. note 1, 10 April 2020.
- 66 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Turkey connected an estimated 672 MWAC to the grid in 2020 for total of 6,667.4 MWAC from Turkish grid operator TEIAS, cited in E. Bellini, "Turkey added 672 MW (AC) of PV capacity in 2020", pv magazine, 14 January 2021, <https://www.pv-magazine.com/2021/01/14/turkey-added-672-mw-ac-of-pv-capacity-in-2020>; but industry leaders believe the actual figure is 10-20% higher, from discrepancy with industry estimates from H. Karacaoglan, KRC Consulting (Germany), cited in idem.
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- 69 America's share based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, from National Renewable Energy Laboratory (NREL), provided by Masson, op. cit. note 1, 25 May 2021, and from Solar Energy Industries Association (SEIA) and Wood Mackenzie, *U.S. Solar Market Insight – 2020 Year in Review – Executive Summary* (Washington, DC: 2021), p. 5, <https://www.seia.org/research-resources/solar-market-insight-report-2020-year-review>. **Figure 28** based on IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, on Becquerel Institute, op. cit. note 1, and on country-specific data and sources provided throughout this section.
- 70 The United States added 19.2 GW for a total of 95.5 GW (all in DC), from NREL, op. cit. note 69. The United States added 19,221.11 MW in 2020, and increase over previous record year based on 15,103 MW installed in 2016, all from SEIA, "Solar industry research data", <https://www.seia.org/solar-industry-research-data>, viewed 16 March 2021; up over 2019 from SEIA and Wood Mackenzie, op. cit. note 69, p. 5; total year-end capacity was 97.7 GW, from SEIA, "U.S. solar market insight", <https://www.seia.org/us-solar-market-insight>, updated 16 March 2021, and was 97.2 GW, from SEIA, "Solar data cheat sheet", <https://www.seia.org/research-resources/solar-data-cheat-sheet>, updated 16 March 2021. Note that these data are all provided in DC. The United States added an estimated 14,889.9 MW (4,510 MW of small-scale plus 10,379.9 MW of utility-scale facilities) of solar PV capacity in 2020, for a year-end total of 73,813.7 MW at end-2020, from US EIA, *Electric Power Monthly with Data for December 2020* (Washington, DC: February 2021), Table 6.1, <https://www.eia.gov/electricity/monthly/archive/february2021.pdf>. These data omit capacity from facilities with a total generator nameplate capacity less than 1 MW, from idem. In addition, the 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. Finally, note that total US solar PV capacity exceeded 76 GW at the end of 2019, from 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>.
- 71 SEIA and Wood Mackenzie, op. cit. note 69, pp. 5, 6. If counting only capacity additions, solar PV accounted for 42.2% based on total solar PV capacity additions of 14,889.9, followed by wind power (14,172.9 MW), natural gas (6,022.6 MW), hydropower (173.3 MW), geothermal (31.8 MW) and biopower (8.8 MW), all from US EIA, op. cit. note 70, Table 6.1. Note that these figures do not account for more than 13 GW of capacity taken offline in 2020, most of which was conventional steam coal, from idem.
- 72 SEIA and Wood Mackenzie, op. cit. note 69, pp. 6, 8. California added 3,904 MW, followed by Texas (3,425 MW) and Florida (2,822 MW); Virginia was fourth, adding 1,406 MW, and all of these states saw increases relative to 2019, from idem, p. 8.
- 73 Calculated based on solar PV net generation in 2020 from utility-scale systems (87,743 GWh) and from small-scale systems (41,740 GWh), both from US EIA, op. cit. note 70, Table 1.1.A, and on total utility-scale facility net generation of 4,009,085 GWh (plus previously noted small-scale solar PV generation), from idem, Table 1.3.B.

- 74 Based on 8.4 GW of utility-scale capacity added in 2019, from SEIA and Wood Mackenzie, op. cit. note 70, p. 9, and 14 GW added in 2020, from SEIA and Wood Mackenzie, op. cit. note 69, p. 5; total of 59,772 MW, from SEIA, "Solar Industry Research Data", op. cit. note 70.
- 75 SEIA and Wood Mackenzie, op. cit. note 69, p. 5. The solar investment tax credit was extended and will remain at 26% for projects that begin construction in 2021 and 2022; it will fall to 22% in 2023 and 10% in 2024 for commercial projects (and the residential credit will end), from D. Wagman, "US to extend Investment Tax Credit for solar to 2024", pv magazine, 22 December 2020, <https://www.pv-magazine.com/2020/12/22/us-to-extend-investment-tax-credit-for-solar-to-2024>. As of early 2021, another 11.2 GW was already under construction, from SEIA and Wood Mackenzie, op. cit. note 69, p. 14. Investment tax credit details, from SEIA, "Solar Investment Tax Credit (ITC)", <https://seia.org/initiatives/solar-investment-tax-credit-itc>, viewed 28 April 2021. The ITC, established in 2005, provided a 30% investment tax credit for projects that began construction by the end of 2019. The credit stepped down to 26% in 2020, and it was scheduled to drop to 22% in 2021 and 10% from 2022 onwards for commercial and utility projects, and residential systems owned by companies. However, at the end of 2020, the 26% credit was extended for two years. It will decline to 22% in 2023, and, in 2024, will fall to 10% for commercial and utility-scale systems and to zero for residential installations owned by homeowners.
- 76 SEIA and Wood Mackenzie, op. cit. note 69, p. 5.
- 77 Ibid., p. 14.
- 78 Third consecutive year, 4% decline relative to 2019, and non-residential installations of 2.1 GW (2,074 MW) in 2020, all from SEIA and Wood Mackenzie, op. cit. note 69, pp. 5, 13. Total non-residential capacity at end-2020, from SEIA, "Solar industry research data", op. cit. note 70. The non-residential market faced the worst pandemic-related delays of any US segment and struggled with development timelines, interconnections, permitting and approval processes at the local level, from SEIA and Wood Mackenzie, op. cit. note 69, pp. 5, 12.
- 79 The US residential sector installed 3,194 MW of capacity in 2020, from SEIA and Wood Mackenzie, op. cit. note 69, p. 5; year-end total of 19,078.5 MW, from SEIA, "Solar industry research data", op. cit. note 7.
- 80 E. F. Merchant, "The highs and lows for solar in 2020", Greentech Media, 30 December 2020, <https://www.greentechmedia.com/articles/read/the-highs-and-lows-for-solar-in-2020>. The SEIA said 65,000 jobs had been lost as of May, or the equivalent of five years of growth, and in June roofer and solar installer PetersenDean filed for Chapter 11 bankruptcy, from idem. Layoffs and bankruptcies were due largely to the inability to find customers through traditional door-to-door sales, from E. F. Merchant, "A new response to coronavirus: Giving solar away for free", Greentech Media, 23 April 2020, <https://www.greentechmedia.com/articles/read/one-response-to-the-coronavirus-giving-solar-away-for-free>. Shifting to online and price cuts also from idem; E. F. Merchant, "How the coronavirus pandemic has impacted US solar so far", Greentech Media, 28 September 2020, <https://www.greentechmedia.com/articles/read/how-the-coronavirus-pandemic-has-already-reshaped-u-s-solar>; E. F. Merchant, "SunPower halts all global manufacturing, cuts employee workweek", Greentech Media, 20 April 2020, <https://www.greentechmedia.com/articles/read/sunpower-halts-production-cuts-employee-workweek>. Sunrun, the leading US installer, had a limited-time lease contract offer of no money upfront and USD 1 per month for the first six months, from Merchant, "A new response to coronavirus", op. cit. this note. New customer acquisition models required additional investment but also enabled companies to reach a broader, larger audience, from SEIA and Wood Mackenzie, op. cit. note 69, p. 17.
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- 83 P. Mints, SPV Research, *The Solar Flare*, 22 December 2020, p. 6; S. Kim, "Why is California having rolling blackouts?" Newsweek, 19 August 2020, <https://www.newsweek.com/california-heat-wave-rolling-blackouts-power-outage-electricity-shortage-1526144>.
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- 88 ABSOLAR, "Energia solar fotovoltaica no Brasil – Infográfico ABSOLAR", no. 31 (4 May 2021), <https://www.absolar.org.br/mercado/infografico>. Challenging economic conditions (among top solar installers) in Argentina and Brazil, in particular, from I. Sagardoy, Fundacion 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. 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](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_RE-Auctions_Status-and-trends_2019.pdf). The priority of taking actions related to the pandemic led to delays in the discussion in Brazil of a legal framework for distributed generation in 2020, from Baitelo, op. cit. note 17, 31 March 2021.
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- 90 Mexico ended 2020 with an estimated 5,001 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Figure of 7.7 GW in Brazil, from ABSOLAR, op. cit. note 87.
- 91 Figure of 68.6% from ABSOLAR, op. cit. note 87.

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- 99 Chile's year-end capacity was 3,484 MW, with another 3,695 MW under construction and 15,520 MW approved, from ACERA, op. cit. note 12, pp. 3, 5.
- 100 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 101 Installations were up 11% over 2019, based on additions of 18.2 GW in 2020, from SolarPower Europe, op. cit. note 4, p. 3; and were up 23.7% in 2020 based on additions of 19.3 GW in 2020, from IEA PVPS and Becquerel Institute, op. cit. note 1, 6 May 2021, and additions of 15.9 GW in EU-27 and the United Kingdom in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 23, less the 0.3 GW installed in the United Kingdom in 2019, from UK BEIS, "Solar photovoltaics deployment in the UK", <https://www.gov.uk/government/statistics/solar-photovoltaics-deployment>, updated 30 January 2020.
- 102 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 103 Figure of 0.5 GW (545 MW) added and year-end total of 13.9 GW (13,873 MW), based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Figure of 4.1 GW in 2015, based on cumulative installed capacity of 5,528 MW at end-2014 and 9,601 MW at end-2015, from UK BEIS, "Renewable electricity capacity and generation", Table 6.1. Renewable electricity capacity and generation, <https://www.gov.uk/government/statistics/energy-trends-section-6-renewables>, viewed 16 April 2021. The country added 545 MW for a total of 13.9 GW in 2020, from Solar Energy UK, cited in M. Hall, "UK added 545 MW of solar last year to hit 13.9 GW", *pv magazine*, 21 January 2021, <https://www.pv-magazine.com/2021/01/21/uk-added-545-mw-of-solar-last-year-to-hit-13-9-gw>; added 217 MW in 2020 (down from 273 MW in 2019), from UK BEIS, op. cit. note 13, p. 16; and added 166 MW for a year-end total of 13,516 MW, from UK BEIS, op. cit. note 101, Table 1, viewed 16 April 2021. Note that the official statistics in the BEIS table 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. About 60% of new capacity in 2020 was in large-scale ground-mounted projects, and the remainder was in rooftop (mostly commercial) systems, from Solar Energy UK, cited in Hall, op. cit. this note.
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- 108 EurObserv'ER, op. cit. note 30, p. 15. The year 2019 saw the first major projects commissioned in Europe that were without direct subsidies and outside of volumes allocated for auctions (under PPAs), from idem, p. 11.
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- 110 All challenges except land availability from Gilligan, op. cit. note 109; land availability from, for example, "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>; land availability and grid constraints from SolarPower Europe, op. cit. note 109, pp. 50, 76; Solarplaza, *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*, no. 5, op. cit. note 25, p. 28.
- 111 SolarPower Europe, op. cit. note 4, p. 5. However, this share was down from 79% installed in the top five countries in 2019, from idem.
- 112 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 6. France added 0.9 GW, from idem. Additions were the Netherlands (2.8 GW), Spain (2.6 GW), Poland (2.2 GW) and France (0.9 GW), from SolarPower Europe, op. cit. note 4, p. 5. Belgium became a gigawatt market for the first time in 2020, from R. Rossi, SolarPower Europe, Brussels, personal communication with REN21, 25 May 2021.
- 113 SolarPower Europe, op. cit. note 4, p. 20, and based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Italy added 0.8 GW for a year-end total of 21.7 GW, from Becquerel Institute, op. cit. note 1.
- 114 Increase relative to 2019 based on Germany added 3,835 MW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, p. 85; added 4,885 MW for a total of 53,932 MW in 2020, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Germany added 4.8 GW in 2020 for total of 54.6 GW, from SolarPower Europe, op. cit. note 4, pp. 5, 20. In 2020, Germany added 4.88 GW for total of 53.6 GW; by comparison, annual additions were 3.94 GW in 2019, 2.96 GW in 2018 and 1.75 GW in 2017, from German federal network agency, the Bundesnetzagentur, cited in S. Enkhart, "Germany installed 4.88 GW of solar in 2020", *pv magazine*, 1 February 2021, <https://www.pv-magazine.com/2021/02/01/germany-installed-4-88-gw-of-solar-in-2020>, and Germany added 4,801 MW for a year-end total of 53,848 MW, based on 49,047 MW at the end of 2019 and 53,848 MW at the end of 2020, from BMWi and AGEE-Stat, op. cit. note 12, p. 7.
- 115 Commercial share based on 2020 additions of 2,887 MW (up 6% over 2019 additions), from Bundesverband Solarwirtschaft e. V. (BSW-Solar), "Solar boom on private rooftops", 2 February 2021, <https://www.solarwirtschaft.de/en/2021/02/02/solar-boom-on-private-rooftops>.
- 116 Ibid. Share of annual market based on additions of 867 MW, from idem. Note that solar PV won nearly all auctioned capacity



- in technology-neutral tenders during the year, from SolarPower Europe, "Spotlight on GW EU solar markets: Germany comes out on top despite new EEG revision changing support policy framework", 2 February 2021, <https://www.solarpowereurope.org/spotlight-on-gw-eu-solar-markets-germany-on-top-despite-new-eeg-revision-changing-the-support-policy-framework>.
- 117 BSW-Solar, op. cit. note 115. Homeowners added 1,131 MW of capacity in systems up to 10 kW, from idem.
- 118 Roughly half from BSW-Solar, "Statistical Figures of the German Solar Power Industry (Storage / Mobility)" (Berlin: 2021), [https://www.solarwirtschaft.de/datawall/uploads/2021/02/BSW\\_Faktenblatt\\_Stromspeicher\\_Update\\_2020.pdf](https://www.solarwirtschaft.de/datawall/uploads/2021/02/BSW_Faktenblatt_Stromspeicher_Update_2020.pdf), and more than 90% of residential rooftop systems were installed with battery storage in 2020, from SolarPower Europe, *European Market Outlook for Residential Battery Storage 2020-2024* (Brussels: October 2020), p. 3, <https://www.solarpowereurope.org/european-market-outlook-for-residential-battery-storage>. The storage market was up 50% for third consecutive year, from BSW-Solar, "Solar battery boom", 18 February 2021, <https://www.solarwirtschaft.de/en/2021/02/18/solar-battery-boom>. Estimated total solar battery storage capacity of 1.9 GWh, based on data from EUPD Research (2020), *Energiewende im Kontext von Atom- und Kohleausstieg – Update 2020*, Berlin, cited in BSW-Solar, "Statistical Figures of the German Solar Power Industry (Storage/Mobility)", op. cit. this note; about 88,000 systems installed in 2020 for a total of 272,000 units, from idem; estimated total battery storage capacity at year's end was around 2.4 GWh, from BSW-Solar, "Solar battery boom", op. cit. this note. Residential storage linked to solar PV is supported in Germany with rebates, from P. Hannen, "Germany has 270,000 residential batteries linked to PV", 19 February 2021, <https://www.pv-magazine.com/2021/02/19/germany-has-270000-residential-batteries-linked-to-pv>.
- 119 Removed in July and Germany's capacity passed the 52 GW level in August 2020, from S. Enkhardt, "Germany breaches 52 GW mark with 409 MW of new solar in August", pv magazine, 1 October 2020, <https://www.pv-magazine.com/2020/10/01/germany-breaches-52-gw-mark-with-409-mw-of-new-solar-in-august>. The government pledged in September 2019 to lift the cap, but its removal was not official until July 2020. This delay is believed to have slowed installations of smaller rooftop systems in August (as Germany approached the 52 GW mark), the weakest month of 2020 (at least as of end-September), from idem. The revised feed-in law, which was enacted in December, maintains the feed-in payment for systems up to 300 kW and owners of systems 300-750 kW have two options: to receive the payment (at half the level of smaller systems) with permission to self-consume the electricity generation, or to build the project under the tender scheme for utility-scale solar PV and without the ability to self-consume, from Enkhardt, op. cit. note 114; S. Enkhardt, "Germany introduces new renewable energy law", pv magazine, 17 December 2020, <https://www.pv-magazine.com/2020/12/17/germany-introduces-new-renewable-energy-law>.
- 120 H. Shukla, "Germany's new Climate Action Plan focuses on augmenting solar and wind capacities", Mercom India, 24 September 2020, <https://mercomindia.com/germany-new-climate-action-plan/>; N. T. Prasad, "Germany's solar tender oversubscribed, lowest tariff dips to €0.049/kWh", Mercom India, 29 October 2020, <https://mercomindia.com/germany-solar-tender-oversubscribed>.
- 121 C. Menke, "Photovoltaics – the key to the energy transition", BSW-Solar, <https://www.solarwirtschaft.de/en/topics-of-interest/photovoltaics>, viewed 24 March 2021.
- 122 Figure of 50.6 TWh (gross generation) in 2020 (up from 46.4 TWh in 2019), from BMWI and AGEE-Stat, op. cit. note 12, p. 6; share of generation from Fraunhofer ISE, op. cit. note 12. Solar PV share of net generation for public electricity supply was 10%, from Bundesnetzagentur, cited in BSW-Solar (2021), "Statistical Figures of the German Solar Power Industry (Photovoltaics)", Berlin, [https://www.solarwirtschaft.de/datawall/uploads/2021/02/BSW\\_Faktenblatt\\_Photovoltaik\\_Update\\_2020-1.pdf](https://www.solarwirtschaft.de/datawall/uploads/2021/02/BSW_Faktenblatt_Photovoltaik_Update_2020-1.pdf). Solar PV generation was up from 45.8 TWh in 2018 and 46.4 TWh in 2019, from idem.
- 123 Steady growth from Dutch New Energy, *Nationaal Solar Trendrapport 2021*, cited in E. Bellini, "Netherlands deployed 2.93 GW of solar in 2020", pv magazine, 21 January 2021, <https://www.pv-magazine.com/2021/01/21/netherlands-deployed-2-93-gw-of-solar-in-2020>. In 2020, 2.93 GW added, up from 2.57 GW in 2019, 1.69 GW in 2018, 853 GW in 2017, for total of more than 10.1 GW, from idem. Drivers from SolarPower Europe, op. cit. note 4, p. 11.
- 124 The Netherlands added 3,036 MW for a total of 10,213 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; nearly half from SolarPower Europe, op. cit. note 4, p. 11. The year-end total was 9.2 GW, from idem, p. 20, and it was more than 10.1 GW, from Dutch New Energy, op. cit. note 123. Residential installations totalled 1.09 GW at end-2020, up from 873 GW in 2019, from idem. About 16 GW of additional capacity was under construction in the Netherlands at year's end, from idem.
- 125 SolarPower Europe, op. cit. note 4, p. 11.
- 126 Dutch New Energy, op. cit. note 123.
- 127 Spain added 2,806 MW in 2020 for a total of 12,716 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. This was down 40% based on additions of 4,751 MW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, p. 85, and down 18% based on 3,256 MW added in 2020 and 3.97 GW added in 2019, from APPA Renovables, cited in P. Sanchez Molina, "Spain installed 3.2 GW of solar last year", pv magazine, 15 February 2021, <https://www.pv-magazine.com/2021/02/15/spain-installed-3-2-gw-of-solar-last-year>. Spain had 8,914 MW<sub>AC</sub> at end of 2019 and 11,547 MW<sub>AC</sub> at the end of 2020, for a net increase of 2,633<sub>AC</sub>, from Red Eléctrica de España (REE), "Potencia instalada nacional (MW)", as of 31 December 2020, <https://www.ree.es/datos/publicaciones/series-estadisticas-nacionales>. Added 3,256 MW, including 623 MW distributed and 2,633 MW utility-scale projects, for a year-end total of about 11 GW (it is not known if these data are in AC or DC), from APPA Renovables, cited in Sanchez Molina, op. cit. this note.
- 128 SolarPower Europe, op. cit. note 4, p. 13. Private PPAs lacked direct government support, from Sanchez Molina, op. cit. note 127.
- 129 SolarPower Europe, "Spotlight on GW EU solar markets: Spain leads PPA subsidy-free market growth", 29 January 2021, <https://www.solarpowereurope.org/spotlight-on-gw-eu-solar-markets-spain-leads-ppa-subsidy-free-market-growth>.
- 130 The residential sector experienced unprecedented growth in 2020, and figure of 30% growth in self-consumption market, based on data from Unión Española Fotovoltaica, cited in P. Sanchez Molina, "Solar for self-consumption keeps growing in Spain", pv magazine, 29 January 2021, <https://www.pv-magazine.com/2021/01/29/solar-for-self-consumption-keeps-growing-in-spain>. The self-consumption market in 2020 was 596 MW, up from 459 MW in 2019; the industrial sector had the largest portion (56%), followed by commercial (23%) and residential (19%), from idem. The market grew less than expected because the small to medium enterprise sector was significantly affected by the pandemic, from SolarPower Europe, op. cit. note 4, pp. 13, 84.
- 131 REE, "The Spanish Electricity System – End of Year Forecast 2020" (Madrid: December 2020), with estimated data as of 11 December 2020, <https://www.ree.es/en/datos/publicaciones/annual-system-report/spanish-electricity-system-preliminary-report-2020>.
- 132 Poland added 2,636 MW for a total of 3,936 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Added 1,850 MW in 2020 for year-end total of 3,150 MW (or 3.6 GW), from SolarPower Europe, op. cit. note 4, pp. 20, 54. Drivers from idem, p. 13; SolarPower Europe, "Spotlight on GW EU solar markets: Poland sees growing micro-installations and positive policy developments", 22 January 2021, <https://www.solarpowereurope.org/spotlight-on-gw-eu-solar-markets-poland-sees-growing-micro-installations-and-positive-policy-developments>. Favourable policies included net metering and feed-in tariffs, from idem.
- 133 For example, see M. Willuhn, "Statkraft greens Polish steel with 10-year PPA", pv magazine, 21 January 2021, <https://www.pv-magazine.com/2020/01/21/statkraft-greens-polish-steel-with-10-year-ppa>; J. R. Martín, "Polish coal giant doubles down on 2.5GW solar push despite business retrenchment", PV-Tech, 15 April 2020, <https://www.pv-tech.org/news/polish-coal-giant-doubles-down-on-2.5gw-solar-push-despite-business-retrenc>.
- 134 Switzerland from D. Stickerberger, "Rekordzubau bei der Schweizer Photovoltaik 2020", Swissolar, 3 March 2021, <https://www.swissolar.ch/services/medien/news/detail/n-n/rekordzubau-bei-der-schweizer-photovoltaik-2020>. Switzerland's market grew at least 30% relative to 2019, to record levels with

- estimated additions of at least 430-460 MW, from idem. Denmark from Z. Shahan, "400,000+ solar co-owners in giant community solar park initiative In Denmark & Poland", CleanTechnica, 5 December 2020, <https://cleantechnica.com/2020/12/05/400000-solar-co-owners-in-giant-community-solar-park-initiative-in-denmark-poland>. Five parks were in operation by the end of 2020 and the rest were expected in 2021 and 2022; the initiative is a partnership of Danish pension fund Industriens Pension and Better Energy (Denmark), from idem. R. Withlock, "Lithuania welcomes world's first online consumer platform for purchasing remote solar panels", Renewable Energy Magazine, 25 March 2020, [https://www.renewableenergymagazine.com/pv\\_solar/lithuania-welcomes-world-s-first-online-consumer-20200325](https://www.renewableenergymagazine.com/pv_solar/lithuania-welcomes-world-s-first-online-consumer-20200325). In addition, what is believed to be Europe's largest rooftop system (12 MW) went online in October at an Audi factory in Győr, Hungary, from Z. Shahan, "Largest rooftop solar system in Europe goes online... on Audi factory", CleanTechnica, 9 October 2020, <https://cleantechnica.com/2020/10/09/largest-rooftop-solar-system-in-europe-goes-online-on-audi-factory>.
- 135 Clean Energy Regulator, cited in Australian Energy Council, *Solar Report* (Melbourne: January 2021), p. 3, [https://www.energycouncil.com.au/media/jv4blk2l/final-pdf-australian-energy-council-solar-report\\_-jan-2021.pdf](https://www.energycouncil.com.au/media/jv4blk2l/final-pdf-australian-energy-council-solar-report_-jan-2021.pdf); B. Church, "End of year forecast for the Australian PV solar market (2020)", Sunwiz, <https://www.sunwiz.com.au/end-of-year-forecast-for-the-australian-pv-solar-market-2020>, viewed 16 March 2021. Additions in the Northern Territory were down 17%, but by small amounts in terms of actual capacity, with 28.88 MW added in 2019 and 24 MW installed in 2020, from Australian Energy Council, op. cit. this note, p. 5. Rank based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.
- 136 M. Maisch, "Australia's renewables pipeline continues to grow at record speed led by solar PV", pv magazine, 23 July 2020, <https://www.pv-magazine-australia.com/2020/07/23/australias-renewables-pipeline-continues-to-grow-at-record-speed-led-by-solar-pv>.
- 137 P. Crossley, University of Sydney, Sydney, Australia, personal communication with REN21, 9 April 2021; M. Lewis, "Bushfire recovery – more than just new poles", Energy Networks Australia, 30 January 2020, <https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/bushfire-recovery-more-than-just-new-poles>.
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- 139 Increase over 2019 based on generation data in 2019 (solar total of 18,126 GWh) from Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne, March 2020), p. 9, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf>; 2020 data (solar total of 22,510 GWh) from Clean Energy Council, op. cit. note 12, p. 9; shares of Australia's total electricity generation from idem, p. 9; generation from small-scale solar PV overtook hydropower as Australia's second largest generator of renewable electricity (after hydropower), from idem, pp. 9, 70.
- 140 D. Carroll, "Australia deployed 2.6 GW of rooftop PV in 2020", pv magazine, 8 February 2021, <https://www.pv-magazine.com/2021/02/08/australia-deployed-2-6-gw-of-rooftop-pv-in-2020>.
- 141 Based on the following: Australia's rooftops saw 2,642 MW added in 2020 (up from 2,355 MW added in 2019) for a year-end total of 12,895 MW, from IEA PVPS, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. If we assume that all off-grid capacity is also under 100 kW, then 2,662 MW was added in 2020 (up from 2,380 MW in 2019), for a year-end total of 13,199 MW, from idem (both sources). About 2.6 GW was added (in 333,978 installations) in 2020, up from 2.2 GW (in 284,000 installations) in 2019, from Clean Energy Regulator, cited in Australian Energy Council, op. cit. note 135, p. 3; note that final installations could be higher because consumers have up to a year to register their new systems, from idem. Just under 3 GW was added in 2020, up from 2.1 GW in 2019, from *Sunwiz Annual Report*, cited in J. Sykes, "What is driving record rooftop solar volumes in Australia?" Renewable Energy World, 3 February 2021, <https://www.renewableenergyworld.com/solar/what-is-driving-record-rooftop-solar-volumes-in-australia>. Australia added 3,043 MW of rooftop solar PV capacity (in 378,451 systems) in 2020 (up from 2.2 GW in 2019) for a year-end total of 13,415 MW, from Clean Energy Council, op. cit. note 12, pp. 7, 17.
- 142 Clean Energy Council, op. cit. note 12, pp. 8, 62. Batteries were installed at 22,661 households in 2019, from idem, p. 62.
- 143 J. Deign, "What other countries can learn from Australia's roaring rooftop solar market", Greentech Media, 3 August 2020, <https://www.greentechmedia.com/articles/read/what-the-us-can-learn-from-australias-roaring-rooftop-solar-market>; Australian Energy Council, op. cit. note 135, p. 3; B. Match, "Forget toilet paper, Australians are panic-buying PV", pv magazine, 19 March 2020, <https://www.pv-magazine.com/2020/03/19/forget-toilet-paper-australians-are-panic-buying-pv/>; Sykes, op. cit. note 141. Residential solar prices continued a decade-long downwards trend in Australia during 2020, down 13.2%, from Solar Choice Price Index, cited in idem.
- 144 Figure of 2.7 million from Clean Energy Council, op. cit. note 12, p. 74; more than 2.66 million from Clean Energy Regulator, cited in Australian Energy Council, op. cit. note 135, p. 3.
- 145 APVI, op. cit. note 138.
- 146 First to face zero operational demand from G. Parkinson, "South Australia fast-tracks energy plan to dodge blackouts and meet 100% renewables goal", RenewEconomy, 19 June 2020, <https://reneweconomy.com.au/south-australia-fast-tracks-energy-plan-to-dodge-blackouts-and-meet-100-renewables-goal-43196>; other information from J. Deign, "How South Australia is dealing with rampant solar growth", Greentech Media, 21 September 2020, <https://www.greentechmedia.com/articles/read/how-south-australia-is-dealing-with-rampant-solar-growth>. See also Clean Energy Council, op. cit. note 12, pp. 18, 71. Rooftop solar PV met more than 70% of South Australia's electricity demand at times during 2020 and, in October, became the world's first major jurisdiction to be powered entirely by solar power for one hour; 77% of this was from rooftop systems, from idem, pp. 18, 71.
- 147 Clean Energy Council, op. cit. note 12, p. 34; N. Harmsen, "Power granted to switch off household solar in SA to prevent statewide blackout", ABC News (Australia), 18 June 2020, <https://www.abc.net.au/news/2020-06-19/solar-boom-puts-sa-at-risk-of-another-statewide-blackout/12372558>. Energy authorities in South Australia used their power to switch off residential solar systems remotely for the first time in March 2021, from D. Keane, N. Harmsen and S. Tomevska, "Solar panels switched off by energy authorities to stabilise South Australian electricity grid", ABC News (Australia), 17 March 2021, <https://www.abc.net.au/news/2021-03-17/solar-panels-switched-off-in-sa-to-stabilise-grid/13256572>. Several states (including Victoria, Western Australia and New South Wales) also announced a number of large battery storage projects in 2020, from Clean Energy Council, op. cit. note 12, p. 56.
- 148 See, for example, 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>.
- 149 Grid challenges from, for example, J. Scully, "1GW of Australian solar at risk of curtailment following system strength warning", PV-Tech, 28 July 2020, <https://www.pv-tech.org/system-strength-issues-in-north-queensland-could-result-in-1gw-of-solar-cur>; S. Vorrath, "Grid problems now the biggest turnoff for renewable energy investment in Australia", RenewEconomy, 29 July 2020, <https://reneweconomy.com.au/grid-problems-now-the-biggest-turnoff-for-renewable-energy-investment-in-australia-73144>; lack of policy and target clarity, and regulatory risks, from T. Gunaratna, Clean Energy Council, Australia, personal communication with REN21, 11 April 2021, and from 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>; barriers to investment, delayed and cancelled projects from G. Parkinson, "Victoria's biggest solar farm starts sending power to grid after long delays", RenewEconomy, 9 September 2020, <https://reneweconomy.com.au/victorias-biggest-solar-farm-starts-sending-power-to-grid-after-long-delays-80694>. See also P. Hannam, "'Murray Five' solar farms get approval to resume full energy output", *Sydney Morning Herald*, 24 April 2020, <https://www.smh.com.au/business/markets/murray-five-solar-farms-get-approval-to-resume-full-energy-output-20200424-p54n2b.html>.

- 150 Matich, op. cit. note 148; 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>.
- 151 N. Filatoff, "The weekend read: The plan to REZurrect Australia's large-scale segment", pv magazine, 17 October 2020, <https://www.pv-magazine-australia.com/2020/10/17/the-weekend-read-the-plan-to-rezurrect-australias-large-scale-segment>. The government of New South Wales was the first to call for interest in a proposed 3 GW REZ; after receiving 27 GW of bids, the state announced an additional 8 GW REZ, from idem. See also Clean Energy Council, op. cit. note 12, p. 7.
- 152 Matich, op. cit. note 148.
- 153 New Zealand from T. Niall, "Biggest solar farm in country installed on Auckland wastewater lake", stuff, 2 October 2020, <https://www.stuff.co.nz/environment/climate-news/122936916/biggest-solar-farm-in-country-installed-on-auckland-wastewater-lake>. Solar PV and electricity storage are advancing on the Cook Islands, from E. Bellini, "Solar-plus-storage for the Cook Islands", pv magazine, 7 September 2020, <https://www.pv-magazine.com/2020/09/07/solar-plus-storage-for-the-cook-islands>; the Fijian government-owned utility signed an agreement with the International Finance Corporation (IFC) for a 15 MW solar PV project to reduce reliance on imported fuels, from J. S. Hill, "Fiji set to build biggest solar project in Pacific Islands", RenewEconomy, 28 October 2020, <https://reneweconomy.com.au/fiji-set-to-build-biggest-solar-project-in-pacific-islands-37084>, and has seen rapid growth in behind-the-meter commercial rooftop systems since 2015, with about 4 MW installed by early 2020 and many more systems planned, from R. D. Prasad and A. Raturi, *Solar Energy for Power Generation in Fiji: History, Barriers and Potentials*, in A. Singh, ed., *Translating the Paris Agreement into Action in the Pacific. Advances in Global Change Research*, vol. 68 (January 2020), [https://link.springer.com/chapter/10.1007/978-3-030-30211-5\\_8](https://link.springer.com/chapter/10.1007/978-3-030-30211-5_8). Micronesia launched a tender for utility-scale solar-plus-storage capacity, from E. Bellini, "Micronesia launches tender for utility scale solar-plus-storage", pv magazine, 12 May 2020, <https://www.pv-magazine.com/2020/05/12/micronesia-launches-tender-for-utility-scale-solar-plus-storage>. New Caledonia aims for 100% renewable electricity by 2030 and was developing an agricultural-solar PV project in 2020, from P. Zubrinich, "Agrivoltaics in New Caledonia", pv magazine, 28 February 2020, <https://www.pv-magazine-australia.com/2020/02/28/agrivoltaics-in-new-caledonia>; the country also saw the completion of a 16 MW solar PV plant with 10 MW of storage in late 2019, to which another solar-plus-storage facility will be added, from idem. Papua New Guinea launched a pilot scheme allowing businesses to install and operate grid-connected rooftop systems as part of the country's effort to achieve 100% renewable energy by 2050, from "PNG's first rooftop solar trial officially begins in Port Moresby", PNG Power, Ltd., 4 December 2019, <https://www.pngpower.com.pg/index.php/news/view/pngs-first-rooftop-solar-trial-officially-begins-in-port-moresby>. Tonga aims for 70% renewable electricity by 2030 and signed contracts in 2020 for more solar-plus-storage projects to provide 24-hour-a-day electricity access, from J. S. Hill, "Tonga signs more solar/storage projects as it aims for 70 pct renewables", RenewEconomy, 21 April 2020, <https://reneweconomy.com.au/tonga-signs-more-solar-storage-projects-as-it-aims-for-70-pct-renewables-49782>.
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- 155 Bellini, op. cit. note 153.
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- 290 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 58. Another source put the increase in energy yield from single-axis tracker bifacial systems as much as 35%, while also reducing the levelised cost of energy by 16% compared with conventional monofacial systems, from SERIS, cited in "Global PV costs fall 13% in 2019; Bifacial offers higher returns at over 93% of sites", Reuters Events, 10 June 2020, <https://newenergyupdate.com/pv-insider/global-pv-costs-fall-13-2019-bifacial-offers-higher-returns-over-93-sites>; an NREL study in 2019 revealed production gains of up to 9%, from NREL, "Bifacial solar advances with the times—and the sun", viewed 13 April 2021, <https://www.nrel.gov/news/features/2020/bifacial-solar-advances-with-the-times-and-the-sun.html>. A SolarPro study found bifacial yield increases of up to 11% for fixed-tilt systems and 27% for tracker systems compared with similarly rated traditional panels, from Botti, op. cit. note 289.
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- 303 Only Europe from G. Cañadas, "The state of PV recycling: building a solar circular economy", *Rated Power*, 15 March 2021, <https://ratedpower.com/blog/pv-recycling>; only the EU and Washington State have laws that mandate panel recycling, from Johnson, op. cit. note 299; New York state as of 2020 from D. Mulvaney and M. D. Bazilian, "The downside of solar energy", *Scientific American*, 1 December 2019, <https://blogs.scientificamerican.com/observations/the-downside-of-solar-energy>. In the EU, under the WEEE (Waste Electrical and Electronic Equipment) directive of 2012, installers are accountable for electronic waste (including solar panels and inverters) and producers must recycle; in Japan, project developers and owners are responsible for their own panel disposal and must pay into a decommissioning fund; and Washington state has a stewardship and takeback programme requiring every panel supplier to provide a plan for recycling by 2022, all from Wesoff and Beetz, op. cit. note 297.
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- 306 Clyncke, op. cit. note 301.
- 307 Japan from Heath et al., op. cit. note 297, and from Clyncke, op. cit. note 301. Several organisations in Japan accept solar PV modules, but only one specialises in recycling modules and the process is limited, from idem. India from U. Gupta, "Establishing a solar module recycling system in India", pv magazine, 31 December 2020, <https://www.pv-magazine.com/2020/12/31/establishing-a-solar-module-recycling-system-in-india>. United States from Sylvia, op. cit. note 305. The SEIA is leading an industry-wide recycling initiative with five partners; by end-2020 there were 12 recycling locations across the country and three more were pending, from Wesoff and Beetz, op. cit. note 297. First Solar has long had a recycling programme that recovers up to 90% of its modules, from Deign, op. cit. note 299; First Solar, "First Solar recycling recovers up to 90% of materials", viewed 12 April 2021, <https://www.firstsolar.com/en/Modules/Recycling>.
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- Recovery Corporation, PV Industries and Lotus Energy – are working on recycling and product stewardship, from Gunaratna, op. cit. note 149, 12 April 2021.
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## CONCENTRATING SOLAR THERMAL POWER (CSP)

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- 5 Ibid.
- 6 Ibid.
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- 16 NREL, "Concentrating Solar Power Projects: ISCC Duba 1", <https://solarpaces.nrel.gov/iscc-duba-1>, updated 31 January 2017.
- 17 See sources in endnote 1.
- 18 Ibid.
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## SOLAR THERMAL HEATING

- 1 Revised gross additions for 2019 included in this GSR (26.1 GW<sub>th</sub>) are significantly lower than those published in GSR 2020 (31.3 GW<sub>th</sub>) for two reasons: First, the Chinese Solar Thermal Industry Federation (CSTIF) adjusted downwards its number for China's new additions in 2019, from 22.75 GW<sub>th</sub> (a preliminary figure, available as of early 2020) to 20 GW<sub>th</sub>. Second, data for new additions in China are based on produced collector area, rather than on annual installations in China; as a result, export volumes have been included in China's national statistics for 2020 and earlier years. In past editions of the GSR, this has resulted in a double counting of some collector area because the majority of coated vacuum tubes installed worldwide are purchased from China. The one exception is Turkey, which imposed a high import tax on Chinese vacuum tubes in July 2011, resulting in high national vacuum tube production capacities that supply most of national demand. To correct the newly added solar thermal capacity in China, newly added vacuum tube collector capacities in large solar thermal markets outside of China and Turkey were subtracted from the produced collector volume in China for 2019 and 2020. The result has been a further reduction to the number for China's additions during 2019 (relative to data in GSR 2020). Because China dominated global gross additions in 2019 and 2020, downwards adjustments to China's additions also had a downwards effect on the data published for annual global sales (see endnote 5), from M. Spörk-Dür, AEE - Institute for Sustainable Technologies (AEE INTEC), Austria, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), April 2020.
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- 3 Changes to support policies increased demand significantly in Germany and the Netherlands in 2020, whereas the expiration of support policies in India, Poland and the United States resulted in strong declines in solar thermal capacity additions during the year, from Ibid.
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- 9 The total installed capacity of air collectors declined to 1 GW<sub>th</sub> at the end of 2020 (1.1 GW<sub>th</sub> at the end of 2019) due to 0.05 GW<sub>th</sub> of air collector technology that went out of operation in 2020 after a lifetime of 20 years, from Spörk-Dür, op. cit. note 1.
- 10 **Figure 32** based on the latest market data available for gross additions of glazed and unglazed water collectors (not including concentrating collectors), at the time of publication, for countries that together represent 96% of the world total. Data from original country sources include gross national additions and were provided to REN21 as follows: D. Ferrari, Sustainability Victoria, Melbourne, Australia; W. Weiss, AEE INTEC, Vienna, Austria; D. Johann, Brazilian Solar Thermal Energy Association (ABRASOL), São Paulo, Brazil; H. Cheng, Shandong SunVision Management Consulting, Dezhou, China (5% were subtracted from the Chinese additions reported by Cheng, because the figures included vacuum tube collectors that were manufactured in China and exported to other countries). The 5% subtracted represents the average share of China's produced vacuum tube collector area that was exported to other key markets in the years 2015 to 2019 (for countries where final new additions were available); P. Kastanias, Cyprus Union of Solar Thermal Industrialists (EBHEK), Nicosia, Cyprus; A. Liesen, BSW Solar, Berlin, Germany; C. Trivasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; J. Malaviya, Solar Thermal Federation of India (STFI), Pune, India; E. Shilton, Elsol, Kohar-yair, Israel; F. Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milan, Italy; N. Jaeger, Holland Solar, Utrecht, Netherlands (preliminary estimation for the Netherlands, share of flat plate and vacuum tubes were applied as in 2019 – latest data available); T. Kousksou, University of Pau and the Pays de l'Adour, Pau, France (for Morocco; share of vacuum tube and flat plate collectors was not available); D. Garcia, Solar Thermal Manufacturers Organisation (FAMERAC), Mexico City, Mexico; P. Dias, Solar Heat Europe, Brussels, Belgium (for Portugal); J. Staroscik, Association of Manufacturers and Importers of Heating Appliances (SPIUG), Warsaw, Poland; K. Kritzinger, Centre for Renewable and Sustainable Energy Studies, University of Stellenbosch, Stellenbosch, South Africa; P. Polo, Spanish Solar Thermal Association (ASIT), Madrid, Spain; A. Baccouche, ANME, Tunis, Tunisia; K. Ülke, Bural Heating, Kayseri, Turkey; B. Heavner, California Solar & Storage Association (CALSSA), Sacramento, California, United States, all personal communications with REN21, February-April 2021.
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## WIND POWER

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- 2 Figure of 45% based on installations in 2015 of 63.8 GW, from GWEC, op. cit. note 1, p. 51, and 53% increase based on additions of 60,877 MW in 2019, from idem, p. 53.
- 3 GWEC, *Global Offshore Wind Report 2020* (Brussels: 5 August 2020), p. 24, <http://gwec.net/global-offshore-wind-report-2020>; WWEA, "World wind power deployment: Some delays in 2020 due to Covid-19, but bright future prospects", 6 November 2020, <https://wwindea.org/world-wind-power-deployment-some-delays-in-2020-due-to-covid-19-but-bright-future-prospects>; various impacts of pandemic from, for example, GWEC, op. cit. note 1, p. 53; B. Backwell and S. Mullin, GWEC, "2020 In review: End of year special", The Offshore Wind Podcast, December 2020, <https://gwec.net>.
- 4 Based on year-end 2020 capacity of 742,689 MW and year-end 2019 capacity of 650,199 MW, from GWEC, op. cit. note 1, p. 53, and double total capacity at end-2014 (370 GW), from idem, p. 52. Year-end global capacity was 733,276 MW, from IRENA, op. cit. note 1. China accounts for most of the difference between data from GWEC and IRENA. See endnote 26. Note that annual additions reported in this section are gross additions unless otherwise noted, but most countries did not decommission capacity during the year. **Figure 34** based on historical data from GWEC, op. cit. note 1, pp. 51-52; data for 2021 based on sources provided in endnote 1.
- 5 China's market was driven by the cut-off to the national feed-in tariff at year's end, and the US market was driven by a scheduled step-down in the production tax credit as of 1 January 2021 (the step-down was postponed in December), from GWEC, op. cit. note 1, p. 6. Rest of world based on data from idem, p. 53.
- 6 See, for example, infrastructure, policy and regulatory challenges in India, from GWEC, "China blows past global wind power records, doubling annual installations in 2020", 18 March 2021, <https://gwec.net/china-blows-past-global-wind-power-records-doubling-annual-installations-in-2020>; slow permitting or lack thereof was an issue in Germany and Italy, from WindEurope, *Wind Energy in Europe: 2020 Statistics and the Outlook for 2021-2025*, p. 23, <https://windeurope.org/data-and-analysis/product/wind-energy-in-europe-in-2020-trends-and-statistics>; lack of interconnections in Chile, Vietnam and other countries, and permitting processes in the Philippines, and financing in Ethiopia from GWEC, op. cit. note 1. Record installations based on the following: Argentina (added 1,014 MW), Australia (1,097 MW), Chile (684 MW), Japan (551 MW), Kazakhstan (300 MW) and Sri Lanka (88 MW), from GWEC, op. cit. note 1, p. 53, and from GWEC, "Global Wind Statistics 2020: Status as end of 2020" (Brussels: March 2020); Norway (1,532 MW) from WindEurope, op. cit. this note, pp. 11, 13; and the Russian Federation (715 MW), from WWEA, op. cit. note 1.
- 7 At least 49 countries and Tanzania, based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from F. Zhao, GWEC, Copenhagen, personal communication with REN21, 26 April 2021. At least 55 countries in 2019 based on data from GWEC, "Global Wind Statistics 2019: Status as End of 2019" (Brussels: March 2020), and from Zhao, op. cit. this note, 13 April 2020. In 2018, at least 47 countries 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>. Tanzania added its first commercial wind farm, from Future Power Technology, "A look at Tanzania's first wind farm", [https://power.nridigital.com/future\\_power\\_technology\\_jul20/tanzania\\_wind\\_farm](https://power.nridigital.com/future_power_technology_jul20/tanzania_wind_farm), viewed 27 April 2021, and from GWEC, "Global Wind Statistics 2020", op. cit. note 6.
- 8 Based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from Zhao, op. cit. note 7, 26 April 2021.
- 9 GWEC, op. cit. note 1, p. 17; 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](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 Collaborating Centre on Climate & Energy Finance (FS-UNEP) 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", *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", International Monetary Fund, 26 April 2019, <https://blogs.imf.org/2019/04/26/falling-costs-make-wind-solar-more-affordable>; FS-UNEP and BloombergNEF, op. cit. note 9, p. 29.
- 11 GWEC, op. cit. note 1, p. 46; GWEC, *Global Wind Market Outlook Update Q3 2019* (Brussels: September 2019), p. 2; GWEC, *Global Wind Report 2019* (Brussels: March 2020), p. 37, <https://gwec.net/global-wind-report-2019>; 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>. In 2020, about 56% of the market was driven by feed-in tariffs (FITs) (China), 19% was driven by the US Production Tax Credit, followed by auctions and tenders (19.7%), and green certificates and other mechanisms (totalling a combined 4.6%), from GWEC, op. cit. note 1.
- 12 BloombergNEF, cited in GWEC, op. cit. note 1, p. 7.
- 13 EU share and five Member States (Denmark, Ireland, Germany, Portugal and Spain), from WindEurope, op. cit. note 6, p. 19, and from I. Komusanac, WindEurope, personal communication with REN21, 12 April 2021. If the United Kingdom were still an EU member, the total share from wind would be 16% and the country would be on this list as well, from idem, both sources.
- 14 Denmark's share of consumption based on total of 16,353 gigawatt-hours (GWh) of wind energy generation and total electricity supply (including imports) of 34,104 GWh, for a share of 48%; share of net generation from wind based on total of 16,353 GWh from wind energy in 2020 and 27,907 GWh of total net generation, for a share of 58.6%, all from Danish Energy Agency, "Monthly energy statistics, electricity supply", <https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics>, viewed 1 March 2021. Denmark's share of consumption was 46.1%, from Wind Denmark, "2020 bød på rekordhøj produktion fra landets vindmøller", 2 January 2021, <https://winddenmark.dk/nyheder/2020-boed-paa-rekordhoej-produktion-fra-landets-vindmoeller> (using Google Translate), and it would have been closer to 51%, if not for curtailment during the year, from idem.



- 15 List of countries based on data from WindEurope, op. cit. note 6, p. 19. Data for **Ireland** based on EIRGRID GROUP, "System and Renewable Summary Report", <http://www.eirgridgroup.com/how-the-grid-works/renewables>, viewed 28 February 2021; **United Kingdom** (24.18%), based on 34,948 GWh generation onshore plus 40,662 GWh generated offshore, and total UK generation of 312,759 GWh in 2020, 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 25 March 2021; **Portugal** from Associação Portuguesa de Energias Renováveis (APREN), *Portuguese Renewable Electricity Report* (Lisbon: December 2020), p. 1, <https://www.apren.pt/contents/publicationsreportcarditem/portuguese-renewable-electricity-report-december2020.pdf>; **Germany** share of gross generation in 2020 was 23.2%, based on wind energy gross generation of 130,965 GWh (including 103,662 GWh onshore and 27,303 GWh offshore), 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 2021) (Dessa-Roßlau: February 2021), p. 46, [https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare\\_Energien\\_in\\_Zahlen/Zeitreihen/zeitreihen.html](https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html), and on 565.3 terawatt-hours (TWh) of total gross generation (not including pumped storage) in 2020, from AG Energiebilanzen e.V., "Bruttostromerzeugung", *Strommix – Stromerzeugung nach Energieträgern 1990-2020* (Stand Februar 2021), <https://ag-energiebilanzen.de/4-0-Arbeitsgemeinschaft.html>, viewed 5 May 2021. Note that the share of national production in 2020 was 27.1%, from Fraunhofer ISE, "Annual wind share of electricity production in Germany", Energy-Charts, [https://energy-charts.info/charts/renewable\\_share/chart.htm?en&c=DE&share=wind\\_share](https://energy-charts.info/charts/renewable_share/chart.htm?en&c=DE&share=wind_share), updated 19 April 2021, and wind energy's share of national gross consumption in Germany was 23.6%, from BMWi and AGEE-Stat, op. cit. this note, p. 46. **Spain** from Red Eléctrica de España (REE), "2020, the year with the 'greenest' energy thanks to record wind and solar photovoltaic generation", press release (Madrid: 12 March 2021), <https://www.ree.es/en/press-office/news/press-release/2021/03/2020-the-year-with-the-greenest-energy-thanks-to-record-wind-and-solar-photovoltaic-generation>. Other European countries with shares of 10% or higher included **Belgium** (14%), **Lithuania** (13%), **Netherlands**, **Romania** and **Austria** (all 12%), **Estonia** (11%) and **Croatia** (10%), all based on data from ENTSO-E and corrected with data from national transmission service operators and governments and cited in WindEurope, op. cit. note 6, p. 19. Shares were 27% in the United Kingdom, 25% in Portugal, 22% in Spain and 20% in Sweden, from Komusanac, op. cit. note 13.
- 16 **Uruguay** generated 40.4% of its electricity with wind energy in 2020, based on production of 5,437.7 GWh from wind energy and 13,470.5 GWh total, from Ministerio de Industria, Energía y Minería (MIEM), Balance Energético Nacional Uruguay, "Balance preliminar 2020", <https://ben.miem.gub.uy/preliminar.php>, viewed 16 April 2021. **Nicaragua** generated 27.62% of total net electricity output with wind energy, from Instituto Nicaragüense de Energía (INE), Ente Regulador, "Generación neta de energía eléctrica sistema eléctrico nacional año 2020", [https://www.ine.gob.ni/DGE/estadisticas/2020/Generacion\\_Neta\\_2020\\_actagost20.pdf](https://www.ine.gob.ni/DGE/estadisticas/2020/Generacion_Neta_2020_actagost20.pdf), viewed 1 March 2021; and wind energy accounted for 23.58% of total electricity generation, from INE, Ente Regulador, "Generación bruta de energía eléctrica sistema eléctrico nacional año 2020", [https://www.ine.gob.ni/DGE/estadisticas/2020/Generacion\\_Bruta\\_2020\\_actagost20.pdf](https://www.ine.gob.ni/DGE/estadisticas/2020/Generacion_Bruta_2020_actagost20.pdf), viewed 1 March 2021.
- 17 Share of generation in 2020 based on estimated total global electricity generation of 25,849.92 TWh and total wind generation of 1,590.19 TWh, from Ember, *Global Electricity Review 2021* (London: 2021), <https://ember-climate.org/project/global-electricity-review-2021>. Global totals for 2020 were estimated by summing total electricity generation and electricity generation per energy source in 36 countries where 2020 national sources (including official government data and utility data) were available, comprising 90% of global generation. See Ember, "Methodology", <https://ember-climate.org/global-electricity-review-2021/methodology>, viewed 7 April 2021. Note that by the end of 2020, there was enough wind power capacity in operation to provide an estimated 6.38% of global electricity generation, based on GWEC, "Global Wind Energy Statistics 2020 Database", provided by Zhao, op. cit. note 7, 26 April 2021.
- 18 Share of market in 2019 (including Turkey), and total year-end capacity (including Turkey), based on data from GWEC, op. cit. note 1, p. 53; Asia (including Turkey) and China shares of market in 2020, based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and revised data for Spain (1,720 MW added), from Komusanac, op. cit. note 13. Asia's share in 2018 was 51.9% (also including Turkey), based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 7; and the share in 2017 was 48%, based on data from GWEC, *Global Wind Report – Annual Market Update 2017* (Brussels: April 2018), p. 17, <http://files.gwec.net/files/GWR2017.pdf>.
- 19 Regional shares based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from Komusanac, op. cit. note 13. Numbers in text are based on regional groupings that include Turkey as part of Asia, rather than Europe, and Mexico as part of Latin America, rather than North America. Other regional shares include Oceania (Australia and New Zealand added capacity) with 1.3% of the total added in 2020, Africa with almost 0.8%, and the Middle East with 0.1%, all from idem.
- 20 GWEC, op. cit. note 1, pp. 48, 53; Europe projects delayed to 2021 from Komusanac, op. cit. note 13.
- 21 GWEC, "Global Wind Statistics 2020", op. cit. note 6; Komusanac, op. cit. note 13.
- 22 Based on data from GWEC, op. cit. note 1, p. 53, from WindEurope, op. cit. note 6, p. 11, and from Komusanac, op. cit. note 13. **Figure 35** based on country-specific data and sources provided throughout this section, and largely drawn from the following: GWEC, op. cit. note 1; GWEC, "Global Wind Statistics 2020", op. cit. note 6; WindEurope, op. cit. note 6; WWEA, op. cit. note 1.
- 23 Based on data from GWEC, op. cit. note 1, p. 53; WindEurope, op. cit. note 6, p. 11; WWEA, op. cit. note 1; GWEC, "Global Wind Statistics 2019", op. cit. note 7; WindEurope, *Wind Energy in Europe in 2019: Trends and Statistics* (Brussels: 2020), p. 10, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf>.
- 24 Grid connections from G. Baiyu, "Despite coronavirus, China aims for renewables grid parity", China Dialogue, 2 June 2020, <https://chinadialogue.net/en/energy/despite-coronavirus-china-aims-for-renewables-grid-parity>. China recovered quickly from the economic impacts of the pandemic, and the rapid recovery enabled project installations and manufacturing to bounce back as early as March; also, grid companies undertook measures to address bottlenecks and connect as much capacity as possible during the year, from GWEC, "A gust of growth in China makes 2020 a record year for wind energy", 21 January 2021, <https://gwec.net/a-gust-of-growth-in-china-makes-2020-a-record-year-for-wind-energy>.
- 25 China added an estimated 52,000 MW in 2020, including 48,940 MW onshore and 3,060 MW offshore, for a year-end total of 288,320 MW (278.3 GW onshore and nearly 10 GW offshore), and added 26,785 MW in 2019, all preliminary data from Chinese Wind Energy Association (CWEA), provided by GWEC, op. cit. note 1, p. 53, and GWEC, "Global Wind Statistics 2020", op. cit. note 6; and added 52 GW (48.9 GW onshore and 3.1 GW offshore) for a year-end total of 288.32 GW (278.19 GW onshore and 10.13 GW offshore), all preliminary data from H. Yu, CWEA, Beijing, personal communication with REN21, 12 May 2021; and China added 52,000 MW in 2020 for a total of 290,000 MW, from WWEA, op. cit. note 1. In 2018, global capacity additions totalled 50.7 GW, from GWEC, op. cit. note 1, p. 51.
- 26 Net additions of 72,380 MW, for a total of 281,530 MW, are official data based on 209,150 MW in operation at end of 2019 and 281,530 MW in operation at end of 2020, from China Electricity Council (CEC), cited in China Energy Portal, "2020 electricity & other energy statistics (preliminary)", 22 January 2021, <https://chinaenergyportal.org/en/2020-electricity-other-energy-statistics-preliminary>; and additions of 71.67 GW of grid-connected wind power capacity (68.61 GW onshore and 3.06 GW offshore) for a total of 281 GW (271 GW onshore and 9 GW offshore), from National Energy Board, cited in National Energy Administration (NEA), "Transcript of the online press conference of the National Energy Administration in the first quarter of 2021", 30 January 2021, [http://www.nea.gov.cn/2021-01/30/c\\_139708580.htm](http://www.nea.gov.cn/2021-01/30/c_139708580.htm) (using Google Translate). Note that these data are based on grid-connected capacity; in addition, "Due to differences in statistical standards, confirmation of moment of grid connection, and other reasons, there are certain discrepancies in data on total and newly installed generation capacity", from CEC cited in idem. China added a total of 71.7 GW, from C. Richard, "China reports 72GW wind connected to grid in record-breaking 2020", *Windpower Monthly*, 22 January

- 2021, <https://www.windpowermonthly.com/article/1705268/china-reports-72gw-wind-connected-grid-record-breaking-2020>. China added 68.6 GW of onshore wind capacity to the grid in 2020, from China's NEA, cited in GWEC, op. cit. note 1, p. 45, and GWEC, op. cit. note 24. However, CWEA estimates that 26 GW of this total was installed by the end of 2019 and only connected to the grid in 2020. Not including the 26 GW, new onshore installations in 2020 totalled 48.9 GW, and the amount of capacity installed and grid-connected in 2020 was about 45.4 GW, from GWEC, op. cit. note 1, p. 45, and GWEC, op. cit. note 24. In addition, some experts believed that the official Chinese numbers did not match observations on the ground, and that massive installations at year's end would have created supply constraints, for which there was little evidence in early 2021, from J. Deign, "What is going on with China's crazy clean energy installation figures?" Greentech Media, 2 February 2021, <https://www.greentechmedia.com/articles/read/what-is-going-on-with-chinas-crazy-clean-energy-installation-figures>. Note that the GSR uses GWEC/CWEA data for China rather than official data, which vary depending on government agency; GWEC/CWEA use these numbers because of the delay of grid connection in China, from GWEC, op. cit. note 1, p. 74. The difference in statistics among Chinese organisations and agencies results from the fact that they count different things. There are no Chinese statistics that provide actual grid-connected capacity, and discrepancies among available statistics can be large. In general, installed capacity refers to capacity that is constructed and usually has wires carrying electricity from the turbines to a sub-station (i.e., CWEA annual statistics); capacity qualifies as officially grid-connected (i.e., included in CEC statistics) once certification is granted and operators begin receiving the FIT premium payment, which at times has required weeks or even months. In recent years, due to transmission constraints in China, there often were lags of several months from when turbines were wire-connected to the sub-station until the process of certification and payment of the FIT premium was complete. In 2020, there was a great rush to ensure that projects were officially deemed to be grid-connected before the end of the year in order to guarantee receipt of the expiring onshore FIT; the higher, official statistics include capacity that was connected to the grid during the year at wind projects that were installed in 2020, as well as those from previous years. Data cited by CWEA are based on information collected from the industry during 2020 and early 2021, and are believed to most closely reflect the status of the market in China. All based on information provided in past years by GWEC and CWEA, as well as updates for 2020 and confirmation of accuracy provided by Yu, op. cit. note 25.
- 27 GWEC, op. cit. note 1, pp. 45, 49, 71; GWEC, "China blows past global wind power records", op. cit. note 6; GWEC, op. cit. note 24; Richard, op. cit. note 26. These were all projects that were approved through 2018.
- 28 GWEC, op. cit. note 1, p. 49. See also Everchem, "Chinese wind subsidies to end in December. China's renewable power price and subsidy: 'new' design in 2020?" 28 October 2020 / 29 January 2020, <https://everchem.com/chinese-wind-subsidies-to-end-in-december>.
- 29 See, for example, Reuters, "China to stop subsidy for offshore renewables, eyes 2021 start for green quota trading", Nasdaq, 23 January 2020, <https://www.nasdaq.com/articles/china-to-stop-subsidy-for-offshore-renewables-eyes-2021-start-for-green-quota-trading-2020>; Everchem, op. cit. note 28; Bloomberg News, "China boosts renewable power subsidies 7.5% to \$13 billion", MSN, 18 June 2020, <https://www.msn.com/en-us/money/markets/china-boosts-renewable-power-subsidies-7-5-to-13-billion/ar-BB15E9sk>; I. Shumkov, "China to reduce subsidies for renewables by 30% in 2020", Renewables Now, 22 November 2019, <https://renewablesnow.com/news/china-to-reduce-subsidies-for-renewables-by-30-in-2020-677495>. China introduced the feed-in tariff for onshore wind power in 2009 and for offshore wind in 2014, from Everchem, op. cit. note 28.
- 30 Deficit and backlog from Everchem, op. cit. note 28; EurObserv'ER, *Wind Energy Barometer* (Paris: March 2020), p. 3, <https://www.eurobserv-er.org/wind-energy-barometer-2020>. The deficit situation was worsened by pandemic, from Baiyu, op. cit. note 24; competing subsidy-free from Reuters, op. cit. note 29. The cumulative deficit for all renewables amounted to the equivalent of USD 50 billion at the end of 2020, from Credit Suisse, cited in J. Wong, "China's green-power funding is blowing in the wind", *Wall Street Journal*, 21 April 2021, <https://www.wsj.com/articles/chinas-green-power-funding-is-blowing-in-the-wind-11619003815>. One source notes that wind and solar power projects benefit from lower technology costs, but other costs – such as curtailment, taxes on land, financing and initial development – remain high (accounting for 20% or more of wind and solar power project costs) and are barriers to grid parity, from Baiyu, op. cit. note 24.
- 31 GWEC, op. cit. note 1, p. 46.
- 32 360doc.com, "Multi-pictures: overview of the details of photovoltaic and wind power installed capacity and power generation in various provinces across the country in 2020", 17 February 2021, [http://www.360doc.com/content/21/0217/07/73752269\\_962367138.shtml](http://www.360doc.com/content/21/0217/07/73752269_962367138.shtml) (using Google Translate). Wind power accounted for more than 20% of power capacity in Inner Mongolia (25.5%), Gansu (24.4%), Ningxia (23.2%), Hebei (22.8%), Xinjiang (21.7%) and Qinghai (20.9%), from idem.
- 33 Continued to shift from Ibid.; 40% from National Energy Board, op. cit. note 26.
- 34 Top provinces for total from 360doc.com, op. cit. note 32. Top provinces for additions in 2020 were Inner Mongolia (5.9 GW), Henan (5.5 GW) and Shanxi (4.7 GW), from Yu, op. cit. note 25, 10 May 2021.
- 35 M. Lifang, China Renewable Energy Industries Association, cited in G. Baiyu, "Offshore wind takes off in China", China Dialogue, 9 October 2020, <https://chinadialogue.net/en/energy/china-offshore-wind-power-growth>.
- 36 Figure of 16.6 TWh of potential curtailed, and 3% curtailment rate, from National Energy Board, op. cit. note 26; down from 4% (16.9 TWh) in 2019, based on data from NEA, "Wind power grid-connected operation in 2019", 28 February 2020, [http://www.nea.gov.cn/2020-02/28/c\\_138827910.htm](http://www.nea.gov.cn/2020-02/28/c_138827910.htm) (using Google Translate); targeted cap of 5% for 2020 was set in China's Clean Energy Consumption Action Plan (2018–20), from Z. Tong, "Greening of renewable sector", *China Daily*, 20 January 2021, <http://www.chinadaily.com.cn/a/202101/20/WS60077241a31024ad0baa3b71.html>. Note that the rate of average curtailment was 2% in 2020, per NEA, 30 January 2021, provided by F. Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 26 March 2021. National curtailment was 7% (27.7 TWh) in 2018, based on data from NEA, "Wind power grid-connected operation in 2019", op. cit. this note; 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](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](http://www.nea.gov.cn/2017-01/26/c_136014615.htm) (using Google Translate).
- 37 In Xinjiang, the curtailment rate fell 3.7 percentage points in 2020, to 10.3%; Gansu's declined 1.3 percentage points, to 6.4%, and Western Inner Mongolia's fell 1.9 percentage points, to 7.0%, from National Energy Board, op. cit. note 26. In Xinjiang, the curtailment rate fell more than 9 percentage points in 2019 relative to 2018, to 14%; Gansu's declined 11.4 percentage points in 2019, to 7.6%; Inner Mongolia's fell nearly 3 percentage points in 2019, to 7.1%, based on 2019 data from NEA, "Wind power grid-connected operation in 2019", op. cit. note 36, and on 2018 data from NEA, "2018 added solar PV capacities", *Finance World*, 28 January 2019, <https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&fr=pc> (using Google Translate).
- 38 Based on total power production in 2020 of 7,623,600 GWh and total wind energy production of 466,500 GWh (based on grid-connected capacity), for a share of 6.1%, from CEC, op. cit. note 26. This was up from a share of 5.5% in 2019, based on total annual generation of 7,326,900 GWh and wind energy generation of 405,300 GWh, from idem. Wind energy produced 5.2% of total in 2018 based on generation of 365.8 TWh that year, 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 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](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", op. cit. note 36.
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- 59 ACPA, op. cit. note 58, p. 6. In the fourth quarter 10,593 MW was added, from idem.
- 60 Ibid., p. 9.
- 61 Ibid., p. 4; 38 million from ACPA, "Wind industry closes record 2020 with strongest quarter ever", 4 February 2021, <https://cleanpower.org/news/wind-industry-closes-record-2020-with-strongest-quarter-ever>. A further 17.3 GW was under construction with 17.5 GW in the advanced development stage (more than one quarter of this for offshore projects in US federal waters), from idem.
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- installed capacity, from ACPA, op. cit. this note. Texas leads for total utility-scale capacity (30.2 GW), from US EIA, cited in Bowers and Comstock, op. cit. note 58.
- 63 US EIA, cited in Bowers and Comstock, op. cit. note 58. The 100% PTC was scheduled to phase out at year's end for wind power projects that began construction in 2016, from GWEC, op. cit. note 57. In December, Congress passed a one-year extension of the PTC and investment tax credit (ITC) for land-based wind power, and a 30% ITC for offshore projects that start construction from the beginning of 2017 through 2025, from D. Wagman, "US to extend Investment Tax Credit for solar to 2024", pv magazine, 22 December 2020, <https://www.pv-magazine.com/2020/12/22/us-to-extend-investment-tax-credit-for-solar-to-2024>.
- 64 Demand from utilities from ACPA, op. cit. note 58, p. 18. Utilities commissioned 4,918 MW of new wind power capacity in 2020, from idem.
- 65 A total of 5,444 MW was contracted through PPAs, and announcements down, from ACPA, op. cit. note 58, pp. 4, 19. New wind power PPAs reached a record 8.7 GW in 2019, 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](https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/4q2019_marketreport). 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](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, *U.S. Wind Industry Quarterly Market Report*, op. cit. this note, pp. 3, 4. At year's end, more than 16 GW of projects was in the pipeline (just over half of the capacity) had a PPA in place; utilities accounted for 70% of the capacity under construction or in advanced development, from ACPA, op. cit. note 58, p. 18.
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- 76 Fastest growing from R. Fiestas, quoted in GWEC, op. cit. note 57; 33.9 GW from idem; number of countries based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6.
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- with 2,623 MW and wind energy accounted for 7% of generation during the year, from Compañía Administradora del Mercado Mayorista Eléctrico S.A. (CAMMESA), *Informe Mensual Principales Variables del Mes* (Buenos Aires: December 2020), pp. 12, 17, 23, <https://portalweb.cammesa.com/memnet1/Pages/descargas.aspx>. Share of generation based on 9,406 GWh of electricity generated with wind energy and total generation of 134,173 GWh, from idem. Chile's year-end capacity was 2,657 MW and wind energy accounted for 7.1% of annual generation, from Asociación Chilena de Energías Renovables y Almacenamiento AG. (ACERA), *Estadísticas Sector de Generación de Energía Eléctrica Renovable* (December 2020), pp. 1, 3, <https://acera.cl/wp-content/uploads/2021/01/2020-12-Bolet%C3%ADn-Estad%C3%ADsticas-ACERA.pdf>. Chile ended the year with another 1.5 GW under construction – completion was pushed into 2021 due to pandemic-related delays, from GWEC, op. cit. note 1, pp. 53, 56. Another 1,823 MW was under construction at end-2020 and 4,426 MW had been approved, from ACERA, op. cit. this note, pp. 3, 5.
- 82 Mexico added 574 MW for a total of 6,789 MW, Panama added 66 MW for a total of 336 MW, and Peru added 38 MW for a total of 411 MW, from GWEC, op. cit. note 57, and GWEC, "Global Wind Statistics 2020", op. cit. note 6.
- 83 Among top 10 and declined 45%, based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6. Policy and regulatory changes from R. Lozano, Emerging Leaders in Environmental and Energy Policy Network, Mexico, personal communication with REN21, 11 April 2021. Political challenges and rule changes in 2020 also from J. Villamil, "Why Mexico is pushing to slow down clean energy", Bloomberg, 16 July 2020, <https://www.bloomberg.com/news/articles/2020-07-16/why-mexico-is-pushing-to-slow-down-clean-energy-quicktake>; cancellation of auctions in 2019 from GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 4; 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>. Mexico ended the year far off track from its generation targets for 2021 (30% renewable electricity) and 2024 (35%), from Villamil, op. cit. this note. See also A. Stillman, "Mexico judge suspends controversial power law indefinitely", Bloomberg, 19 March 2021, <https://www.bloomberg.com/news/articles/2021-03-19/mexico-judge-suspends-nationalistic-electricity-law-indefinitely>, and "Mexico faces potential 'tsunami' of arbitration cases over electricity reform", BNAmericas, 9 April 2021, <https://www.bnamericas.com/en/interviews/mexico-faces-potential-tsunami-of-arbitration-cases-over-electricity-reform>.
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- 85 IEA, op. cit. note 54.
- 86 "Global corporate clean energy purchasing up 18% in 2020", Renewable Energy World, 27 January 2021, <https://www.renewableenergyworld.com/solar/global-corporate-clean-energy-purchasing-up-18-in-2020>. Brazil signed a record 1,057 MW of corporate PPAs for renewables (not only wind power), accounting for most of the 1.5 GW signed in Latin America during 2020, from BloombergNEF, cited in idem. That said, at least one PPA was signed in Mexico for a 105 MW wind farm, from A. Danigelis, "Bayer signs PPA for wind power in Mexico", 27 August 2020, <https://www.environmentalleader.com/2020/08/bayer-wind-power-mexico>.
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- 88 WindEurope, op. cit. note 6, p. 12; permitting delays in Germany from R. Hinrichs-Rahlwes, European Renewable Energy Federation, personal communication with REN21, 6 April 2021.
- 89 Many markets across the EU collapsed as a consequence of the shift away from FITs, with the diversity and number of investors declining, from S. Gsänger, WWEA, Bonn, personal communication with REN21, 20 April 2021.
- 90 WindEurope, op. cit. note 6, p. 12.
- 91 Norway added 1,532 MW for a total of 3,980 MW, from WindEurope, op. cit. note 6, pp. 11, 12, 13.
- 92 J. Agyepong-Parsons, "Europe's largest wind farm finished despite reindeer protests", Windpower Monthly, 21 August 2020, <https://www.windpowermonthly.com/article/1692420/europes-largest-wind-farm-finished-despite-reindeer-protests>. Due to its size and the geography of the chosen area, Fosen Vind is partitioned into a group of six individually named wind farms for a total of 1 GW, from Komusanac, op. cit. note 13.
- 93 The Russian Federation added 713 MW for a total of 905 MW, and 2018 auction, from WindEurope, op. cit. note 6, pp. 11, 14; added 0.7 GW for a total of more than 1 GW as of early 2021, from T. Lanshina, *Russia's Wind Energy Market: Potential for New Economy Development* (Bonn: Friedrich Ebert Stiftung, March 2021), pp. 5, 6, <https://wwindea.org/wp-content/uploads/2021/03/210319-FESMOS-windenergy-en.pdf>. See also E. Gerden, "Russia more than triples capacity in 2020 but now faces delays", Windpower Monthly, 26 November 2020, <https://www.windpowermonthly.com/article/1701020/russia-triples-capacity-2020-faces-delays>. The Russian Federation's largest wind farm (210 MW) was commissioned in December 2020, from Novawind Rosatom, "Electricity and power from the Rosatom's Kochubeyevskaya Wind Farm have entered the wholesale market", press release (Moscow: 11 January 2021), [http://novawind.ru/eng/press/news/news\\_item.php?page=375](http://novawind.ru/eng/press/news/news_item.php?page=375).
- 94 Only major economy from Lanshina, op. cit. note 93, p. 6, and from S. Gsänger, P. Teschendorf and L. Gürth, preface in idem, p. 5. Wind power accounted for 0.4% of the Russian Federation's generating capacity (0.13% of generation) as of early 2021, from idem. Awarded capacity from E. Nikolaev, Russianwind, presentation for WWEA webinar "Wind power around the world", 7 April 2021, <https://wwindea.org/wweweabinar-wind-power-around-the-world>. Total installed capacity rose from 136 MW in 2018 to 191 in 2019 and 905 MW in 2020; a total of 3,351 MW is expected until 2024 due to tenders in past years, from idem.
- 95 Based on data from WindEurope, op. cit. note 6, p. 11, and from GWEC, "Global Wind Statistics 2020", op. cit. note 6. The United Kingdom added 598 MW (115 MW onshore and 483 MW offshore) for a total of 24,167 MW, from WindEurope, op. cit. note 6. The country's end-2020 capacity totalled 24,665 MW (14,282 MW onshore and 10,383 MW offshore) (preliminary data), up from a total of 24,095 MW (14,125 MW onshore and 9,971 MW offshore), from UK BEIS, "Renewable electricity capacity and generation", Main Table, <https://www.gov.uk/government/statistics/energy-trends-section-6-renewables>, viewed 16 April 2021. The UK added 598 MW (115 MW onshore and 483 MW offshore) for a total of 23,937 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.
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- 99 WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13.
- 100 Based on data from WindEurope, op. cit. note 6, p. 11; WindEurope, op. cit. note 23, p. 10.
- 101 Gross additions were down 1.5% and net additions were down 8%, based on data from WindEurope, op. cit. note 6, p. 11; WindEurope, op. cit. note 23, p. 10; and Komusanac, op. cit. note 13. The countries that installed more in 2020 than in 2019 were Belgium, Croatia, Finland, Luxembourg, the Netherlands and Poland, based on data from WindEurope, op. cit. note 6, p. 11, and from Komusanac, op. cit. note 13.
- 102 WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13.

- 103 Based on data from WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13. France added 1,104.8 MW added in 2020 for year-end total of 17,616 MW, from Le Réseau de Transport d'Électricité (RTE), *Bilan Electrique 2020* (Paris: 2020), p. 54, [https://assets.rte-france.com/prod/public/2021-03/Bilan%20electrique%202020\\_0.pdf](https://assets.rte-france.com/prod/public/2021-03/Bilan%20electrique%202020_0.pdf), and added 1,105 MW for total of 17,616 MW, from RTE, *Panorama de l'Électricité Renouvelable* (Paris: 31 December 2020), p. 17, [https://assets.rte-france.com/prod/public/2021-02/Panorama%20EnR\\_T4\\_2020\\_.pdf](https://assets.rte-france.com/prod/public/2021-02/Panorama%20EnR_T4_2020_.pdf).
- 104 Poland added 731 MW in 2020 (up from 53 MW in 2019) for a year-end total of 6,614 MW, all onshore, from WindEurope, op. cit. note 6, p. 11, and WindEurope, op. cit. note 23, p. 10.
- 105 Based on data from WindEurope, op. cit. note 6, p. 11. France added 1,318 MW (net 1,303 MW) for a total of 17,949 MW, Italy added 137 MW for a total of 10,852 MW, and Sweden added 1,007 MW for a total of 9,992 MW, from WindEurope, op. cit. note 6, and from Komusanac, op. cit. note 13.
- 106 The Netherlands added 486 MW onshore and 1,493 MW offshore (total additions 1,979 MW) for a year-end total of 6,784 MW (4,174 MW onshore and 2,611 MW offshore), from WindEurope, op. cit. note 6, pp. 7, 11. In 2019, the country added 0.3 GW, from Komusanac, op. cit. note 13. The Netherlands added nearly 2 GW for a total of almost 6.6 GW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.
- 107 WindEurope, op. cit. note 6, pp. 7, 11; P. Shreshtha, "Ørsted fully commissions 'largest' Dutch offshore wind farm", Energy Live News, 1 December 2020, <https://www.energylivenews.com/2020/12/01/orsted-fully-commissions-largest-dutch-offshore-wind-farm>.
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- 109 Ibid. The Zeewolde project will have 322 MW of capacity, from idem.
- 110 Ibid.
- 111 Ibid. Community-owned projects accounted for only a small fraction of the country's wind (and solar) power capacity in 2020, but the Dutch government plans to require that all projects coming online from 2030 be at least 50% locally owned, from idem.
- 112 Ranking in region and capacity data from WindEurope, op. cit. note 6, p. 11, and from Komusanac, op. cit. note 13; global ranking also based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6. Spain added 1,720 MW in 2020 for a total of 27,446 MW, from Asociación Empresarial Eólica (AEE), cited in "Spain increases wind capacity by 1.7GW in 2020", reNEWS Biz, 24 February 2021, <https://renews.biz/66696/spain-increases-wind-capacity-by-172gw-in-2020>.
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- 114 Watson Farley & Williams, "What you need to know about the Spanish renewable sector's first auction mechanism introduced in 2021", 17 December 2020, <https://www.wfw.com/articles/what-you-need-to-know-about-the-spanish-renewable-sectors-first-auction-mechanism-introduced-in-2021>.
- 115 REE, op. cit. note 15.
- 116 WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13, 28 April 2021.
- 117 Germany added 1,650 MW gross (1,431 MW onshore and 219 MW offshore) and decommissioned 222 MW for a total of 62,627 MW (54,938 MW onshore and 7,689 MW offshore), from WindEurope, op. cit. note 6, pp. 7, 11, 17. Germany's additions in 2020 round up to 1.7 GW, from Komusanac, op. cit. note 13. Germany's net increase in capacity was 1,446 MW in 2020 (1,227 MW onshore and 219 MW offshore), for a year-end total of 62,167 MW (with 54,420 MW onshore and 7,847 MW onshore), from BMWi and AGEE-Stat, op. cit. note 15, p. 7. Germany added a gross of 1,668 MW (net 1,446 MW) for a total of 62,850 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6. WindEurope data are used in text to ensure consistent methodology across all countries in Europe.
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- 124 WindEurope, op. cit. note 6, p. 18. Wind energy generated an estimated 417 TWh in the EU during the year, from WindEurope, op. cit. note 23, p. 8.
- 125 Figure of 1.9 percentage points from Komusanac, op. cit. note 13; causes from WindEurope, op. cit. note 6, p. 18. See also "Renewables achieve clean energy record as COVID-19 hits demand", Renewable Energy World, 6 April 2020, <https://www.renewableenergyworld.com/2020/04/06/renewables-achieve-clean-energy-record-as-covid-19-hits-demand>. Denmark, Germany and Ireland each covered almost 50% of their electricity demand with wind energy in February, due in part to volatile weather and to the large COVID-related demand drop from early February through March, which had the biggest impact on fossil and nuclear generation, but also a general trend of increasing share of wind capacity and generation, all from idem.
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- 127 Australia added 1,097 MW for a total of 7,376 MW, from Clean Energy Council, *Clean Energy Australia Report 2021* (Melbourne: 2021), pp. 84, 88, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf>. This was up from a record 837 MW installed in 2019 for a total of 6,279 MW, from idem, p. 88. By year's end, more than 21 projects were under construction or financially committed, representing additional capacity totalling over 4 GW, from idem, p. 84. Australia added 1,097 MW for a total of 7,296 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.
- 128 Clean Energy Council, op. cit. note 127, pp. 45, 46, 49; figure of 41% from Business Renewables Centre Australia, cited in idem, p. 49.
- 129 Clean Energy Council, op. cit. note 127, p. 89.
- 130 Wind power generated 22,605 TWh, accounting for 9.9% of Australia's total generation, from *Ibid.*, p. 9. Increase over 2019 output based on generation of 19,487 TWh in 2019, accounting for 8.5% of Australia's total generation, from Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), pp. 6, 9, 79, 81, <https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf>.
- 131 Based on data from Green Energy Markets, cited in Clean Energy Council, op. cit. note 127, p. 86. In 2019, the top three states/territories for share of generation from wind energy were 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 130, 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. For more information, and different statistics, for Victoria, see E. Ingram, "Australia's Victoria doubles share of wind in generation mix in four years", 22 March 2021, <https://www.renewableenergyworld.com/wind-power/australias-victoria-doubles-share-of-wind-in-generation-mix-in-four-years>.
- 132 Clean Energy Council, op. cit. note 127, pp. 4-5, 8. Clean Energy Council, op. cit. note 130, pp. 4, 7. See also Solar PV section in this chapter for more on challenges in Australia. 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 variable 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 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>.
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- 136 Numbers of countries by region based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6; cumulative combined capacities in the regions, and in South Africa, Egypt and Morocco, all from idem, from GWEC, op. cit. note 133, and from GWEC, op. cit. note 1, p. 53.
- 137 Diversify energy mix from, for example: Future Power Technology, op. cit. note 7; T. Smith, "How Egypt banks on renewables to meet likely energy demand surge", ESI Africa, 16 July 2020, <https://www.esi-africa.com/industry-sectors/renewable-energy/how-egypt-banks-on-renewables-to-meet-likely-energy-demand-surge>; T. Smith, "Wind plans for Ghana gaining momentum", ESI Africa, 21 July 2020, <https://www.esi-africa.com/industry-sectors/renewable-energy/wind-plans-for-ghana-gaining-momentum>; and (in Mozambique) GWEC, op. cit. note 1, p. 65. Lower costs and meet rising demand from, for example: Smith, "How Egypt banks on renewables to meet likely energy demand surge", op. cit. this note. Reduce reliance on imports from, for example: B. Bungane, "MIGA supports Djibouti's first utility-scale wind project", ESI Africa, 6 May 2020, <https://www.esi-africa.com/industry-sectors/renewable-energy/miga-supports-djiboutis-first-utility-scale-wind-project>; B. Bungane, "Siemens Gamesa lands contract to build Djibouti's first wind farm", ESI Africa, 26 February 2020, <https://www.esi-africa.com/industry-sectors/generation/siemens-gamesa-lands-contract-to-build-djiboutis-first-wind-farm>; Smith, "Wind plans for Ghana gaining momentum", op. cit. this note. Free up oil and gas for export from, for example, Smith, "How Egypt banks on renewables to meet likely energy demand surge", op. cit. this note.

- 138 Bungane, "MIGA supports Djibouti's first utility-scale wind project", op. cit. note 137; Bungane, "Siemens Gamesa lands contract to build Djibouti's first wind farm", op. cit. note 137; Smith, "Wind plans for Ghana gaining momentum", op. cit. note 137.
- 139 GWEC, op. cit. note 133; "Barriers to foreign Investment", in Future Power Technology, op. cit. note 7; 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>. See also IEA, op. cit. note 54.
- 140 Based on data from GWEC, "China installed half of new global offshore wind capacity during 2020 in record year", 25 February 2021, <https://gwec.net/china-installed-half-of-new-global-offshore-wind-capacity-during-2020-in-record-year>, from WindEurope, op. cit. note 6, p. 11, from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from Yu, op. cit. note 25. Note that GWEC has a figure of 24,837 MW for all of Europe, from idem, whereas Europe had a total 25,013 MW of offshore wind power capacity in operation at end-2020, from WindEurope, op. cit. note 6, pp. 11, 17. An estimated 5.2 GW (including only those projects with entire capacity in operation) was added to grids around the world in 2020, from World Forum Offshore Wind, *Global Offshore Wind Report 2020*, cited in A. McCorkell, "WFO: Record growth for offshore wind in 2020 despite Covid-19", Windpower Monthly, 9 February 2021, <https://www.windpowermonthly.com/article/1706847/wfo-record-growth-offshore-wind-2020-despite-covid-19>.
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- 142 GWEC, op. cit. note 140.
- 143 China added 3.1 GW for a total of 10.13 GW (preliminary estimates), from Yu, op. cit. note 25, and added 3,060 MW for a total of 9,996 MW, from GWEC, op. cit. note 1, p. 53.
- 144 GWEC, op. cit. note 1, p. 49; "China's offshore wind energy industry post-2021", reve, 22 October 2020, <https://www.evwind.es/2020/10/22/chinas-offshore-wind-energy-industry-post-2021/77839>.
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- 153 WindEurope, op. cit. note 152, p. 34.
- 154 Europe added 2,918 MW for a total of 25,013 MW, and no offshore capacity was decommissioned during the year, from WindEurope, op. cit. note 6, pp. 11, 17; down 20% from WindEurope, op. cit. note 152, p. 9. At the end of 2020, Europe had a total of 5,402 grid-connected turbines in 116 offshore wind farms, including some with partial grid connection) across 12 countries, from WindEurope, op. cit. note 152, pp. 7, 9.
- 155 The Netherlands added 1,493 MW for a total of 2,611 MW, Belgium added 706 MW for a total of 2,261 MW, the United Kingdom added 483 MW for a total of 10,428 MW, Germany added 219 MW for a total of 7,689 MW and Portugal added 17 MW for a total of 25 MW, all from WindEurope, op. cit. note 6, p. 11. See also WindEurope, op. cit. note 152, p. 10. Data from GWEC are similar with the exceptions of the United Kingdom (483 MW added for total of 10,206 MW) and Germany (237 MW added for total of 7,728 MW), from GWEC, "Global Wind Statistics 2020", op. cit. note 6.
- 156 The UK pipeline totalled more than 41 GW by early 2021, from GWEC, op. cit. note 1, p. 30. The UK slowdown was a result of time between the Contracts for Difference rounds 1 and 2, from GWEC, op. cit. note 140.
- 157 Lowest in nearly a decade from WindEurope, op. cit. note 152, p. 11; no projects under construction from Deutsche WindGuard, op. cit. note 123, p. 3; all planned projects had been installed from Hermann, op. cit. note 118. Germany's offshore wind tenders in 2017 and 2018 had a long period of time before commissioning deadlines, which caused a gap in projects due to the shift from administrative tariffs to auctions, from Komusanac, op. cit. note 13. New law and offshore tender volumes from Die Bundesregierung, "Mehr Rückenwind für den Strom – auch seitens der EU", 22 January 2021, <https://www.bundesregierung.de/breg-de/themen/klimaschutz/fuer-mehr-windenergie-auf-see-1757176>, viewed 27 April 2021. See also BMWi, "Altmaier: 'Deutschland baut seine Vorreiterrolle im Bereich Windenergie auf See weiter aus'", 9 December 2020, <https://www.bmw.de/Redaktion/DE/Pressemitteilungen/2020/12/20201209-altmaier-deutschland-baut-seine-vorreiterrolle-im-bereich-windenergie-auf-see-weiter-aus.html>.

- 158 WindEurope, op. cit. note 152, p. 11.
- 159 Figure of 62 MW (83% of the global total) and pipeline, from WindEurope, op. cit. note 152, pp. 20, 21. The Windfloat Atlantic project has a total of 25 MW; in Scotland, the 50 MW Kincardine project, which will use five 9.5 MW floating turbines, was under construction in 2020, from idem.
- 160 WindEurope, op. cit. note 152, pp. 7, 14. The other countries with offshore capacity are Sweden, Finland, Ireland, Portugal, Spain, Norway and France, from idem.
- 161 Ibid., pp. 6-7, 32-33. The total includes EUR 2.1 billion (USD 2.58 billion) in offshore transmission infrastructure, from Komusanac, op. cit. note 13.
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- 193 China accounted for 67%, and "subsidy-free" onshore wind projects represented 96% of China's approved capacity, from GWEC, op. cit. note 191.
- 194 Figure of 13 countries or regions based on the following: GWEC database, provided by Zhao, op. cit. note 7, 27 April 2021; several countries in Europe, Ecuador and India from GWEC, op. cit. note 191; WindEurope, op. cit. note 6, p. 23; Windpower Monthly/Windpower Intelligence, "Tender Watch", <https://www.windpowermonthly.com/tender-watch>, viewed 7 March 2021. In order of awarded capacity, these countries were: India (2.2 GW), Germany (1.5 GW), Poland (900 MW), the Netherlands (759 MW) Ireland (479 MW), Greece (472 MW), France (258 MW) and Ecuador (110 MW), from GWEC, op. cit. note 191. Italy also held several (technology-neutral) auctions during the year, from WindEurope, op. cit. note 6, p. 23. An auction also was held in the US state of New Jersey, based on data from Windpower Monthly/Windpower Intelligence, op. cit. this note, and from New Jersey Board of Public Utilities, "New Jersey offshore wind solicitation #2", <https://njoffshorewind.com>.
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- 199 Gsänger, op. cit. note 89, 7 May 2020 and 14 April 2021. All wind-specific auctions in Germany had average winning bids above EUR 62 (USD 76.2) per MWh and around the ceiling price and above prices from previous years, from Komusanac, op. cit. note 13. See also BMWi, "Ausschreibungsergebnisse Windenergie an Land", <https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/ausschreibungsrunden-windenergie-an-land-balkendiagramm.pdf>, viewed 27 April 2021, and Bundesnetzagentur, "Completed tenders", [https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen\\_Institutionen/Ausschreibungen/Wind\\_Onshore/BeendeteAusschreibungen/BeendeteAusschreibungen\\_node.html](https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Ausschreibungen/Wind_Onshore/BeendeteAusschreibungen/BeendeteAusschreibungen_node.html), viewed 27 August 2021. Awarded bid prices fell significantly in the 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 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, pp. 7, 11, <https://wwindea.org/download/community-power-study-september-2019>, and from Gsänger, op. cit. note 89, 7 May 2020. Note that the final onshore wind tender of 2020 was not undersubscribed, from Richard, "German onshore wind reverses trend with successful tender", op. cit. note 120; but the first of 2021 was undersubscribed, with the average winning bid price up slightly relative to the final tender in 2020, from C. Richard, "Developers stay away from German onshore wind tender", Windpower Monthly, 30 April 2021, <https://www.windpowermonthly.com/article/1714500/developers-stay-away-german-onshore-wind-tender>.
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## ENERGY EFFICIENCY, RENEWABLES AND DECARBONISATION

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