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RENEWABLES 2020
GLOBAL STATUS REPORT

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RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY

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

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

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

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

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Global Trends in Renewable Energy Investment (GTR) is an annual report jointly prepared by the Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, BloombergNEF and the UN Environment Programme (UNEP). *Global Trends in Renewable Energy Investment* grew out of efforts to track and publish comprehensive information about international investments in renewable energy. The 2020 edition of the GTR explores the most recent developments, signs and signals in the financing of renewable power and fuels. Information is presented by type of investment, technology and economy. It also provides an outlook on financing trends for the next decade.

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

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FOREWORD

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

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

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

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

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

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

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

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

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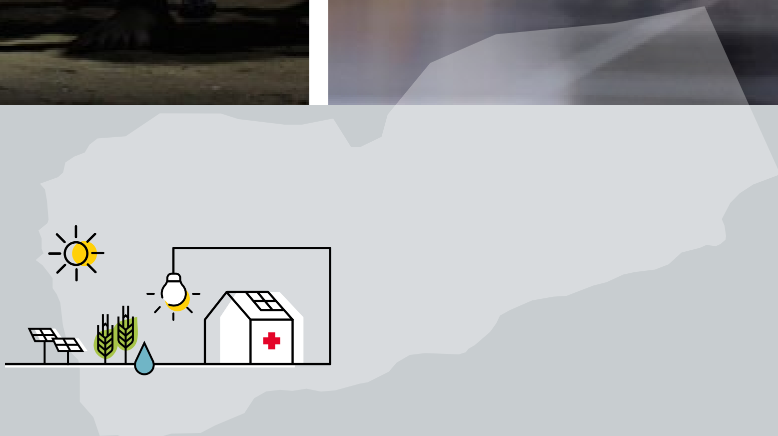
June 2020

RENEWABLES PROVIDING BASIC SERVICES TO COMMUNITIES, YEMEN



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

EXECUTIVE SUMMARY

01 GLOBAL OVERVIEW

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

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

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

As of 2018, modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11% of TFEC, only a slight increase from 9.6% in 2013. The highest share of renewable energy use (26.4%) was in electrical uses excluding heating, cooling and transport; however, these end-uses accounted for only 17% of TFEC in 2017. Energy use for transport represented some 32% of TFEC and had a low share of renewables (3.3%), while the remaining thermal energy uses accounted for more than half of TFEC, of which 10.1% was supplied by renewables. Overall, the slow growth in the renewable energy share of TFEC indicated the complementary roles of energy efficiency and renewables in reducing the contribution of fossil fuels in meeting global energy needs.

Among the general public, support for renewable energy continued to advance alongside rising awareness of the multiple benefits of renewables, including reduction of carbon dioxide (CO_2) and other greenhouse gas emissions.

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

At the same time, while some countries were phasing out coal, others continued to invest in new coal-fired power plants, both domestically and abroad. In addition, funding from private banks for fossil fuel projects has increased each year since the signing of the Paris Agreement in 2015, totalling USD 2.7 trillion between 2016 and 2019. Although energy-related CO_2 emissions remained stable in 2019, the world is not on track to limit global warming to well below 2 degrees Celsius (°C), let alone 1.5 °C, as stipulated in the Paris Agreement.

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

BUILDINGS

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

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

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

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

INDUSTRY

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

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

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

TRANSPORT

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

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

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

POWER

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

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

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

02 POLICY LANDSCAPE

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

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

CROSS-SECTORAL TARGETS AND POLICIES

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

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

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

RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

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

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

HEATING AND COOLING POLICY

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

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

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

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

TRANSPORT POLICY

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

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

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

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

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

POWER POLICY

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

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

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

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

POLICIES FOR SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

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

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

03 MARKET AND INDUSTRY TRENDS

BIOENERGY

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

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

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

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

Global biofuels production

increased

5% in 2019.

GEOTHERMAL POWER AND HEAT

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

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

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

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

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

HYDROPOWER

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

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

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

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

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

OCEAN POWER

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

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

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

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

SOLAR PHOTOVOLTAICS (PV)

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

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

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

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

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

CONCENTRATING SOLAR THERMAL POWER (CSP)

Global CSP capacity in operation grew exclusively in emerging markets.

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

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

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

SOLAR THERMAL HEATING AND COOLING

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

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

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

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

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

WIND POWER

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

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

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

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

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

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS (DREA)

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

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

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

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

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

05 INVESTMENT FLOWS

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

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

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

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

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

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

06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

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

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

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

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

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

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

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

07 ENERGY EFFICIENCY AND RENEWABLES

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

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

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

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

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

08 FEATURE: PUBLIC SUPPORT FOR RENEWABLES

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

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

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

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

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

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

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

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

01

CLIMATE EMERGENCY DECLARATIONS AROUND THE WORLD

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

01 GLOBAL OVERVIEW

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

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

KEY FACTS

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

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

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

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

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

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

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

Despite an increase in final energy demand, global **energy-related carbon dioxide (CO_2) emissions** did not grow in 2019, following two years of increases.[12] This flattening was due mainly to declines in emissions from the power sector in some countries, which were related mostly to improvements in energy efficiency and to rising shares of renewable energy, but also to some extent to fuel switching from coal to gas.[13]

SIDEBAR 1. The COVID-19 Crisis and Renewable Energy

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

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

The carbon intensity of electricity systems also dropped, and cities across the globe benefited from unusually high air quality. Nonetheless, the concentration of CO_2 in the atmosphere continued to rise to record levels even as emissions decreased, highlighting that a structural shift would still be necessary to reach long-term climate and development targets.

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

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

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

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

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

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

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

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

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

As the focus has shifted **from rescue to recovery**, governments have considered options for "building back better"[i]. A comprehensive study of fiscal recovery packages[ii] concluded that "green" recovery measures, such as investment in renewables and building efficiency, are more cost effective than traditional stimulus measures, creating more jobs and delivering higher returns. Renewable energy also offers a range of other proven benefits, including increasing energy security, reducing emissions and improving human health.

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

i A term adopted by the international community in the Sendai Framework for Disaster Risk Reduction 2015-2030.

ii The study considered 700 stimulus responses to the 2008 financial crisis and surveyed 231 central bank officials, finance ministry officials and other economic experts from G20 countries on the relative performance of 25 major fiscal recovery archetypes.

Source: See endnote 1 for this chapter.

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

- Climate strikes – driven by young people – took place in at least 150 countries worldwide, reflecting a growing sense among youth of the urgency of action on climate change.[14] By year's end, 1,480 jurisdictions – spanning 28 countries and covering 820 million citizens – had issued "climate emergency" declarations.[15] In parallel, opinion polls across several countries demonstrated increased awareness of climate change and strong public support for renewable energy.[16]
- More institutions committed to divesting[i] either fully or partially from fossil fuels, including the European Investment Bank, Norway's sovereign wealth fund and the US investment bank Goldman Sachs.[17] Combined, global divestment totalled USD 11 trillion of managed assets by year's end.[18] Meanwhile, the first major divest-invest conference in the Global South was held with delegates from more than 44 countries.[19]
- The G5 Sahel heads of state endorsed Desert to Power, an initiative by the African Development Bank that aims to guarantee access to renewable electricity in 11 African countries in the Sahel region.[20]
- Globally, 77 countries, 10 regions and more than 100 cities announced their commitment to net zero carbon[ii] emissions by 2050, and the European Commission proposed a European Green Deal roadmap to create the first carbon-neutral continent by 2050.[21]
- The Zero Carbon Buildings for All Initiative, launched in 2019 at the United Nations Climate Action Summit, aims to develop decarbonisation roadmaps for buildings and to mobilise USD 1 trillion in funding by 2050.[22] In the maritime industry, leaders launched the Getting to Zero Coalition with the objective of operating zero emission vessels along deep-sea trade routes by 2030.[23]
- More than half of the countries that have submitted Nationally Determined Contributions (NDCs) towards reducing greenhouse gas emissions under the Paris Agreement have noted interest in implementing a carbon tax; however, by year's end carbon pricing initiatives were in place in only 47 countries around the world, covering 20% of global emissions.[24] Furthermore, although 132 NDC plans mentioned renewables in the context of the power sector and 112 mentioned energy efficiency, only 25 plans mentioned renewable energy in the context of heating and cooling, and 25 in the context of transport.[25]
- Several cities adopted commitments to reduce greenhouse gas emissions, including 94 mayors who announced their support for a Global Green New Deal for cities, committing to limiting global warming to 1.5 degrees Celsius (°C) above pre-industrial levels.[26] As of mid-year, nearly 10,000 cities and local governments had committed to jointly reducing emissions through the Global Covenant of Mayors for Climate & Energy.[27]

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

Investment in renewable energy again grew in 2019, albeit slowly, and much more investment flowed to renewable power technologies than to other electricity-generating technologies, including coal, natural gas and nuclear power generating plants.[28] Overall, global new investment in renewable power and fuels grew 2% compared to 2018 – as costs continued to decrease – reaching some USD 301.7 billion.[29] Wind and solar power accounted for nearly all of this investment; notably, investment in wind power outweighed investment in solar power for the first time since 2009.[30]

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

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

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

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

ii Net zero carbon emissions and carbon neutrality refer to the achievement of a state in which every tonne of CO_2 emitted to the atmosphere is compensated by an equivalent tonne removed (e.g., sequestered). In the case of carbon neutrality, emissions can be compensated by carbon offsets. See Glossary and K. Levin, J. Song and J. Morgan, "COP21 glossary of terms guiding the long-term emissions-reduction goal", World Resources Institute, 2 December 2015, https://www.wri.org/blog/2015/12/cop21-glossary-terms-guiding-long-term-emissions-reduction-goal.

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

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

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

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

BOX 1. Renewable Energy in Cities

Cities play an important role in the effort to address climate, energy and sustainable development issues. They account for around two-thirds of global final energy use and some three-quarters of global CO_2 emissions. At the same time, local governments have a direct impact on the daily lives of their citizens, such as through urban planning decisions or providing urban services, including public housing, waste and wastewater management, and public transport. They are well positioned not only to grow the use of renewable energy in municipal operations, but also to encourage and support the deployment and use of renewables in cities more broadly. Thus, cities can play a major role in advancing the transition towards renewable energy in the heating and cooling and transport sectors, to accelerate deployment in the power sector, and to foster the integrated approaches needed to decarbonise energy use in all sectors.

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

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

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

Despite the growing deployment of renewable energy around the world, the share of renewables in **total final energy consumption** (TFEC) has seen only a moderate increase. As of 2018[i], modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11% of TFEC, only a slight increase from 9.6% in 2013.[40] The largest portion was renewable electricity (5.7% of TFEC), followed by renewable heat (4.3%) and transport biofuels (1.0%).[41] (→ *See Figure 1.*)

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

However, this means that other energy sources (predominantly fossil fuels, growing at a rate of 1.3% annually) accounted for 71% of the total increase in energy demand, highlighting the challenge that renewables faced in gaining greater TFEC shares during the five-year period.[46] (→ *See Figure 2.*) This slow progress points to the complementary roles of energy efficiency and renewables in reducing the contributions of fossil fuels in meeting global energy needs.

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

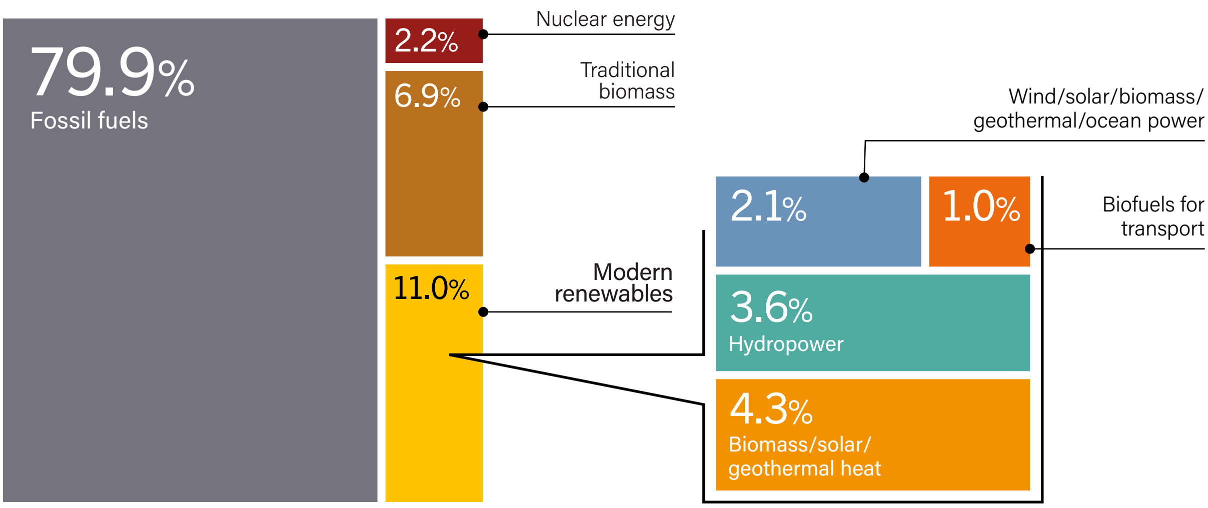
The share of renewables in final energy demand varies depending on how this energy is used. The highest share of renewable energy use is in the power sector (excluding electricity for heating, cooling and transport), such as lighting and appliances in buildings, where it continues to grow quickly.[47] However, these end-uses accounted for only 17% of TFEC[ii] in 2017.[48] Energy use for transport represented some 32% of TFEC, and had the lowest share of renewables (3.3%).[49] The remaining thermal[iii] energy uses, which include space and water heating, space cooling and industrial process heat, accounted for more than half (51%) of TFEC; of this, some 10.1% was supplied by renewables.[50] (→ *See Figure 3.*)

i At the time of publication, global data for TFEC and the contribution of energy sources to meet energy demand were available for the year 2017; values for 2018 are estimates. See Methodological Notes for more information.

ii Electricity generation still accounts for a far greater portion of primary energy consumption. See Glossary for definitions.

iii Applications of thermal energy include space and water heating, space cooling, refrigeration, drying and industrial process heat, and any use of energy other than electricity that is used for motive power in any application other than transport. In other words, thermal demand refers to all end-uses of energy that cannot be classified as electricity demand or transport.

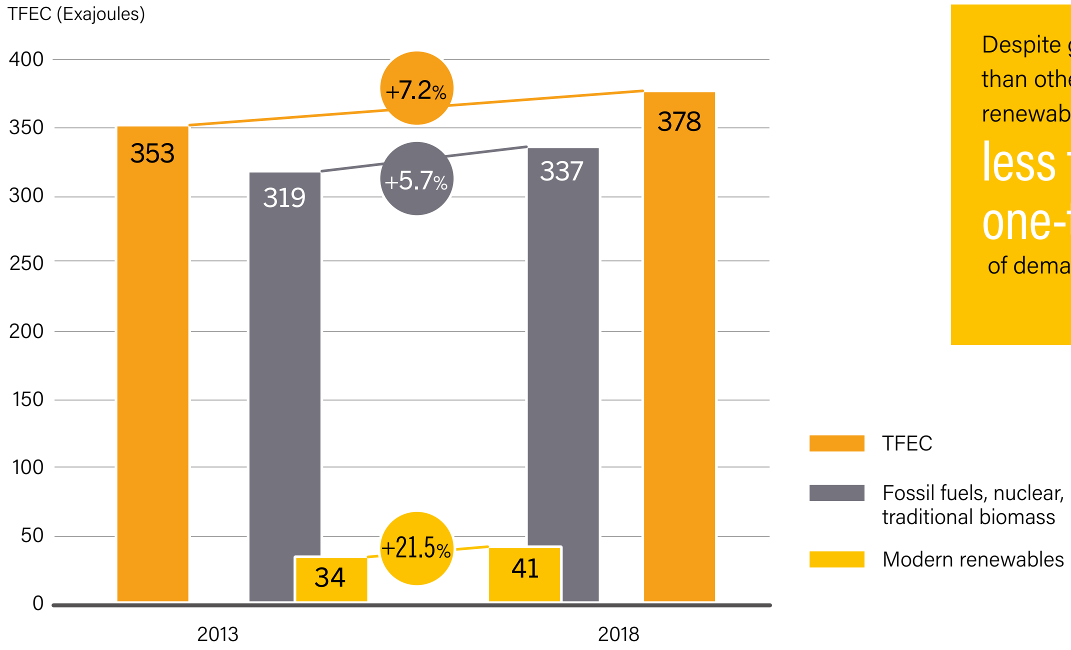
FIGURE 1. Estimated Renewable Share of Total Final Energy Consumption, 2018



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

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

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



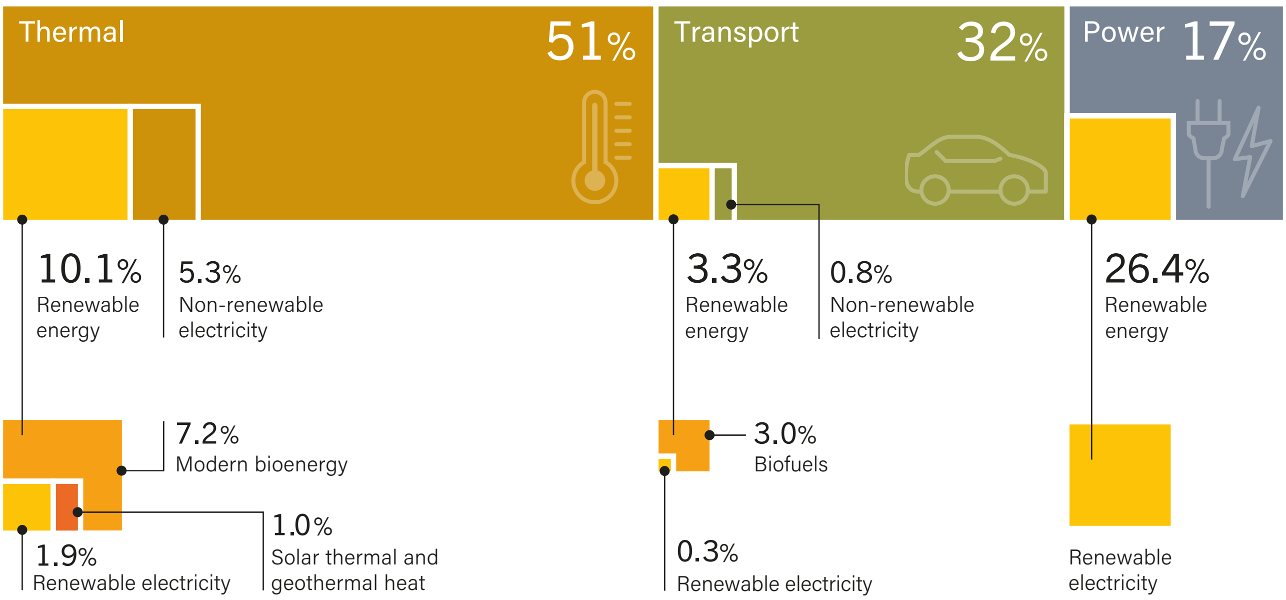
Despite growing faster than other energy sources, renewables made up

less than one-third

of demand growth.

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

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



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

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

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

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

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

In many countries, investment in new fossil fuel production and related infrastructure continued. While some countries were phasing out coal, others invested in new coal-fired power plants, both domestically and abroad. Many coal-fired plants announced closures in Europe and the United States, whereas most of the still-operating and new plants were located in developing and emerging Asia.[57] Public finance from China funded by far the largest amount of coal capacity in other countries, followed by funding from Japan, the Republic of Korea, France, Germany and India, nearly all of which was directed towards developing and emerging countries.[58] Funding from private banks for fossil fuel projects also has increased annually since the signing of the Paris Agreement in 2015, totalling USD 2.7 trillion between 2016 and 2019.[59] Conversely, the European Investment Bank announced in 2019 that it would stop funding fossil fuel projects beginning in 2021.[60]

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

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

Although energy-related CO_2 emissions were stable in 2019, the world is **not on track** to limit global warming to 2 °C.

Table 1. Renewable Energy Indicators 2019

		2018	2019
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	296.0	**301.7**
POWER			
Renewable power capacity (including hydropower)	GW	2,387	**2,588**
Renewable power capacity (not including hydropower)	GW	1,252	**1,437**
Hydropower capacity[2]	GW	1,135	**1,150**
Wind power capacity	GW	591	**651**
Solar PV capacity[3]	GW	512	**627**
Bio-power capacity	GW	131	**139**
Geothermal power capacity	GW	13.2	**13.9**
Concentrating solar thermal power (CSP) capacity	GW	5.6	**6.2**
Ocean power capacity	GW	0.5	**0.5**
HEAT			
Modern bio-heat demand (estimated)[4]	EJ	13.9	**14.1**
Solar hot water demand (estimated)[5]	EJ	1.4	**1.4**
Geothermal direct-use heat demand (estimated)[6]	PJ	384	**421**
TRANSPORT			
Ethanol production (annual)	billion litres	111	**114**
FAME biodiesel production (annual)	billion litres	41	**47**
HVO biodiesel production (annual)	billion litres	6.0	**6.5**
POLICIES[7]			
Countries with renewable energy targets	#	169	**172**
Countries with renewable energy policies	#	158	**161**
Countries with 100% renewable energy in primary or final energy targets	#	1	**1**
Countries with 100% renewable heating and cooling targets	#	1	**1**
Countries with 100% renewable transport targets	#	1	**1**
Countries with 100% renewable electricity targets	#	57	**61**
Countries with heat regulatory policies	#	23	**23**
Countries with biofuel blend mandates[8]	#	70	**70**
Countries with feed-in policies (existing)	#	87	**87**
Countries with feed-in policies (cumulative)[9]	#	113	**113**
Countries with tendering (held during the year)	#	48	**41**
Countries with tendering (cumulative)[9]	#	98	**109**

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

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

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

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

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

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

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

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

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

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

Table 2. Top Five Countries 2019

Annual Investment / Net Capacity Additions / Production in 2019

Technologies ordered based on total capacity additions in 2019.

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

Total Capacity or Generation as of End-2019

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

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

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

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

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

[4] Not including heat pumps. Data are from 2015.

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

BUILDINGS

The buildings sector consumes around one-third of final energy and releases some 28% of global energy-related CO_2 emissions.[63] Energy use in the sector is growing at around 1% per year, as global increases in both population and the building floor area continue to overcome any reductions in demand resulting from energy efficiency measures.[64] Renewable energy is the fastest growing source of energy for buildings, yet in 2017 it met less than 14% of total energy demand in the sector.[65] (→ *See Figure 4.*) Energy efficiency remains critical for curbing demand and for increasing the share of renewables in final energy consumption in buildings.[66] (→ *See Energy Efficiency chapter.*)

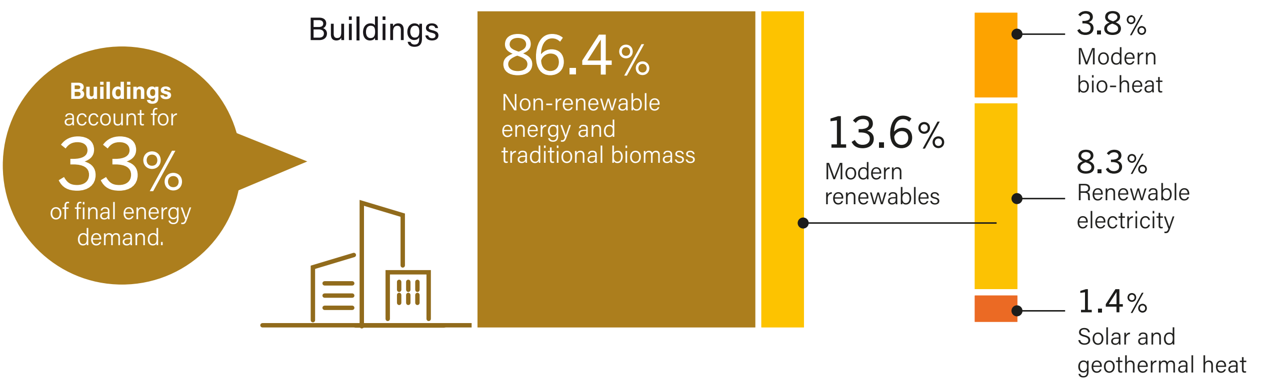
Around 77% of global final energy demand in buildings in 2017 was for **heating and cooling**[i] end-uses, including space heating and cooling, water heating and cooking.[67] Total heating and cooling demand has grown slowly (0.6% annually since 2010), although energy used for cooling (around 6% of building energy consumption) – the fastest growing energy end-use in buildings – rose 4% per year between 2010 and 2018.[68] The remaining final energy demand in buildings (23% in 2017) is for **electrical end-uses**[ii], including lighting and appliances.[69] Global electricity use in buildings rose moderately during 2010-2018, at more than 2% per year.[70]

Overall, energy for heating and cooling remains highly dependent on fossil fuels. In 2018, modern renewables contributed an estimated 10.1% of heating and cooling demand in buildings, up from 8% in 2010.[71] (→ *See Figure 5.*) Most of this increase was due to growth in renewable electricity for heat and in solar thermal, while the share of modern bioenergy remained stable.[72]

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

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

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



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

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

Modern bioenergy represents the largest source of renewable energy use in the buildings sector and directly provided around 4.6% of total heat demand in buildings in 2018[i].[73] However, bioenergy use in buildings is growing only slowly and its share has remained relatively stable, as bio-heat consumption has grown at the same rate as building thermal demand.[74] Renewable electricity supplies the second largest renewable heat demand.[75]

Solar thermal and **geothermal heat** together contributed some 2.0% of thermal energy demand in buildings in 2018.[76] Demand for these sources has grown more rapidly than bioenergy use in recent years, although starting from a smaller base.[77] (→ *See Market and Industry chapter.*)

Renewable energy delivered by **district heating and cooling networks** supplies a minor share of building heat demand worldwide.[78] Nevertheless, some European countries have achieved high shares of renewables in the district heat supply (more than 50% in at least six countries as of 2017[ii]).[79] Shares also are growing significantly in Lithuania as well as in Finland, France and Switzerland, among others – helping to boost the share of renewables in Europe's buildings.[80]

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

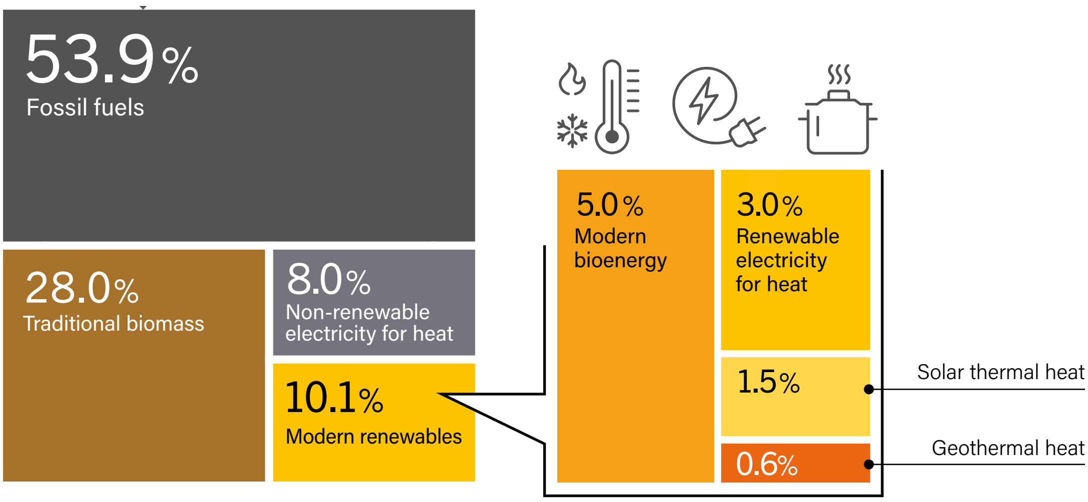
Several initiatives and studies demonstrating the benefits of electrification of buildings were launched or completed in 2019, notably covering specific regions of the United States as well as multiple countries around the world.[83] In Europe, electrification is considered a central element of the strategy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

Overall, the global share of renewable electricity used for heating and cooling in buildings was an estimated 3% in 2018, up from around 2% in 2010.[85] Over this period, electricity contributed more than one-third of the overall demand growth for renewable building heat, the most of any renewable energy source.[86] However, most of this increase was due to the growing share of renewables in the global electricity supply, rather than to rising electrification of heating in buildings.[87]

The use of traditional biomass for **cooking** – predominantly in open fires or inefficient indoor stoves – leads to significant health problems, particularly in developing and emerging economies. In these countries, the use of gaseous fuels[iii] overtook traditional biomass use in 2009 and reached 48% of the population in 2018 (compared to 37% for traditional biomass).[88] The share of the population using coal in rural areas and kerosene in urban areas was 2% each in 2018.[89] At the same time, the share of electric cooking rose to 7%; however, the use of renewable energy for cooking depends on the overall renewable electricity share in national power grids.[90]

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

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



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

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

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

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

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

At the same time, global efforts to decarbonise buildings, specifically through **net zero carbon/energy buildings**[i], are simultaneously promoting the uptake of renewables in the sector.[98] As of early 2020, 6 states and regions, 28 cities, and 48 businesses and organisations had signed the Net Zero Carbon Buildings Commitment.[99] In 2019, the EU's Energy Performance in Buildings Directive mandated that new *public* buildings in the region[ii] be "nearly zero energy buildings", and the standard was set to apply to *all* new buildings starting from 2021.[100]

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

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

Only
51 countries
defined actions on renewables in buildings in their NDC commitments.

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

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

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

INDUSTRY

Energy use in industry[i] accounts for around 35% of total final energy consumption.[106] Direct energy-related industrial CO_2 emissions (excluding agriculture and land use) make up some 23% of the global total.[107] Energy use in the sector is growing modestly at less than 1% per year, although in certain energy-intensive sub-sectors such as chemicals and non-ferrous metals processing, energy use has grown much faster (between 2% and 3.5% per year).[108]

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

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

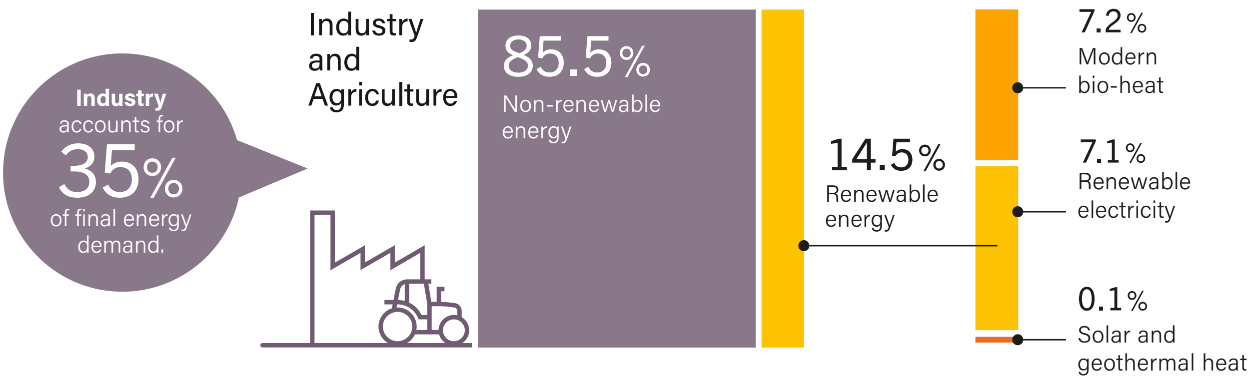
Within the industrial sector, the most energy-intensive sub-sectors – those with the highest process temperatures – also use the lowest shares of renewable energy.[115] The sectors with the highest penetration of renewables are pulp and paper (46%), wood products (37%) and food industries (27%); in each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

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

Policy attention to the use of renewables in industry is limited, but some support policies and other measures were introduced or announced in 2019.[121] The EU announced the development of its Industrial Strategy, although early details did not include firm commitments for the uptake of renewable energy in industry.[122] Also during the year, Australia began the first phase of an AUD 461,000 (USD 322,000) initiative to promote the adoption of renewable energy in process heat; the second phase was launched in January 2020.[123]

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

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



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

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

Projects to use **renewable electricity** in industry – notably in steel production – were announced or completed in 2019. The production of secondary steel (using recycled scrap metal) has potential for electrification with renewables, as up to 25% of these processes are driven by electric arc furnaces.[124] Construction was completed on a USD 250 million steel plant in the US state of Missouri, which upon opening in January 2020 became the country's first steel plant to run on wind energy; solar PV projects in part to produce steel also were announced in Australia and the US state of Colorado.[125] One multinational steelmaker noted its intention to create a fossil-free value chain for steel production based on electric arc furnaces powered by renewable electricity, with some plants based entirely on renewables by 2022.[126]

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

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

During the year, a 20% reduction in energy costs led an Australian mining giant to sign four PPAs for renewable energy at two mines in Chile, with the aim of running the mines on 100% renewable electricity by 2025.[131] In early 2020, an Argentinian mining company signed a 10-year PPA with a wind power plant to cover 50% of the mine's electricity demand.[132]

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

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

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

New projects were completed or announced in 2019 to use renewable electricity to produce

steel and cement

and to power mining operations.

TRANSPORT

Energy for the transport sector accounted for around one-third (32%) of total final energy consumption globally in 2017.[138] However, transport remains the sector with the lowest share of renewable energy: in 2017, the vast majority (96.7%) of global transport energy needs were met by oil and petroleum products (including 0.8% non-renewable electricity), with small shares met by biofuels (3.0%) and renewable electricity (0.3%).[139] (→ *See Figure 7.*) These shares remain unchanged from the previous year.

Despite gains in **energy efficiency**, particularly in road transport, global energy demand in the transport sector increased 2.2% annually on average between 2007 and 2017.[140] This was due mostly to the growing number and size of vehicles on the world's roads (and increases in tonne-kilometres and passenger-kilometres travelled), as well as to a reduction in average passenger-kilometres travelled per person for buses, and to a lesser extent to rising air transport.[141] (→ *See Energy Efficiency chapter.*) The result of the increased energy demand has been a global increase in greenhouse gas emissions from the transport sector, even as transport emissions in some regions (such as the EU and the United States) have fallen.[142] The sector as a whole accounted for nearly one-quarter of global energy-related greenhouse gas emissions in 2019.[143]

Many countries lack a **holistic strategy** for decarbonising transport, although cities often are well placed to take more comprehensive action, especially in road transport.[144] Such strategies include reducing the overall need for motorised transport; transitioning to more efficient transport modes, such as (renewables-based) public transport and rail or non-motorised transport, and "active transport" (such as walking and cycling); and improving vehicle technology and fuels, such as through higher fuel efficiencies and emission standards along with greater incorporation of renewable energy[i,145]

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

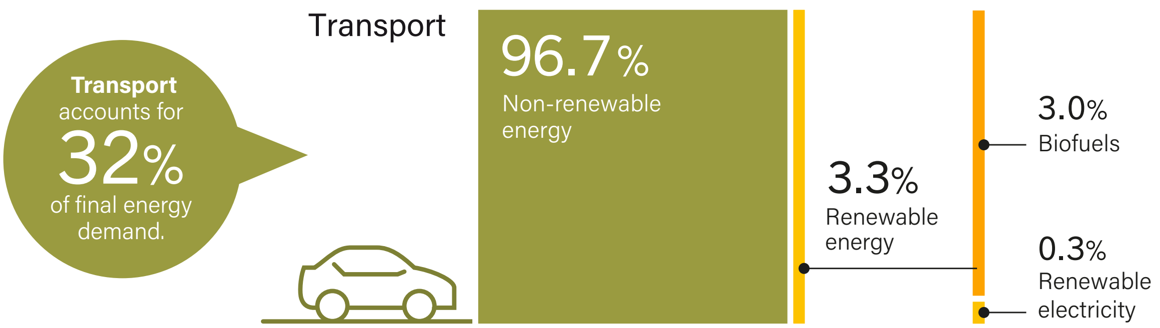
Growth in **biofuels** continued in 2019, and they remain by far the largest contributor of renewable energy to the transport sector. Although rarely linked directly to renewable sources, the expansion of **EVs** and the use of electricity in transport also advanced during the year. Electrified vehicles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

Overall, the transport sector is **not on track** to meet global climate targets for 2030 and 2050.[150] By the end of 2019, around 80% of countries worldwide had acknowledged the transport sector's role in mitigating emissions by including transport in their NDCs under the Paris Agreement.[151] However, just 11% of the NDCs included measures for renewables-based transport.[152]

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

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

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



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

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

The number of electric passenger cars on the road neared 7.2 million in 2019 (3.4 million of them in China), up 40% from the previous year.[155] Also during the year, investments in charging infrastructure further enabled the electrification of road transport, including the first electric highway in Latin America.[156] China reportedly installed more than 1,000 EV charging stations *per day* in 2019.[157] (→ *See Systems Integration chapter.*) Increased electrification of transport can help to dramatically reduce CO_2 emissions in the sector, particularly in countries that are reaching high renewable shares in their electricity mix.[158] EVs also offer the potential for significant final energy savings, as they are inherently more efficient than comparable internal combustion engine vehicles.[159]

However, only limited examples exist of direct **policy** linkages between EVs and renewable electricity.[160] As of early 2020, only one country (Austria) and three cities had an e-mobility policy or target that was directly linked to renewables.[161] Nevertheless, at least 28 cities and 39 countries or states/provinces had *independent* targets both for EVs and for renewable power generation, which could result in greater use of renewables for transport, especially when combined with financial incentives or other policy support.[162] In addition, by early 2020 at least 18 jurisdictions (national and sub-national)[ii] had committed to banning sales of new fossil fuel vehicles or internal combustion engine vehicles in favour of lower-emission alternatives (sometimes explicitly EVs) by 2050 or before, up from 12 jurisdictions a year before.[163] Some cities such as Madrid (Spain) also have greatly restricted circulation of fossil fuel vehicles.[164] (→ *See Transport section in Policy Landscape chapter.*)

Partly in response to these policy developments, some private companies have committed to using renewable electricity in their EV fleets.[165] This trend also is apparent among some new mobility service companies, including micro-mobility services, which have expanded rapidly since emerging in 2017.[166] (→ *See Box 2.*) Although many challenges remain for scaling up EVs, further electrification of road transport has the potential to ease the integration of solar PV and wind power by providing balancing services to the grid[iii].[167] Vehicle-to-grid (V2G)[iv] is still in its infancy, but during 2019 more pilots were launched and more companies invested in the technology.[168]

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

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

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

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

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

Many more cities are running public urban rail systems on electricity, sometimes directly linked to renewables and in other cases using biofuels. The first urban train service in Japan relying entirely on renewable energy sources began running in March 2019.[171] Also in 2019, Melbourne (Australia) connected a 128 MW solar PV system to its grid network specifically to power the city's tram system.[172]

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

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

i Heavy-duty vehicles constitute the fastest-growing source of oil demand worldwide. Even though they account for less than a quarter of total freight activity, they account for three-quarters of the energy demand and CO_2 emissions from freight. See endnote 179 for this chapter.

BOX 2. Renewables in New Mobility Services

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

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

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

Source: See endnote 166 for this chapter.

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

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

Maritime transport consumes around 10% of the global energy used in transport and is responsible for around 2% of global energy-related CO_2 emissions; so far, renewables do not feature significantly in the maritime fuel mix.[182] In 2019, the International Maritime Organization agreed on stricter energy efficiency targets and new fuel and emission standards beginning in January 2020, and the industry called for speed limits on commercial vessels to reduce emissions.[183]

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

By the end of 2019, at least four new **ports** had joined the World Ports Climate Action Program to advance reductions in maritime transport emissions in support of the Paris Agreement, adding to the seven founding ports the year before.[187] Ports outside of the programme also have committed to decarbonising. For example, the Port of Houston (United States) agreed to purchase renewable electricity port-wide starting in 2020, making it the first US port to administer such a programme.[188] Also, the Port of Gothenburg (Sweden) began offering LBG to ships.[189] The use of "cold ironing"[ii] offers the potential to increase the use of renewable electricity when ships are at berth, depending on the share of renewables in the port's electricity mix; this was a capability in nearly 80 ports by the end of 2019, three-quarters of which are located in Europe.[190]

Aviation accounts for around 11% of the total energy used in transport and for just over 2.5% of global energy-related CO_2 emissions.[191] Despite the more than 50% decrease in carbon emissions per passenger-kilometre between 1990 and 2019 (due to fuel efficiency improvements), global demand for air travel has increased, and emissions from commercial air travel have grown more rapidly than expected.[192] In 2019, new policy measures were aimed at helping to put aviation on track towards decarbonisation – including new taxes to discourage air travel in France and Germany.[193]

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

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

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

i Alternative fuels for heavy-duty vehicles refer to alternative propulsion systems to the traditional diesel (or petrol) internal combustion engine and are not exclusively from renewable sources. Alternative fuels include biofuels, synfuels or low-carbon liquid fuels produced from agriculture crops or waste, liquefied natural gas (LNG) or compressed natural gas (CNG), and biomethane. Other propulsion systems that are reaching commercial viability include hydrogen fuel cells, electric and hybrid vehicles, and electric roads (electric-powered vehicles where the energy source is external, for example through overhead wires). Another option under development is the use of solar PV for road surfaces to charge vehicles while they are in motion.

ii Cold ironing consists of connecting a ship to the power grid while at berth in a port so that the electricity demand from the ship while hotelling is supplied directly by the grid rather than by the generator on the ship, which is typically diesel powered.

iii The ICAO considers such fuels to be a sustainable alternative when they are produced from three families of bio-feedstock: the family of oils and fats, or triglycerides, the family of sugars and the family of lignocellulosic feedstock. See ICAO, "Alternative Fuels: Questions and Answers", https://www.icao.int/environmental-protection/Pages/AltFuel-SustainableAltFuels.aspx, viewed 14 April 2020.

iv Drop-in biofuels have properties enabling them to replace fossil fuels directly in transport systems, or to be blended at high levels with fossil fuels.

POWER

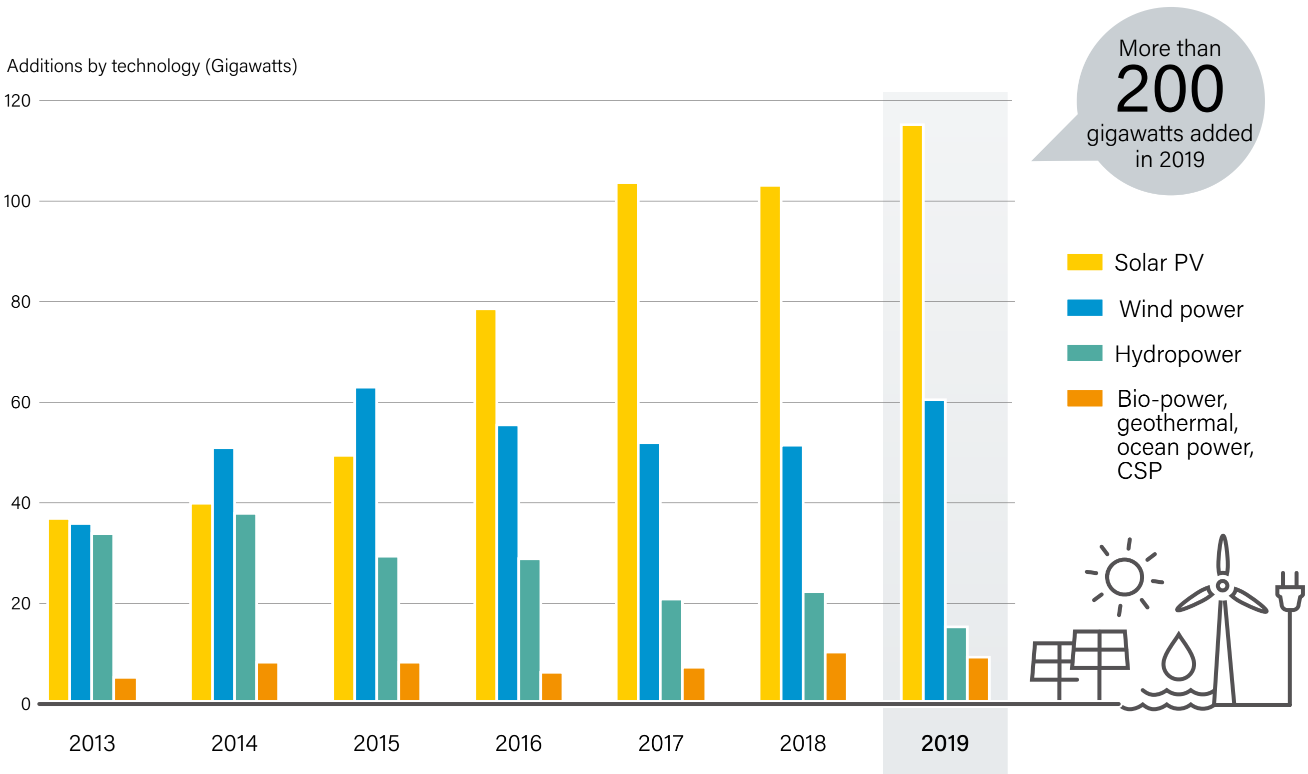
More than 200 GW of new renewable power generating capacity was installed in 2019, raising the global total to 2,588 GW by year's end.[198] (→ *See Figure 8*.) Installations were well above 2018 levels, maintaining the more than 8% average growth rate of installed renewable power capacity over the previous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

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

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

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

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



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

Source: See endnote 198 for this chapter.

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

By the end of 2019, at least 32 countries had more than 10 GW of renewable power capacity (including hydropower) in operation, up from 19 countries in 2009.[207] The shift is even more impressive when excluding hydropower, as markets for both solar PV and wind power have grown dramatically in recent years. At least 17 countries had more than 10 GW of non-hydropower renewable capacity at the end of 2019, up from 5 countries in 2009.[208] As in previous years, the top country for non-hydropower renewable capacity was China, followed by the United States, Germany, India, Japan and the United Kingdom; the top countries for non-hydro renewable power capacity per inhabitant were Iceland, Denmark, Sweden, Germany and Australia.[209] (→ *See* ***Reference Table R2.***)

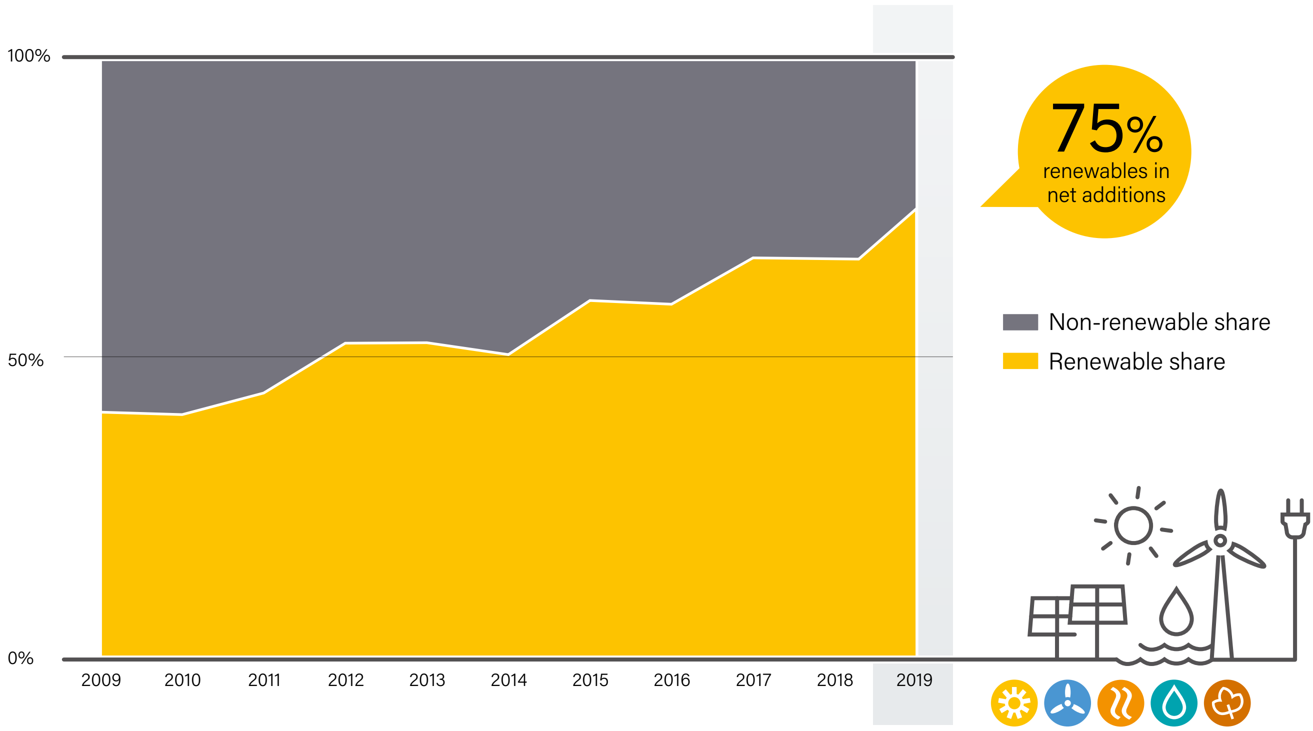
Overall, installed renewable energy capacity was enough to provide an estimated 27.3% of global electricity generation[i] at the end of 2019.[210] Hydropower still made up the majority (58%) of this estimated generation share, followed by wind power (22%), solar PV (10%) and bio-power (8%).[211] (→ *See Figure 10.*)

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

Renewable electricity shares are rising rapidly in many countries and regions. Over the past decade, the EU saw strong growth in its share of renewables in electricity generation, up from 19% in 2009 to an estimated 35% in 2019.[212] In certain European countries, the shift was even more dramatic, such as in Denmark (from 39% to 77%), Germany (16% to 42%) and the United Kingdom (8% to 38%).[213] In the United States, the share of renewable electricity generation increased from 10.2% to 17.4% between 2009 and 2019.[214] The renewable share of electricity generation in China grew from 16.6% to 26.4%, despite a more than doubling of total electricity production during the decade.[215] The share of renewables in electricity generation also increased

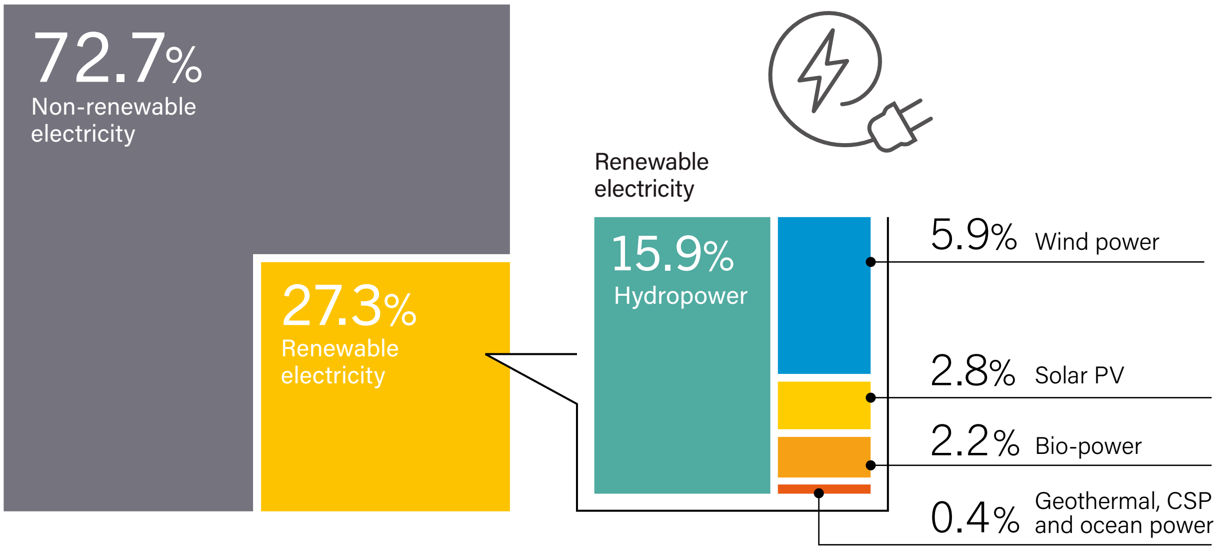
i Methodological adjustments and data revisions contribute in part to the variation of the share of renewable energy in global electricity production between GSR years. Data should not be compared with previous years, and this value is not intended to suggest any trend.

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



Source: See endnote 203 for this chapter.

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



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

Source: See endnote 211 for this chapter.

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

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

Policy attention to renewable energy remained focused on the power sector in 2019. Although few countries set new or revised targets during the year, action continued at a sub-national level. The total number of countries that held renewable power auctions decreased during the year (from 48 to 41), but the capacity being auctioned increased significantly, and several new countries held auctions for the first time, raising the total number of countries having used this policy to 109.[219] Feed-in tariffs were present in 113 jurisdictions at year's end.[220]

As in previous years, developments in the renewable power sector continued to be influenced heavily by government **policy and regulatory frameworks**. Policy uncertainty in China and India, among other drivers, contributed to slowdowns in the national solar PV markets, and in Spain the removal of the so-called Sun Tax in late 2018 contributed to growth in the rooftop solar PV market in 2019.[221] In Germany, regulatory issues including permitting, planning and a proposed setback regulation for wind turbines led to a contraction in the country's onshore wind power market of roughly two-thirds compared to 2018.[222] Developments in the geothermal power and hydropower sectors were both constrained by government policies on permitting and protected areas in some countries.[223] (→ *See Market and Industry chapter.*)

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

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

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

Renewable electricity shares are **rising rapidly** in an increasing number of countries and regions.

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

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

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

The share of electricity generated by variable renewable electricity (wind and solar PV) continued to rise in several countries around the world. While VRE contributed an estimated 8.7% of global electricity production as of the end of 2019, during the year it met much higher shares of generation in some countries, such as Denmark (60%), Uruguay (33%), Ireland (32%), Germany (30%) and Portugal (29%).[236] Overall, at least nine countries produced more than 20% of their electricity from VRE in 2019.[237]

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

Hybrid systems[i], consisting of at least two renewable energy technologies and/or energy storage, are able to provide grid flexibility as well as decrease costs and deliver technical benefits (including higher capacity factors) due to co-localisation.[240] In 2019, hybrid projects combining solar PV, wind and/or energy storage were announced or commissioned in Australia, the Netherlands, the Philippines, the United States and India, where more than 1.4 GW of solar PV and wind hybrid project capacity had been awarded as of late 2019.[241]

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

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

SIDEBAR 2. Renewable Energy-Related Jobs in Energy Access

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

Distributed renewables for energy access (DREA) companies operating locally already contribute significantly to direct and indirect employment in some developing and emerging countries, for example in India, Kenya and Nigeria[ii]. (→ *See Figure 11.*) In India, although the DREA sector is still nascent and just beginning to scale, these companies directly employed 95,000 workers in 2017/18[iii], as many as in the traditional utility-scale power sector. In Kenya, DREA companies accounted for 10,000 jobs – compared to 11,000 provided by the national utility KPLC. Informal employment from DREA during 2017/18 was almost double the size of the direct, formal workforce in these countries: 210,000 informal jobs in India, 15,000 in Kenya and 9,000 in Nigeria.

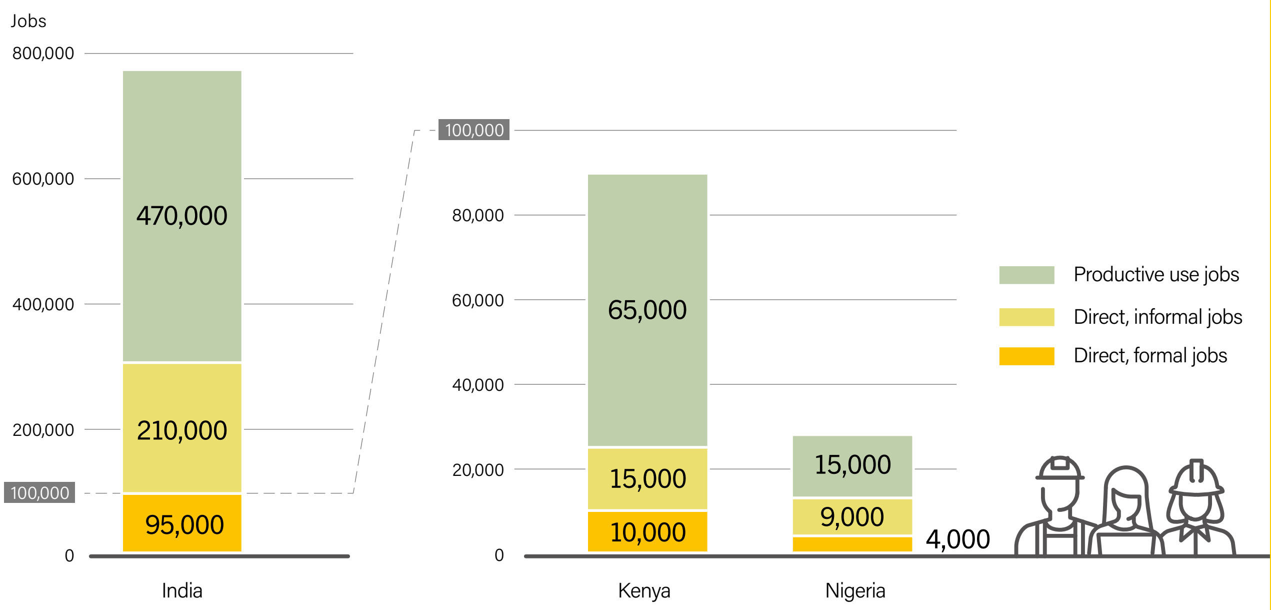
Job creation also is related to productive uses of energy, which are activities that generate income, increase productivity, enhance diversity and create economic value, such as crop irrigation, light mechanical work (for example, water pumping) and small and medium-scale production such as agri-processing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

i This sidebar is drawn primarily from Power for All's *Powering Jobs Census 2019: The Energy Access Workforce*, with additional analysis from the International Renewable Energy Agency (IRENA), including the reports *Renewable Energy and Jobs – Annual Review 2019* and *Renewable Energy: A Gender Perspective* (2019).

ii Only data for India, Kenya and Nigeria were available in Power for All's *Powering Jobs Census 2019*. Although not comprehensive global coverage, data for these countries are presented here to give an indication of status and trends. The *Powering Jobs Census* will be expanded to include all energy-poor countries, ultimately providing a global view.

iii Data were collected across the one-year period from the fourth quarter of 2017 to the fourth quarter of 2018.

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



Source: Power for All.

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

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

Off-grid and decentralised renewable energy systems are increasingly recognised as the most cost-effective solutions for the poorest and most remote communities, providing both livelihoods and income-generating opportunities. Factors that have been identified to help expand employment in the DREA industry include:

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

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

02

COMMUNITY POWER ENTERPRISES, JAPAN

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

02 POLICY LANDSCAPE

KEY FACTS

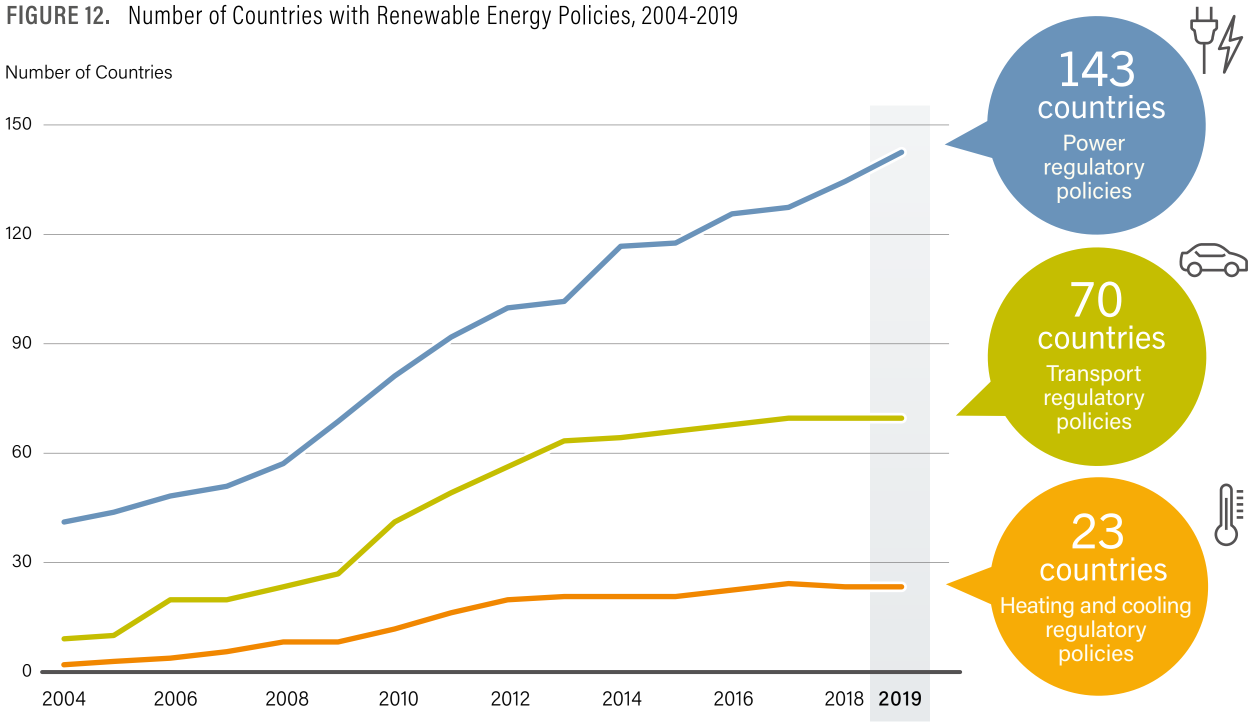
- Effective policy support has been key to the uptake of renewables.
- Policy frameworks continued to evolve in response to changes in renewable energy technologies and markets.
- The focus of policies and targets continued to be on the power sector, with policies for the heating and cooling and transport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

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

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

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

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



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

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

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

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

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

SIDEBAR 3. Trade Policy, Trade Agreements and Renewables

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

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

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

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

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

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

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

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

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

Source: See endnote 4 for this chapter.

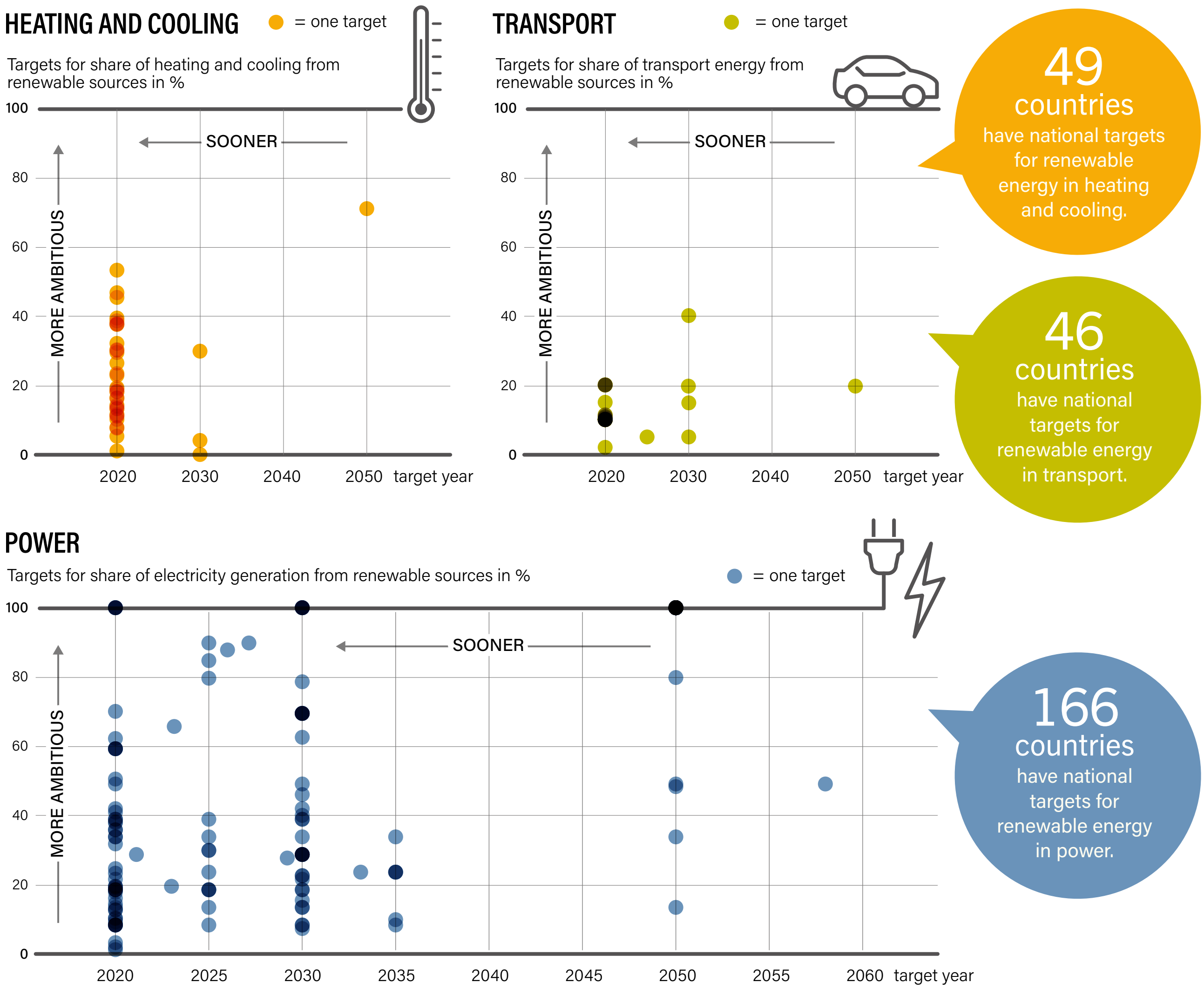
CROSS-SECTORAL TARGETS AND POLICIES

Renewable energy policies typically are enacted at a single level of governance and tend to focus on a single end-use sector. Strategies to align renewable energy policy across multiple levels of governance and across multiple economic sectors are rare. Although most renewable energy policies are not integrated or co-ordinated across sectors or levels of governance, examples of integration and co-ordination are emerging. Co-ordinated policy efforts often are organised under national or state-/provincial-level energy or climate change strategies. For example, in 2019 Scotland introduced a comprehensive programme that sets out policies at multiple levels of governance (national and local) to promote renewables across all sectors of the economy.[5] Also, the Netherlands offered EUR 5 million (USD 5.6 million) to support the production of renewable electricity, renewable gas, renewable heat, and combined heat and power for companies, institutions and non-profit organisations.[6]

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

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

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

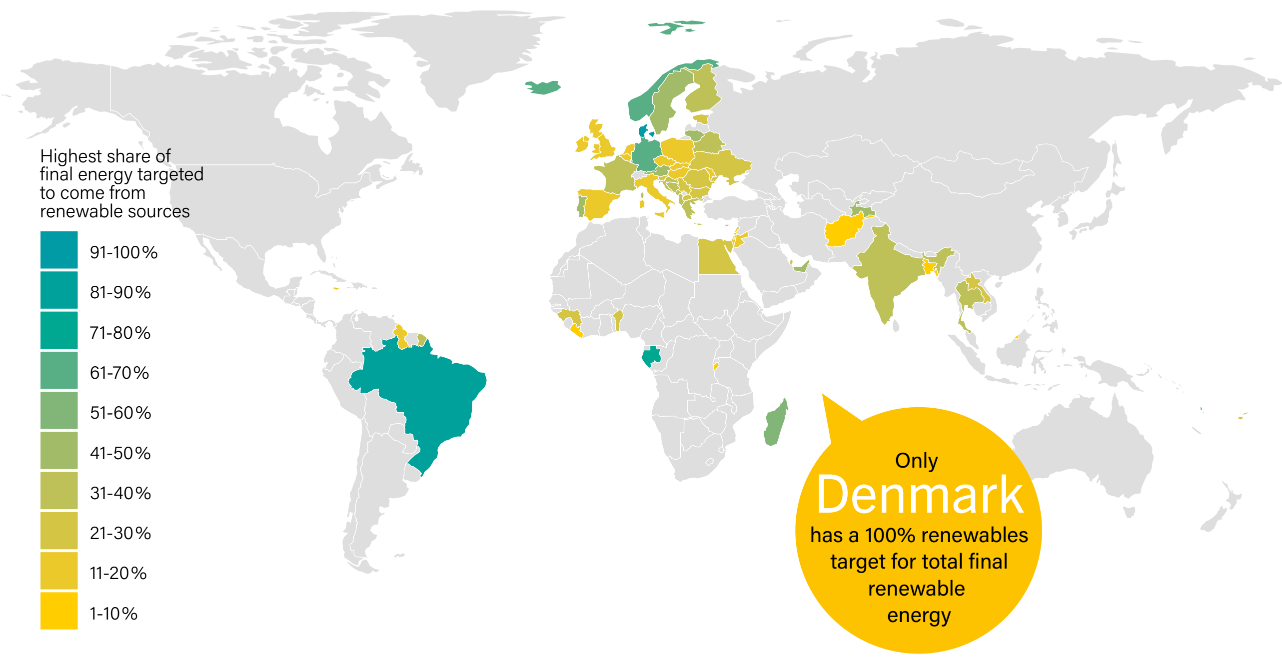


Note: Each dot can represent more than one country and is based on the highest target that a country has set at the national level. Figure includes only countries with targets in these sectors that are for a specific share from renewable sources by a specific year, and does not include countries with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

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

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

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



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

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

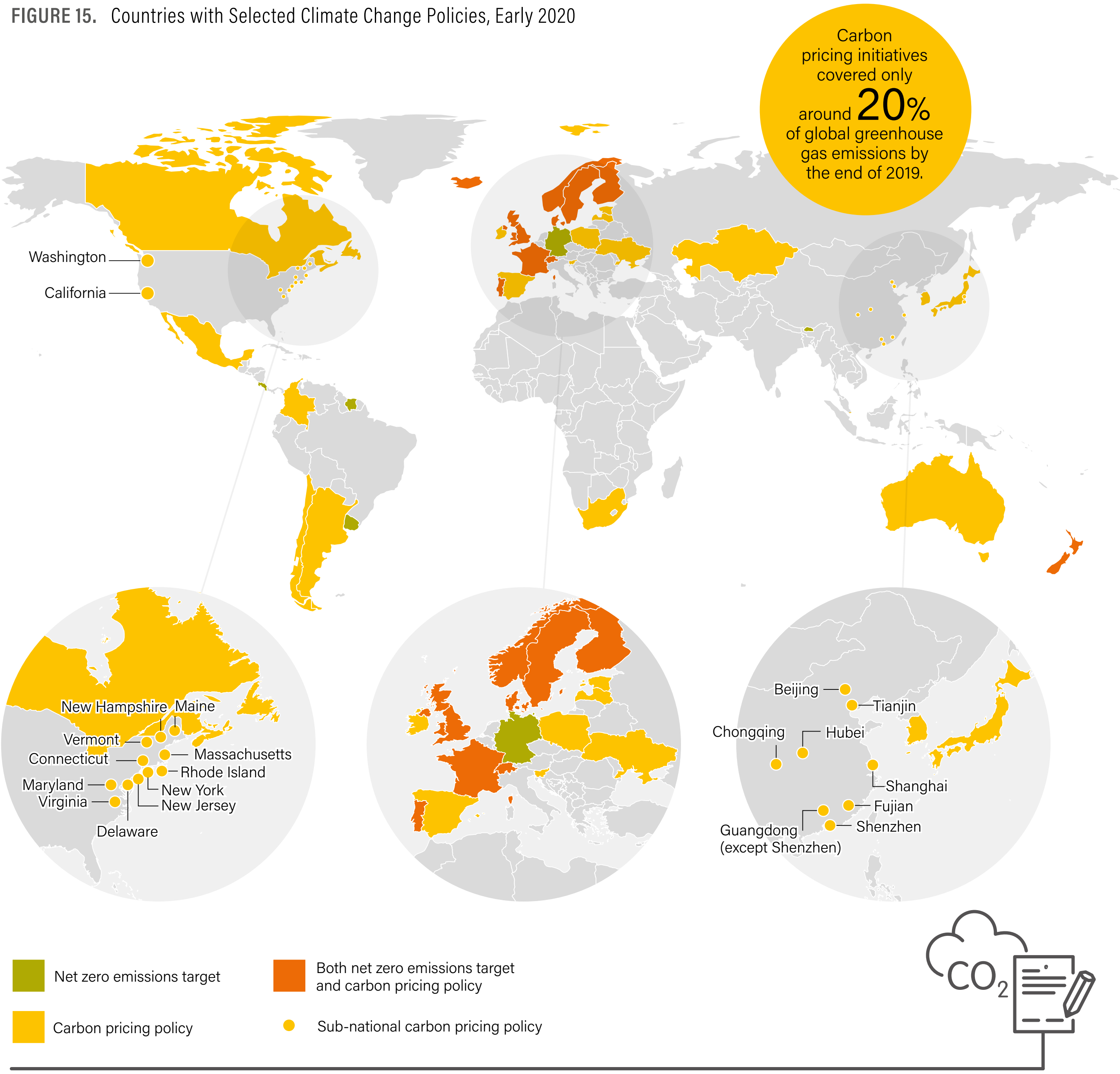
Just one new country adopted an economy-wide renewable energy target during 2019.

RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

Policies enacted to help mitigate climate change can directly or indirectly stimulate renewable energy deployment across all end-use sectors by mandating a reduction or elimination of greenhouse gas emissions, phasing out the use of fossil fuels and/or increasing the costs of energy from fossil fuels relative to renewables.[9] Climate change policies include banning or phasing out fossil fuels, enacting targets to reduce greenhouse gas emissions (including, for example, "net zero"[i] commitments), and development and participation in carbon pricing and emissions trading programmes. (→ *See Figure 15.*)

i Net zero carbon emissions and carbon neutrality refer to the achievement of a state in which every tonne of CO_2 emitted to the atmosphere is compensated by an equivalent tonne removed (e.g., sequestered). See Glossary. In contrast, a gross zero target would reduce emissions from all sources to zero. In a net zero scenario, emissions are "allowed" as long as they are offset by removals. Reaching net zero emissions may be linked to activities such as carbon offsetting, and does not necessarily include the use of renewable energy.

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



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

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

During 2019, some jurisdictions enacted policies that tie **climate change mitigation** directly to increasing the deployment of renewable energy. Costa Rica launched an economy-wide roadmap to achieve net zero emissions by 2050, which included specifications for policies to increase the use of renewables in industry as well as in the power and transport sectors.[10] Germany's new EUR 54 billion (USD 60.5 billion) climate change plan includes greenhouse gas emissions reduction targets as well as policies to advance the use of renewable energy across the economy.[11] In the US state of New York, new climate change legislation set out targets for reducing greenhouse gas emissions and achieving 70% renewable electricity by 2030.[12]

Other policies to mitigate climate change, including **bans or phase-outs of the use of fossil fuels**, can stimulate the adoption of renewables indirectly. In 2019, Germany committed to shutting down all of its coal-fired power plants by 2038, and Chile announced a plan to phase out coal-fired power generation by 2040.[13] At the sub-national level, the US states of New Mexico and Washington, and the territory of Puerto Rico, committed to closing their coal-fired power plants by 2031, 2025 and 2020, respectively.[14] Many cities worldwide also are focused on banning fossil fuel use for heating and for some forms of road transport. (→ *See Heating and Cooling and Transport sections in this chapter.*)

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

In 2019, the European Commission (with the abstention of Poland) proposed a European Green Deal to create the first carbon-neutral[i] continent by 2050.[16] Two countries in Europe – France and the United Kingdom – committed to national targets for net zero emissions by 2050, while Spain's draft National Energy and Climate Plan would commit the country to a carbon-neutral economy by 2050.[17] Outside of Europe, New Zealand passed legislation to achieve net zero emissions by 2050.[18]

Other countries have committed to greenhouse gas reduction targets other than net zero, while some have decreased their ambitions. In 2019, Denmark agreed on a new target of a 70% reduction in greenhouse gas emissions by 2030.[19] Japan became the 12th country to submit to the United Nations Framework Convention on Climate Change (UNFCCC) its long-term strategy for low-emission development, which outlines the country's plans to reduce emissions in the energy, industry and transport sectors 80% by 2050.[20] The Russian Federation formally adopted the Paris Agreement in 2019; however, by year's end it had abandoned plans to impose emissions quotas, carbon caps on the country's largest emitters and penalties on large businesses that exceed quotas.[21]

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

Carbon pricing and emissions trading schemes also are increasingly widely implemented climate change policies. These measures have the potential to indirectly increase the deployment of renewable energy technologies – or to increase renewable generation – by increasing the relative cost of energy from fossil fuels.[24] At the international level, countries participating in the 2019 UNFCCC negotiations in Madrid failed to decide on regulations for new international carbon markets.[25] Some progress was made at the national level, however: both Singapore and South Africa implemented carbon taxes during the year, and Switzerland agreed to link its emissions trading system to the EU Emissions Trading System starting in 2020.[26]

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

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

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

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

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

HEATING AND COOLING

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

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

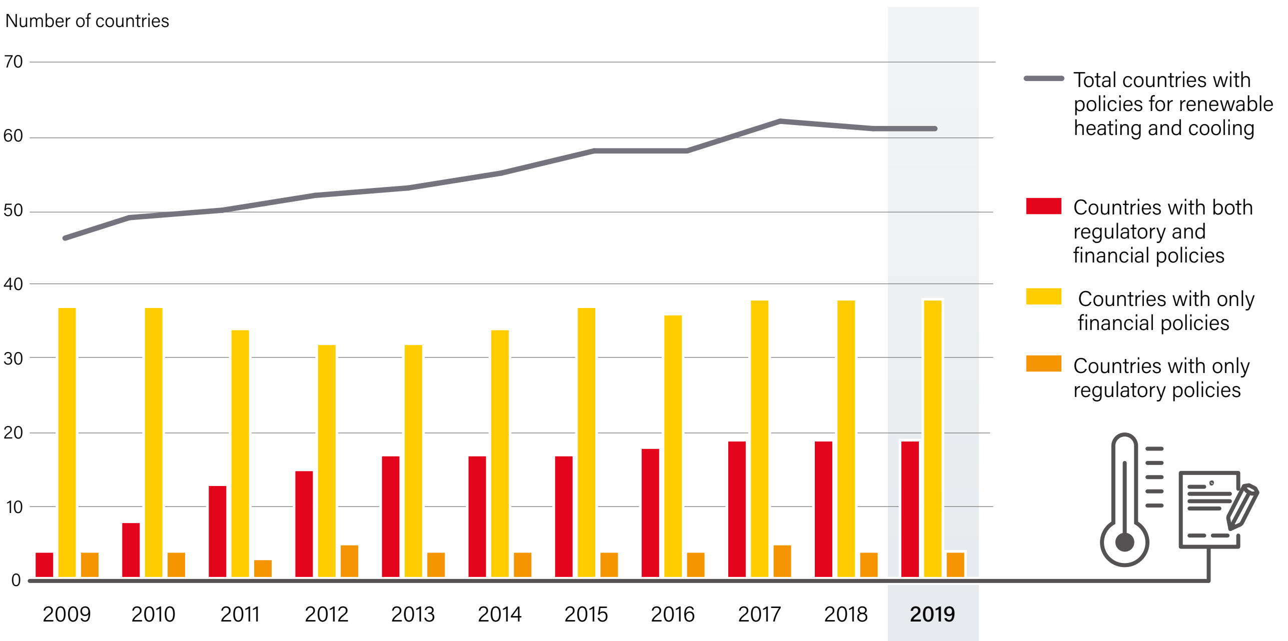
Whereas some renewable heating and cooling policies focus exclusively on either buildings or industry, others do not distinguish between the two. Some policies in the sector are enacted in a bid to save power. For example, Zimbabwe banned the installation of new grid-connected electric water heaters but allowed the installation of water heaters accompanied by on-site solar water heating systems.[34] In some cases, **financial incentives** – including grants and tax credits – have been used to encourage renewable heating and cooling in both industry and buildings. Overall, at least 54 countries had some type of financial policy for the deployment or use of renewable energy in the heating and cooling sector in 2019, a number that has remained stable since 2017.[35] (→ *See Figure 16.*)

Policies that mandate or support the injection of renewable natural gas (RNG)[i] into natural gas pipelines typically result in increased penetration of renewables in both the building and industrial sectors[ii]. In 2019, France announced EUR 7-9 billion (USD 8-10 billion) in support for RNG under the umbrella of a mandatory target of 10% RNG in the country's gas grid by 2030.[36] Quebec (Canada) adopted a regulation that targets a minimum share of RNG (1% by 2020 and 5% by 2025) to be produced and injected into the provincial gas grid for use in buildings or industry.[37] Also in 2019, the US state of Oregon adopted legislation that creates voluntary targets for RNG injection into the gas grid and directs the state public utility commission to establish mechanisms by which regulated utilities can recover the costs of their RNG investments.[38]

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

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

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



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

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

BUILDINGS

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

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

Mandatory **building energy codes** can play an important role in promoting the deployment of renewables and energy efficiency technologies in buildings – particularly in new construction or retrofits – if they require the deployment of renewable energy systems (often solar PV) and specific standards for energy efficiency.[40] Building energy codes that were mandatory for the entire sector were in place in at least 90 jurisdictions at the national or state/provincial level by the end of 2019.[41] No new renewable energy requirements or energy efficiency mandates were added to national building energy codes during the year. At the local level, however, 23 municipalities in British Columbia (Canada) voluntarily adopted energy efficiency provisions that were more stringent than those in the mandatory provincial building code.[42]

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

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

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

No new countries
have adopted renewable energy financial support policies for heating and cooling since 2017.

i Mandates, or ordinances, typically include a technology-specific requirement, whereas building codes are usually technology-neutral and describe the standard of energy performance that must be met.

ii Equipment performance standards provide a resource to help consumers make informed decisions when selecting renewable energy equipment, and ensure that the equipment works as intended.

iii Electric heat pumps are not strictly a renewable energy technology, but could enable the use of renewable electricity in the heating and cooling sector. See Heat Pumps section in Systems Integration chapter.

iv See Glossary for definition.

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

Indirect policies to incentivise renewables in buildings in 2019 included **banning the use of fossil fuels** for heating. Austria banned the installation of liquid or solid fossil fuel boilers in new buildings from 2020, Norway banned the use of mineral oil to heat buildings from 2020, and the United Kingdom committed to a ban on natural gas boilers in new homes starting in 2025.[54] Poland adopted emissions standards for heating appliances in single-family homes and banned the use of coal in 11 of its 16 regions beginning in 2022.[55]

At the sub-national level, Vienna (Austria) announced a ban on oil and natural gas heaters for 80% of new homes beginning in 2020.[56] Berkeley (California) became the first US city to ban the use of natural gas in most new buildings, and several other cities in the state followed suit later in 2019.[57] Montreal (Canada) committed to phasing out the use of oil for heating by 2030.[58] Rather than banning fossil fuels for heating, Seattle (Washington) implemented a USD 0.24 per gallon (0.06 per litre) tax on heating oil to fund rebates and grants for nearly 3,000 households to transition to electric heat pumps.[59]

Another indirect policy implemented in 2019 to incentivise renewables in buildings was government commitments to **net zero emissions building standards**. Although no national or provincial/state governments made such commitments during the year, several cities adopted standards to require net zero heating and cooling and electricity generation and use. Oslo (Norway) and Heidelberg (Germany) joined 23 other cities[i] that have signed on to C40's Net Zero Buildings Declaration[ii] to ensure that all new buildings operate at net zero carbon by 2030, and all buildings by 2050.[60] A coalition of eight additional cities[iii] pledged in 2019 to decarbonise their existing building stocks by 2050.[61]

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

INDUSTRY

Industrial processes use thermal energy (heat) to meet various energy needs. These demands can be met directly by thermal energy from renewables – including bioenergy, solar heat and geothermal heat – or indirectly from renewable electricity, for example via electric arc furnaces. (→ *See Global Overview.*). In addition, renewable hydrogen can be used to meet certain energy demands within industry[iv,63] (→ *See Box 1.*) Policies focused on the use of renewables in industrial heating and cooling remained scarce in 2019. Only one country, Finland, set an **industry-specific target** during the year, aiming for bio-based fuel oil to replace 10% of heating for construction machines and fitted motors starting in 2021.[64]

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

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

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

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

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

BOX 1. Policies for Renewable Hydrogen

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

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

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

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

Source: See endnote 63 for this chapter.

TRANSPORT

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

Although the global transport sector has the second highest share of total final energy consumption, it remains the sector with the lowest penetration of renewables and continues to rely heavily on fossil fuels.[68] By the end of 2019, only 46 countries had some form of renewable transport target. Although the adoption of renewable energy policies for transport has not been as rapid as in the power sector, policy makers increasingly are exploring expanding the use of renewables in the transport sector as a means to improve local air pollution and meet greenhouse gas emissions targets.[69]

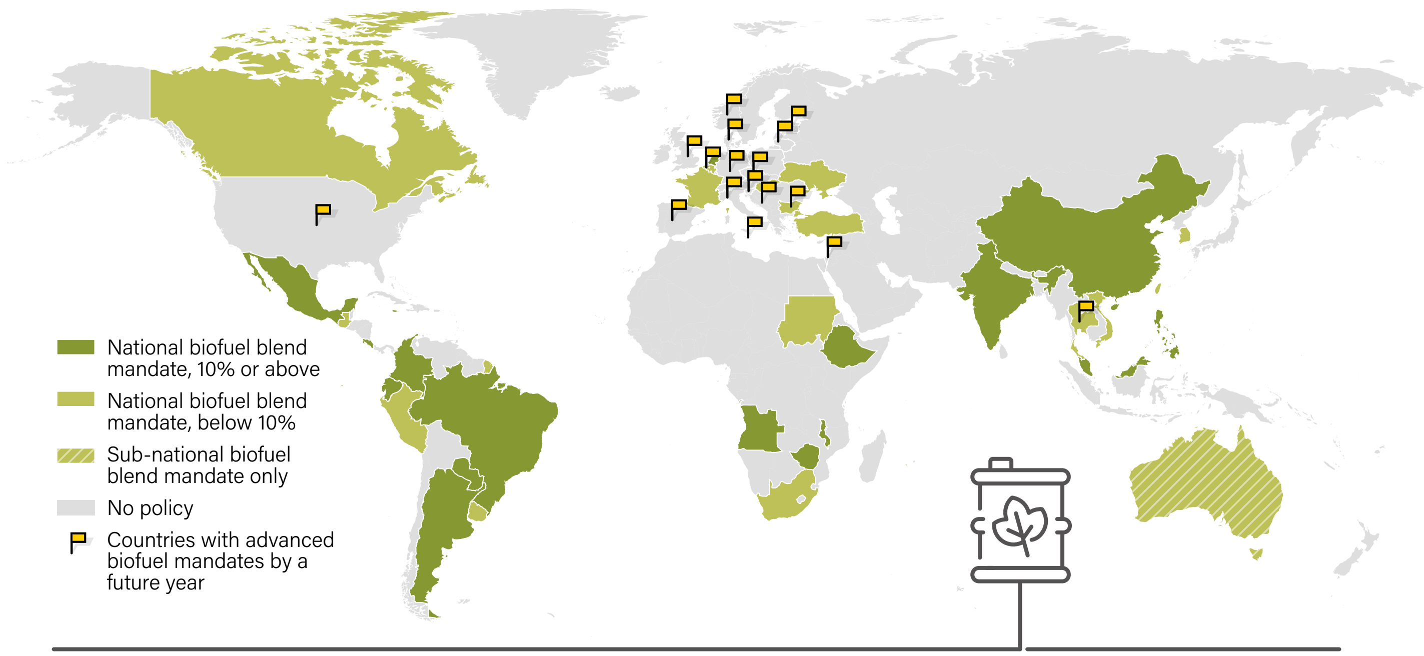
Policies that support the production and use of liquid and gaseous biofuels for transport are the most common type of direct renewable energy policy in the sector, and biofuels continue to make the largest contribution of renewable energy to transport. However, policies aimed at the electrification of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

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

ROAD TRANSPORT

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

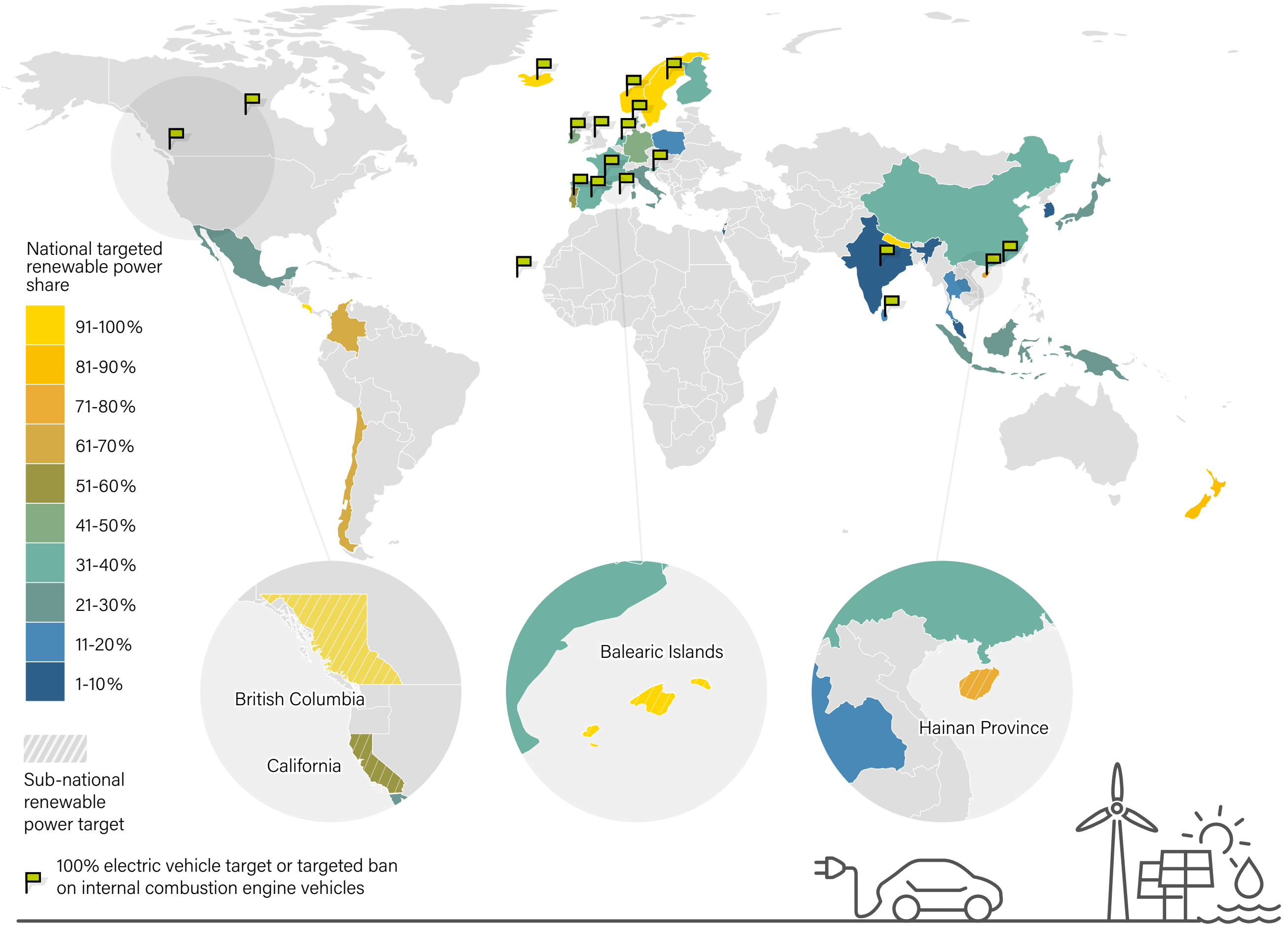
FIGURE 17. National and Sub-National Renewable Transport Mandates, as of End-2019



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

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

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



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

Source: See endnote 2 for this chapter.

At least 18 jurisdictions had

100%

EV targets

or targeted bans on internal combustion engine vehicles by end-2019.

Biofuels in Road Transport

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

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

Several existing mandates were strengthened during 2019.[76] Indonesia launched a mandate for 30% biodiesel blending in petrol (B30, up from the previous B20 requirement), the highest mandatory mix in the world.[77] France raised the minimum biofuel blend to 7.9% in 2019 and 8.2% in 2020.[78] Finland adopted a law to gradually increase the share of biofuels to 30% and the share of advanced biofuels to 10% by 2029 for use in road transport.[79] Brazil approved a new biodiesel blend of B11 (up one percentage point from 2018) and announced approval of the sale and use of B15.[80] By contrast, the US Environmental Protection Agency (EPA) expanded the number of exemptions from biofuel blending that it granted to smaller refiners[ii].[81]

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

Financial incentives to support the production and use of biofuels are less common but do exist. In 2019, Thailand enacted a policy to subsidise the retail price of B10 by THB 2 (USD 0.06) per litre through January 2020, when it would replace B7 as the diesel option at pumps.[85] In the United States, the biodiesel tax credit of USD 1 per gallon (USD 0.26 per litre), which expired in 2017, was extended retroactively to 2022, and the cellulosic ethanol tax credit was extended through 2020.[86] A 2019 resolution in Brazil, part of the country's RenovaBio programme, included an estimated BRL 9 billion (USD 2.2 billion) in support for the ethanol sector and another BRL 4 billion (USD 1 billion) for increased sugarcane production.[87] The programme also introduced **emissions reduction targets** for fuel distributors, with the option to demonstrate compliance by buying **traded emissions reduction certificates** awarded to biofuel producers.[88]

Biofuel blending mandates

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

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

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

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

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

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

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

Electric Vehicles

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

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

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

During the year, targets and **financial incentives** for EVs often were implemented in parallel. Canada announced deployment targets as well as various financial incentives for zero emission vehicles such as EVs.[96] India launched its National Electric Mobility Mission Plan, which includes a target of 7 million hybrid and electric vehicles by 2020, and it also implemented the Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME Phase II) scheme, which includes a USD 1.4 billion budget over three years to reduce the purchase price of hybrids and EVs through rebates.[97] Pakistan approved a national EV policy with targets and incentives aimed at a 30% EV share of all passenger vehicle and heavy-duty truck sales by 2030, and 90% by 2040.[98]

Several governments announced plans for **public procurement** of EVs. As part of its economy-wide roadmap to achieve net zero emissions by 2050, Costa Rica committed to public procurement of electric buses and taxis and the provision of funds to create an electric train line.[99] India's National Electric Mobility Mission Plan calls for replacing the national government's fleet of petrol- and diesel-powered vehicles with EVs.[100] The US state of Virginia dedicated USD 20 million to fund a new initiative to accelerate the deployment of electric school buses, and New York City committed USD 1.1 billion to purchase and deploy 500 electric buses for public transit.[101] Chile's capital city, Santiago, deployed 200 e-buses in 2019 as part of a plan to cut emissions and reduce air pollution.[102]

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

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

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

Indirect Policies for Road Transport

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

Vehicle emissions standards for light-duty vehicles typically apply to greenhouse gas emissions and/or ground-level air pollutants. Both of these forms of emissions standards may indirectly incentivise the uptake of EVs, as manufacturers are required to produce low or zero emission vehicles[ii], and EVs do not directly emit greenhouse gases or air pollutants. In 2019, Kenya adopted Euro 4[iii] vehicle emissions standards to replace the more lenient measures in the country since 2000.[107] At a sub-national level, the US state of Minnesota implemented two standards to reduce emissions of CO_2 and other pollutants from light-duty passenger cars, trucks and sport utility vehicles (SUVs).[108] The EU reached a provisional agreement on the first-ever CO_2 emission standards for trucks.[109]

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

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

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

By the end of 2019,
only 37 countries
had fuel economy policies for light-duty vehicles, and just 5 countries had fuel economy standards for trucks.

Vehicle fuel economy policies and standards help to increase the efficiency of vehicles and limit the amount of fuel that is used (as well as the resulting emissions) to go a given distance. In many jurisdictions, such policies have reduced reliance on fossil fuels for transport, although the impact of such measures may have been offset by trends towards larger vehicles, particularly in recent years. By the end of 2019, only 37 countries had fuel economy policies for light-duty vehicles, a total that is unchanged since 2017.[110] Meanwhile, just five countries – Canada, China, India, Japan and the United States – had fuel economy standards for trucks, with no new countries adopting such standards during 2019.[111]

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

Another indirect policy with the potential to incentivise both EVs and biofuel-based transport is a **ban on fossil fuels in road transport**[ii]. In 2019, both Ireland and Sweden announced plans to ban the sale of new petrol and diesel vehicles by 2030, and Canada announced a similar ban by 2040, while Colombia announced a partial ban.[113] France passed a transport law upholding a ban on the sale of fossil fuel cars by 2040 and facilitating the uptake of EVs.[114] At year's end, China was considering testing a ban on petrol-fuelled vehicles in some parts of the country and setting a timetable to eventually phase out such vehicles.[115] The United Kingdom's ban on sales of new petrol, diesel or hybrid cars was moved up by five years, from 2040 to 2035.[116]

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

One type of indirect policy focused on EVs exclusively is **policy support for EV charging infrastructure**. In 2019, India's FAME Phase II scheme included a target of 2,700 charging stations in cities with more than 4 million inhabitants, as well as fast and ultra-fast charging stations along major highways.[119] Canada announced nearly CAD 100 million (USD 76.5 million) in funding to deploy new EV charging (and hydrogen fuelling) stations.[120] The Netherlands committed to installing 2,000 charging points to support electrification of its national government fleet.[121] At the sub-national level, the US state of New York provided USD 31.6 million to its regulated utilities to build up to 1,075 fast-charging stations to expand EV use.[122]

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

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

AVIATION, RAIL, SHIPPING AND PORTS

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

By the end of 2019, no countries had implemented renewable energy mandates for **aviation**, although four countries (Finland, Norway, Brazil and Indonesia) had announced biofuel aviation targets, while other countries had adopted policies that could indirectly support the use of renewables in the sector.[129] The Finnish government announced a target of a 30% biofuels share in aviation, to be achieved through a biofuel blending obligation.[130] Scotland's 2019 Green New Deal policy package included a net zero aviation commitment by 2040.[131] The United States announced up to USD 55 million in funding for two programmes to support the development of electric aviation technology and powertrain systems, although these are not directly linked to renewable electricity.[132]

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

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

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

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

BOX 2. Private Sector Initiatives in Renewable Transport

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

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

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

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

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

Source: See endnote 125 for this chapter.

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

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

Some **ports** are adopting targets to increase the use of renewable fuels, increase energy efficiency and/or decrease greenhouse gas emissions. By the end of 2019, at least 11 ports had joined the World Ports Climate Action Programme to develop measures for such goals, up from 7 ports the year before.[137] Also during the year, the Port of Houston in the US state of Texas announced that it would purchase renewable electricity port-wide starting in 2020, making it the first US port to administer such a programme.[138]

For the **rail** sector, a small number of jurisdictions implemented policies aimed at electrification of rail in 2019. Scotland's Green New Deal package includes commitments to electrify its rail network and to use battery-powered trains, and the city of New Delhi (India) approved a target for complete electrification of its railway network by 2022-2023.[139] However, neither effort was linked specifically to renewables.

POWER

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

Many jurisdictions have adopted targets for renewable capacity and generation, as well as policies aimed at promoting both large- and small-scale renewable power to achieve these targets. In 2019, targets continued to be the most popular form of intervention to spur investment in both large-and small-scale renewables. By the end of the year, 166 countries had in place some form of renewable electricity target, up from 162 countries in 2018.[141] In addition, corporate sourcing of renewables continued to advance during the year, due in part to government support policies.[142] (→ *See Box 3.*)

Several countries adopted new targets in 2019. For example, Pakistan committed to a renewable electricity target of 30% by 2030, and Mauritius committed to a target of 35% renewables by 2025 in its Renewable Energy Roadmap 2030 for the Electricity Sector.[143] Angola set a goal of 800 megawatts (MW) of renewables (representing 74% of its installed power base) by 2025.[144] Ghana adopted a target to increase the share of renewable electricity in the energy mix in order to reduce dependence on traditional biomass, provide distributed renewable energy options for off-grid communities, and promote local content and local participation in the renewables industry by 2030.[145]

At the sub-national level, the Australian Capital Territory committed to 100% renewable electricity starting in 2020.[146] At least three large US cities (Chicago, Los Angeles and Philadelphia) also committed to 100% renewable electricity by 2045.[147]

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

BOX 3. Corporate Sourcing of Renewable Electricity

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

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

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

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

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

Source: See endnote 142 for this chapter.

Development Act to increase its renewable electricity target from 10 gigawatts (GW) to 27 GW by 2025.[148] Nine Latin American countries[i] set a collective target of 70% renewable electricity by 2030.[149] Bulgaria, France and Greece all pledged to update their national renewable electricity targets[ii] for 2030.[150] The Republic of Korea increased its renewable electricity target to 35% by 2040, more than four times the previous target.[151]

CENTRALISED RENEWABLE ELECTRICITY

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

Feed-in policies[iii] have been used to promote both large-scale, centralised renewable energy and decentralised renewables. By the end of 2019, feed-in policies were in place in 113 jurisdictions at the national, state or provincial levels, with no change from 2018.[153] (→ *See **Reference Table R11**.*)

A number of jurisdictions updated their existing feed-in tariff programmes to keep up with changing market conditions. China announced new FIT amounts for large-scale solar PV, which became effective from July 2019.[154] These new FIT amounts were coupled with a scheme to award capacity through a reverse auction, where interested parties bid for a premium to be paid on top of regional benchmark electricity prices[iv].[155] China also implemented new FITs for centralised ground-mounted solar PV systems.[156] In Spain, in response to litigation sparked by retroactive reductions in financial support amounts in the FIT programme, the government approved a plan in 2019 to offer 7% in guaranteed returns for more than a decade to renewable energy projects that agree to scrap ongoing lawsuits over the FIT phase-out[v].[157]

i The nine countries are Chile, Colombia, Costa Rica, the Dominican Republic, Ecuador, Guatemala, Haiti, Honduras and Peru.

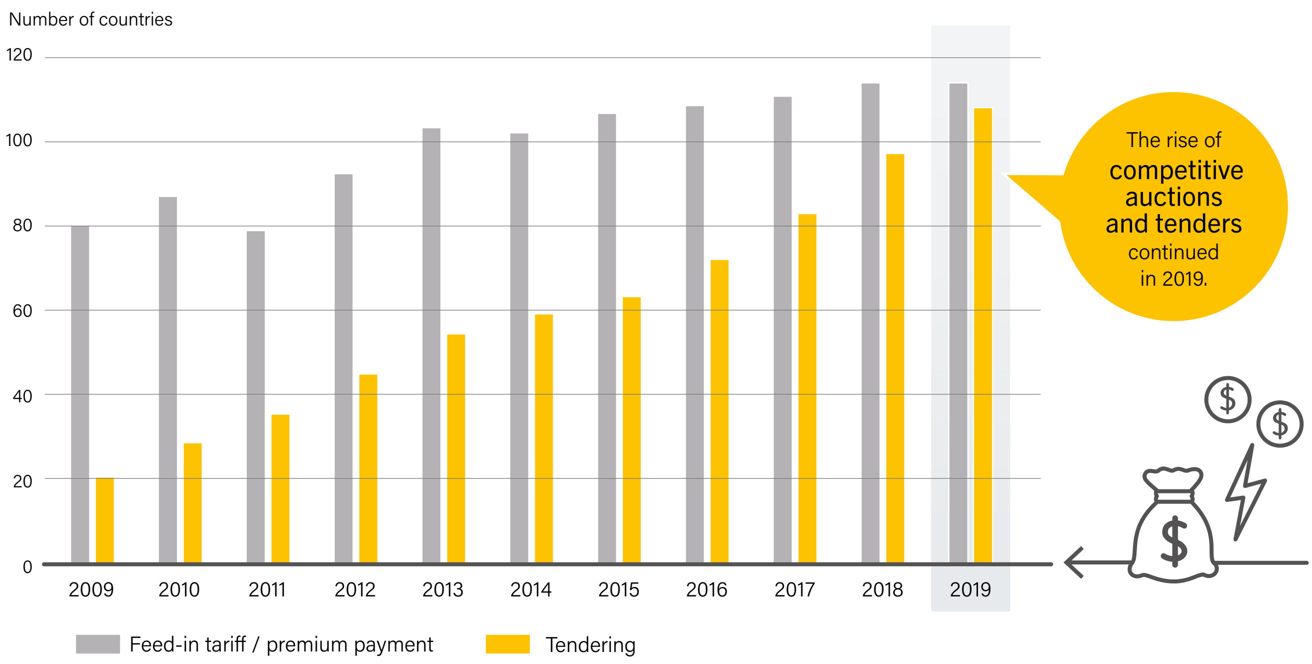
ii The increases were as follows: France from 32% to 33%, Greece from 31% to 35% and Bulgaria from 25% to 27%.

iii Feed-in policies may focus on a certain type or scale of renewable energy technology or may apply to many types and scales of technologies.

iv In June 2018, China imposed installation caps and reduced the FIT for solar PV projects in the country. The 2018 policy change was highlighted as the main reason for the large decrease in renewable energy investment in China that year, which had a significant impact on total global investment in renewables. See Investment chapter in GSR 2019.

v Plants up and running before 2013 will be offered a fixed 7.398% remuneration rate until 2031, but these incentives will be denied to firms still pursuing litigation over the FIT cuts or those already granted compensation after winning court disputes. Those pledging to give up lawsuits or the related compensation will become eligible.

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



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

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

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

A number of US states and territories updated their **RPS quota obligations** in 2019. New Mexico committed to an RPS of 100% "carbon-free" electricity by 2045, with at least 80% from renewable sources.[160] Nevada and Maryland committed to 50% renewable generation by 2030, and Puerto Rico set a 100% RPS by 2050.[161]

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

Many countries continued to turn to competitive **auctions and tenders** in lieu of feed-in policies to deploy large-scale, centralised renewable energy projects.[164] During 2019, renewable energy auctions or tenders were held in at least 41 countries at the national or state/provincial level, down from 48 countries in 2018[ii].[165] However, the total number of countries that have used this mechanism increased to 109 (up from 98 in 2018) as new countries held tenders during the year for the first time.[166] Of the at least 68 auctions held in 2019, most focused exclusively on solar PV or wind power, and some included solar PV plus storage (also called solar-plus-storage); just two of the auctions were technology-neutral (among renewable energy technologies).[167] (→ *See **Reference Table R12**.*)

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

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

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

Also during the year, at least 11 new countries either adopted auction policies for renewable energy or held auctions for the first time. Ukraine's Law on Renewable Energy Auctions went into effect, introducing auctions in the country.[175] Poland's energy regulator launched a wind and solar electricity auction, and Pakistan announced plans to introduce renewable energy auctions starting from December 2019.[176] Mongolia introduced proposed amendments to its Renewable Energy Law that, if passed, would introduce a renewable energy auction in the country.[177] At year's end, Kenya was developing the mechanisms required to establish an auction system as provided for in the country's Energy Act of 2019.[178]

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

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

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

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

DISTRIBUTED RENEWABLE ELECTRICITY

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

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

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

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

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

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

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

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

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

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

i Distributed generation, also called on-site generation or decentralised generation, is the term for generation of electricity from sources near the point of consumption, as opposed to centralised generation sources such as large power plants. Distributed generators can be renewable (e.g., rooftop solar PV) or fossil-based (e.g., distributed natural gas generation). This chapter focuses only on policies that support renewable distributed generation.

ii A distributed energy resource is a resource sited close to customers that provides all or some of a customer's electricity needs, and that also can be used by the system to reduce demand, provide supply, or satisfy energy, capacity or ancillary needs. Distributed energy resources can include distributed generation, storage, demand response, EVs and microgrids. In many instances, policy and legislation do not focus exclusively on distributed renewable energy generation. Rather, distributed generation is included as part of a broader policy or legislative activity that is focused on all distributed energy resources.

iii Virtual net metering utilises the same compensation mechanism and billing schemes as net metering without requiring that a customer's distributed general system (or share of a system) be located directly on site. See Glossary.

COMMUNITY RENEWABLE ENERGY ARRANGEMENTS

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

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

CCAs have been around for over a decade, and increasingly cities are using them as a means to procure more renewable energy than is offered by the local utility.[213] In Japan, municipal governments in Yamagata and Gunma prefectures provide renewable energy to consumers through CCA-like arrangements.[214] In the United States, San Diego voted to approve a CCA programme in co-ordination with other cities in the region for the purpose of achieving 100% renewable energy by 2035.[215]

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

After ending its "Sun Tax"[iii] in late 2018, Spain passed new solar PV regulations that allow for self-consumption from individually owned residential rooftop systems as well as from shared installations.[216] Portugal announced new provisions for collective self-consumption, which provide a legislative framework for energy communities and enable homeowners and businesses that are willing to become prosumers[iv] to aggregate their efforts in collective projects and to share generation units.[217] A few regions in Belgium adopted new legislative frameworks promoting collective self-consumption of renewable energy.[218] In the United States, the state of Maine approved new community solar PV legislation, and Maryland extended the end date for its community solar PV pilot programme from 2020 to 2024.[219]

SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

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

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

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

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

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

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

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

iv Prosumers both produce and consume electricity.

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

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

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

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

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

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

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

Also during the year, a directive from the US Federal Energy Regulatory Commission required system operators and transmission organisations in the United States to open wholesale energy, ancillary service and capacity markets to energy storage resources.[236] At the sub-national level, New York provided USD 280 million for energy storage projects as part of a USD 400 million investment to achieve the state's energy storage deployment target of 3 GW by 2030.[237] In Massachusetts, regulations were adopted to give owners of energy storage systems the right to generate revenue from selling into the Forward Capacity Market and to participate in net metering programmes.[238]

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

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

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

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

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

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

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

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

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

Table 3. Renewable Energy Targets and Policies, 2019

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies: 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	Fiscal Incentives and Public Financing: Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
High Income Countries													
Andorra			●						●			●	
Antigua and Barbuda	P	●											
Argentina	P	●	●	●	●	●			●	●[6]	●[6]	●	●, ☆[6]
Australia	E(R), E*(N), P*	●	☆*	●	◖	◖	●	●	◖, ○				●, ☆[6]
Austria	E, P, HC, T		●		●	●		●		★[6]	●		●[6], ◖[6]
Bahamas, The	P	●											
Bahrain	P(R), E(R)	●			●				●				●
Barbados[1]	P	●			●					●			●
Belgium	E(N), P, HC, T			◖	◖	●		●	●, ○	●[6]	●		◖
Bermuda			☆*										
Brunei Darussalam	E, P												
Canada	P*	●	◖	◖	◖	☆*		☆	◖	●[6]	●[6]		●, ☆[6,7], ★*[7]
Chile	E(R), P(R)	●	●	●	●			●	●	●[6]	●[6]		●, ☆[6]
Croatia	E(R), P, HC, T		●			●							●[6]
Cyprus	E, P, HC, T		●		●	●			●				●
Czech Republic	E, P, HC, T		●			●		●		●[6]	●		●[6]
Denmark	E(R), P, HC, T		●[6]		●	●	●[8, 9]	●	●, ○	●[6]	●		●[6]
Estonia	E(R), P, HC, T		●			●						●	●, ☆[6]
Finland	E, P, HC(R), T(R)		●			☆	★	●	●	☆[6], ●[7]		●	●[6]
France	E(R), P(N), HC, T	●	●			☆	●[8], ★	●	●, ○	●[6]	●[6]		★[6]
Germany	E(R), P(R), HC, T		●, ☆*			●	●	●	●, ○	●	●		●[6], ★
Greece	E(R), P(R), HC(R), T		●	●	●	●	●[8]	●	●, ○	●[6]	●		●, ☆[6]
Hungary	E, P, HC, T		●		●	●			●	●			●[6]
Iceland	E, T	●				●							
Ireland	E(R), P(R), HC, T	●	●			☆	●[8]	●	●, ○	★[6]			☆[6,7]
Israel	E, P, T	●	●	●	●		●		●	●[6]			●
Italy	E, P, HC, T		●		●	●			●, ○	●	●[6]		●[6,7], ★*
Japan	E, P	●	●					●	●, ○	●			●, ☆[6]
Korea, Republic of	E(R), P(N)	●		●	●	●	●	●		●	●	●	●[6]
Kuwait	E(R), P	☆							●				
Latvia	E, P, HC, T		●		●	●			●	●			
Liechtenstein			●										
Lithuania	E(R), P, HC(R), T(R)		●[6]	●	●	●	●[8]		○	●[6]			●, ★[6]
Luxembourg	E, P, HC, T		☆			●							●, ☆[6]
Malta	E, P, HC, T		●		●	●			●	●			●[6]
Monaco													
Netherlands	E, P, HC, T		●		●	●	●[8]	●	●, ○	★[6]	●[6]	●	☆[6]
New Zealand	P	●			◖	●							●
Norway	E, P, T	☆		●		●[7]	●	●	●	●			●[6]
Oman	E(R), P(N)	☆							●				
Palau	E, P	●		●									
Panama	E	●	●		●	●			●	●	●	●	
Poland	E, P, HC(R), T		●	●		●		●	●, ○	●			●[6], ★
Portugal[2]	E(R), P(R), HC(R), T(R)		●	●		●	●	●	○	●			●, ☆[6]
Qatar	E(R), P(R), T	●							●				
San Marino		☆	●										
Saudi Arabia	E(R), P(R)	●			●				●				
Seychelles	P	●			●				●, ○	●	●		●
Singapore	P	●			●				●				●
Slovak Republic	E, P, HC, T		●			●		●		●[7]			●[6]
Slovenia	E, P, HC, T		●		●	●		●	●	●	●		●[6]
Spain[3]	E, P(R), HC, T				☆	●	●[8]		●	★	●	●	●[6]
St. Kitts and Nevis													
Sweden	E, P, HC, T		● (grey)	●		●		●		●	●		●
Switzerland	E, P		●					●		●			●[6]
Trinidad and Tobago	P	☆								●	●		
United Arab Emirates	E, E*(N), P	●		◖	◖		●		◖, ○			◖	◖
United Kingdom	E, E*(N), P, HC, T		● (grey)	●		☆	●[8]	●	●, ◗	●		●	●[6], ☆[7]
United States	E*, P*, P(R), T		◖	☆*	☆*	●, ◖	●, ◖	◖	◖	●	●[7], ◖[7]		●[6], ☆*[7], ★*
Uruguay	HC(N)	●			●	●	●		●	●		●	●[6]

Note: Please see key on last page of table.

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

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Upper-Middle Income Countries													
Albania	E, P, T	●	●	●	●	●		●	●	●	●	●	●
Algeria	E, P(R)	●	●						●			●	●
Armenia	P	●	●		●				●				●[6]
Azerbaijan	P	●											●
Belarus	E, P		●	●						●			●
Belize	P	●							●				
Bosnia and Herzegovina	E, P	●	●						●				
Botswana									●	●			●
Brazil	E(R), P	●			●	☆			●, ○	●	●		●
Bulgaria	E(N), P, HC, T		●			●							●[6]
China	E, P(R), HC, T	●	☆	☆		◖	●		◖, ○, ●[7]	●	●	●	●, ☆[6,7]
Colombia	E(R), P(R)					●			○	●	●		●
Costa Rica	P	●	●		●	●			●	●[6]			
Cuba	P	●											
Dominica	P	●											
Dominican Republic	E(R), P(R)		● (grey)		●				●	●	●		●
Ecuador		☆	●			●			●	●			●
Equatorial Guinea		☆											
Fiji	E, P	●								●	●		
Gabon	E, P	●											
Grenada	E, P	●			●					●			
Guatemala	E, P	●			●	●			●	●	●		
Guyana	E, P	●								●			
Iran	P	●	●							★	●	●	●
Iraq	P(R)	●							●, ○				
Jamaica	E, P	●			●	●			●	●	●		
Jordan	E(R), P(R), HC	●	●		●		●		●	●			●, ☆[6]
Kazakhstan	P	●	●					●	●				●
Lebanon	E(R), P, HC	☆			●				●	●[6]			●[6]
Libya	E(R), P(R), HC									●			
Macedonia, North	E, P, HC, T	★	●							●[6]			●[6]
Malaysia	P, HC(N)	●	●	●	☆	☆			●, ○	●			●
Maldives	P	●	●						●				
Marshall Islands	P	☆								●			
Mauritius	P	●			●				●, ○	●			●[6]
Mexico	E(R), P, HC				●	●			●, ○	★	●		●, ☆[6], ★
Montenegro	E, P, HC, T	●	☆			●			●				
Namibia	P	●					●						
Nauru		●											
Paraguay	P	●				●				●			
Peru	E(R), P(R)	●	●	●	●	●			●	●			●
Romania	E, P, HC, T			●	★	●		●					●[6]
Russian Federation	E(R), P	●	●						●, ○				●
Samoa	E, P	●											
Serbia	E, P, HC, T		●			●							●
South Africa	P	●		●		●	●		●	●			●[6]
St. Lucia	E, P	●			●					●			
St. Vincent and the Grenadines[1]	P	●			●								
Suriname		☆			●				●				
Taipei, China	E(R), P(R)		☆								☆		
Thailand	E, P, HC, T	●	●		●	●				●		●	●[6], ★[7]
Tonga	P	●							●, ○				
Turkey	E(R), P	●	●[6]		●	●	●[8]		●, ○				●[6]
Turkmenistan		●											
Tuvalu	P	●											
Venezuela	P	☆											

Note: Please see key on last page of table.

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

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Regulatory Policies: Electric utility quota obligation/RPS	Regulatory Policies: Net metering/billing	Regulatory Policies: Biofuel blend, renewable transport obligation/mandate	Regulatory Policies: Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Regulatory Policies: Tradable REC	Regulatory Policies: Tendering	Fiscal Incentives and Public Financing: Reductions in sales, energy, CO_2, VAT or other taxes	Fiscal Incentives and Public Financing: Investment or production tax credits	Fiscal Incentives and Public Financing: Energy production payment	Fiscal Incentives and Public Financing: Public investment, loans, grants, capital subsidies or rebates
Lower-Middle Income Countries													
Angola	E	●	●			●							●
Bangladesh	E, P	●							●	●			●
Bhutan	P, HC	●											
Bolivia	P	●	●	●	●				●	●		●	●
Cabo Verde	P	●			●				●, ○	★	●	●	
Cambodia	P	●							○				
Cameroon	P	●								●			
Congo, Republic of	P	●											
Côte d'Ivoire	E, P	●							●	●			
Djibouti	E (N), P(R)	●											
Egypt	E(R), P(R)	●	●		●				●	●[6]			●
El Salvador		●							●	●	●	●	●
Eswatini		●							●				
Georgia													●[6]
Ghana	E, P	●	●	●	●	●		●	○	●			●
Honduras	E(R), P(R)	●	●		●				●	●	●		
India	E(R), P, P*(R), HC, T(R)	●	●, ◖	●	◖	●		●	●, ○, ◐	●	●	●, ◖	●[6], ★*[7]
Indonesia	E(R), P	●	●	●		☆			●	●	●		●
Kenya	P, HC	●	●		●				●	●		●	●
Kiribati	P	●											
Kosovo	E, P, HC		●										
Kyrgyz Republic				●						●			●
Lao PDR	E	●											
Lesotho	P	☆			●				●	★	●	●	●
Mauritania	E(R), P	●											
Micronesia, Federated States of	P	●			◖								
Moldova	E, P, HC, T	☆	●		●	●			●				●
Mongolia	E, P	●	●						●	●			
Morocco	E(R), P(R), HC	●			●				●, ○				●[6]
Myanmar	P	●								●			
Nicaragua	P	☆	●							●	●		●
Nigeria	P	●	●	●					●, ○	●			●
Pakistan		●	●		●			●		●			●
Palestine, State of[5]	E, P	●	●		●				●	●			
Papua New Guinea	P	●											
Philippines	P	●	●	●	●	●			●	●	●	●	●, ☆[6]
São Tomé and Príncipe	P	●											
Solomon Islands	P	●											
Sri Lanka	P, T	●	●	●	●	●			●	●		●	●
Sudan	E(R), P(R)	●				●							
Timor-Leste	P	●											
Tunisia	E(R), P	●			●				●, ○	●			●[6]
Ukraine	E, P, HC, T	●	☆		●	●				●			●[6]
Uzbekistan	E, P	☆							●		★		
Vanuatu	E, P	●	●							●			
Vietnam	E(R), P, T	●	●	●	●	●		●	○	●	●		●
Zambia		●	●						●, ○	●			●

Note: Please see key on last page of table.

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

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Low Income Countries													
Afghanistan	E, P	●							●				
Benin	E, P	☆							●				
Burkina Faso	P	●							●, ○	●	●	●	
Burundi	E, P	☆											
Central African Republic		●											
Chad		●											
Comoros	P	●											
Congo, Democratic Republic of the	P	●											
Eritrea	P	☆											
Ethiopia	P	●				●			●, ○				
Gambia	P	●							○	●			
Guinea	E, P	●								●			
Guinea-Bissau	P	☆							○				
Haiti	E(R), P(R)	●											●
Korea, Democratic People's Republic		●											
Liberia	E, P, T	☆				●				●			
Madagascar	E, P	●							●	●			
Malawi	E, P, HC	●	●			●	●		●	●			●
Mali	E, P	●							○	●			●
Mozambique	P, HC	☆	●			●				●			●
Nepal	E, P, T	●	●					●	●	●	●		●
Niger	E, P	●							●	●			
Rwanda		●	●						●	●	●		●
Senegal	P	●	●	●	●				●	●			
Sierra Leone	P, HC	●											
Somalia		●											
South Sudan	P												
Syria	E(R), P(R)	☆	●		●				●	●	●		
Tajikistan	E, P	●	●							●			●
Tanzania	E, P	☆	●		●				●	●		●	●
Togo	E, P	●								●			
Uganda		●	●						●	●			●
Yemen	E(R), P(R)	●											
Zimbabwe		●				●			○	●			●

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

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

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

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

[2] FIT support removed for large-scale power plants.

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

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

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

[6] Includes renewable heating and/or cooling technologies.

[7] Includes aviation, maritime or rail transport.

[8] Heat FIT

[9] Fossil fuel heating ban

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

Source: See endnote 2 for this chapter.

03

HARVESTING GEOTHERMAL ENERGY IN RURAL COMMUNITIES, EL SALVADOR

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

03 MARKET AND INDUSTRY TRENDS

KEY FACTS

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

BIOENERGY

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

BIOENERGY MARKETS

Biomass contributes the highest share to the global energy supply of all renewable energy resources. It provides energy not only for heating and transport, but also to produce electricity.[3] Including the traditional use of biomass[i], bioenergy contributed an estimated 12%, or 45.2 exajoules (EJ), to total final energy consumption in 2018.[4]

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

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

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

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

Bio-heat Markets

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

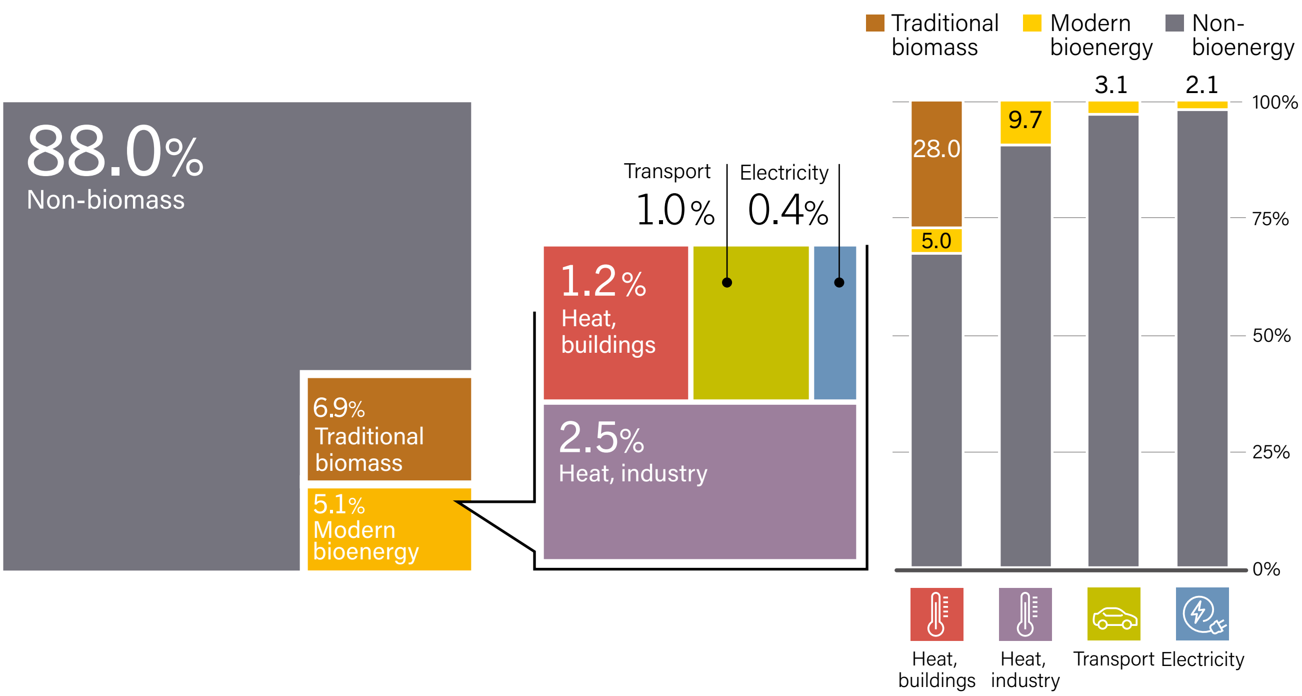
The **traditional use of biomass** in developing and emerging economies supplies energy for cooking and heating in simple and usually inefficient fires or stoves.[9] (→ *See Distributed Renewables chapter.*) The amount of biomass used in traditional applications has decreased slightly in recent years, from 27.2 EJ in 2010 to an estimated 26 EJ in 2018.[10] The decline is due in part to efforts to reduce traditional biomass use and to improve access to clean fuels, given the negative effects of biomass burning on local air quality, the associated health impacts and the unsustainable nature of much of the biomass supply for these uses.[11]

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

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

Of this total, 8.9 EJ was used directly to provide heat for **industry and agriculture**.[14] Bio-heat demand in these sectors grew 1.8% annually on average between 2013 and 2018, and bio-heat met 9.3% of the sectors' heat requirements in 2018.[15] Industries that handle biomass – notably paper and board, sugar and other food products, and wood-based industries – often use their residues for energy purposes. In the paper and board sector, for example, 40% of energy use is derived from biomass sources, including the "black liquor" produced in paper manufacture.[16] Bioenergy is not yet widely used in other industries. However, biomass and waste fuels met around 6% of the cement industry's energy needs in 2017, mainly in Europe where they provided around 25% of the energy used in cement making.[17]

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



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

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

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

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

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

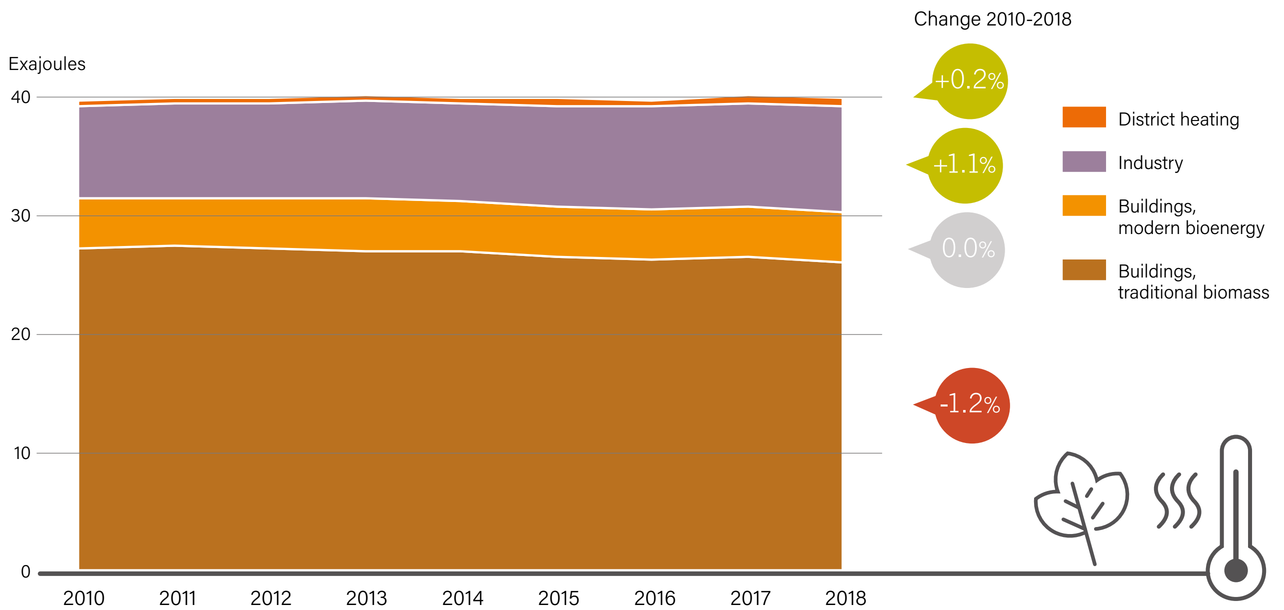
Biomass can produce heat for residential building use through the burning of wood logs, chips or pellets produced from wood or agricultural residues. The informal use of wood and other biomass to heat individual residences is prevalent in developing and emerging economies as well as in more developed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

Modern use of bio-heat in buildings has been concentrated in the EU, which accounted for 47% of this total use in 2018.[27] France, Italy, Germany and Sweden accounted for around half of the EU's bio-heat demand.[28] Most bio-heat demand in the EU (as elsewhere) is residential, although this has not increased much since 2010 and varies greatly by year depending on climatic conditions.[29] Systematic country data on biomass heating for 2019 were available for only a few European countries.[30]

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

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

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



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

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

Despite growth in the use of biogas for heating, and particularly in the production of biomethane and its introduction into gas grids, biogas provided only 4% of bio-heat in European buildings in 2018.[34] North America followed the EU for bioenergy use in buildings. In 2018, more than 2 million US households (2% of the total) relied on wood or wood pellets as their primary heating fuel – using a total of 0.4 EJ – and a further 8% of households used wood as a secondary heat source.[35] Wood use was concentrated in rural areas, with one in four rural households combusting wood for primary or secondary space heating.[36] In Canada, the residential heating sector used some 0.13 EJ of bio-heat from wood fuels in 2018.[37] Pellet sales in North America totalled around 2.7 million tonnes.[38]

In addition to direct use of bio-heat in industry and buildings, bioenergy provided some 0.7 EJ to **district heating systems** in 2018; of this total, 51% was used in industry and agriculture, and the rest in buildings.[39] Bioenergy use in district heating grew 5.7% annually on average during 2013-2018, and bio-heat accounted for 95% of the heat supplied by renewable sources to district systems in 2018.[40]

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

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

Transport Biofuel Markets

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

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

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

Global **ethanol** production increased 2% to 114 billion litres in 2019, up from 111 billion litres in 2018.[52] Large increases in several countries more than made up for a drop in production in the United States, the major producer.[53] The United States and Brazil, the two leading producers, accounted for 50% and 33% of global production, respectively, followed by China, India, Canada and Thailand.[54]

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

In Brazil, ethanol production increased 7% to a record 35.3 billion litres.[59] Higher ethanol prices encouraged production ahead of the introduction of the RenovaBio[iii] system at the start of 2020.[60] Most Brazilian ethanol comes from sugar cane, and as of the end of 2019 some 370 sugar ethanol mills were operating across the country.[61] Brazil also produced around 1.4 billion litres of ethanol from corn (up 75% from 2018), with 10 production plants in operation and more corn-based capacity under construction to take advantage of the expected rise in ethanol demand under RenovaBio.[62]

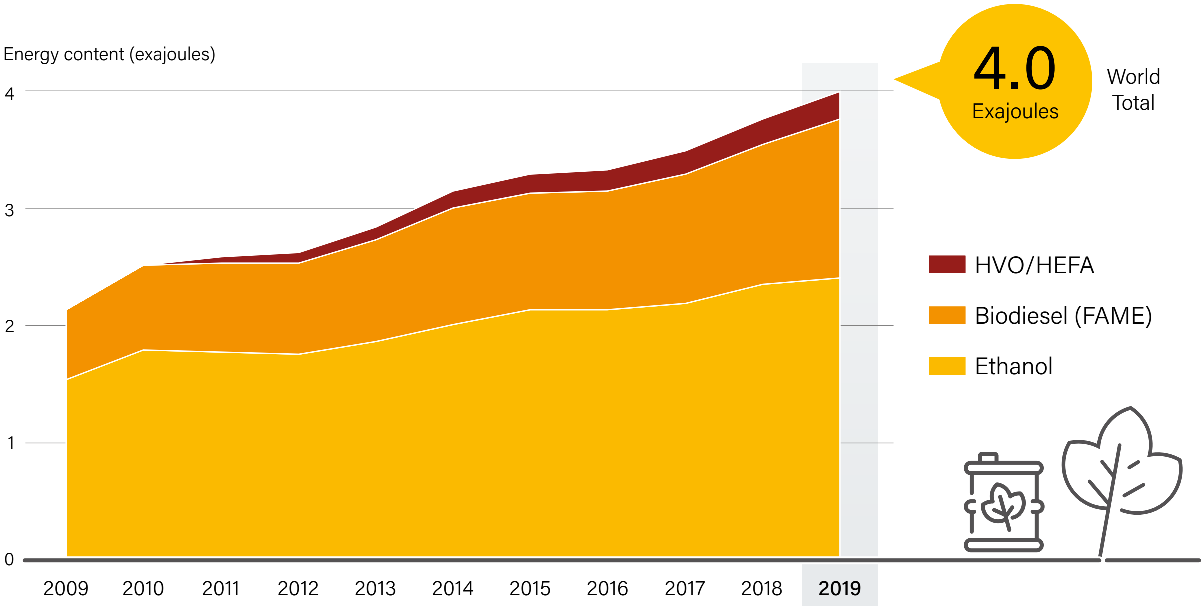
China's ethanol production increased to 4 billion litres in 2019, up from 3.3 billion litres in 2018, to meet growing domestic demand.[63]

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

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

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

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



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

Source: See endnote 50 for this section.

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

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

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

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

Global production of biodiesel increased **13%** in 2019, with Indonesia overtaking the United States as the largest producer.

Indonesia's biodiesel production nearly doubled in 2019 to 7.9 billion litres, up from 4 billion litres in 2018.[76] Excess production capacity and new production plants came online in response to a new policy emphasis on meeting the country's B20 (20% biodiesel) blending target in transport, which was established in 2016 but had not yet been achieved; the expansion of production resulted in higher domestic biodiesel use.[77]

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

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

In Argentina, biodiesel production decreased 9% to 2.5 billion litres, as the weaker US market and ongoing US duties on biodiesel imports discouraged trade.[82] Argentine biodiesel exports fell from 1.6 billion litres in 2018 to 1.2 billion litres in 2019.[83]

The production of **HVO/HEFA** continued its robust growth of recent years, rising 12% from 6 billion litres in 2018 to 6.5 billion litres in 2019.[84] Production was concentrated in Finland, the Netherlands and Singapore, although US capacity also grew strongly.[85]

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

In Europe, the use of biomethane for transport increased 20% in 2018 (latest data available) to 8.2 PJ.[89] Sweden remained the region's largest biomethane consumer, using nearly 60% of the total, followed by Germany, Norway and the United Kingdom, where use of the fuel grew by a factor of four to 0.6 PJ in 2018.[90]

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

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

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

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

Bio-power Markets

Global bio-power capacity increased an estimated 6% in 2019 to around 139 gigawatts (GW), up from 131 GW in 2018.[98] China had the largest capacity in operation by the end of 2019, followed by Brazil, India, Germany, the United Kingdom, Sweden and Japan.

Total bioelectricity generation rose some 9%, from 546 terawatt-hours (TWh) in 2018 to around 591 TWh in 2019.[99] In recent years, growth has been concentrated in the EU and in Asia, particularly in China, Japan and the Republic of Korea. China extended its lead as the largest country producer of bio-power, followed by the United States.[100] The other major producers in 2019 were Brazil, Germany, India, the United Kingdom and Japan.[101]

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

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

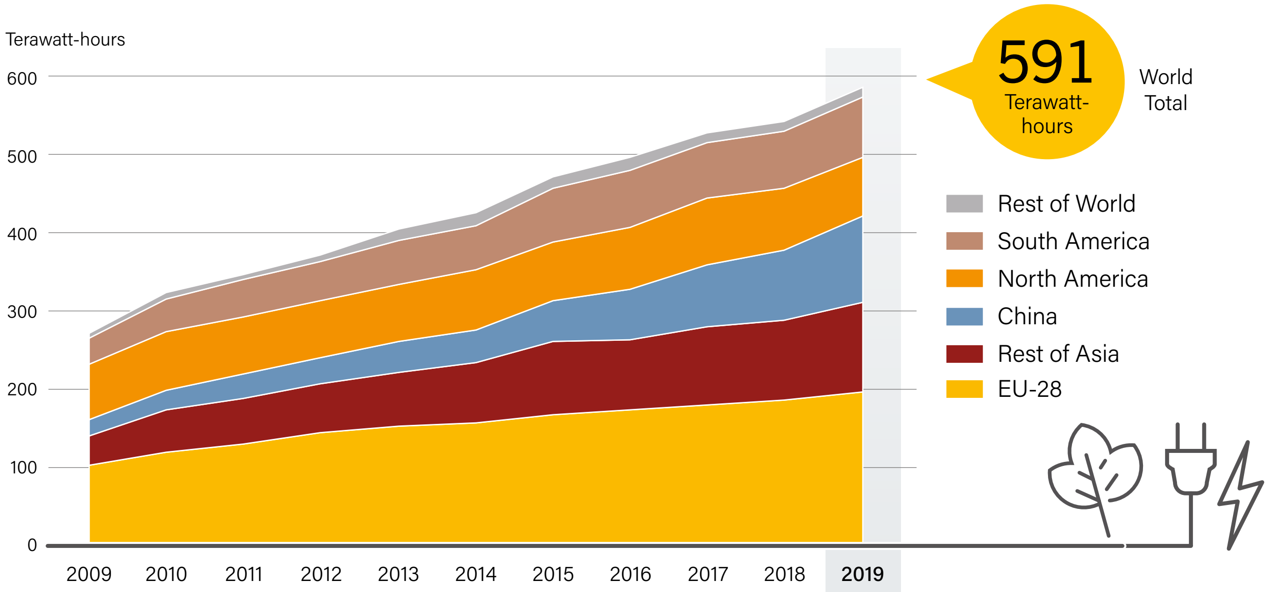
Japan's growth in bio-power capacity and generation remained strong during the year, stimulated by the Feed-in Tariff scheme.[109] The capacity of dedicated bio-power plants increased 8% to 4.3 GW, and generation grew 18% to 24 TWh.[110] In the Republic of Korea, bio-power generation rose 50% to 10.9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

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

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

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

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



Source: See endnote 105 for this section.

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

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

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

The use of biogas to co-generate electricity and heat has risen as well. By the end of 2019, some 132,000 biogas digesters were in operation worldwide.[126] More than 100,000 of the units were in China, followed distantly by Europe (around 18,000) and the United States, where some 2,200 sites in all 50 states were producing biogas.[127]

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

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

In the Middle East, a new biogas power plant at the Mazoon Dairy Company in Oman, which uses biogas from cattle waste to provide process energy as well as fertiliser, became the first such facility in the region.[132] In the United Arab Emirates, Dubai Municipality announced plans to build a biogas power plant at the Warsan Sewage Treatment that would reduce some 31,000 tonnes of carbon dioxide (CO_2) emissions annually.[133]

BIOENERGY INDUSTRY

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

Solid Biomass Industry

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

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

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

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

The global trade in wood pellets initially relied on subsidiary companies established by major users such as Drax (United Kingdom) and RWE (Germany), which, in the absence of alternatives, invested in vertically integrated supply chains to meet their own demand. More recently, however, the market has shifted to third-party supply from major producers such as Enviva (United States), Graanul Invest (Baltic States) and Pinnacle Renewable Energy (Canada), as well as smaller-scale regional suppliers such as An Viet Phat (Vietnam) and FRAM Renewable Fuels, Highland Pellets and Pacific Bioenergy (all United States).[141] These companies have invested in production capacity and logistics to match long-term supply contracts from major power producers in Europe and Asia.[142]

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

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

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

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

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

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

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

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

triple

global production capacity.

Liquid Biofuels Industry

The liquid biofuels industry is concentrated on the production of ethanol, FAME biodiesel and increasingly HVO/HEFA, which together make up the bulk of global biofuels production and use. In 2019, the industry, particularly in the United States, was negatively affected by trade and other restrictions that constrained production in some markets. Several US ethanol plants, including facilities belonging to the two largest US producers, POET and Archer Daniels Midland, had to cut production because of constraints to domestic demand and export opportunities.[157] In addition, eight US biodiesel plants were closed, and other plants operated at reduced capacity, although several new biodiesel plants also came online or were being planned in the country.[158]

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

In North America, nearly 4 billion litres of additional renewable diesel[i] production capacity was under construction at year's end, and HVO production capacity was rising steadily, mainly in the United States.[161] Growth was stimulated by the country's RFS and particularly by the Low Carbon Fuel Standard in California.[162] World Energy (United States) announced a USD 350 million expansion project to complete the conversion of a former oil refinery in Paramount, California to produce up to 1.3 billion litres of renewable diesel, biojet fuel, green gasoline and renewable propane.[163] Ryze Renewables (United States) was building two projects in the US state of Nevada with a combined capacity of 568 million litres per year, and Marathon Petroleum (United States) was in the process of converting its oil refinery in North Dakota to produce 700 million litres annually by late 2020.[164]

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

ENI opened a newly converted biorefinery in Gela, Italy that can produce nearly 1 billion litres of HVO per year, and planned to invest another EUR 93 million (USD 104 million) in a plant to pretreat waste feedstocks.[167] In Sweden, the oil company ST1 invested SEK 1.5 billion (USD 160 million) in a hydrogen plant to produce 250 million litres annually of HVO, due to start operation in 2020.[168] PKN Orlen (Poland) began producing HVO from used cooking oil and vegetable fats at its plants in Płock and Litvínov to help meet rising demand.[169]

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

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

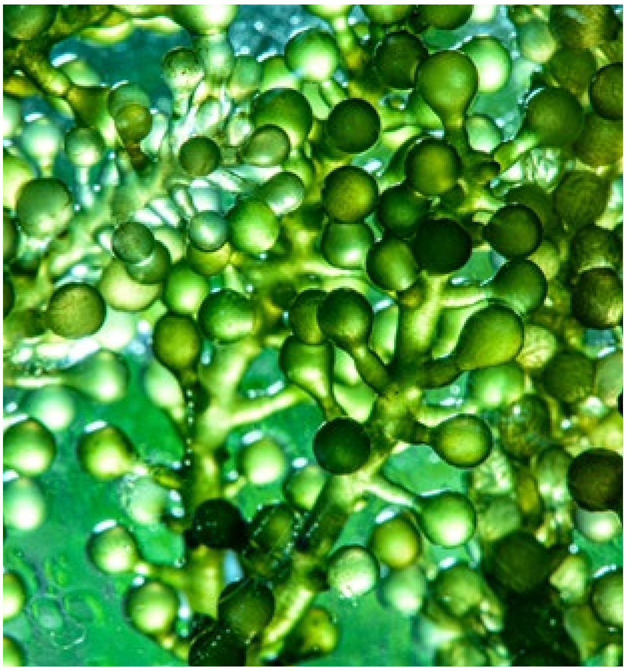
Many pathways are under development to produce advanced biofuels, including bio-based fuels (from an array of feedstocks) in the form of ethanol, butanol, diesel jet fuel, gasoline, biomethanol and mixed higher alcohols.[174] The most advanced pathways include the production of ethanol from cellulosic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

So far, few cellulosic ethanol production plants have reached their design output due to ongoing technical and commercial challenges.[175] For example, the POET-DSM plant in Emmetsburg, Iowa in the United States halted routine production in 2019 to concentrate instead on research and development (R&D) to improve plant performance.[176] Meanwhile, VERBIO (Germany) purchased DuPont's commercial-scale cellulosic ethanol plant in Iowa, which ceased operations in 2017, and is converting the plant to produce methane from straw using anaerobic digestion, starting in 2020.[177]

More positive trends were observed elsewhere in 2019. In Europe, Clariant (Switzerland), which had been operating a demonstration cellulosic ethanol plant in Germany, announced that it was building a full-scale commercial plant in Romania.[178] The company also licensed its technology for a large-scale plant in the Slovak Republic and negotiated licences in China and Poland.[179] ENI (Italy) took over the Biochemtex cellulosic ethanol plant in Crescentino, Italy – which was closed following the failure of the parent company in 2017 – and planned to restart production in 2020.[180]

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

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



it down in 2016 due to technical problems, restarted production with a goal of 30 million litres in 2019 and 50 million litres in 2020.[181] Raizen (Brazil) built up production levels at its plant in Costa Pinto, to around 12 million litres in 2017/2018 and an expected 40 million litres (the rated capacity) in 2018/2019.[182]

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

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

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

Although biofuels replaced only 0.1% of aviation fuel in 2018, developments in the sector in 2019 aimed to reduce emissions and to boost collaboration among potential aviation biofuel producers, airlines and airports, driven by industry carbon reduction targets.[189] SkyNRG announced plans to develop Europe's first dedicated sustainable aviation fuel plant, using regional waste and residue streams in the Netherlands.[190] Amsterdam's Schiphol airport pledged to invest in the facility, and the Dutch airline KLM committed to purchasing 75,000 tonnes annually from the plant for 10 years; in addition, SHV (Netherlands), a leader in distribution of liquefied petroleum gas, said it would buy the bioLPG produced as a by-product.[191]

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

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

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

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

Gaseous Biomass Industry

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

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

Biogas can be upgraded to biomethane by removing the CO_2 and impurities, facilitating its injection into natural gas pipelines when appropriate quality standards can be met.[202] Increasingly, policy makers have considered this as an important route to decarbonising the heating and transport sectors.[203] Systems for producing and converting biogas to biomethane were widely deployed in 2019, with the refined biomethane either being injected into natural gas pipelines for use for heating or being used directly for transport.

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

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

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

The move to biomethane has stimulated the active interest of large international players. ENGIE (France) had a portfolio of more than 80 biomethane projects in 2019; the company planned to produce some 18 PJ annually by 2020 and to invest EUR 2 billion (USD 2.24 billion) in the technology by 2030.[209] The industrial gas supplier Air Liquide (France) has attributed the 30% growth in revenue of its Global Markets and Services Division in 2018 (to USD 494 million) to the company's biogas-related activities in Europe and North America.[210]

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

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

Bioenergy with Carbon Capture and Storage or Use

Many low-carbon scenarios depend on the capture and storage of carbon dioxide emitted when bioenergy is used to produce heat, electricity or transport fuels.[212] Removal from the atmosphere of CO_2 produced in bioenergy production, which is considered part of the carbon cycle, is seen as having a double benefit that leads to "negative emissions".[213] Although policy makers and analysts have shown rising interest in such options, in the absence of strong policy drivers that might make projects economically attractive, very few projects demonstrating these technologies have operated at scale so far.[214]

Examples exist of CO_2 from bioenergy projects being separated and used for various industrial applications, but only around five commercial-scale projects using bioenergy with carbon capture and storage (BECCS) were in operation at the end of 2019.[215] These included a large-scale project at an Archer Daniels Midland (United States) ethanol distillery in the US state of Illinois, which captured around 1 million tonnes of CO_2 per year, and four other projects that were linked to ethanol distilleries in Canada and the United States.[216]

Additional pilot-scale projects demonstrating carbon capture were pursued during the year. Drax Power, working with C-Capture (United Kingdom), invested GBP 400,000 (USD 525,000) in a pilot carbon capture project at its large-scale bio-power plant in the United Kingdom – the first such project in Europe.[217] CO_2 Solutions (Canada) installed a carbon capture unit at the Saint Félicien pulp mill in Quebec, Canada; the unit uses an enzymatic technology to capture 30 tonnes of CO_2 per day, which is then reused at an adjacent greenhouse complex.[218]

KEY FACTS

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

GEOTHERMAL POWER AND HEAT

GEOTHERMAL MARKETS

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

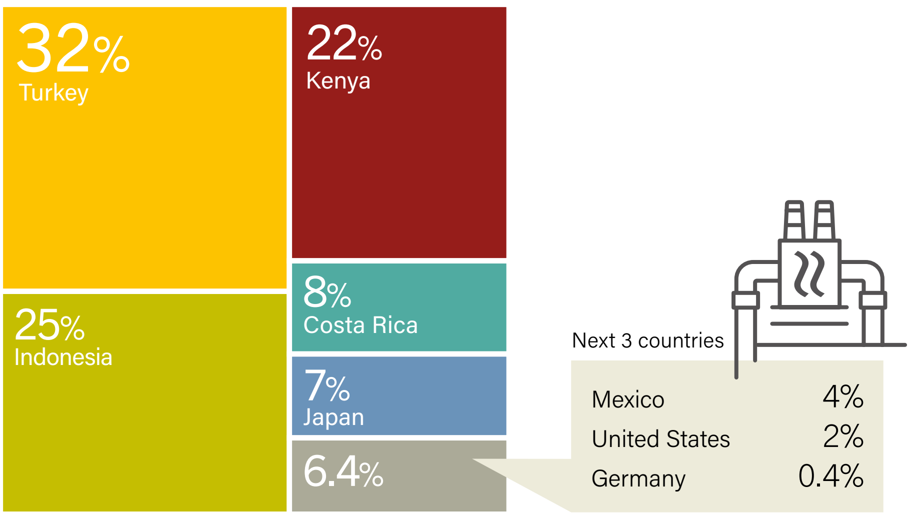
An estimated 0.7 GW[iii] of new **geothermal power** generating capacity came online in 2019, bringing the global total to around 13.9 GW.[2] As in 2018, Turkey and Indonesia remained in the lead for new installations, followed closely by Kenya. Together, these three countries represented three-quarters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

i When geothermal resources are used for electricity generation, a portion of the electricity is used for "indirect" thermal applications, such as cooling (air conditioning) and heating (via heat pumps or through electric resistance).

ii This does not include the renewable final energy output of ground-source heat pumps. See Systems Integration chapter.

iii Net additions were somewhat lower due to decommissioning or derating of existing capacity.

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



Source: See endnote 4 for this section.

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

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

Following capacity expansion of 219 MW in 2018, Turkey brought online a net additional capacity of 232 MW in 2019.[8] Among the units entering operation was the 32 MW Unit 6 at the Pamukören complex.[9] A 30 MW unit also was added to Maspo Energy's existing 10 MW facility, and the company was continuing feasibility studies for a third unit.[10] In 2019, Turkey ranked fourth globally for total geothermal power capacity, with 1.5 GW.[11]

The bulk of Turkey's geothermal capacity has been built over the last decade in response to a technology-specific feed-in tariff (FIT) in place since 2011.[12] In 2019, the country's geothermal industry leadership awaited new subsidy schemes to replace the expiring FIT, suggesting that uncertainty about renewal of the FIT may have been holding back financing and investments in new projects.[13] At an average project cost of USD 4 million per megawatt, the current growth of 200-250 MW per year represents USD 1 billion in annual investment going forward.[14] In early 2020, with its subsidy scheme under review, the Turkish government indicated that its support for renewables would continue.[15]

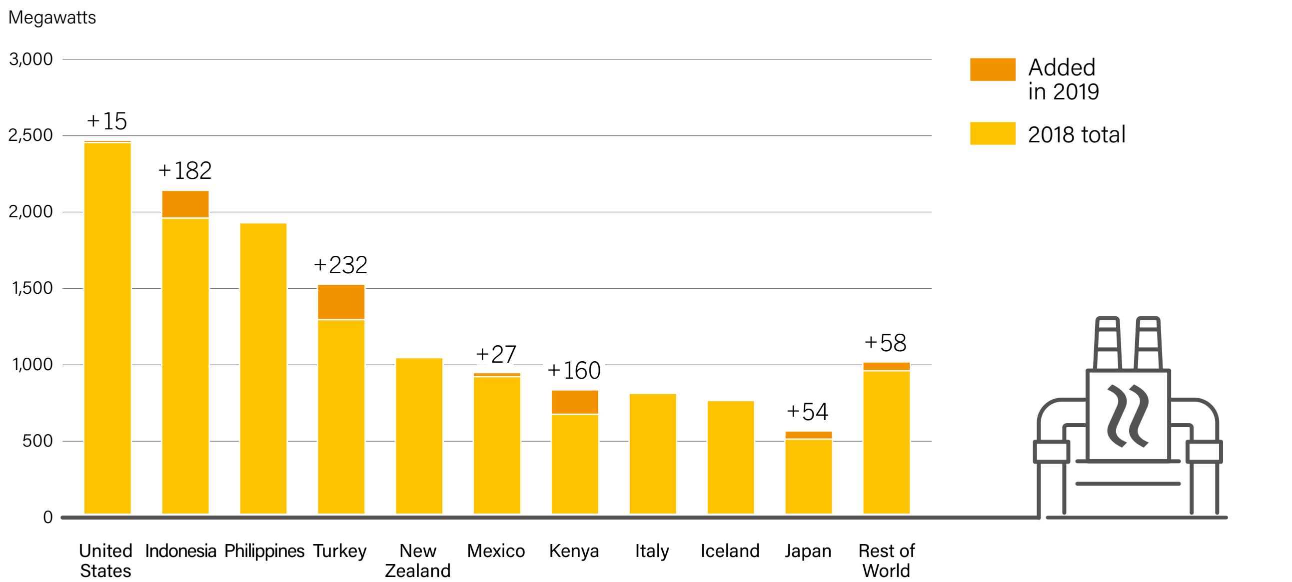
Turkey's geothermal sector also faced mounting community concern about the potential adverse impacts of air emissions (mainly hydrogen sulphide) and groundwater contamination (heavy metals) from existing geothermal power plants on public health, wildlife and agricultural output (primarily olives and figs).[16] (→ *See Feature chapter.*) Most of the country's geothermal plants are located in the agricultural regions of western Anatolia, bordering the Aegean Sea.[17] Also of concern, carbon dioxide emissions from Turkey's geothermal operations, which range from 1.0 to 1.3 kilograms of CO_2 per kWh at the time of plant commissioning, are nearly 10 times above the global average.[18] Recent observations suggest that CO_2 emission rates at the country's geothermal fields decline over time, although outcomes vary by facility.[19]

Indonesia added 182 MW of geothermal capacity in 2019, following the 140 MW added in 2018, for a year-end operating total of 2.1 GW.[20] Construction was completed on three units: the 42.3 MW Sorik Marapi Unit 1 in North Sumatra, and the 55 MW Lumut Balai and the 85 MW first stage of the Muara Laboh facility, both in South Sumatra.[21] The Sorik Marapi is expected to expand to five generating units and a total of 240 MW by 2023, with the second unit to be ready by the end of 2020.[22]

i If a geothermal power plant extracts heat and steam from the reservoir at a rate that exceeds the rate of replenishment across all its boreholes, additional wells may be drilled over time to tap additional steam flow, provided that the geothermal field overall is capable of supporting additional steam flow.

ii In general, a power plant's net capacity equals gross capacity less the plant's own power requirements and any seasonal derating. In the case of geothermal plants, net capacity also would reflect the effective power capability of the plant as determined by the current steam production of the field. This defines its running capacity, as opposed to the total nameplate capacity of its generator(s). For the United States, most of the difference between nameplate and running capacity (about 800 MW) results from plant derating at the Geysers geothermal field in California, which is not able to produce enough steam, due to productivity decline, to operate at nameplate capacity. See endnote 6 for this section.

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



Source: See endnote 5 for this section.

The Indonesian government's target for 23% renewables in the energy mix by 2025 assumes that geothermal power capacity will reach 7 GW (supplying 7% of the energy mix).[23] In an effort to mitigate geothermal project risk and to stimulate investment to achieve its target, the government pursued exploratory drilling in three separate locations during 2019.[24] The World Bank is spearheading the financing of this drilling, and in 2019 the Bank approved a USD 150 million loan to Indonesia accompanied by USD 127.5 million in grants from the Green Climate Fund and the Clean Technology Fund.[25]

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

Elsewhere in Asia, most geothermal power capacity is located in Japan and the Philippines. Japan's geothermal capacity has expanded very little in recent years despite plentiful resources, which made 2019 relatively eventful. The 7.5 MW Matsuo Hachimantai geothermal power plant was completed in Iwate Prefecture in the north-eastern part of Honshu. As is common for geothermal projects, the development timeline was lengthy: initial research for the single-flash[i] plant began in 2011, exploration started in 2015, and resource development began in 2017.[28] At the time of completion, Hachimantai was the largest geothermal plant to be built in Japan in more than 20 years.[29] By mid-2019, the double-flash 46.2 MW Waisabizawa plant began operation in neighbouring Akita Prefecture.[30]

These Japanese projects benefited from government support of surface surveys and exploratory drilling, designed to advance Japan's geothermal resource development efforts. To mitigate the risk and the large upfront cost of further development, in 2019 the Japanese government announced geothermal exploration grants to support 7 new projects in addition to 17 projects already under way.[31]

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

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

Kenya closely followed Turkey and Indonesia for new installations (160 MW), and ended the year with 0.8 GW of total capacity.[39] The country is Africa's most active market for geothermal power and the only one on the continent to add capacity in 2019. Units 1 and 2 of the Olkaria V project came online with better-than-expected results, delivering more than 160 MW of power to the national grid.[40] Also of note in Kenya was the African Development Bank's issuance of a partial risk guarantee in support of the long-delayed Menengai geothermal project.[41] With the requisite drilling already complete, the guarantee was expected to hasten construction of the initial three 35 MW units.[42] In addition, the Geothermal Risk Mitigation Facility, a regional organisation focused on the funding and acceleration of geothermal energy in East Africa, provided a grant for Kenya's Baringo-Silali project (anticipated initial capacity of 300 MW), where the first well was drilled successfully in late 2019.[43]

Costa Rica ranked fourth globally for newly installed capacity. The 55 MW Las Pailas II geothermal plant was completed, finalising the complex that also includes the 35 MW Las Pailas I, which came online in 2011.[44] The Las Pailas II production field encompasses 21 wells with an average depth of 2,200 metres.[45] During 2019, Costa Rica's national utility indicated that the plant was an important step towards national goals to decarbonise the economy, as well as a welcome diversification from hydropower during a dry period and partial relief from resultant electricity imports.[46] The country's capacity reached 262 MW by year's end, second only to Mexico in Latin America.[47]

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

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

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

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

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

The **United States** remains the global leader for installed geothermal power capacity, despite little recent growth.

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

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

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

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

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

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

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

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

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

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

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

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

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

Two regions in France have seen notable expansion of local geothermal resources, mostly for district heating. In the Paris region, district heating systems have gradually increased their geothermal heating capacity in recent years, with more progress made in 2019 and new future plans announced. In December, the community of Champs-sur-Marne (eastern suburbs of Paris) launched a EUR 40 million (USD 44.8 million) district heating project that will supply heat to the equivalent of 10,000 homes; the renewable energy component of the supply is expected to be 82%.[79] With drilling under way, the local community was invited to invest in the project to allow residents to take a direct financial stake in its benefits.[80] (→ *See Feature chapter.*) For the nearby communities of Drancy and Bobigny, drilling of four boreholes commenced in 2019, with project completion expected by 2021.[81]

After demonstrating notable success in 2018, producing one of the hottest geothermal wells in continental Europe, geothermal prospects in the Alsace region of France dimmed over the course of 2019.[82] Early in the year, the French government indicated a likely curtailment to its support (still in question as of early 2020), which is critical for deep geothermal projects in the country.[83] Later in 2019, scientists suspected that two strong earthquakes in the Strasbourg area were linked to local drilling and associated well stimulation activity (→ *see Industry section in this chapter*), although the correlation was refuted by a project developer.[84]

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

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

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

GEOTHERMAL INDUSTRY

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

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

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

The importance of EGS technology to expand the opportunities for the geothermal industry – along with the need to lower project risk, capital cost and cost of capital – was underscored by an extensive US government study published in 2019.[93] The study revealed that geothermal power capacity in the United States might grow to a range of 6-13 GW with current methods and technology, whereas significant further expansion would require extensive use of deep-EGS resources and would entail drilling on a scale rivalling the country's oil and gas industry.[94]

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

Notable innovations in geothermal energy during the year included completion of a demonstration facility by the Canadian company Eavor.[97] The technology takes advantage of directional drilling techniques developed in the oil and gas industry to create a closed-loop system that circulates a working fluid to siphon heat from hot sub-surface rock (several kilometres deep) without bringing any geothermal fluid (brine) to the surface. In addition to eliminating surface emissions of CO_2 and hydrogen sulphide, the continuous closed loop of the working fluid reportedly creates a thermosiphon effect (bringing hot fluid up on one side as cold fluid descends on the other) that mitigates the energy demand from pumping that is associated with other geothermal techniques.[98]

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

KEY FACTS

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

HYDROPOWER

HYDROPOWER MARKETS

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

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

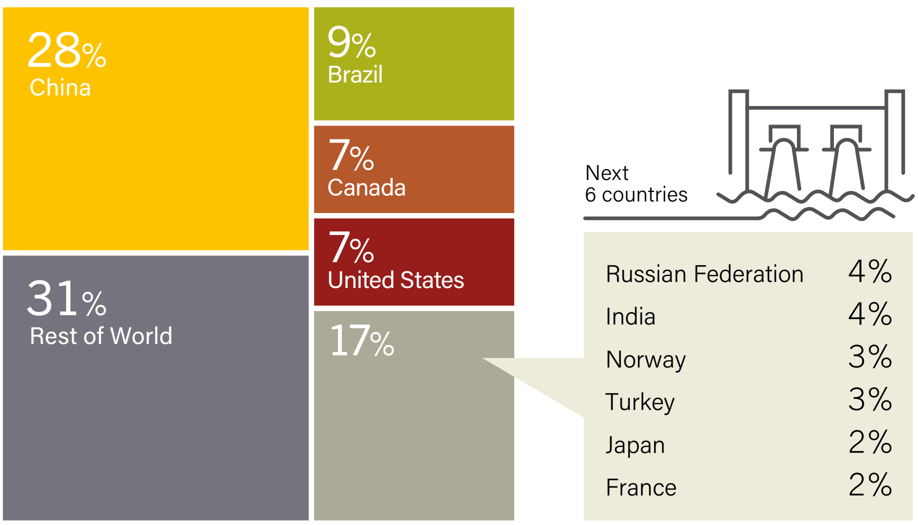
Brazil took the lead in commissioning new hydropower capacity in 2019, followed by four countries in Asia: China, Lao PDR, Bhutan and Tajikistan.[4] (→ *See Figure 27.*) This marked the first year since at least 2004[iii] in which China did not maintain a wide-margin lead over all other countries for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

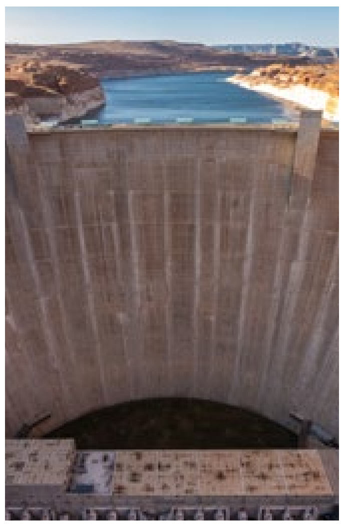
i Where possible, all capacity numbers exclude pure pumped storage capacity unless otherwise specified. Pure pumped storage plants are not energy sources but means of energy storage. As such, they involve conversion losses and are powered by renewable and/or non-renewable electricity. Pumped storage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

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

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

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

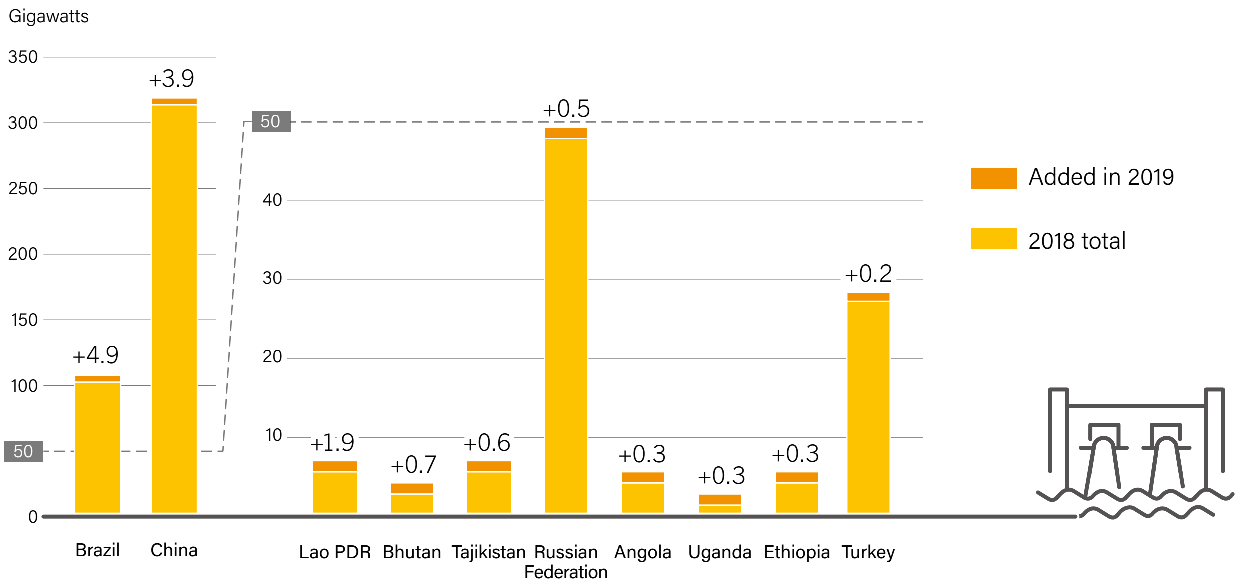




Note: Totals may not add up due to rounding.

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

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



Source: See endnote 4 for this section.

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

Despite Brazil's apparently robust market in 2019, the country's incremental hydropower development is increasingly constrained by available resources. Only around 12 GW (23%) of the remaining greenfield capacity potential (of unit size larger than 30 MW) lies in areas that are not restricted for ecological or social reasons.[11] That remaining potential is further constrained by socio-political limitations as well as the environmental costs associated with development, which are estimated to be about an order of magnitude larger than what is typical for wind power and solar PV in Brazil.[12] While hydropower's still-dominant contribution to Brazil's electricity mix is in gradual decline, the combined contribution of wind energy and solar PV is growing rapidly, rising from 8.8% in 2018 to 10.3% in 2019.[13]

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

Peru added 132 MW of hydropower to its grid, mostly in the form of recommissioned capacity such as the 82 MW Callahuanca plant.[17] The Callahuanca plant dates back to 1938, but the structure was damaged by landslides in 2017 and became inoperable.[18] In 2019, Peru generated 30.2 TWh from hydropower, or around 57% of its total electricity supply.[19]

In Bolivia, the second unit (69 MW) at the San Jose complex was completed, following the commissioning of the plant's first (55 MW) unit in 2018.[20] The country is experiencing a relative oversupply of capacity (3 GW against a peak demand of 1.8 GW in 2019), which the current government blames on a lack of system planning in years past.[21] Nonetheless, portions of the country do not have adequate electricity supply due to lack of transmission capability.[22] At the end of 2019, Bolivia had 735 MW of hydropower capacity, providing 34% of its electricity supply.[23]

More hydropower capacity was added across Asia than in any other region during 2019, with several countries bringing plants online. China led the region for newly installed capacity, but for the first time in many years the country did not lead the world by a wide margin; instead, it trailed Brazil to rank second globally. China added 3.87 GW (excluding pumped storage) in 2019, about half the additions of 2018, for a year-end total of 326.1 GW.[24] China's total completed hydropower projects during the year represented investment of CNY 81.4 billion (USD 11.6 billion), an increase of 16.3% over 2018.[25]

While China's hydropower capacity grew 1.2%, generation increased 5.7% to 1,302 TWh in 2019.[26] Even so, hydropower is having trouble keeping up with rising demand. Annual capacity additions have declined somewhat in recent years, both in absolute terms and as a share of overall electricity demand. During the five-year period 2014-2019, China's hydropower capacity grew 15%, and due to higher capacity utilisation hydropower generation grew nearly 23%.[27] Meanwhile, overall electricity demand rose over 30%.[28]

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

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

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

Hydropower output in neighbouring Vietnam also was constrained by dry conditions during the year. With reservoir flows declining 20-50%, generation fell more than 18% from January through October relative to the same period in 2018.[39] With no immediate relief in sight and rapidly growing electricity demand, the country's priority is to balance the need for electricity generation against other demands on the limited supply of water.[40] As part of this effort, Vietnam signed an agreement for the output of another Lao PDR hydropower plant that is scheduled to be completed by 2022.[41] Vietnam also added 80 MW of its own hydropower capacity in 2019, for a total of 16.8 GW.[42]

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

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

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

India saw only modest expansion of its hydropower assets in 2019 (154 MW), with all added capacity from units less than 25 MW in size, raising the total to 45.3 GW.[53] India's electricity generation from hydropower surged 15.9% during 2019 to nearly 162 TWh.[54]

In March 2019, India finalised a decision to re-designate all hydropower assets larger than 25 MW as being renewable energy capacity, a change in accounting rules that advances India towards its commitment under the Paris climate agreement to meet 40% of its electricity from renewable sources by 2030.[55] The change also may improve prospects for new large projects that now could qualify for certain renewable energy incentives and preferential financing terms (green bonds).[56] In July, after years of delays and being rejected by a government advisory committee on the grounds of excessive ecological and social costs, the proposed 2.88 GW Dibang hydropower project in Arunachal Pradesh received renewed government support.[57]

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

The Russian Federation added 0.5 GW of hydropower capacity in 2019, through new construction and rehabilitation of existing facilities, for a total of 48.5 GW.[59] Among notable projects completed were the 320 MW Nizhe-Bureyskaya plant in the eastern Amur region and a 143 MW unit at the Ust-Srednekanskaya facility, which will provide much-needed electricity to the Magadan region of the Russian Far East, where demand grew 13% in 2018.[60] The latter project has suffered long delays since its conception decades ago.[61] Total hydropower generation in the Russian Federation in 2019 was over 190 TWh, representing 17.6% of all supply.[62]

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

Across the African continent, several countries completed projects for a total of 0.9 GW added in 2019.[67] Most of this came online in Angola, Ethiopia and Uganda. Angola's plans for rapid expansion of hydropower capacity advanced during the year with the completion of the fifth 338 MW turbine at the Laúca station, bringing the country's total to 3.4 GW.[68] The 2.07 GW facility was expected to be completed and in commercial operation in 2020.[69]

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

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

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

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

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

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

i This excludes 22.9 GW of US pumped storage capacity.

ii A reservoir created by a dam.

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

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

HYDROPOWER INDUSTRY

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

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

Refurbishment and **modernisation (including digitalisation) of ageing hydropower facilities** (mainly in Europe and North America) improves the efficiency of resource utilisation, plant operations and maintenance, and resource planning and management.[88] In turn, such efforts help the hydropower infrastructure to support wider energy systems and, specifically, the integration of rising shares of VRE.[89]

In the Russian Federation, modernisation of the hydropower fleet continues to be a priority. In addition to building new facilities, RusHydro (the country's largest hydropower operator and the fourth largest in the world) has emphasised rehabilitation and upgrades of its older plants.[90] Since the start of its modernisation and rehabilitation programme in 2011, RusHydro has added over 400 MW of capacity at existing facilities.[91] In addition to capacity improvement, such efforts aim to increase operational efficiency, reliability and safety, in part through plant digitalisation.[92]

The industry also is focused on encouraging electricity market design that reflects the **value of hydropower and pumped storage for system flexibility** to ensure that investment continues.[93] In some markets, particularly those without compensation for capacity reserves or ancillary services, the narrowing spread between peak and off-peak energy prices (due in part to growth in zero marginal cost VRE) is undermining the profitability of both hydropower and pumped storage assets.[94] Pumped storage plants in particular can break even[i] only if the energy produced carries a sufficient premium relative to energy consumed.[95] Long-term stability of policies and market structures is particularly important for the hydropower industry due to long project timelines and high upfront capital costs of projects.[96]

Climate change also is posing increased risk to the industry, which is working to reduce both the **impacts of a changing climate** on hydropower output and the potential impacts of hydropower development on the global climate. Increasingly, the industry is incorporating climate variability and its impacts on hydrological conditions into project planning, design and operational plans.[97] Incorporating other renewable energy technologies – such as solar PV and wind power – with hydropower projects is one option that the industry is adopting to reduce risk and support system resilience.[98] At the same time, the industry is working to consider and manage the greenhouse gas impacts of hydropower projects, which are location dependent.[99]

In 2019, industry leaders published guidelines to provide a practical approach to identify, assess and manage climate risks to hydropower projects and to provide international industry good practice on how to incorporate climate resilience into hydropower project planning, design and operation.[100]

Another global focus of the industry is on sustainability in a broader sense, which requires an **integrated approach to resource management** that balances several priorities, including electricity generation, maintaining water quality, supply of water for non-energy needs such as irrigation, flood control, sediment management and other impacts on communities and natural resources, all while maximising project benefits equitably.[101] As part of this effort, industry documents released in 2019 aimed to guide hydropower developers and operators to improve outcomes for their projects and other stakeholders on two additional topics: the sharing of socio-economic benefits of hydropower projects, and the management of potential impacts arising from associated erosion and sedimentation upstream and downstream of a hydropower project site.[102]

Major hydropower technology providers in the world included Andritz Hydro (Austria), Bharat Heavy Electricals (India), Dongfang Electric (China), GE (United States), Harbin Electric (China), Hitachi Mitsubishi Hydro (Japan), Impsa (Argentina), Power Machines (Russian Federation), Toshiba (Japan) and Voith (Germany).

Operating results and outlook for some industry leaders[ii] remained mixed in 2019. GE reported losses in its hydropower segment, due in part to continued competitive pressure from other turbine manufacturers and other renewable energy technologies, and further reinforced by the global trend towards electricity auction mechanisms.[103] The company's hydropower operations continued to experience declines in the growth of orders and increased project costs.[104] Andritz Hydro also reported a "subdued" global market and a decline in sales for the fourth year running (down 3% for the year), in line with a perennial decline in order intakes.[105]

Voith Hydro reported a moderate recovery in the hydropower market during 2019. Modernisation projects and service on existing facilities dominated business in the Americas and Europe, while predominantly new construction was being planned and tendered in Asia and Africa.[106] Voith advanced the development of a high-performance pump turbine during the year, which led to securing a contract for six reversible turbines for the 2 GW Snowy 2.0 project in Australia.[107]

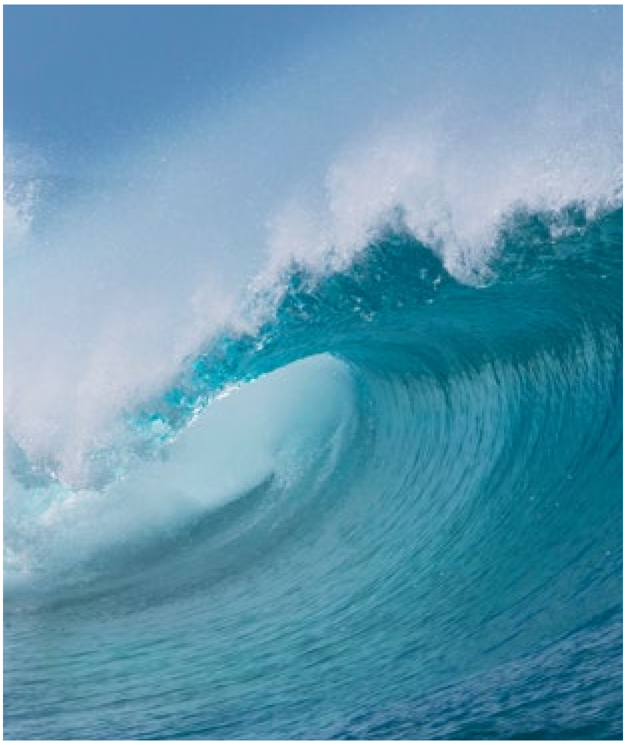
In 2019, the European Commission and 19 partners in industry, academia and research launched an EUR 18 million (USD 20.2 million) initiative to demonstrate how modern hydropower systems can provide the flexibility and power grid services required to integrate larger shares of variable solar and wind power into the electricity supply.[108] The project will test enhanced variable- and fixed-speed hydropower turbine systems and other related solutions, concluding in 2023 with a roadmap and recommendations for governments, regulators and industry.[109]

i A roughly 80% cycle efficiency means that energy sold needs to carry a 25% premium over energy consumed (1/0.8 = 1.25).

ii Provider-specific information noted based on availability of reports on operations.

KEY FACTS

- Ocean power generation rose substantially in 2019, surpassing 45 GWh.
- The industry began moving from small-scale demonstration and pilot projects towards semi-permanent installations and arrays of devices.
- Maintaining revenue support to ocean power technologies is considered paramount for allowing the industry to achieve greater maturity.



OCEAN POWER

OCEAN POWER MARKETS

Ocean power[i] represents the smallest share of the renewable energy market. Although the resource potential of ocean energy is enormous, the technologies are still in the early stages of development.[1] (→ *See Sidebar 4.*) Net additions[ii] in 2019 were around 3 MW, bringing the total operating installed capacity to an estimated 535 MW at year's end.[2]

Two tidal barrages using mature turbine technologies[iii] – the 240 MW La Rance station in France (installed in 1966) and the 254 MW Sihwa plant in the Republic of Korea (2011) – represent more than 90% of total installed capacity.[3]

Tidal stream and wave power are the main focus of development efforts. Advancements in these technologies have been concentrated largely in Europe, especially the United Kingdom. However, generous revenue support and ambitious R&D programmes in Canada, the United States and China have spurred increased development and deployment.[4]

Tidal stream devices are approaching maturity, with design converging on horizontal-axis turbines mounted on the sea floor or attached to a floating platform.[5] These devices have demonstrated considerable reliability in performance, and electricity generation rose substantially in 2019, owing to an increase in operating hours.[6] Total generation surpassed 45 GWh, with tidal stream devices in European waters alone generating 15 GWh in 2019 (up 50% from 2018).[7]

Wave power devices have not yet seen convergence on design, owing to the complexity of extracting wave energy from a variety of wave conditions and the wide range of possible operating principles.[8] Developers generally have chosen one of two distinct pathways for wave energy development: devices above 100 kW target utility-scale electricity markets, whereas smaller devices, usually below 50 kW, are intended primarily for specialist applications (oil and gas, aquaculture, maritime monitoring and defence).[9]

Although the potential of ocean power is enormous, the technologies are still in the **early stages of development.**

i Ocean power technologies harness the energy potential of ocean waves, tides, currents and temperature and salinity gradients. In this report, ocean power does not include offshore wind, marine biomass or floating solar.

ii A proportion of current installed capacity is removed or redeployed each year as demonstration projects reach their term or advance to a subsequent phase of testing. In Europe, for example, 10.3 MW of wave energy capacity had been decommissioned as of end-2019, following the successful completion of testing programmes.

iii The same in-stream technologies used in some types of hydropower plants.

SIDEBAR 4. The History of Ocean Power

Modern ocean power devices are the product of highly advanced industrial and technological systems, yet their earliest antecedents date back over 200 years. The first patent for an ocean energy device was filed in Paris by French mathematician Pierre-Simon Girard in 1799; the first operational plant was built in 1910 and was used to light and power a home. From 1855 to 1973, the United Kingdom alone granted over 300 patents for wave energy devices. Attempts to develop ocean thermal energy conversion (OTEC) started in the 1880s, and the first plant was built in Cuba in 1930, generating 22 kW of electricity before being destroyed in a storm.

The first large-scale ocean power facility, the La Rance tidal barrage in France, was built in the 1960s using proven hydropower turbine technologies. However, other methods for generating electricity from the ocean did not attract significant interest until the oil crisis of the 1970s. The US government invested USD 260 million in research and committed to producing 10 GW of electricity from OTEC systems by 1999, but ultimately no plants were commissioned[i]. The UK Department of Energy commissioned studies and ran a wave energy programme aimed at upscaling prospective devices, and the University of Edinburgh developed a device prototype and installed the first wave tank. As the oil crisis eased, interest waned and ocean power was largely abandoned, receiving very little funding in the 1980s and 1990s.

From the early 2000s onwards, ocean power experienced a resurgence, spurred by concerns about climate change and by the adoption of ambitious renewable energy objectives and policies. International co-operation was strengthened in 2001 with the establishment of the Ocean Energy Systems technology collaboration programme under the auspices of the International Energy Agency. The European Marine Energy Centre (EMEC) was established in 2003, providing an essential proving ground for devices by allowing for grid-connected testing in harsh weather conditions. More than 20 developers have since tested devices at EMEC.

In 2016, MeyGen deployed the first turbine of a planned 86 MW tidal stream array in the Pentland Firth, Scotland, marking a key milestone on the path to commercialisation. Progress has also been made in developing novel applications for ocean power technologies. In 2017, for example, EMEC began harnessing the excess electricity generated at one of its tidal testing sites to produce hydrogen, which is then used in a variety of fuel, power and heat applications. In 2018, Naval Group deployed a 450 kW Microsoft data centre at an EMEC wave test site, using wave energy to power the device and seawater for cooling.

The trajectory of ocean power has been volatile. On the one hand, a number of countries have invested considerable public funds into R&D, and large companies and private investors have become increasingly involved in device and project development. The EU turned its attention to ocean power for its potential to increase energy security and lower greenhouse gas emissions, while also creating jobs amid an economic downturn. On the other hand, government funding has been inconsistent, while the industry, in a bid to entice investors, overpromised what it could deliver in the near term and underestimated the technical challenges and costs. A number of bankruptcies ensued, large investors and energy companies withdrew, and the momentum generated by past public support slowed as private sector investors lost confidence.

Overall, the outlook for ocean power is positive. Costs are declining, and capital expenditure is lower than expected at this stage of development. Ongoing technological progress and development activity are encouraging, with the industry moving beyond pilot projects towards semi-permanent installations and arrays of devices exporting electricity to the grid, and significant investments and deployments were planned for 2020 and beyond.

i A 50 kW plant was tested for three months in 1979. The Department of Energy was poised to award a contract for a 40 MW pilot plant in 1982, but this did not come to fruition because of a change in the administration.

Source: See endnote 1 for this section.

OCEAN POWER INDUSTRY

Following a turbulent 2018, during which one industry leader ceased operations amid discouraging forecasts and limited development opportunities, the ocean power industry regrouped in 2019 and continued its gradual advance towards commercialisation.[10]

Tidal stream benefited from significant new investments of public funds and policy measures to support development. Three full-scale devices based on novel design principles were deployed for testing, although overall capacity additions were limited as developers prepared for large deployments totalling 9 MW in 2020.[11]

In Canada, the government of Nova Scotia offered a feed-in tariff of between CAD 385 and CAD 530 (USD 295 and USD 405) per MWh for demonstration projects, and as of the end of 2019 five developers were approved for a total of up to 22 MW.[12] During the year, two permits were awarded under Nova Scotia's demonstration permits programme: 2 MW to Jupiter Hydro and 1.5 MW to Nova Innovation.[13] A total of 7 MW (of the 10 MW maximum) was permitted under the programme.[14]

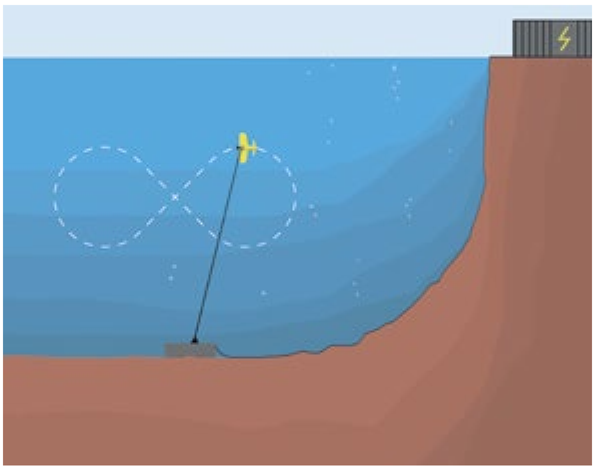
DP Energy and Sustainable Marine Energy continued to advance the Uisce Tapa project under development at the Fundy Ocean Research Centre for Energy (FORCE) in Nova Scotia. The CAD 117 million (USD 85.8 million) project aims to install a 9 MW array of six Andritz Hammerfest turbines and is supported by a Canadian government grant of CAD 29.8 million (USD 21.9 million).[15] Other provinces also are making progress on ocean power, particularly as a means to provide electricity to remote communities in Canada.

In the United Kingdom, a number of innovative cross-border collaborations and test deployments occurred in 2019, and some tidal devices demonstrated their reliability by generating electricity continuously throughout the year. In a large boost for the sector, Interreg France (Channel) England[i] announced that it would contribute EUR 28 million (USD 31 million) to the Tidal Stream Industry Energiser (TIGER) project – 70% of the project's EUR 47 million (USD 52 million) budget.[16] Led by the UK's Offshore Renewable Energy Catapult, TIGER brings together 19 partners from the United Kingdom and France to install 8 MW of capacity in and around the English Channel region.[17] The long-term objective is to cut generating costs from the current EUR 300 (USD 336) per MWh to around EUR 150 (USD 168) per MWh by 2025.[18]

Having entered its 25-year operational phase in 2018, Scotland's MeyGen tidal stream array (the world's largest at 6 MW) generated continuously in 2019, the longest period of uninterrupted generation to date from a commercial-scale tidal array.[19] The developer, SIMEC Atlantis Energy Ltd (United Kingdom), holds a seabed lease that would allow it to build the project out to 398 MW.[20] In 2019, SIMEC announced development of the next phase of the project, which will add a further 80 MW of capacity.[21] The company also was awarded a GBP 1.5 million (USD 1.8 million) government grant to develop a subsea connection hub for the next phase of the project.[22]

Also in Scotland, Nova Innovation's three-turbine 0.3 MW array in the Bluemull Sound of the Shetland Islands continued to generate consistently, with the turbines accumulating more than 20,000 operational hours as of December 2019.[23] Orbital Marine Power (formerly Scotrenewables Tidal Power) began building an optimised model of its SR2000 twin-turbine floating tidal power device, the Orbital O2, which it planned to deploy at EMEC in 2020.[24] Orbital also raised GBP 7 million (USD 9 million) through a crowdfunding campaign.[25]

Minesto (Sweden), which in 2018 successfully demonstrated the ability of its "energy kite"[ii] to harness relatively low-energy tidal streams and ocean currents, signed a power purchase agreement with the Faroe Islands utility for up to 2.2 MW of installed tidal capacity and obtained the required consents.[26] In May 2019, the Welsh government announced its continued support for Minesto's commercial development in Wales, awarding EUR 14.9 million (USD 16.7 million) of EU funding through the Welsh European Funding Office.[27] Minesto's long-term plan is to



i Interreg is a series of programmes to stimulate co-operation between regions in and out of the European Union, funded by the European Regional Development Fund. Interreg France (Channel) England was set up to foster economic development in the south of the United Kingdom and north of France by funding innovative projects that have a sustainable cross-border benefit. See Interreg, "About the programme", https://www.channelmanche.com/en/programme/about-the-programme.

ii Minesto's Deep Green device comprises a turbine integrated with a wing, which is tethered to the seabed and operates in a manner similar to an airborne kite.

deploy a commercial tidal energy array of up to 80 MW capacity at its Holyhead Deep site, eight kilometres off the coast of north-west Wales.[28] Minesto also was awarded a EUR 2.4 million (USD 2.7 million) grant as part of the TIGER project to install and operate a device at a grid-connected test site off the French coast.[29]

France remains an attractive location for tidal stream development, owing to its competitive grid-connected test centres, active support from regional and local governments, and the potential for scaling up projects in the future.[30] Two turbines were deployed in 2019: a 1 MW vertical-axis turbine at Paimpol-Bréhat (HydroQuest Ocean), which has already surpassed six months of continuous operation, and a short-term test deployment of a 20 kW horizontal-axis turbine at Ria d'Etel (Guinard Energies).[31]

Wave power advanced steadily in 2019, with a range of test deployments hitting the water in Europe and China, the announcement of significant new public funding and a number of developers pursuing novel device designs. More than 4 MW of deployments were planned in 2020, mostly of full-scale, high-capacity devices in Europe.[32]

In Europe, 0.6 MW was added through six individual units in 2019. Ocean Power Technologies (OPT) deployed a 3 kW device in the North Sea, where it supports an autonomous communications and remote monitoring platform used by Premier Oil.[33] The deployment began a nine-month lease that includes a purchase option. Another OPT device in the Adriatic Sea marked a full year of maintenance-free continuous operation in 2019.[34] In Portugal, AW-Energy deployed its 350 kW WaveRoller device, and commissioning work is under way to connect the device to the local electricity network.[35] Deployments also took place in Belgium, France and Italy.[36] In the United Kingdom, Wave Energy Scotland (WES) awarded GBP 9 million (USD 12 million) to 11 wave projects.[37]

In the United States, a 1.25 MW wave energy device was transported to the state of Hawaii for testing.[38] The country continued to provide funding for ocean power, with a focus on wave power devices and associated technology. In 2019, the US Department of Energy's Water Power Technologies Office awarded USD 25 million in research projects with the aim of reducing capital costs and shortening project development times.[39] The three topic areas for funding were early-stage device design, advancement of new power take-off (PTO) devices and control systems, and the consolidation of scientific knowledge and understanding of potential environmental impacts.

In China, the government supported its first megawatt-level test site (the Wanshan Wave Energy Demonstration Project) with an overall budget of RMB 151 million (USD 22 million), and a consortium began building two 500 kW test units.[40] The Guangzhou Institute of Energy Conversion completed the first open-sea test of a floating wave energy platform, which was successfully connected to the power grid of a remote island.

Carnegie Clean Energy (Australia) resumed construction of its CETO 6 device, having entered into voluntary administration in 2018 after a net loss of some AUD 45 million (USD 31 million) in 2018-19.[41] Carnegie continued to operate its Garden Island Microgrid in Western Australia, delivering more than 1,000 MWh to the country's largest naval base.[42] Wave Swell Energy also began construction of its 250 kW wave energy device.[43]

Bombora (United Kingdom) was on schedule to deploy its mWave device in mid-2020 and was progressing through the consenting phase of a proposed 2 MW project in Lanzarote, Spain, which it aimed to commission in 2022.[44] The novel device sits below the water surface and harnesses the pressure of overhead waves, an approach that the company hopes will allow it to overcome the survivability challenges facing wave energy devices.

Other ocean power technologies, such as **ocean thermal energy conversion** (OTEC) and **salinity gradient**, remain well short of commercial deployment, and only a handful of pilot projects have been launched. Nonetheless, novel applications continue to be developed. In 2019, for example, the Indian government approved the construction of a new OTEC-powered desalination plant.[45]

Technology improvements and steep cost reductions are still needed for ocean power to become competitive, and the industry is yet to receive the clear market signals it needs to take the final steps to commercialisation.[46] The lack of consistent support schemes for demonstration projects has proven especially challenging for developers, who have struggled to build a compelling business case, and the sector remains highly dependent on public funding to leverage private investment.[47]

Uncertainty regarding environmental interactions has often led regulators to require significant data collection and strict impact assessments, which can be costly and threaten the financial viability of projects and developers.[48] Current scientific knowledge suggests that the deployment of single devices poses little risk to the marine environment, but the impacts of multi-device arrays are not well understood.[49]

Continuing revenue support is considered paramount for increasing investment certainty by providing predictable returns until the industry achieves greater maturity.[50] As of 2018, more than EUR 6 billion (USD 6.9 billion) had been invested in ocean power projects worldwide, of which 75% was from private finance.[51] A 2018 European Commission implementation plan estimates that EUR 1.2 billion (USD 1.4 billion) in funding is needed by 2030 to commercialise ocean power technologies in Europe, requiring equal input from private sources, national and regional programmes, and EU funds.[52]

KEY FACTS

- Solar PV markets saw more capacity installed than ever before, with the strong demand in Europe, the United States and emerging markets making up for a substantial decline in China.
- Corporate purchasing expanded considerably, and self-consumption (increasingly with battery storage) was an important driver for new distributed systems in some countries.
- The industry continued to face strong competition which, coupled with policy uncertainties, resulted in extremely low bids at some auctions and thin margins for developers and manufacturers; at the same time, competition and price pressures encouraged more efficient manufacturing and ongoing innovation.
- Solar PV accounted for high shares of electricity generation in countries including Honduras (10.7%), Italy (8.6%), Greece (8.3%), Germany (8.2%) and Chile (8.1%).

SOLAR PHOTOVOLTAICS (PV)

SOLAR PV MARKETS

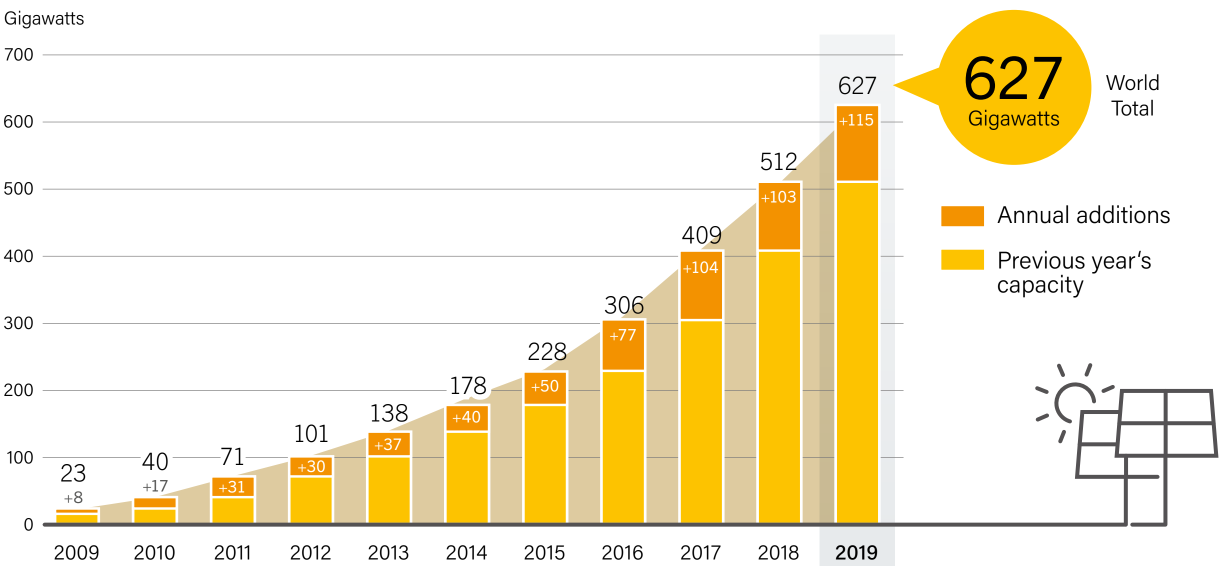
Following a year in which global solar photovoltaics (PV) additions were stable or even contracted slightly, in 2019 the solar PV market increased an estimated 12% to around 115 GW[i,1] The decade ended with strong demand in Europe, the United States and emerging markets around the world, more than making up for a substantial decline in China, the single largest market.[2] Not including China, the global market for solar PV grew about 44% in 2019.[3] The global total of 627 GW, which includes on- and off-grid capacity, compares to a total of less than 23 GW only 10 years earlier.[4] (→ *See Figure 28.*)

Demand for solar PV is spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of locations – for residential and commercial applications and increasingly for utility-scale projects – even without accounting for the external costs of fossil fuels.[5] In some markets, this is becoming the case for solar-plus-storage as well.[6] In 2019, an estimated 18 countries added at least 1 GW of new capacity, up from 11 countries in 2018, and all continents contributed significantly to global growth.[7] By the end of 2019, at least 39 countries had a cumulative capacity of 1 GW or more, up from 31 countries one year earlier.[8]

In several countries, solar PV already plays a significant role in electricity generation.[9] By the end of 2019, 22 countries had enough capacity in operation to meet at least 3% of their electricity demand with solar PV, and 12 countries had enough

i For the sake of consistency, the GSR endeavours to report all solar PV capacity data in direct current (DC); where data are known to be in AC, that is specified in the text and endnotes. See endnotes and Methodological Notes for further details.

FIGURE 28. Solar PV Global Capacity and Annual Additions, 2009-2019



Note: Data are provided in direct current (DC). Totals may not add up due to rounding.

Source: Becquerel Institute and IEA PVPS. See endnote 4 for this section.

for at least 5%.[10] For the full year, solar PV accounted for around 10.7% of total generation in Honduras and substantial shares also in Italy (8.6%), Greece (8.3%), Germany (8.2%), Chile (8.1%), Australia (7.8%) and Japan (7.4%), among others.[11] Enough capacity was in operation worldwide by year's end to produce around 2.8% of global electricity generation.[12]

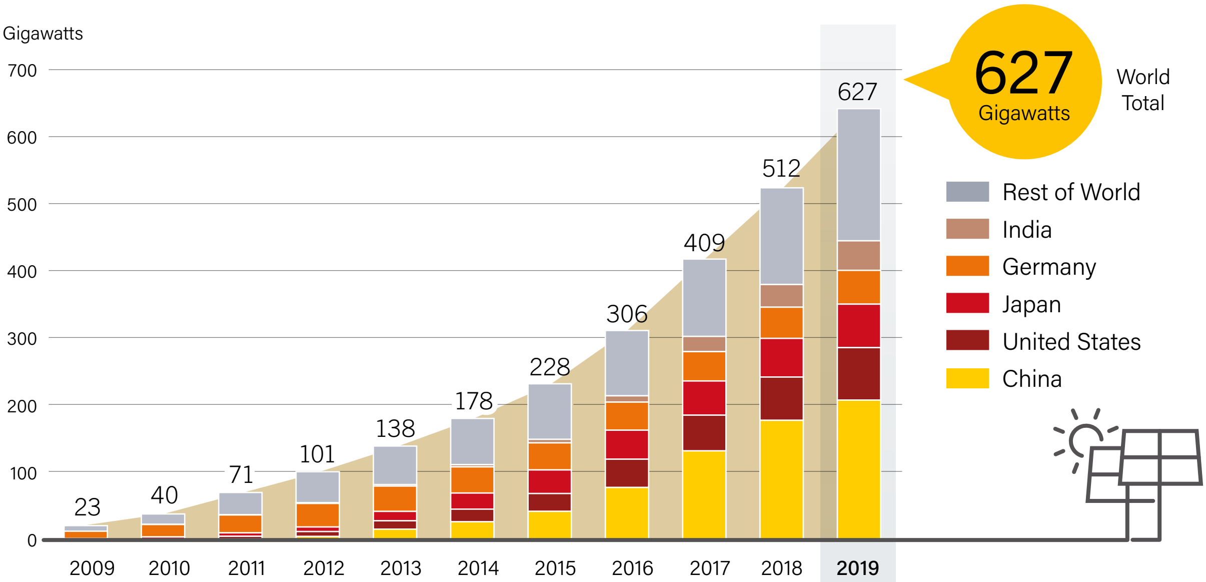
There are still challenges to address in order for solar PV to become a major electricity source worldwide, including policy and regulatory instability in many countries, and financial and bankability challenges.[13] As the level of penetration rises, solar PV is having an increasing effect on electricity systems, raising the importance of effectively integrating solar energy under varying technical and market conditions in a fair and sustainable manner.[14] Opposition from incumbents is generally lower than a decade ago, and many utilities are actively engaging in solar PV deployment and operations, including distributed generation; however, challenges remain in several countries and among some actors, particularly some in the fossil and nuclear industries.[15]

In most countries, the need still exists for support schemes for solar PV, as well as for adequate regulatory frameworks and policies governing grid connections.[16] Government policies – particularly traditional feed-in tariffs (FITs), feed-in premiums and tenders – continued to drive most of the global market in 2019.[17] Corporate purchasing of solar PV expanded considerably, and self-consumption was an important driver of the market for new distributed systems in several countries.[18] Although still a small share of the annual market, a number of purely competitive (without direct government support) large-scale systems were being constructed in 2019; interest in this segment is significant and growing quickly.[19]

For the seventh consecutive year, Asia eclipsed all other regions for new installations, accounting for half of global additions, despite declines in the region's top three markets (China, India and Japan).[20] Asia was followed by Europe (17%) and the Americas (15%).[21] China continued to dominate the global market (and solar PV manufacturing), accounting for around 26% of the year's capacity additions, but this compares with 44% in 2018.[22] The top five national markets – China, the United States, India, Japan and Vietnam – were responsible for around 56% of newly installed capacity, down from around three-quarters in 2018 as the global market becomes less concentrated; the next five markets were Spain, Germany, Australia, Ukraine and the Republic of Korea.[23] The annual market size required to rank among the top 10 countries more than doubled in 2019, reaching 3.1 GW[i].[24] At year's end, the leading countries for cumulative solar PV capacity remained China, the United States, Japan, Germany and India, and the leaders for capacity per inhabitant were Germany, Australia and Japan.[25] (→ *See Figure 29.*)

i This is the capacity additions of the country that ranked tenth for annual installations, the Republic of Korea.

FIGURE 29. Solar PV Global Capacity, by Country and Region, 2009-2019



Note: Data are provided in direct current (DC).

Source: See endnote 25 for this section.

Despite China's year-end rally with more than 12 GW brought online in December alone, the country's annual solar PV market declined almost 32% (following a 15% drop in 2018), to 30.1 GW newly installed (including 17.9 GW of utility-scale and 12.2 GW of distributed[i] solar PV).[26] Although installations fell for the second consecutive year and were down in almost every region of China, 12 provinces added more than 1 GW each and the country's total additions were more than double those of the next largest national market, the United States.[27] (→ *See Figure 30* and ***Reference Table R16.***) The leading provincial installer in 2019 was Guizhou (3.4 GW), one of China's poorest provinces, followed by Shandong (2.6 GW) and Hebei (2.4 GW).[28] By year's end, China's cumulative grid-connected capacity of around 204.7 GW was almost twice the national solar PV target (105 GW by 2020) that was established in 2016.[29]

China's market decline in 2019 was due largely to policy uncertainty. The country is in the process of restructuring its renewable energy market – shifting from high-speed capacity growth and dependence on direct financial support through uncapped FITs, to deployment of high-quality technologies and systems through auctions and subsidy-free deployment to reduce costs and improve overall performance.[30] The national government ceased approvals for new subsidised projects at the end of May 2018, and took more than a year to provide clarity on a revised FIT policy.[31] Multiple delays in publication of policy implementation rules pushed back completion dates for several large solar PV projects.[32] The market also was tempered by ongoing delays in FIT payments for existing facilities; challenges related to grid connections, land availability and access to finance; an increase in module exports, which curbed expected domestic price reductions and left developers waiting for prices to come more in line with their bids; and more positive and clear guidance for wind power projects, which led some developers to prioritise wind deployment.[33]

Countries that ranked among the top 10 for new solar PV installations added

3.1 GW

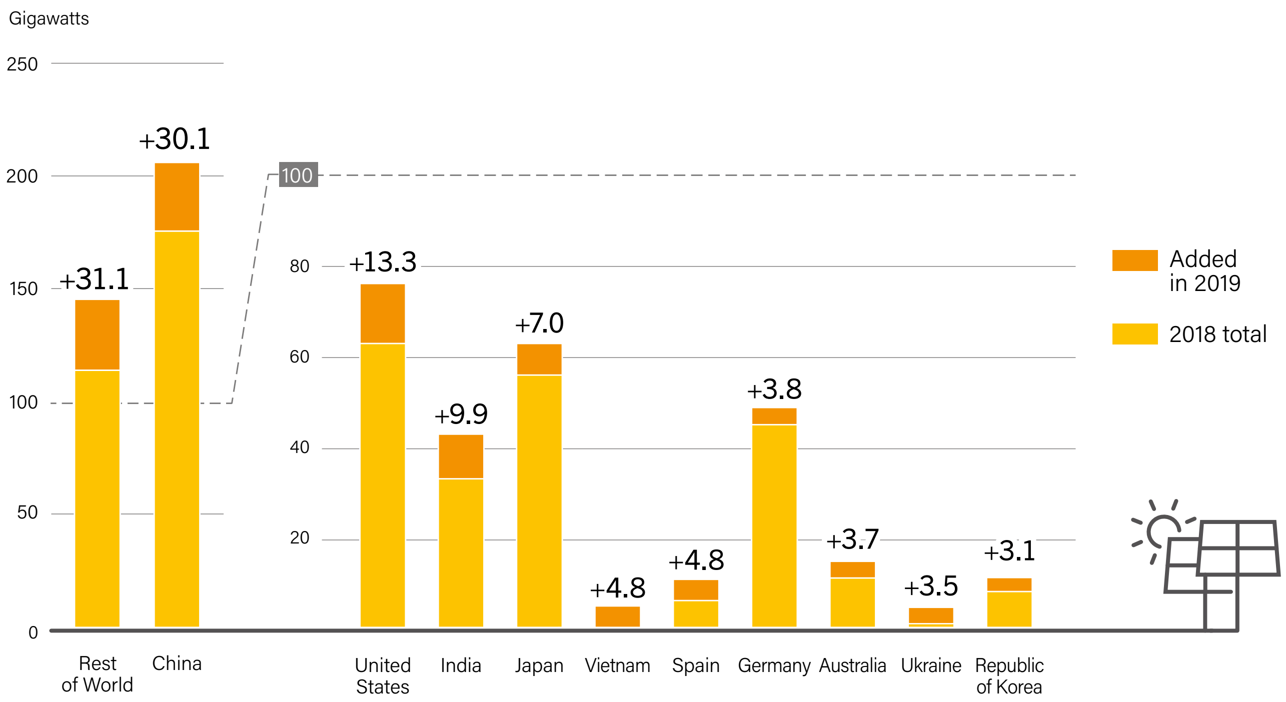
or more.

As part of China's transition to a market without direct policy support by 2021, a bidding scheme was launched to select solar PV projects for FIT support as well as those for "grid-parity"[ii], and by July the government approved 22.8 GW and 14.8 GW of capacity respectively.[34] For a variety of reasons, however, less than

i "Distributed" solar PV in China includes ground-mounted systems of up to 20 MW that comply with various conditions, in addition to commercial, industrial and residential rooftop systems. Distributed generation consists largely of commercial and industrial systems and, increasingly, residential and floating projects. See endnote 26 for this section.

ii Grid parity in China refers to market-driven with no FIT support, but with priority off-taking. See endnote 34 for this section.

FIGURE 30. Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2019



Note: Data are provided in direct current (DC).

Source: See endnote 27 for this section.

10 GW of FIT-supported projects were executed and only about 2 GW of grid-parity projects became operational during the year.[35]

China's market for large ground-mounted systems declined around 23% in 2019, and distributed installations (which include residential) were down 41%, but annual installations of residential systems (at 4.2 GW) increased 74% relative to 2018 and exceeded the official full-year target of 3.5 GW.[36] Centralised utility power plants (>20 MW) accounted for more than 59% of annual grid-connected installations (and 69% of the year-end total), with distributed systems making up the remainder.[37]

Curtailment of solar energy in China continued to fall, down 1 percentage point from 2018 to average 2% (or a total of 4.6 TWh) for the year.[38] Most curtailment (87%) occurred in the north-west region, and the curtailment rate was highest in Tibet (24.1%, down 19.5 percentage points), but it declined in every province except Qinghai, which saw a large increase in renewable power capacity and a decline in load.[39] Reduced curtailment and rising capacity helped increase China's solar PV output from grid-connected systems more than 26% relative to 2018, to 224 TWh.[40] As a result, solar PV's share of total electricity generation (from grid-connected sources) in the country rose to 3% in 2019 (2.6% in 2018).[41]

The second largest market in Asia and the third largest globally was India, which added an estimated 9.9 GW in 2019 for a total of 42.8 GW.[42] India targets 100 GW of installed solar PV, including 40 GW of rooftop solar capacity, by the end of 2022.[43]

India's annual installations were down in 2019, following significant growth in 2018.[44] Reasons for the decline were many: India's economic slowdown, tariff caps and higher costs associated with tender participation, payment delays, renegotiation of power purchase agreements (PPAs) in Andhra Pradesh, challenges related to land acquisition, lack of transmission infrastructure and of access to grid connections, liquidity issues and lack of financing (due in many cases to delays in tariff adoption).[45] Curtailment also acted as a deterrent to new installations, and the severity was worsened by a decline in power demand due to the slowing economy.[46] In August, the national government called for "must run" status for solar and wind power projects, but lacked the ability to strictly enforce the rules.[47] Even so, generation from solar power for the year was up 27% relative to 2018.[48]

Large-scale projects accounted for more than 85% of India's newly installed capacity and represented the vast majority of total solar PV operating capacity.[49] Around 35 GW of tenders was announced in India during 2019, down 8% relative to 2018, with more than 15.8 GW of projects auctioned (up 2%).[50] But several tenders were undersubscribed and, as in 2018, many auctions were cancelled retroactively.[51] Nonetheless, by the end of 2019 nearly 24 GW of large-scale capacity was reportedly in the pipeline.[52]

India's rooftop market declined in 2019 for the first time in five years.[53] The contraction was due largely to the economic slowdown combined with liquidity issues, as well as challenges to net metering and lengthy approval processes in some states.[54] An estimated 1.1 GW of distributed and off-grid capacity was installed during the year.[55] The rooftop market continued to consist mainly of large commercial and industrial companies (which together account for more than 70% of total capacity), as well as government entities (including Indian Railways) and educational institutions, all seeking to reduce their electricity bills; comparatively few residential customers can afford the upfront costs.[56]

In 2019, 26 countries in the EU-28 **added more capacity** than they installed in 2018.

The market in Japan also contracted, for the fourth consecutive year, and was down significantly from the peak year (2015).[57] Japan's market continued to suffer from grid constraints, lack of available land and of low-cost financial resources, high prices of solar generation (Japan's prices are some of the world's highest) and high labour costs.[58] Even so, Japan progressed towards the national target of 82 GW by 2030: around 7 GW was added during 2019, for a total of 63 GW.[59] For the year, solar PV accounted for an estimated 7.4% of Japan's total electricity generation, up from 6.5% in 2018.[60]

By late 2019, 530,000 residential solar PV systems in Japan, totalling some 2 GW of capacity, reached the end of their 10-year contract period and exited the country's FIT scheme; as a result, and to increase resilience of supply, many system owners increased their focus on self-consumption and on achieving net-zero energy use by combining solar PV with energy storage.[61] Power companies, home builders and others introduced new programmes for post-FIT residential systems, offering to purchase surplus solar electricity and renewable energy credits for their own use or resale to achieve corporate renewable energy targets.[62]

In contrast to other large markets in Asia, Vietnam saw a surge in installations as developers rushed to win attractive FIT rates before they expired mid-year, rocketing the country to fifth place globally for additions.[63] More than 8.9 GW of large projects had been approved by year's end, including around 4.5 GW of capacity that came online at the end of June.[64] During all of 2019, an estimated 4.8 GW was added (up from 106 MW in 2018 and 8 MW in 2017) for a total of 4.9 GW.[65] Vietnam's interest in solar PV is largely to meet rising electricity demand, which has grown an average of 10% annually in recent years due to population growth and economic expansion.[66] Post-June, increasing concerns about grid congestion in the sunniest regions led the government to incentivise new projects in provinces with lower solar resources; in December, the national government urged a suspension of authorisations for all new solar facilities until further notice.[67]

Other Asian countries that added substantial capacity in 2019 included the Republic of Korea, which installed an estimated 3.1 GW for a total of 11.2 GW, followed by Chinese Taipei, Pakistan, Turkey, Malaysia (approaching 0.6 GW) and Kazakhstan (0.5 GW).[68] Chinese Taipei (added 1.4 GW) aims for 20 GW by 2025, but faces several challenges including policy uncertainty, a struggling manufacturing sector and difficulties securing needed land.[69] Pakistan had another strong year, adding 1.3 GW for a total of 3.4 GW.[70]

Turkey's annual installations declined significantly for the second consecutive year, due to an economic downturn, lack of available financing and other challenges; the country installed 0.9 GW for a

total of 8 GW.[71] In its first attempt to support small-scale systems, Turkey introduced net metering in 2019.[72] Numerous additional countries in Asia brought projects online or held tenders during the year, including Cambodia, which held its first solar PV tender.[73]

Europe moved ahead of the Americas to rank second for additions (nearly 20.4 GW), and maintained its second-place regional ranking for total operating capacity.[74] Demand rose significantly in the EU and beyond: Ukraine, for example, installed a record 3.5 GW (surpassing 1 GW for the first time), thanks to a generous FIT and a scheduled reduction, to place third in all of Europe and ninth globally, while the Russian Federation brought online its largest solar PV plant (75 MW) to date, part of a pipeline of projects allocated in a 2016 auction.[75]

The EU-28[i] added around 16 GW of grid-connected solar PV, nearly double the 8.2 GW installed in 2018, bringing total capacity close to 131.7 GW.[76] Most markets in the region have moved beyond FITs and were driven in 2019 by the competitiveness of solar generation – which is increasing interest in self-consumption (particularly combined with digital technologies and storage) and in corporate renewable power sourcing (including via direct bilateral PPAs) – as well as by governments looking to meet national renewable energy targets through tenders.[77] At the same time, new challenges are emerging, including access to grid connections, land availability and planning permission (particularly in some areas that already have a large installed base), and a shortening of PPA time periods with the shift towards merchant deals[ii].[78]

In 2019, 26 of 28 countries in the EU added more capacity than they installed in 2018; even so, around three-fourths of new capacity came online in only five countries.[79] Spain (4.8 GW) was the top installer for the first time in 11 years, followed by Germany (3.8 GW), the Netherlands (2.4 GW), France (0.9 GW) and Poland (0.8 MW).[80] The Netherlands' installations were up an estimated 66%, led by the country's rooftop market, and Poland saw its installations quadruple in response to rising incentives for rooftop systems and the extension of net metering.[81] For cumulative capacity, Bulgaria, Denmark and Hungary each exceeded 1 GW for the first time in 2019.[82] The leaders Germany and Italy together were home to more than half of the EU's cumulative capacity at year's end, but their shares are declining as markets expand elsewhere.[83]

Spain added nearly 4.8 GW in 2019, up from less than 0.3 GW in 2018, for a total exceeding 9.9 GW.[84] The high level of installations was due mostly to the commissioning of projects tendered in 2017 to meet the country's EU obligations, as well as to Spain's first PPA- and wholesale-based plants, and rooftop installations for self-consumption.[85] Installation of rooftop systems picked up considerably following the elimination of Spain's "Sun Tax" in November 2018 and the streamlining of the permitting process.[86] By year's end, grid constraints were the primary barriers to large-scale project implementation.[87] In response to an influx of applications for grid connection that far exceed Spain's expected demand growth, the government tightened grid connection rules as of 2020.[88]

Annual demand in Germany was up almost 33% relative to 2018, with more than 3.8 GW added in 2019 for a total exceeding 49 GW.[89] The market was driven primarily by self-consumption and FIT premiums; limited volume tenders for large (>750 kW) ground-mounted systems accounted for less than 20% of added capacity.[90] The number of prosumers[iii] in Germany increased by almost 100,000 between February 2019 and January 2020.[91] An estimated one of every two rooftop installations was sold with a battery storage system.[92] In late 2019, the German government announced a new goal of 98 GW of solar PV by 2030, and removal of the 52 GW feed-in tariff cap was under discussion.[93] Solar PV generated an estimated 8.2% of Germany's electricity during the year.[94]

i EU throughout this text refers to the EU-28, including the United Kingdom. Not including the UK, EU additions in 2019 were over 15.7 GW for a year-end total of more than 118 GW. See endnote 76 for this section.

ii Merchant deals (or projects) are those with no regulated or contracted income. The electricity generated is sold into competitive wholesale markets.

iii Individuals, families, commercial enterprises and energy co-operatives that produce electricity with solar PV and consume at least some of it locally.

The United Kingdom's FIT, a key policy for supporting rooftop solar, closed to new applicants at the end of March 2019.[95] In response, new residential installations fell 94% in May.[96] Paralysis caused by uncertainty over Brexit as well as policy changes also resulted in reduced investment in community solar projects.[97] The country had its slowest year since at least 2010, with an estimated 0.3 GW added, well below the 2015 peak (4.2 GW), bringing total capacity to 13.4 GW.[98] By year's end, however, the pipeline of large-scale projects was reportedly more than 6 GW.[99]

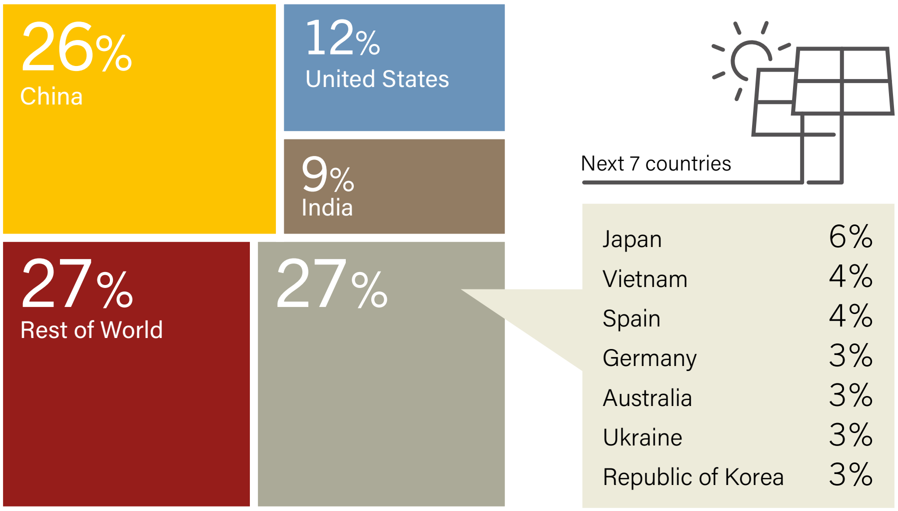
Across Europe, the number of direct bilateral PPAs continued to climb, and solar PPAs are becoming increasingly competitive with wholesale power markets in some countries.[100] Europe's largest PPA was signed in 2019 for a 708 MW solar PV project portfolio in Spain and Portugal.[101] The year also saw the region's first large-scale PPA for a crowdfunded project; this financing approach represents one of the many innovations taking place in Europe, the United States and elsewhere to aggregate risk and enable the spread of PPAs beyond utilities and large energy-consuming corporations to smaller offtakers and to new countries.[102] By early 2020, around 8.4 GW of solar PV capacity was operating or planned under PPAs in Europe, with the largest portion in Spain (4.4 GW), followed by Italy (1.9 GW) and Germany (over 1 GW).[103]

The Americas represented around 15% of the global market in 2019, due largely to the United States, which ranked second globally for both new installations and cumulative capacity.[104] (→ *See Figure 31.*) The country added 13.3 GW for a total exceeding 76 GW.[105] Solar PV accounted for nearly 40% of all new US power capacity additions in 2019, the largest share to date.[106] California again led all states in added capacity (3.1 GW), followed by Texas (1.4 GW) and Florida (1.4 GW).[107] Hawaii led in the adoption of rooftop solar per capita, followed by California and Arizona.[108] Utility-scale solar PV generated 69 TWh, or 1.7% of US utility-scale generation in 2019; small-scale systems generated an additional estimated 35 TWh.[109]

The US market as a whole grew 23% in 2019.[110] It was led by the utility-scale sector, which expanded 37%, to 8.4 GW, and accounted for 63% of US additions.[111] Non-residential[i] installations declined for the second consecutive year (down 7%), due to policy changes and interconnection delays in some key states.[112] But the residential sector had a record year, up 15% to 2.8 GW, driven by ever more attractive economics in many emerging states, as well as by power shutoffs (associated with wild fires) and new-build homes in California.[113] California achieved a target of 1 million solar roofs in late 2019, and the state's mandate to install solar on most new homes entered into force at the start

i Includes commercial, government, non-profit and community solar PV systems.

FIGURE 31. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2019



Source: See endnote 104 for this section.

of 2020.[114] Also towards the end of 2019, the National Community Solar Partnership was relaunched with the aim of expanding affordable access to solar energy for all US households by 2025.[115]

The US rush to complete projects, large and small, and to contract for new ones during 2019 was driven in part by impending cuts in the federal investment tax credit (ITC)[i].[116] Project developers and small commercial installers stockpiled modules and other equipment to take advantage of the 30% ITC, and installers were at capacity during the second half of the year.[117] Falling technology costs and rising renewable energy commitments also drove demand, including in the US Midwest, which historically has favoured wind energy.[118] A record high of new solar PPAs (30.6 GW) was signed or announced, bringing the cumulative contracted project pipeline to 48.1 GW.[119] Voluntary purchasing accounted for 57% of new procurement in 2019, with an estimated 14% driven by state renewable portfolio standards.[120] Innovations such as aggregation[ii] continued to open the market for smaller businesses as well as large corporations.[121]

Rapidly falling costs of solar PV and battery installations have led to a surge in solar PV-plus-storage projects across the United States by enabling them to begin competing with natural gas-fired generation.[122] In 2019, the number of US solar-plus-storage projects announced or already online increased from 16 to 38, and in California most new utility-scale solar was being proposed with some storage capacity.[123] Interest in solar-plus-storage is rising in the residential market as well, particularly in Hawaii and in California, where consumers seek energy resiliency and reliability.[124] (→ *See Systems Integration chapter.*)

To the south, several countries in Latin America and the Caribbean continued their rapid expansion, despite challenging economic conditions in some countries, thanks largely to an abundance of solar resources, falling prices and favourable political climates until 2019.[125] The region's top installers were Brazil (adding 2 GW), Mexico (nearly 2 GW) and Argentina (0.5 GW).[126] Several other countries brought online significant capacity, including Colombia, which commissioned a 86 MW plant, and Jamaica, which completed the Caribbean's largest solar PV facility (51 MW) – the plant is expected to provide the island's lowest-cost electricity.[127] Numerous countries called for public bids for future solar PV projects.[128]

Brazil added more than 2 GW in 2019 and ended the year with nearly 4.5 GW.[129] An estimated 650 MW of large-scale capacity was brought online, including the first solar PV plant in Latin America to be built with a digital sub-station.[130] By year's end, around 5.7 GW of additional permitted solar PV projects was in advanced stages of development, and there was a growing interest in new opportunities for bilateral PPAs.[131] Several large-scale projects reached record-setting low bid prices in government auctions, with plans to sell at least 30% of their electricity into the wholesale market.[132] Brazil's distributed solar PV segment (defined as <5 MW) saw the most growth during 2019 in terms of capacity added (1.4 GW), investments and jobs, driven by net metering and rising energy prices.[133] The segment was led by residential systems but saw growing shares of commercial and rural systems.[134] An end-of-year push to install distributed systems resulted from proposed policy changes, including a debate under way regarding revisions to the national net metering mechanism.[135]

Innovations such as crowdfunding and aggregation are opening PPA markets to more participants.

i The ITC provided a 30% investment tax credit for projects that began construction by the end of 2019. The credit steps down to 26% in 2020, 22% in 2021 and 10% from 2022 onwards for commercial and utility projects, and for residential systems owned by companies; it falls to zero in 2022 for residential installations owned by homeowners. See endnote 116 for this section.

ii For example, a large corporation acts as "anchor tenant", providing a strong credit rating to support project financing, and enabling the developer to build a larger project than the corporation requires. The developer then negotiates separate PPAs for the additional capacity with smaller purchasers, who have differing credit ratings, and who benefit from lower transaction costs and reduced complexity. Alternatively, a number of companies jointly negotiate an agreement, aggregating their individual capacity requirements in order to organise a larger deal and, thereby, to more cost-effectively acquire a PPA. See endnote 121 for this section.

Mexico continued to lead the region for its cumulative capacity, which rose an estimated 62% compared with 2018 to more than 5 GW.[136] Several large plants came online, including a 220 MW facility that will sell electricity into the wholesale market.[137] The country also completed what was reportedly the first large-scale project in Latin America to combine solar PV and battery storage.[138] However, the Mexican government cancelled all plans for renewable energy auctions, raising concerns about the impact on solar PV deployment after 2020.[139] Mexico also had substantial rooftop capacity, totalling 818 MW at the end of 2019.[140]

Across the Pacific, Australia saw record additions in the small, medium and large-scale segments, and ranked eighth globally for installations.[141] Around 3.7 GW was added during 2019, increasing the country's total capacity to 14.7 GW.[142] Although output from solar PV was affected by haze and fallout from the bushfires across much of the country, generation rose 55% in 2019, to 18.1 TWh, or 7.8% of Australia's total.[143] Deployment has been driven by several factors, including falling system prices, increasing awareness of the benefits of solar PV to businesses and households, and the corporate market for PPAs.[144]

Corporate solar PPAs continued to be announced in Australia, although at a slower pace than in 2018, with solar PV accounting for 82% of the 400 MW that was newly contracted in 2019.[145] An important innovation in Australia during the year was the development of retail PPAs, in which buyers (particularly a growing number of mid-scale buyers) contract for power via a retailer.[146] Among the new smaller agreements was a seven-year PPA signed by the Sydney Opera House for solar and wind power projects and a residential solar PPA for home buyers in a Western Australia housing development.[147] The number of merchant projects (selling on the spot market) rose as well.[148]

Australia's capacity in large-scale (>5 MW) solar PV projects saw record increases.[149] Yet small-scale (<100 kW) household and commercial rooftop solar PV continued to be the largest sector in Australia by far, as both the number and average size of new systems continued to rise.[150] Annual installations increased 35% over 2018, to nearly 2.2 GW added (287,504 new systems), for a year-end total approaching 10.4 GW (2.3 million systems).[151] During the year, small-scale systems powered the equivalent of more than 2.6 million households, accounting for 5.3% of the country's total electricity generation.[152] In addition, 22,000 small-scale batteries were installed in 2019, bringing Australia's household storage capacity to more than 1 GWh.[153]

Rapid growth in solar (and wind) generation is transforming Australia's electricity landscape, reducing electricity prices and air emissions while pushing out coal-fired power plants (which are increasingly unreliable and expensive to operate).[154] The vast scale of installations in 2018 and 2019 – well beyond expectations – resulted in an overcrowded grid and connection delays as transmission investment failed to keep up with the growth in renewable energy.[155] By mid-year, grid connections for large projects were increasingly time-consuming and costly (reducing revenue for projects once they were online); this challenge – combined with a lack of clarity about state and federal policies and targets, and the increase in regulatory risks as well as curtailment – led to delayed and cancelled projects, and raised barriers to investment.[156] The rooftop sector also has experienced problems related to the ability of distribution networks to integrate high penetration rates of solar energy with battery technology.[157]

The Australian Energy Market Operator (AEMO) responded by starting to upgrade grids in key regions and by creating renewable energy zones.[158] AEMO also is working on an integrated roadmap for efficient development of the country's national electricity market over the coming decades.[159] By early 2020, frustration over grid congestion led Victoria to break away from national electricity rules to fast-track transmission upgrades and ensure grid-connection for large projects.[160]

The Middle East and Africa also saw substantial solar PV installations in 2019. An estimated 6.7 GW was added for a year-end total of 15.1 GW, an 80% increase in cumulative capacity across these two regions.[161] As in 2018, the largest installer in the Middle East was the United Arab Emirates, which aims to achieve 50% renewable energy by 2050.[162] Commercial operations began at the 1,177 MW Sweihan facility in Abu Dhabi, the world's largest single-site solar project at the time of completion, expected to cover the electricity requirements of 90,000 people.[163] In addition, Dubai allocated the fifth phase (0.9 GW) of its 5 GW Mohammed bin Rashid Al Maktoum Solar Park.[164] At year's end, the United Arab Emirates had more than 1.7 GW of solar PV in operation, including at least 125 MW of rooftop capacity under Dubai's Shams initiative.[165]

Other noteworthy installers in the Middle East included Saudi Arabia, where production began at the country's first grid-connected solar PV plant (0.3 GW Sakaka) in late 2019; Jordan (added 0.6 GW), where at least two large plants were completed and efforts continued towards the goal to install solar PV on all of the nation's 7,000 mosques; and Israel, which completed its largest solar PV park (120 MW) and added a total of 0.8 GW.[166] Kuwait and Oman added large projects to their pipelines, and Iraq launched a tender for 755 MW of capacity.[167] Policy makers in several countries – including Jordan, Oman, Saudi Arabia and the United Arab Emirates – have reduced electricity tariffs and are

starting to prioritise distributed solar PV, particularly in Dubai, but many countries are still struggling to find the right mix of policy, financing and procurement options.[168]

Across Africa, as costs fall, solar PV is viewed increasingly as a means to diversify the energy mix, to meet rising demand while limiting the growth of CO_2 emissions and to provide energy access.[169] But considerable challenges remain, including a lack of suitable financing tools, ongoing subsidies to fossil fuels in many countries as well as social and political unrest in some, a reliance on tenders for new capacity and a race to the bottom in bid prices.[170] Even so, several countries brought projects online during 2019, including the first large plants in Kenya (50 MW), Mozambique (40 MW), Namibia (45 MW) and Zambia (54 MW), among many others.[171] The largest solar PV plant in all of Africa, Egypt's Benban solar complex, became fully operational in late 2019; the facility, covering more than 37 square kilometres of desert and with a capacity of nearly 1.5 GW, is expected to provide electricity to 1 million people.[172] At the other end of the spectrum of scale, several countries saw numerous rooftop and other small-scale systems come into operation during the year. South Africa, for example, had more than 100 MW of rooftop systems by the end of 2019.[173] (→ *See Distributed Renewables chapter for more on access and small-scale solar PV.*)

Many other countries on the African continent held solar PV tenders or had large plants being planned, under construction or commissioned, including Morocco, which had several solar PV-concentrating solar thermal power (CSP) complexes under way.[174] Also in 2019, a plan was unveiled to dramatically expand solar PV (and CSP) capacity in Botswana and Namibia to reduce reliance on energy imports and enable the export of surplus electricity to surrounding countries.[175] Regional efforts also were under way to expand the use of solar PV across the continent.[176] At year's end, Africa's top countries for cumulative solar PV capacity were South Africa with 3.4 GW (added 1 GW), Egypt with nearly 2.3 GW (added 1.65 GW), Algeria with 0.5 GW (no additions) and Kenya (added 0.2 GW for a total of 0.3 GW).[177]

Around the world, even as favourable economics are raising interest in distributed[i] systems, especially for commercial and industrial uses (as well as off-grid), large utility-scale projects continued to dominate the global market for newly installed capacity.[178] (Even the size of distributed systems is trending larger in many countries.[179]) The move towards ground-mounted large-scale systems is due at least in part to the growing use of tenders and auctions, and increasingly also to PPAs, whether in Europe, Australia or new markets such as Vietnam.[180]

Solar PV plants are approaching the scale of fossil-fired power plants as developers aim to drive down the price of solar electricity.[181] The size and number of large projects continued to grow during 2019, with more than 50 solar PV plants of 50 MW and larger completed, and such plants were operating in at least 44 countries[ii] by year's end.[182] Developers commissioned at least 35 projects that were 200 MW or larger.[183] In addition to those mentioned previously, new facilities included a 420 MW solar complex in Vietnam; Spain's 494 MW Mula plant (reportedly Europe's largest solar PV project at year's end); China's largest (500 MW) project without direct financial support (which will compete against coal- and natural gas-fired plants); and India's 2 GW Pavagada Solar Park, which began development in 2016 and was completed in 2019.[184]

Operating capacities of many new

solar PV

plants are approaching the level of fossil-fired power plants as developers aim to drive down the price of solar electricity.

Large-scale ground-mounted plants can cover vast areas, raising concerns about potential environmental impacts, grid-connection challenges and the use of agricultural lands.[185] The potential for rooftop solar systems remains enormous, and many countries, such as India, have established large rooftop programmes and targets.[186] The relatively small market for floating solar also continues its rapid expansion, driven by the limited availability and high costs of land in many places.[187] Floating projects bring new risks and generally higher costs than ground-mounted facilities, but economies of scale in project sizes are helping to reduce associated costs.[188] (→ *See Sidebar 3 in GSR 2019.*)

Most floating solar PV projects are sited in Asia, but they can be found from Africa to Europe to the Americas.[189] During 2019, China completed several large plants, including a 70 MW project at a former coal mining area in Anhui Province; India held a tender for a floating solar PV project (70 MW); Portugal held a tender to seek engineering, procurement and construction contractors for 10 floating solar PV plants (50 MW total) and, in early 2020, Vietnam announced pilot auctions for an eventual 400 MW.[190] Floating projects also are being constructed

i Distributed refers to systems that provide power to grid-connected consumers, or to the grid, but on distribution networks rather than bulk transmission, or off-grid systems. See endnote 178 for this section.

ii Countries that added their first 50-plus MW plants in 2019 include Argentina, Belgium, Colombia, Jamaica, the Russian Federation, Saudi Arabia and Vietnam. See endnote 182 for this section.

offshore, with a pilot project completed off the Dutch coast in the North Sea, and plans were announced for projects off the coasts of the United Arab Emirates, the Republic of Korea and Singapore.[191] A total floating capacity of at least 2.4 GW was expected to be operating in 35 countries by year's end, with projects completed or under way in almost every region.[192]

Other niche markets that minimise land requirements include building-integrated PV, which is progressing only slowly (a highlight in 2019 being a new high-rise building in China with a 460 kW façade), and the emergence of plans among mainstream auto manufacturers, particularly in Asia, to incorporate solar cells into electric vehicles.[193] Agricultural PV[i] also is an emerging sector that can address concerns associated with land use, especially with the growing availability of bifacial systems (see later discussion).[194] Several studies have highlighted the advantages, including improved crop yields, reduced evaporation, rainwater harvesting (with modules), provision of shade for livestock and prevention of wind and soil erosion, as well as additional income for farmers from electricity production.[195] In 2019, a total of more than 2.9 GW of capacity was operating in Japan and elsewhere, and plans were announced for new projects, including a 1 GW agricultural PV livestock farming project in Malaysia.[196]

SOLAR PV INDUSTRY

The year reflected a dichotomy of perspectives on the health and prosperity of the solar PV industry. On the one hand, competition drove declining prices, which in turn opened new markets, while the pressure of lower prices and expectations of rising global demand encouraged expanded and more efficient manufacturing, the entrance of new companies into the sector and ongoing pursuit of innovation. On the other hand, the relentless competition, coupled with policy vagaries and uncertainty, prompted highly competitive bids at some auctions – resulting in razor-thin margins for some developers and manufacturers – and contributed to ongoing consolidation.

Globally, solar PV prices continued to decline in 2019.[197] The price of modules fell around 12% during the year, to a world average of USD 0.36 per watt, but with significant variations in price from country to country.[198] A ramp-up in manufacturing along the supply chain in recent years, due to overly optimistic expectations about global demand growth (particularly in China), held down prices for polysilicon, wafers, cells and modules.[199] Innovations and improvements in design and operation also helped to reduce operations and maintenance (O&M) costs.[200] By one estimate, the global benchmark levelised cost of electricity (LCOE) from solar PV declined 17% relative to 2018.[201]

Tenders and auctions saw bid prices[ii] drop to new lows in 2019, and in some countries they fell below the average price of wholesale electricity.[202] The average bid price across all markets was close to USD 30 per MWh, but bids below USD 20 per MWh became more common towards year's end.[203]

The lowest bid prices were seen in Brazil, Dubai (United Arab Emirates) and Portugal. In Brazil's A-6 auction, solar PV came in with the most competitive final average electricity price among all competing technologies (including wind power and natural gas) at BRL 67.48 (USD 16.48) per MWh.[204] Dubai allocated 0.9 GW of capacity at a price of USD 16.95 per MWh, and Portugal awarded 1.29 GW with a world-record low bid of EUR 14.76 (USD 16.53) per MWh.[205]

Time will tell if the lowest bids will be viable. Outside of locations with a low cost of finance, open desert and excellent solar resources, such as Dubai, a broad range of experts believe that very low bids, such as Portugal's winning price, are possible only because firms made overly optimistic assumptions about future cost reductions (ahead of project construction) or plan for merchant sales at the end of the contract period, betting on the merchant price (until the end of project lifetime) to supplement revenues.[206] Several record-setting low bid prices in Brazil's auctions were made by developers planning to sell at least some of their electricity into the wholesale market.[207]

Direct bilateral PPA prices also reached new lows in 2019 and in early 2020.[208] In the United States, PPA prices were in the range of USD 16 to USD 35 per MWh, and solar PV-plus-storage achieved

i Agricultural PV is defined as use of the same site for both energy and crop production. See endnote 194 for this section.

ii Bid prices do not necessarily equate with energy costs. Also, energy costs vary widely according to solar resource, project size, regulatory and fiscal framework, customer type, the cost of capital and other local influences. Distributed rooftop solar PV remains more expensive than large-scale solar PV but has followed similar price trajectories, and is competitive with (or less expensive than) retail electricity prices in many locations. See endnote 202 for this section.

a new record low in the country of USD 40 per MWh for the Eland project[i] in California's Mojave Desert, which should be operational by 2023.[209] In January 2020, a PPA was signed in Qatar for 800 MW at QAR 57.1 (USD 15.8) per MWh, one of the lowest prices ever recorded.[210] Agreement periods are shortening in Australia, Germany, the United States and elsewhere, with price trajectories flattening (at least in Australia and the United States), and several markets have begun shifting towards the merchant model.[211]

New lows in auction prices, resulting from intense competition (with some instances of bidding below marginal costs to win tenders) – in some cases driven by policy design – constrained margins and brought further consolidation in the industry.[212] Among the casualties in 2019: China-based module manufacturer Hareon Solar was forced into bankruptcy liquidation; Suntech (China), once the leading global manufacturer, again came up for sale or liquidation; another former world leader, Yingli (China), continued to lose money, following several difficult years; Panasonic (Japan) transferred a solar module manufacturing subsidiary in Malaysia to GS-Solar (China), as part of an effort to return its solar business to profitability; Moser Baer Solar (India) began liquidating its assets; and several solar-related companies in Chinese Taipei consolidated to survive through economies of scale.[213]

By contrast, many Chinese cell and module manufacturers benefited from record-low prices for polysilicon, solar wafers and cells, as well as from strong demand from most regions around the world.[214] LONGi, for example, saw both its revenues and net profit rise in 2019, with further improvements in the first quarter of 2020.[215] LONGi and other top-tier vertically integrated companies were able to cope with price declines by expanding production to take advantage of lower costs of new equipment and economies of scale, in some cases through joint partnerships.[216] For example, LONGi and Tongwei signed a strategic co-operation agreement to support each other's supply chains, following on earlier joint ventures and agreements; and GCL-Poly and Zhonghuan Semiconductor announced a plan to further their co-operation by increasing joint manufacturing capacity.[217]

Many companies achieved or announced significant increases in production capacity in 2019, reflecting optimism about future market growth, efforts to maintain market share, as well as policies to promote local manufacturing.[218] By the end of 2019, global crystalline and thin-film cell production and module assembly capacities[ii] were estimated to be 153.1 GW (cell) and 185 GW (module), respectively, up 35% and 29% over 2018.[219]

Much of the expansion occurred in China.[220] China has dominated production and global shipments of solar PV cells and modules since 2011, which means the country also has dominated the prices of cells and modules, influencing the margins that other manufacturers receive.[221] This continued to be the case in 2019. During the year, 123.5 GW of cells and modules were shipped worldwide (up 39% over 2018), mostly from manufacturers in Asia, and particularly China.[222] Of the estimated 78 GW of cell/module volume shipped by the top 10 suppliers, over 80% was shipped by Chinese firms, with the others representing equal shares of the remaining volume and hailing from the Republic of Korea (Hanwha Q-Cells), Chinese Taipei (UREC) and the United States (First Solar).[223]

The solar PV industry **remained vulnerable** to turbulence in some countries, and particularly in China.

The solar PV industry remained vulnerable to turbulence in some countries (the list of countries changing annually), and particularly in China.[224] In China and elsewhere, policy uncertainty as well as policies that are stop-go or poorly designed – including cancelled or postponed auctions – hampered the industry.[225] The industry also was challenged by unreliable or insufficient grid infrastructure (often the reason for revisions to policies and targets), particularly in emerging markets.[226]

Trade policies also continued to affect the solar PV industry in 2019.[227] (→ *See Sidebar 3 in Policy Landscape chapter.*) India imposed new duties on product imports from several other Asian countries and from Saudi Arabia as part of the push towards domestic manufacturing.[228] US tariffs imposed in 2018 on nearly all major sources of solar PV imports, as well as on steel and aluminium[iii], were in place throughout 2019.[229] The United States added tariffs on Chinese solar inverters, and removed India from duty-free status for many products, including solar cells and modules.[230] In addition to tariffs on imports, several countries had measures in place to encourage local production or to penalise the use of foreign-made products.[231]

During the year, the US International Trade Commission found that US tariffs had boosted module manufacturing in the country – including new module plants set up by Hanwha Q-Cells and LG (both Republic of Korea), and by China's Jinko Solar – but had failed to halt the decline of domestic cell makers.[232] The Commission also found that tariffs had softened solar price declines in the United States compared to those experienced globally.[233] Bifacial panels were granted exemption from US import tariffs in June (with a temporary reversal in October[iv]), and US demand for bifacial panels soared in an effort to evade tariffs and improve project efficiency, as well as to stockpile modules to qualify for the 30% federal investment tax credit[v],[234]

i The project includes 400 MW of solar PV capacity and 300 MW/12,000 MWh of energy storage capacity. See endnote 209 for this section.

ii Cell capacity is MW or GW of semiconductor (cell) capacity available to a manufacturer; module assembly capacity is that available to assemble cells into modules.

iii Tariffs on imports of these metals are significant because they are used to manufacture balance-of-systems equipment.

iv In April 2020, a decision was made to remove the exemption again, effective as of 18 May 2020; the tariffs are due to end in 2022.

v The US solar "safe harbor agreement" governs when a solar PV project qualifies for the ITC. Projects that began construction before the end of 2019 qualify for the full 30% credit, which started to step down in 2020. To qualify, one option was to incur 5% of the total cost of a project before the end of 2019, and the easiest way for developers to do that was to buy up panels and inverters.

In spite of the challenges faced by some actors in the solar PV industry, new companies continued to enter in.[235] For example, most of the largest wind power developers in the United States have expanded into solar PV and energy storage, and similar trends are seen in China, India and elsewhere.[236] Oil and gas giants, particularly Europe-based companies, are moving into solar project development and operation, and using solar PV to power their operations around the world.[237]

Competition and price pressures have encouraged investment in solar PV technologies, particularly in cells and modules.

In addition to driving the construction of new, more-efficient manufacturing facilities, competition and price pressures have encouraged investment in solar PV technologies across the entire value chain, and particularly in solar cells and modules, to further improve efficiencies and reduce the LCOE.[238] New record cell and module efficiencies were achieved during 2019.[239] Monocrystalline[i] cell technology, which lost its lead to multicrystalline in 2002, raced ahead for the majority share of global shipments.[240]

Demand for higher-efficiency modules has steered a shift towards Passivated Emitter Rear Cell (PERC)[ii] technology and the next generation of technologies.[241] PERC has become the new standard for the monocrystalline silicon solar cell variety because it increases efficiencies, making it an economically attractive option for many projects.[242] Manufacturers of PERC (particularly China's LONGi) have invested heavily in its commercialisation.[243]

While monocrystalline PERC is the focus of most capacity expansions, and substantial commercial capacity came online in 2019, the industry is already looking beyond PERC.[244] In 2019, several manufacturers were converting or building new factories to produce heterojunction cell technology[iii] (HJT), which offers higher efficiencies and occurs at low temperatures and with fewer production steps than other high-efficiency cell technologies.[245] A number of China-based companies were actively looking into HJT, and some had small production lines in operation.[246] European manufacturers were considering HJT (and other technologies) as an option to regain market share.[247] In late 2019, REC (Norway) started production at a HJT cell and module facility in Singapore.[248]

Researchers also were working to overcome the theoretical efficiency limits of silicon-based solar cells by stacking cells of different types and developing new, more efficient cell technologies.[249] Perovskites[iv], in tandem with crystalline silicon or a thin-film base, are attracting substantial research dollars and seeing increasing efficiencies.[250] Researchers continued to focus on the long-term stability of perovskites, lead content and other challenges during the year.[251] By one estimate, more than a dozen companies worldwide were working on perovskites in 2019 with aims to sell panels soon (although some also pulled out of the market).[252]

Improvements in cell technology and module design have enabled the development of modules with higher power ratings.[253] In 2019, for example, SunPower (United States) launched the industry's most powerful residential panel, at 400-plus watts, and Canadian Solar unveiled what it claimed was the first poly bifacial module of 400-plus watts for large projects.[254] Raising the power rating increases electricity output per module, thereby reducing the number needed for a project, meaning that less space is required and associated land, installation and other costs are reduced.[255]

Bifacial modules, which can capture light on both sides, also offer potential gains in output (and thus a lower LCOE) – with even greater performance gains if used in installations with trackers[v] – although there are ongoing uncertainties about real-world performance.[256] The scale of bifacial exports from China (the largest manufacturer of and market for bifacial panels) and the geographical distribution of demand increased considerably

i Crystalline technologies account for nearly all cell production. Historically, monocrystalline cells have been more expensive but also more efficient (more power per unit of space) than multi- or poly-crystalline cells, which are made of multi-faceted or multiple crystals. See endnote 240 for this section.

ii PERC is a technique that reflects solar rays to the rear of the solar cell (rather than being absorbed into the module), thereby ensuring increased efficiency as well as improved performance in low-light environments.

iii HJT combines advantages of conventional crystalline silicon solar cells with good absorption and other benefits of amorphous silicon thin film technology.

iv Perovskite solar cells include perovskite (crystal) structured compounds that are simple to manufacture and are expected to be relatively inexpensive to produce. They have achieved considerable efficiency improvements in laboratories, with reports of about 3% in 2006 to more than 24% in 2019, and 28% was achieved in a silicon-based tandem cell in 2018. See endnote 250 for this section.

v Trackers enable panels to track the movement of the sun. More and more large ground-mounted projects are using trackers because they flatten the production curve and increase yield. See endnote 256 for this section.

in 2019 thanks to improvements in cell technology.[257] Several manufacturers announced plans to ramp up bifacial production or launched new products in 2019.[258]

Operators are playing a growing role in project development, working to maximise generation and to reduce the LCOE as direct government support declines and solar assets become exposed to market prices.[259] Plant operations are increasingly digital and automated as rising competition pushes companies to further reduce costs, improve system performance and integrate energy storage.[260] Digitalisation, thanks in large part to advances in inverter[i] technology, is helping to improve performance (for example, through predictive maintenance, remote sensing and control, satellite and ground-based as well as numerical solar forecasting schemes) and to provide grid services such as ramping capability and frequency regulation in order to support grid reliability.[261] (→ *See Systems Integration chapter.*)

Remote maintenance and control technologies are improving efficiency and reducing O&M costs as well as outage times.[262] Drone technologies are allowing operators to access and analyse performance data via remote thermographic imaging of facilities.[263] Interest in robotic cleaning is increasing in India, Israel and elsewhere to reduce labour and other costs, save water and improve efficiency.[264] In addition, research is under way to develop surface coverings that can reduce dust deposition on solar panels, an advance that improves system performance and lowers cleaning costs in dusty environments.[265]

Even as solar PV technologies and operations continue to advance, there is concern that low tender bidding and resulting low margins have negatively affected quality along the entire value chain.[266] Poor quality – from product manufacturing and shipping, to project design and construction, to the commissioning and O&M stages – is a concern in a number of countries, as manufacturers feel pressure to cut corners in production or quality control and as developers seek the lowest-cost products.[267] There are many areas where problems can enter in – particularly in emerging markets with rapid deployment as well as political and policy uncertainty.[268] Although the volume of related literature is increasing, there is still limited understanding of the issues involved, and several countries continue to lack quality standards and regulations.[269]

To address some of these quality-related concerns, in 2019 India's Ministry for New and Renewable Energy approved a series of guidelines for solar inverters under a quality control order that was first introduced in 2017.[270] In Bangladesh, concerns about imports of sub-standard products that are threatening sustainability of the domestic market led the national government to introduce minimum quality standards on solar modules, inverters, charge controllers and batteries.[271] Australia made significant progress on a new consumer code to establish minimum standards for consumer protection and good practice for solar PV, batteries and other emerging products and services.[272] Also in 2019, global standards-making organisations continued working to establish rigorous standards for improving the quality of module production and system installation.[273]

Industry efforts to further advance environmental sustainability also continued in 2019. While the technical lifetimes of solar panels can be up to 25-40 years, the volume of decommissioned panels in the coming decade is expected to be large, and research into second-life (reuse) and end-of-life (recycling) options was ongoing in many countries during the year.[274] PV Cycle (France) collected more than 280,000 solar PV panels for recycling.[275] Also in 2019, Jinko Solar, the world's top module manufacturer, became the first solar PV manufacturer to join RE100, pledging to source all of its energy from renewable sources, aiming for 70% by 2023 and 100% by 2025.[276] It was followed, in early 2020, by LONGi, which committed to 100% renewable electricity across its operations by 2028.[277]

i Inverters convert direct current electricity from solar panels to alternating current for the electric grid.

KEY FACTS

- Global CSP capacity in operation again grew exclusively in emerging markets and spread to new countries including Israel, Kuwait and France.
- An estimated 21 GWh of thermal energy storage was operating in conjunction with CSP plants across five continents.
- Levelised costs of energy from CSP continued to decline, with CSP being built increasingly alongside both solar PV and wind power to lower costs and raise capacity value.

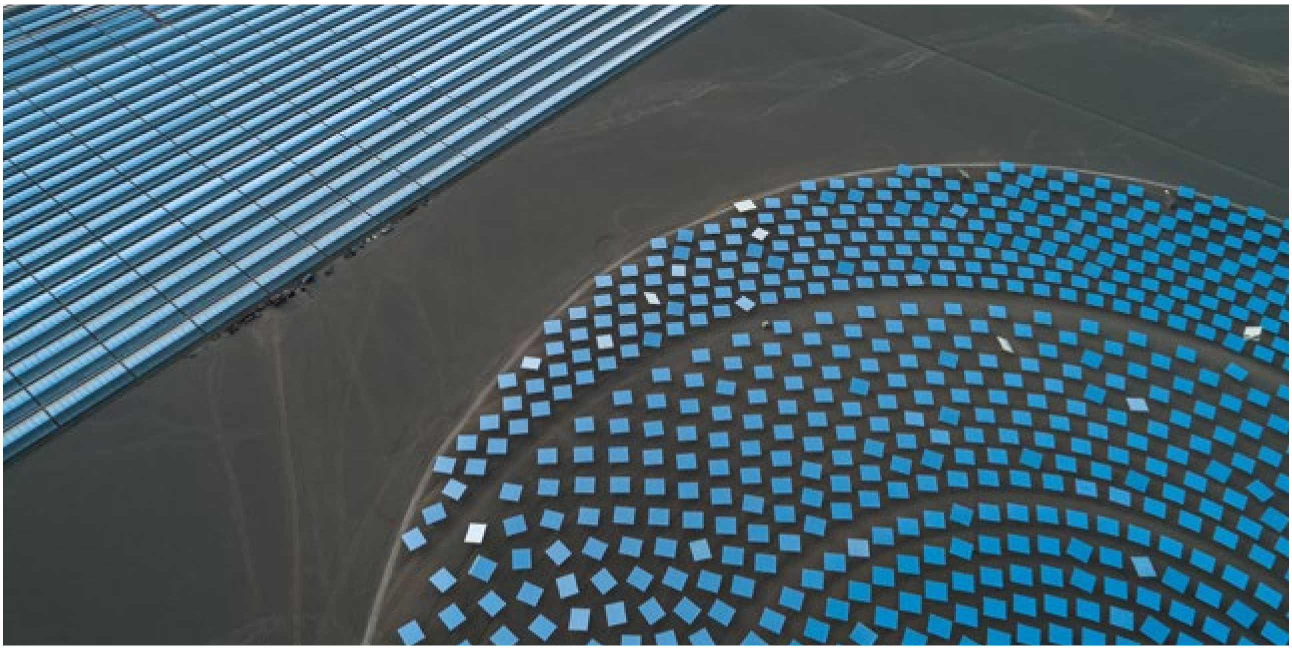
CONCENTRATING SOLAR THERMAL POWER (CSP)

CSP MARKETS

Global CSP[i] capacity grew 11% in 2019 to 6.2 GW[ii], with 600 MW of capacity coming online.[1] This was down from the 700 MW commissioned in 2018 and well below the average annual increase (24%) of the past decade.[2] (→ *See Figure 32 and* ***Reference Table R17.***) However, CSP continued to spread to new markets, and more than 1.1 GW of additional capacity was under construction at year's end.[3]

Five countries brought new CSP plants into operation during the year: Israel led the market in new additions, followed by China, South Africa, Kuwait and France.[4] Israel, Kuwait and France saw the implementation of their first commercial CSP capacity.[5] For the fourth consecutive year, all new CSP capacity came online outside of Spain and the United States, the two leading countries for cumulative capacity since the technology was first commercialised in the 1980s.[6]

For the first time, as much tower capacity as parabolic trough capacity was completed in 2019.[7] Each of these technologies represented around 45% of total additions, and linear Fresnel plants accounted for the remaining 10%.[8] However, parabolic trough plants continue to represent the majority of total global installed capacity. At year's end, the plants under construction worldwide included just under 0.9 GW of trough systems, just under 0.3 GW of tower systems and a 14 MW Fresnel system.[9] With the exception of two hybrid CSP-natural gas plants[iii], all of these plants will include thermal energy storage (TES).[10]

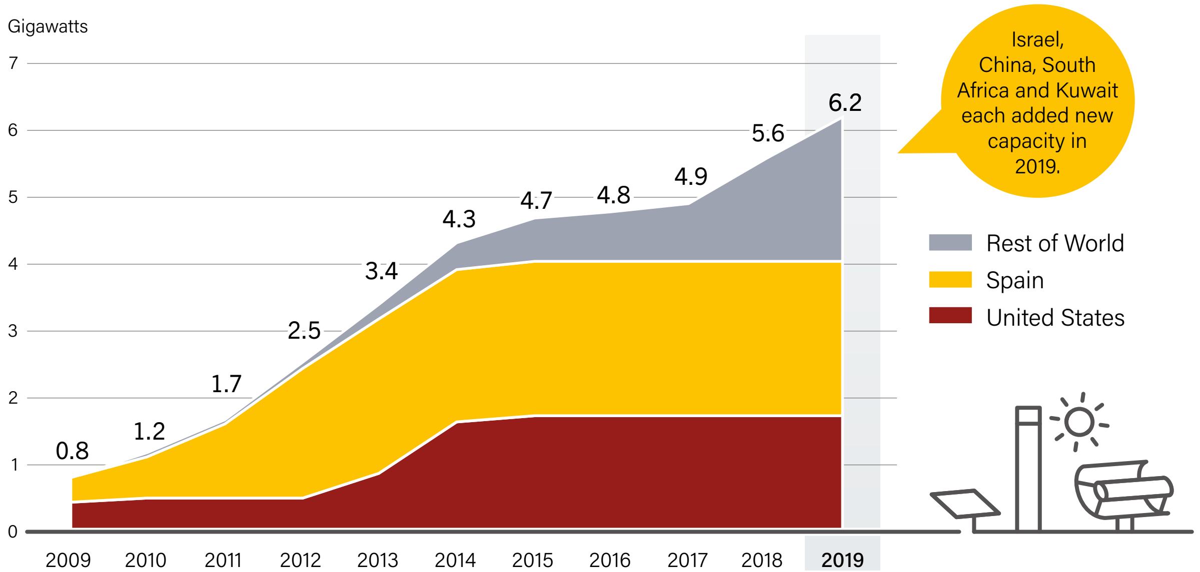


i CSP is also known as solar thermal electricity (STE).

ii GSR 2019 reported that the 150 MW Noor III CSP plant in Morocco entered operations in early 2019. Subsequent reports have indicated that the plant is considered to have begun commercial operations in late 2018. This edition of the GSR has revised CSP market data accordingly. See endnote 1 for this section.

iii The two plants without TES are integrated solar combined-cycle (ISCC) facilities, hybrid plants that use both solar energy and natural gas to produce electricity.

FIGURE 32. Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2009-2019



Source: See endnote 2 for this section.

Israel added more CSP capacity than any other country in 2019, bringing online 242 MW, including the 121 MW Megalim tower plant (no TES) and the 121 MW Negev parabolic trough plant with molten salt storage (4.5 hours; 495 MWh).[11] The projects are Israel's first two commercial CSP facilities and the country's largest renewable energy plants of any type.[12] The Megalim project also includes the world's tallest solar tower, at 240 metres high.[13]

China followed with a total of 200 MW of capacity completed in four CSP plants of 50 MW each, all with molten salt TES.[14] The projects include the Dacheng Dunhuang Fresnel plant (13 hours; 650 MWh), the Power Qinghai Gonghe tower plant (6 hours; 300 MWh), the CPECC Hami tower plant (8 hours; 400 MWh) and the Luneng Haixi tower plant (12 hours; 600 MWh).[15] The first three of the new plants are among 20 CSP "demonstration"[i] plants that were announced by China's National Energy Administration in 2017; 5 of the plants were operational at the end of 2019.[16] The plants completed during the year brought the country's total CSP capacity to 420 MW.[17] At year's end, China had an additional 250 MW of both parabolic trough and tower capacity under construction, in parallel with 2.4 GWh of TES.[18]

In South Africa, the 100 MW Kathu parabolic trough plant (4.5 hours; 450 MWh) entered commercial operations, bringing the country's total installed CSP capacity to 500 MW.[19] An additional 100 MW of tower capacity was approaching construction during 2019.[20] However, further development of the South African CSP sector was in doubt following the release in late 2019 of the country's Integrated Resource Plan (IRP), which makes no capacity allocations for CSP before 2030.[21]

Kuwait brought its first CSP capacity online with the opening of the 50 MW Shagaya parabolic trough plant (9 hours; 450 MWh).[22] This is the first phase of a planned 3 GW renewable energy park that will incorporate multiple renewable energy technologies, including wind power and solar PV.[23]

The Shagaya plant is part of a growing market in the Middle East and North Africa (MENA) region, where 15 plants totalling almost 1.8 GW accounted for nearly 30% of global capacity in operation at the end of 2019.[24] Capacity in the region is expected to increase significantly with completion of the Noor 1 Energy project under construction in the United Arab Emirates.[25] The Noor 1 project will include 700 MW of CSP capacity, consisting of three 200 MW parabolic trough plants and a 100 MW tower plant, coupled with 15 hours of storage capacity.[26]

The smallest CSP plant to reach commercial operations in 2019 was the 9 MW eLLO Fresnel plant (4 hours; 36 MWh), the first commercial CSP facility in France.[27] Although no other commercial CSP projects were being built in Europe during the year, a Chinese consortium was selected for the engineering, procurement and construction of a 52 MW (5 hours; 260 MWh) tower project on the Greek island of Crete; the project is planned for operation in 2020.[28]

In addition, construction continued on the 110 MW Cerro Dominador project in Chile (17.5 hours TES).[29] Construction began in 2014 and has been hampered by delays, but the plant was expected to be operational in 2020.[30] Despite significant past CSP development activity, Cerro Dominador remains the only CSP plant in Chile to have passed the development phase and entered construction.[31]

i While the GSR generally excludes pilot and demonstration facilities from the CSP market data, the Chinese demonstration plants are included due to their scale and the fact that they are being grid connected.

For cumulative capacity in operation, Spain remained the global leader with 2.3 GW at the end of 2019, followed by the United States with just over 1.7 GW.[32] With no new capacity additions in six years, Spain's share of global CSP capacity in operation declined from a high of nearly 80% in 2012 to just under 40% by the end of 2019.[33] The United States, which has added no new CSP capacity since 2015, was home to just under 30% of global CSP capacity by the end of 2019.[34] Neither country had new facilities under construction at year's end, although the Spanish government announced plans to increase installed capacity 5 GW by 2030.[35]

All of the commercial CSP capacity under construction by the end of 2019 was in Asia (China and India), the Middle East (United Arab Emirates and Saudi Arabia) and Latin America (Chile).[36] The pipeline of CSP projects under construction reached around 1.1 GW, with the United Arab Emirates accounting for more than 60% of this capacity.[37]

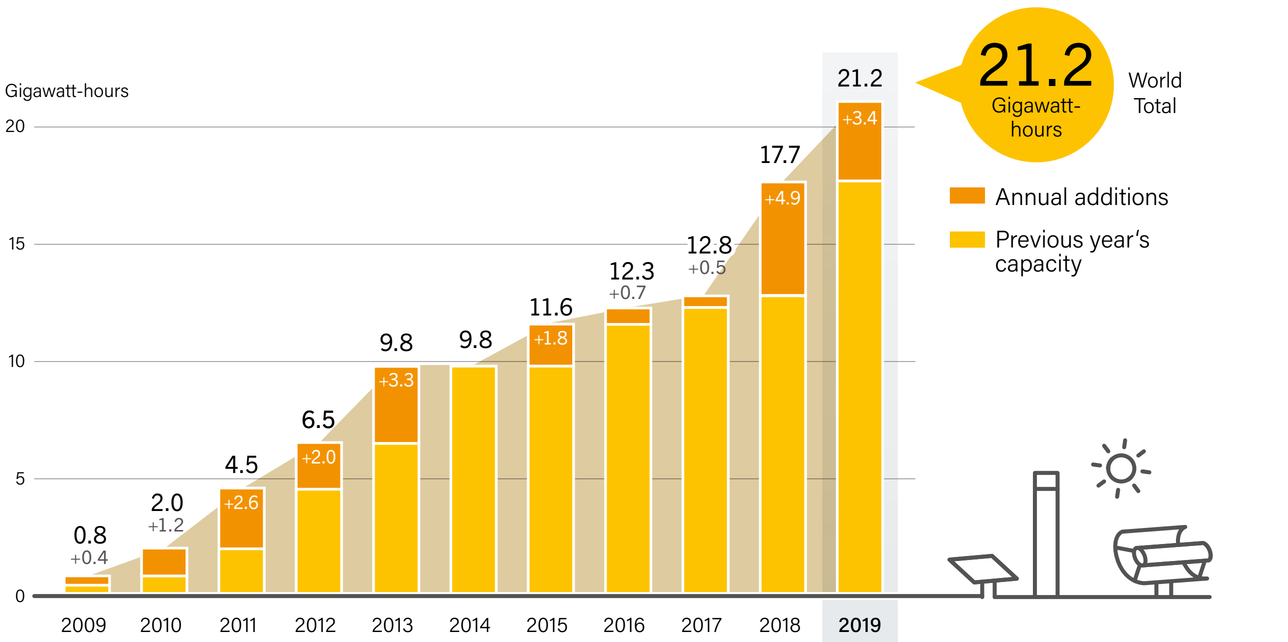
Nearly all of these projects will include thermal energy storage, which improves plant economics and increases system benefits – such as providing relatively dispatchable electricity and grid flexibility – which can support the integration of higher shares of variable renewable electricity in power systems.[38] (→ *See Systems Integration chapter.*)

At the end of 2019, an estimated 21 GWh[i] of TES, based almost entirely on molten salts[ii], was operating in conjunction with CSP plants across five continents.[39] (→ *See Figure 33.*) Of the 23 CSP plants completed globally since the end of 2014, only two do not incorporate TES: an ISCC facility in Saudi Arabia and the Megalim plant in Israel.[40]

i The total TES capacity in MWh is derived from the sum of the individual storage capacities of each CSP facility with TES operational at the end of 2019. Individual TES capacities are calculated by multiplying the reported hours of storage for each facility by their corresponding rated (or net) power capacity in MW.

ii More than 95% of global TES capacity in operation on CSP plants is based on molten salt technology. The remainder use steam-based storage.

FIGURE 33. CSP Thermal Energy Storage Global Capacity and Annual Additions, 2009-2019



Note: Totals may not add up due to rounding.

Source: See endnote 39 for this section.

CSP INDUSTRY

The CSP industry has become increasingly diverse geographically, in terms of the location of commercial plants as well as the origins of developers, investors and contractors involved in project implementation. CSP projects that either entered operations or were under construction during 2019 involved lead developers and investors from at least eight countries including China, France, Israel, Kuwait, Saudi Arabia, Spain, the United Arab Emirates and the United States.[41] Contractors were based in China, Denmark, Israel, Spain and the United States, with Chinese companies involved in almost half of the completed or active projects.[42] By contrast, before 2015 most CSP companies hailed from the United States and Spain.[43]

The Saudi company ACWA Power remained the leading CSP project developer in 2019, with around 700 MW of projects under construction.[44] Other notable developers, investors or owners of CSP plants that either entered operations or were under construction during the year included EIG Global Partners (United States), ENGIE (France), Royal Tech (China), Noy Fund and Shikun & Binui (both Israel), as well as at least 13 other developers from around the world.[45]

The leading companies involved in the engineering, procurement and construction of CSP facilities (ranked in terms of megawatts completed and/or under construction) included Abengoa (Spain), Shanghai Electric (China), Acciona (Spain), General Electric (United States), Sener (Spain), Brightsource (Israel) and China Shipbuilding New Power Company (China).[46]

With the spread of markets around the world, the broadening of supply chains and increasing experiences in the industry, costs have continued to fall.[47] Lower total installed costs combined with longer or more flexible power purchase agreements and higher capacity factors (thanks largely to including TES and the shift towards locations with better resource conditions for CSP) have reduced the cost of electricity from CSP.[48]

A 2019 study estimated that the global weighted average levelised cost of electricity (LCOE) of CSP in 2018 (USD 18.5 per MWh) was 26% lower than it was in 2017, and 46% lower than in 2010.[49] Another study from 2019 estimated that the average LCOE of new CSP capacity with storage was lower than the average LCOE of new natural gas peaking plants under certain circumstances.[50] Despite these advances, developers of CSP with TES faced strong competition from projects coupling solar PV and wind power with battery storage, which were increasingly prevalent in 2019.[51] (→ *See Systems Integration chapter.*)

In many cases CSP and TES capacity are being combined with solar PV and/or wind power capacity in hybrid facilities to lower costs and increase capacity value. For example, Israel's Megalim and Negev CSP plants each are located alongside solar PV plants, and China's new 50 MW Luneng Haixi plant forms part of a 650 MW renewable energy complex that also includes 200 MW of solar PV and 400 MW of wind power capacity, plus 50 MW of storage capacity.[52] The 110 MW Cerro Dominador plant in Chile will incorporate 17.5 hours of TES alongside an existing 100 MW solar PV plant.[53]

CSP capacity has been combined with solar PV and/or wind power capacity in hybrid facilities to lower electricity generation costs.

In 2019, a hybridised project in Morocco that will combine CSP, solar PV and energy storage was awarded by the Moroccan Agency for Sustainable Energy at a tariff of MAD 680 (USD 68) per MWh.[54] Contractual agreements for the United Arab Emirates' Noor Energy 1 project, which will combine 700 MW of CSP capacity with 8.1 GWh of TES and 250 MW of solar PV capacity, were finalised in early 2019 based on a CSP tariff of USD 73 per MWh in parallel with a solar PV tariff of USD 24 per MWh.[55]

Also in 2019, a range of R&D activities were under way that aimed to further reduce the costs of CSP. Some of this work focused on increasing system operating temperatures in order to unlock greater thermal energy efficiencies[i]. For example, a partnership between the French utility EDF and Chinese CSP technology company Shouhang aimed to convert an existing CSP demonstration project from using a steam cycle for thermal power generation to using a closed-loop supercritical CO_2 cycle, which is capable of higher operating temperatures.[56]

In the United States, a government-backed programme at Sandia National Laboratories was focused on developing a CSP central receiver that is capable of operating at temperatures above 1,000 °C, allowing for greater heat concentration.[57] Also in 2019, the US Department of Energy announced USD 30 million in support for 13 research projects, with the goal of improving CSP economics by reducing manufacturing costs, developing new storage technologies and allowing for more autonomous system operations.[58]

R&D attention during the year also was focused on addressing the environmental impacts of CSP. In Europe, for example, researchers were evaluating novel ways to reduce water consumption for heliostat cleaning through the development of ultrasonic cleaning systems and hydrophobic[ii] coatings.[59]

i Higher operating temperatures can enable greater thermodynamic efficiency in the heat transfer processes that are involved in steam-based power generation.

ii Hydrophobic coatings repel water that otherwise might collect on the surface of the heliostat and absorb dust particles from the surrounding air.

KEY FACTS

- China remained the world's largest national market for solar thermal systems, followed distantly by the United States, Turkey, Germany and Brazil.
- Outside China, new additions in the largest solar heating and cooling markets were stable, with growth in some markets balancing declines in others.
- The year saw record-high additions of solar industrial heat capacity, led by Oman, China and Mexico.
- The largest collector manufacturers stabilised their production volumes on average, but small and medium-sized collectors faced increased pressure.

SOLAR THERMAL HEATING AND COOLING

SOLAR THERMAL HEATING AND COOLING MARKETS

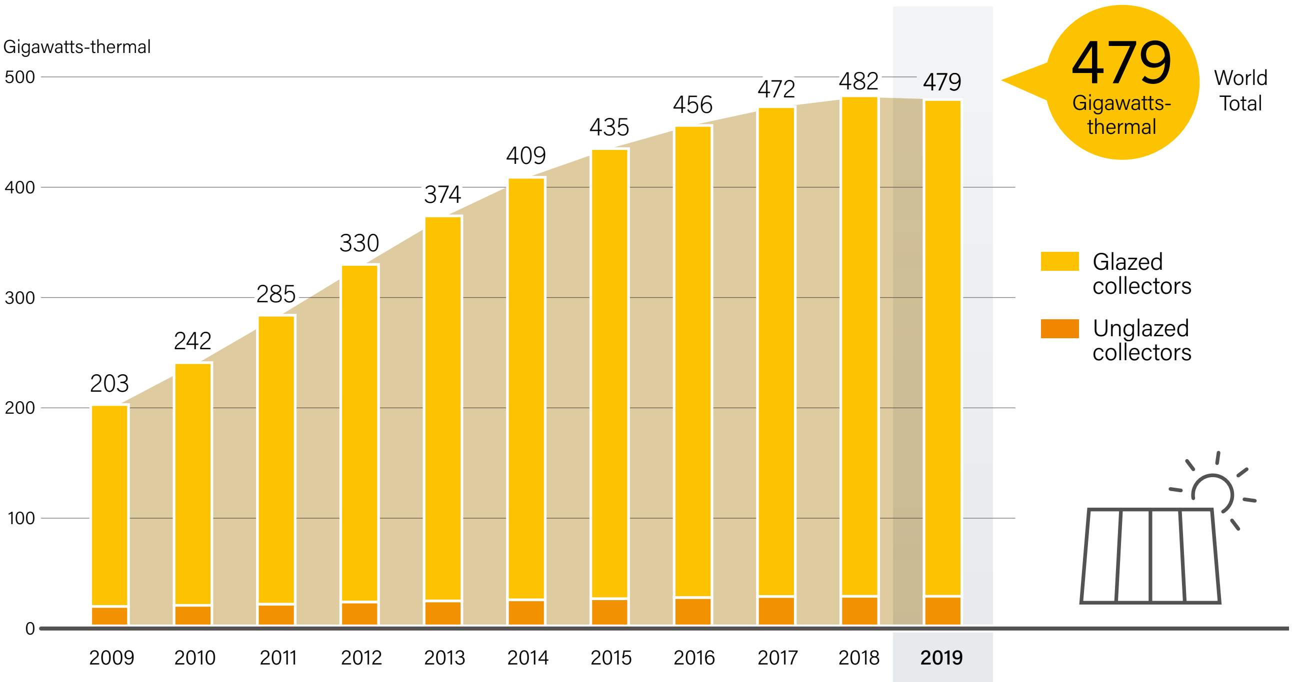
Solar thermal heating and cooling systems served millions of residential, commercial, industrial and public clients in 2019. By year's end, the systems had been sold in at least 134 countries for use in a wide range of applications including hot water, space heating and cooling, product drying and water desalination.[1]

An estimated 31.3 gigawatts-thermal (GW_{th}) of glazed (including flat plate and vacuum tube technology) and unglazed solar collectors was added globally in 2019, and by year's end a total of an estimated 479 GW_{th} was in operation.[2] These three types of solar thermal collectors provided around 389 terawatt-hours (TWh) (1,402 petajoules, PJ) of heat annually by the end of 2019 – equivalent to the energy content of 229 million barrels of oil.[3]

For the first time ever, the estimated cumulative global operating solar thermal capacity declined in 2019, down 1% from the previous year's total of 482 GW_{th}.[4] (→ *See Figure 34 and* ***Reference Table R18.***) The drop is attributed to insufficient new additions in China to meet or exceed the capacity of systems that were retired during the year[i,5] China remained the world's largest national market for solar thermal systems, accounting for 69% of cumulative world capacity, followed distantly by the United States, Turkey, Germany and Brazil.[6] Not including China, global capacity increased 3% to an estimated 148 GW_{th} in 2019, up from 144 GW_{th} in 2018.[7]

i The service life of systems operating in China is assumed to be 10 years. In 2019, the new capacity installed in the country (22.8 GW_{th}) was less than the capacity added 10 years earlier, in 2009, when 29.4 GW_{th} was put in operation.

FIGURE 34. Solar Water Heating Collectors Global Capacity, 2009-2019



Note: Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors.

Source: IEA SHC. See endnote 4 for this section.

In addition to the three main collector types, other technologies such as hybrid, concentrating and air collectors are available to meet specific heat needs. Because annual additions of these technologies are small, they are not yet included in global and national capacity statistics. As of the end of 2019, hybrid or solar PV-thermal technologies provided 608 MW_{th} of thermal capacity (as well as 208 MW of electric power capacity) for space and water heating.[8] In addition, around 554 MW_{th} of concentrating solar thermal capacity provided hot water or steam for commercial and industrial customers.[9] An estimated 1.1 GW_{th} of air collectors for drying and space heating was in operation at the end of 2018 (latest data available).[10]

China again led the world for new installations of glazed and unglazed collectors – accounting for 73% of the total – followed by Turkey, India, Brazil and the United States.[11] The top 20 countries accounted for 94% of global additions in 2019.[12] Global newly commissioned capacity in 2019 (31.3 GW_{th}) was down 7% from 2018, due mainly to an 8% contraction in China.[13] Outside China, new additions in the largest solar heating and cooling markets remained stable in 2019, with growth in Brazil, Cyprus, Denmark, Greece, South Africa and Tunisia balancing declines in Australia, Austria, Germany, Israel, Italy, Poland and Switzerland.[14] (→ *See Figure 35.*)

Among glazed collectors, the transition from vacuum tube to flat plate accelerated in 2019, driven by high demand for flat plate units in China's building industry. Flat plate collectors dominated in the largest European markets and reached a 28% market share in the world's 20 largest solar thermal markets (up from 24% in 2018).[15] The share of vacuum tube collectors among new additions in the 20 largest markets fell to 67% in 2019, from 72% in 2018, although vacuum tube units still represented more than 75% of new installations in China and India and about 50% in Turkey.[16]

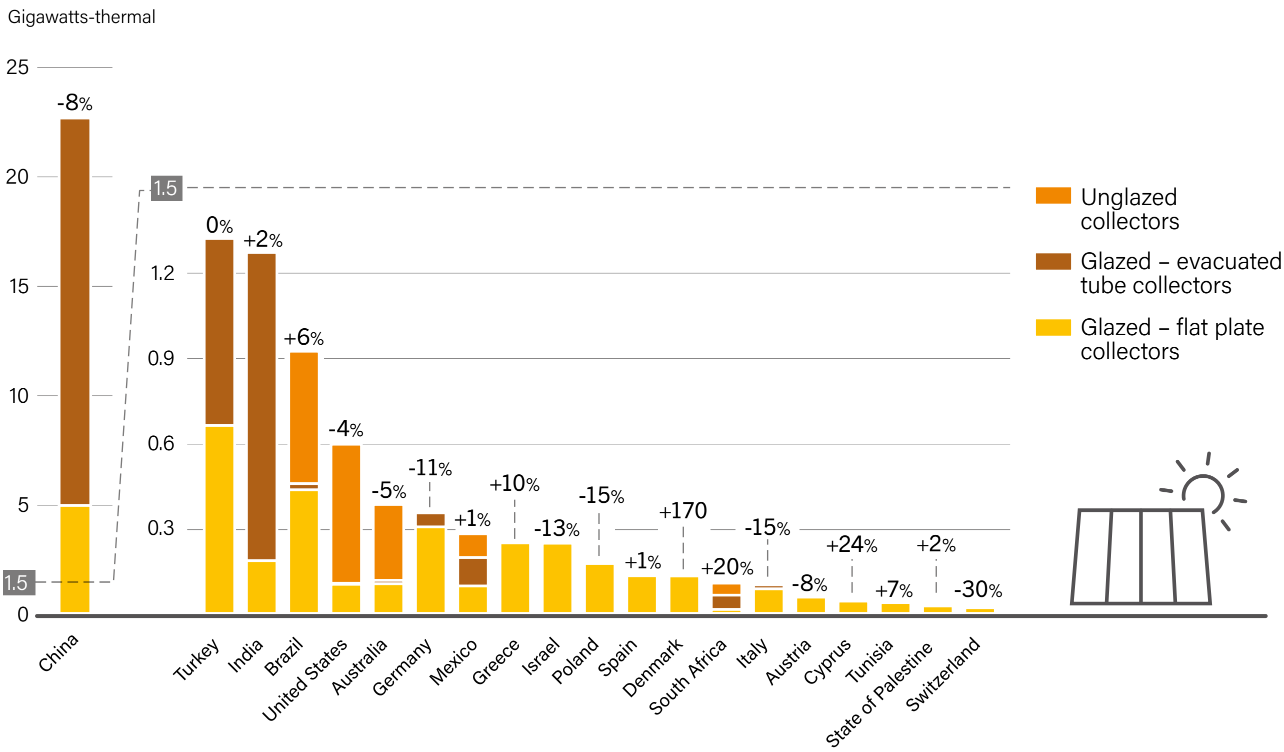
The market share of unglazed collectors, commonly used to heat swimming pools, increased slightly in 2019, to 5%.[17] Unglazed collectors accounted for more than half of all new installations in Australia, Brazil and the United States.[18]

Despite remaining the world's largest installer of solar thermal technologies, China's market has declined 8% annually on average since its record year of 2013.[19] New installations in China in 2019 totalled 22.8 GW_{th}[i], 17 times more than those in Turkey, the second largest market.[20] Shandong was the top Chinese province for both production and installation of solar collectors for the eighth year in a row, followed by Zhejiang and Yunnan.[21] Although sales of vacuum tube collectors fell 13% in China in 2019, demand for flat plate collectors rose 15%, for use on high-rise balconies and for large central hot water systems.[22]

The transition continued in China from small residential solar thermal units to large projects for multi-family residences, tourism and the public sector, with large projects accounting for 74% of Chinese capacity additions in 2019, up from 61% in 2015.[23]

i New additions in China were based on produced collector area, and included export volumes in the national statistics for 2019 and earlier years. The export volumes for previous years were not known at the time of publication, and to the extent possible GSR 2021 will reflect corrected statistics.

FIGURE 35. Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2019



Note: Additions represent gross capacity added.

Source: See endnote 14 for this section.

In many provinces and cities, authorities called on businesses and industry to abide by existing solar building codes by installing solar hot water systems in new and refurbished buildings.[24] Tenders for solar thermal in the construction business represented three-quarters of China's total market volume in 2019.[25]

China saw only limited progress in the use of solar thermal systems for space heating and for industrial and agricultural processes, with 282 MW_{th} installed in the first half of 2019.[26] A key reason for the slow growth was the preference in "green" heating policies for stand-alone heat pumps rather than solar thermal systems to replace coal boilers in the northern provinces. Concerns have arisen around overheating associated with large solar space heating fields during the summer months, as well as the need for an auxiliary heating device and the limited experience of users in operating solar space heating systems.[27]

Turkey's market remained stable in 2019, and the country's 1.32 GW_{th} of new installations was divided roughly equally among flat plate and vacuum tube collectors.[28] Flat plate sales were buoyed by public orders for central hot water systems in hospitals, prisons and refugee camps. Vacuum tube collectors were sold in the residential market and mainly in the colder regions of Turkey (such as middle and eastern Anatolia), as well as for replacement of existing solar water heaters.[29]

Following two years of double-digit expansion (18% in 2018 and 26% in 2017), India's market grew 2% in 2019, with 1.27 GW_{th} of new installations.[30] Vacuum tube collectors again dominated sales – representing 85% of additions – but their share of the market declined relative to 2018 as sales remained stable.[31] Meanwhile, sales of flat plate collectors increased as several tenders prioritised certified collectors, which according to Indian standards apply only to flat plate units.[32]

Three Indian states – Karnataka, Gujarat and Maharashtra – accounted for nearly 90% of the country's additions in 2019.[33] Karnataka remained the leading state, with almost half of newly installed solar thermal systems, and Gujarat overtook Maharashtra to account for around 20% of total sales in 2019.[34] Gujarat's strong growth is attributed to high awareness of solar energy across the state in cities as well as increasingly in semi-urban areas and villages.[35]

Brazil added 0.93 GW_{th} of solar thermal capacity in 2019, up 6% from the previous year.[36] The growing construction industry and increasing demand from new commercial customer groups with high hot water demand – such as restaurants, spas and laundries – contributed to this surge, which followed four years of continuously declining sales in the country.[37]

The United States was the fifth largest market for the three main types of solar thermal collectors in 2019 (600 MW_{th}) and was the largest market for unglazed collectors (487 MW_{th}).[38] The unglazed segment, used mainly to heat swimming pools, accounted for 81% of US additions.[39] The smaller glazed segment remained stable in 2019, following an 8% decline in 2018, despite continuing low oil and natural gas prices and an increasing domestic focus on solar PV.[40] Hawaii's solar obligation and the California Solar Initiative's solar thermal rebate programme, which is set to expire in July 2020, helped to stabilise sales.[41]

The European Union (EU-28) remained the second largest regional market after Asia, with estimated gross additions of 1.5 GW_{th} in 2019, down 1.8% from 2018.[42] More than 10 million solar thermal systems were in operation by year's end.[43] The decline in sales is attributed to the low rate of refurbishment of old heating systems, the low interest in solar thermal systems among installers and the still relatively high cost of residential solar thermal systems in most European countries.[44] In addition, continued discussion about the electrification of residential heat demand generated interest in heat pump solutions among private homeowners and public and commercial clients, which reduced the demand for solar thermal systems.[45]

Annual additions in the two leading EU countries for solar thermal installations – Germany (358 MW_{th}) and Greece (253 MW_{th}) – converged in 2019 due to opposing national trends.[46] The German market continued its decade-long decline (down 11% in 2019), whereas additions in Greece grew 10% for the fifth year in a row due to cost-competitive products, a regulation stipulating a minimum 60% solar hot water share in new buildings and the Energy Savings in Households grant programme.[47] Germany's situation changed in early 2020, however, following a ruling in December 2019 that enabled the provision of grants that cover 40% of the costs of replacing an outdated oil boiler with a natural gas condensing boiler supported by a solar space heating unit.[48]

The globalisation of solar thermal technologies continued in 2019, with sales picking up for example in the Middle East's Gulf region as users in some countries found it financially attractive to use solar thermal rather than electricity to provide domestic hot water.[49] In Saudi Arabia, a gradual reduction in subsidies for electricity (commonly used to heat water) led to greater demand for solar hot water solutions among hotels and the construction industry.[50] Imports of solar thermal systems to the United Arab Emirates reached a record high in 2019 in response to a building regulation in Dubai that requires solar thermal systems on new construction.[51]

In Kuwait, where imported natural gas generates half of all electricity, the government began using solar water heating in public buildings to reduce electricity use and natural gas imports.[52] The country's Sabah Al Ahmed University installed a 0.5 MW_{th} rooftop system on its buildings, and the Kuwaiti Public Authority for Housing Welfare announced plans to install solar water heaters on all new villas that it builds in the coming years.[53]

The year 2019 was a bright period for **solar district heating** in Denmark, China and Germany. Denmark had a record year for new installations, bringing online 10 new solar district heating plants and expanding 5 existing plants, for a total of 134 MW_{th} added (compared to only 6 new plants and 4 expanded plants totalling 47 MW_{th} added in 2018).[54] Denmark consolidated its lead in the global solar district heating market as capacity topped 1 GW_{th} in August 2019, when as many as 113 Danish villages, towns and cities were using solar energy for space heating.[55]

Denmark's strong market was supported by good framework conditions, including high taxes on fossil fuels, sufficient land for cost-effective ground-mounted collector fields and low-cost financing for the non-profit, user-owned utilities that operate the district heating networks.[56] Flat plate collectors were the dominant technology for new solar district heating systems in both Denmark and Germany.

In China, under the state-financed solar district heating programme for Tibet, three solar district heating systems were commissioned in the last quarter of 2019.[57] In October, 1,800 households in the Tibetan town of Shenzha were connected to a district heating system that was designed to cover 75% of its demand with heat from a 14 MW_{th} parabolic trough collector field.[58] An even higher annual solar share of around 90% may be achieved at a new solar district heating plant in the town of Zhongba, where since 2019 a 24.5 MW_{th} flat plate collector field with 15,000 m^3 of seasonal storage has provided households with a total heated floor area of 118,000 m^2.[59] A second 13.4 MW_{th} flat plate collector field began operation in the town of Saga to supply public buildings with 80,000 m^2 of heated floor space.[60]

Outside Tibet, no new large solar space heating systems were reported in China in 2019, as coal boilers were replaced mostly with heat pumps under the green heating policies in the northern provinces.[61]

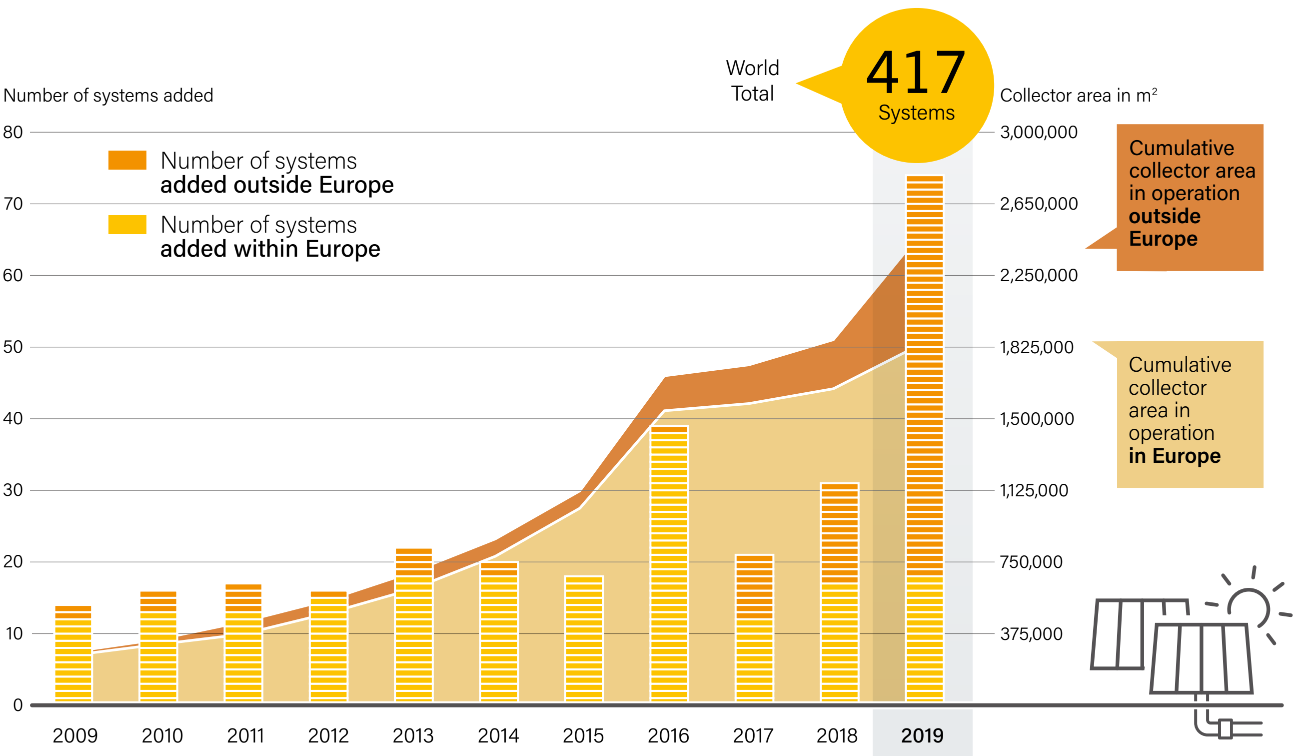
Germany again saw an increase in its solar district heating installed capacity, as a growing number of municipal utilities discovered large solar thermal systems to be an economically feasible solution. Six new systems totalling 9.9 MW_{th} were added in 2019, compared to a total of 5.8 MW_{th} for five smaller solar fields completed in 2018.[62] Three additional systems were under construction as of the end of 2019, including a 10.4 MW_{th} field in Ludwigsburg, which will be Germany's largest solar district heating plant when it comes online in 2020.[63]

The successful development of solar district heating in Denmark, China and Germany has generated interest beyond these countries. In September 2019, the district heating operator in Salaspils, Latvia inaugurated a 15 MW_{th} solar field paired with a wood chip boiler to meet 90% of demand from the local heat network.[64] Solar district heating also attracted interest in Serbia and Kosovo after the European Bank for Reconstruction and Development provided funding for (pre-)feasibility studies. As of early 2020, a feasibility study was completed for the Serbian town of Pancevo, with promising results, and pre-feasibility analyses had been conducted for Belgrade, Bor and Novi Sad in Serbia and Pristina in Kosovo.[65]

Two very large solar district heating projects were delayed in 2019. In China, a 51 MW_{th} solar field intended to meet heating and cooling needs in Turpan (Xinjiang province), one of the country's energy demonstration cities, was put on hold because of funding challenges.[66] The Big Solar Graz project, a planned 154 MW_{th} solar field with 0.9 million m^3 of seasonal storage for district heating in Graz, Austria did not develop further due to conflicts with the project's Danish major financing institution.[67]

In addition to solar district heating, **central solar hot water systems** for large residential buildings, hospitals and prisons sold well in China and Turkey in 2019. In China, 44 such projects were commissioned during the year, each with collector fields of at least 350 kilowatts-thermal (kW_{th}) (500 m^2), for a combined total of 175 MW_{th}.[68] In Turkey, the government ordered central hot water systems for three prisons and three hospitals, for a total of 4.8 MW_{th}.[69] By the end of 2019, at least 417 district heating and central hot water systems were in operation around the world (up from 345 systems in 2018), with a cumulative capacity of 1.73 GW_{th} (including glazed and concentrating solar thermal collectors).[70] (→ *See Figure 36.*)

FIGURE 36. Solar District Heating Systems, Global Annual Additions and Total Area in Operation, 2009-2019



Note: Includes large-scale solar thermal installations for residential, commercial and public buildings. Data are for solar water collectors and concentrating collectors.

Source: IEA SHC. See endnote 70 for this section.

In addition to the growing interest in new water heating installations for public and residential buildings, solar thermal technologies are used increasingly to provide heat for industry around the world. Industry accounts for a large share of global heat demand, and solar energy is suitable for meeting needs in the low-to-medium temperature range (below 400 °C), which account for around 50% of industrial heat demand.[71]

In 2019, global additions of **solar industrial heat capacity** reached a record high of 251 MW_{th}, up from 39 MW_{th} in 2018 and 153 MW_{th} in 2017.[72] The top country for newly installed capacity was Oman – where the Miraah solar steam project developed by Glasspoint (United States) added 180 MW_{th} – followed by China (53 MW_{th}), Mexico (3 MW_{th}), India (2 MW_{th}) and Germany (1 MW_{th}).[73] China and Mexico led in the number of new solar heat for industrial processes (SHIP) systems, with 26 systems each, followed by Germany with 11 new installations.[74] By year's end, at least 817 SHIP systems totalling more than 700 MW_{th} were supplying process heat to factories worldwide.[75]

Solar industrial heat plants in Mexico, Oman and Spain were cost-competitive with fossil fuels, suggesting the potential for further market growth.[76] In many other countries, however, achieving competitiveness against oil and natural gas remained challenging.[77] Consequently, a growing number of governments supplied funding for solar industrial heat installations in 2019, including Austria, China, France, Germany and the Netherlands. Supported by grants, several new large installations were built, including a 3.4 MW_{th} flat plate collector system supplying heat to a French paper mill and a 6.5 MW_{th} field providing heat for floral greenhouses in the Netherlands.[78] As of early 2020, a 10 MW_{th} plant was under construction in France to deliver process heat to a malting plant.[79]

Potential new markets were discovered in 2019 with the installation of the first industrial solar heat plants in Malaysia, Portugal, Saudi Arabia and Senegal.[80] Financed by the World Bank, feasibility studies for selected industry sectors also were conducted in the Middle East and North Africa region, and construction of the first plant within the Word Bank's support programme in Morocco was expected to begin in 2020.[81]

SOLAR THERMAL HEATING AND COOLING INDUSTRY

Manufacturers are producing and delivering a wide range of solar heating and cooling solutions to meet customer needs in the residential, public, commercial and industrial sectors. In 2019, significant consolidation occurred – with large players expanding their market shares mostly through contracts for large capacities or high numbers of systems, and smaller manufacturers (particularly in Europe) struggling because of declining demand.

Although the worldwide solar thermal market declined in 2019, Chinese manufacturers of flat plate collectors expanded their production volume by 21% in response to increased demand from the national construction industry for both façade integration and central collector fields.[82] However, some large manufacturers competed against one another with low-price bids and sacrificed margins to utilise their greatly expanded production capacities.[83] Industry consolidation occurred in Europe in 2019, with the largest flat plate collector manufacturers stabilising their production volumes on average, but small and medium-sized collectors facing increased pressure as demand contracted in several major markets.[84] Consequently, a number of companies in the region's small and medium-sized manufacturer group became insolvent or ceased production during the year.[85]

Two long-time European solar brands, KBB Kollektorbau (Germany) and Kingspan Renewables (Ireland), closed their collector factories, with Kingspan halting completely its manufacturing of solar thermal products.[86] KBB, citing the lack of effective support measures in the renewable heating market as well as falling prices and dwindling margins, announced that it would sell its machinery to an independent business outside Europe and maintain only a sales and engineering team in Berlin.[87]

The insolvencies of manufacturers Aventa Solar (Norway) and Fresnex (Austria) were caused by their inability to secure the necessary funding to increase business volumes and maintain financial health.[88] Investors took over the technologies of both companies: 3 Norske AS purchased the assets of Aventa Solar's polymeric collector technology in 2019, and in early 2020 it announced plans to build up collector production in Jevnaker, Norway under the new name Inaventa Solar.[89] Ecotherm, the former business partner of Fresnex, took over that company's collector technology.[90]

The top markets for solar district heating in 2019 were **China, Denmark and Germany.**

After filing for bankruptcy in May 2019, Austria's turnkey solar heating and cooling system developer S.O.L.I.D. successfully restructured its business with a new investor under the name Solid Solar Energy Systems.[91] S.O.L.I.D. had suffered after its former project partner VKR Holding (Denmark) failed to deliver milestones related to the delayed Big Solar Graz project, a large solar district heating plant that was expected to cover a double-digit share of heat demand in the district heating network of Graz, Austria.[92]

Fluctuations in the volume of contracted projects affected some of the world's larger collector manufacturers in 2019, with some seeing growth and others seeing contractions.[93] Linuo Paradigma, one of the largest collector manufacturers in China, recorded strong sales of large solar hot water systems in the national market.[94] Working with local partners, the company's domestic engineering team designed and installed 6 central solar hot water projects with a capacity of more than 7 MW_{th} each and listed 21 projects with collector areas between 3.5 MW_{th} and 7 MW_{th}, for a total of 154 MW_{th} – the second largest project volume of any company in 2019 after Glasspoint.[95]

On the negative side, a major Turkish flat plate collector manufacturer, Solimpeks, recorded a severe drop in production volumes due to the postponement of a large project that was to have been finalised in 2019.[96] In early 2020, Arcon-Sunmark, the Danish market leader in solar district heating, announced that it would sell its collector factories due to a large financial deficit in recent years.[97] The heavy losses were because of high fluctuations in turnover and low margins in contracted projects. For example, the company had commissioned 10 solar district heating fields in Denmark during the first half of 2019, but business dried up for the rest of the year after an energy savings scheme[i] for utilities expired.[98] Greenonetec (Austria) acquired Arcon-Sunmark's key assets in Denmark, and Solareast Group (China) bought the shares in the company's Asian business.[99]

Technology suppliers of **solar heat for industrial processes** also had a difficult year. Only 30% of the around 80 companies listed in the world database of turnkey SHIP suppliers commissioned a project in 2019, mainly because of low fossil fuel prices, lack of awareness of SHIP technology and a consumer focus on the high upfront costs.[100] A growing number of technology suppliers responded to the challenges of signing contracts with industrial clients by using new manufacturing strategies to reduce costs.

For example, rather than offering solar heat solutions for individual projects, the parabolic trough collector manufacturer Absolicon Solar Collector (Sweden) took the approach of selling complete production lines, with a typical annual capacity of 100,000 m^2.[101] After commissioning its first production line in China in 2018, the company signed agreements in 2019 with Greenline Africa (South Africa) and Ariya Finergy (Kenya) to sell lines for construction in those countries.[102] With this strategy, Absolicon aims to reduce technology costs by producing solar collector fields close to large numbers of potential heat customers, such as the tea industry in Kenya. The company expects to achieve benchmark costs of EUR 250 (USD 280) per kW_{th} to be cost competitive in the target countries.[103] Also in 2019, Trivelli Energia (Italy) signed an agreement with Yaoguo (China) to build a parabolic trough collector production line in China.[104]

Other solar technology suppliers created new, mutually beneficial partnerships with conventional energy technology providers to overcome some of the challenges of developing SHIP projects. These partnerships enable the collaborating companies to offer solutions that meet the heat, steam and/or cooling demands of their customers while minimising the use of fossil fuels.[105] For example, the linear Fresnel collector manufacturer Industrial Solar (Germany) and the boiler producer Gasco (Australia) agreed to collaborate on hybrid solar-fossil systems to expand solar process heat markets in Australia and neighbouring countries.[106]

Several solar collector manufacturers tapped into the wastewater treatment market to widen their sales activities, and joined forces with water separation and purification experts.[107] In early 2019, Rioglass Solar (Belgium), a manufacturer of linear Fresnel collectors, partnered with Condorchem Envitech (Spain), a specialist in multi-effect evaporators, to form Solarvap, a solar-powered wastewater evaporation system.[108] Financed by the issuance of new shares, in early 2020 Industrial Solar (Germany) announced the acquisition of Solarspring (Germany), a manufacturer of membrane-based water treatment systems, to offer clean energy and clean water for industrial customers.[109]

Concentrating collector technologies have been used increasingly for heat and steam production. As with glazed collectors, consolidation occurred in 2019 for manufacturers of concentrating collectors that provide systems for heat and steam at temperatures above 100 °C for boiling, sterilising and cleaning. Glasspoint, which focuses on large deals with oil producers to provide solar steam for enhanced oil recovery, added 180 MW_{th} of parabolic trough collector capacity at the Miraah project in Oman – the largest single project capacity commissioned as of the end of 2019.[110] By contrast, small and medium-sized manufacturers of concentrating solar solutions in Europe, India and Mexico recorded lower sales figures in 2019 than in 2018.[111]

Third-party financers discovered new opportunities in the commercial solar heat market in 2019. Third-party financing avoids the high upfront costs for the clients and in most cases is combined with an operation and maintenance contract with solar thermal specialists over the contractual or repayment period, which reduces the client risk associated with a new technology.[112] For example, the crowdfunding platform ecoligo.investments (Germany), which until 2019 focused on solar electricity projects, funded three solar hot water systems for hotels in Costa Rica and Kenya during the year.[113]

i The energy savings scheme allowed district heating utilities to fulfil their energy-saving mandates by extending existing solar district heating plants or by initiating the construction of new facilities by mid-2019. See endnote 98 for this section.

Third-party financiers

discovered new opportunities in the commercial solar heat market in 2019.

Another model of third-party financing is a heat supply contract, or energy service company (ESCO). Kyotherm (France), which specialises in financing renewable heat projects, played a pioneering role in setting up ESCOs in 2019 by developing and financing what is anticipated to be Europe's largest solar industrial heat plant, a 10 MW_{th} system for a malting plant in France.[114] The malt producer profits from a price below the average price it would pay for heat produced from natural gas combustion. Kyotherm, together with its network of solar thermal project developers, also started contractual negotiations with 11 commercial heat consumers outside France, with plans to sign some project contracts in the first half of 2020.[115]

A few solar heat project developers signed their first heat supply contracts in 2019. NewHeat (France) financed a 3.4 MW_{th} single-axis tracked flat plate collector system to sell heat to the Condat paper mill in southwest France.[116] Azteq (Belgium) signed a solar steam delivery contract with a chemical producer in Antwerp and contracted with Solarlite (Germany) for a parabolic collector field at the client's factory.[117]

Other project developers faced difficulties in developing their ESCOs because some clients have slow decision-making processes or have been reluctant to commit to medium- or long-term contracts. For example, after Millennium Energy Industries (Jordan) signed its first solar heat delivery contract in mid-2019, the client asked for a delay in the installation, and the project had not been realised as of early 2020.[118] SWA Solar Wärme (Austria), established in 2018, completed only one project in 2019 after clients delayed decisions because of a temporary halt in national funding for large-scale projects.[119]

SHIP project developers in Asia shifted their ESCO businesses away from solar thermal technology, finding it more economical to design heat delivery contracts based on heat pumps. Linuo Paradigma's newly founded subsidiary for developing heat supply contracts realised its first two projects in 2019, both with air-source heat pumps.[120] Aspiration Energy (India), which announced big plans for solar industrial heat supply contracts in 2017, did not close a single deal with solar heat in 2019 and focused only on heat pump solutions.[121]

Solar thermal air conditioning and cooling remained a niche market in 2019. A handful of sorption chiller manufacturers promoted solar thermal cooling systems in southern Europe and the Middle East.[122] After realising publicly effective reference projects in 2018, Fahrenheit (Germany) contracted seven new solar thermal cooling projects in 2019: two smaller projects in Europe – in an office building in the Netherlands and a family residence in Germany – which were commissioned by the end of the year, and five projects across Australia, Dubai (United Arab Emirates), India, Morocco and Pakistan, which were still under construction at year's end.[123]

In Italy, despite high investment subsidies under the national Conto Termico 2.0, the solar thermal cooling market did not pick up in 2019. Maya (Italy), a joint venture with Yazaki (Japan) installed only one solar air conditioning system in the country (at a hospital), with a second system under construction at year's end.[124] Customer demand failed to materialise because in many cases solar heat-driven cooling systems were not cost-effective compared to gas-driven heat pumps or electricity-driven compression chillers, both of which are established air conditioning technologies.[125]

The German-Indian joint venture VSM Solar increased sales efforts for its solar cooling technology, mainly among hospitals and corporate buildings.[126] The company refurbished a solar air conditioning system with 225 tonnes of refrigeration at an IBM building in Bangalore, India and signed a strategic alliance with Blue Star, a large HVAC manufacturer in India, promoting the large power-saving potential compared to electricity-driven cooling units.[127] Newly founded Solid Solar Energy Systems (Austria) finished the design phase for an industrial cooling system for the engine manufacturer AVL in Graz, Austria.[128]

Although Thermax (India) was no longer actively promoting solar thermal cooling solutions in 2019, its competitors – other sorption chiller manufacturers such as Energy Concepts (United States) and Shuangliang (China) – redirected their thermal cooling solutions to utilise waste heat (rather than a solar collector field) to drive the cooling machines, as a way to lower investment costs.[129]

In an important step towards the standardisation of solar cooling systems, the world's first standard for space cooling and ventilation systems was published in Australia following seven years of preparation.[130] The standard includes methods for calculating energy consumption and determining the thermal comfort of space heating and cooling devices and ventilation systems for five different solar air conditioning technologies.[131]

KEY FACTS

- The global wind power market saw its second largest annual increase, with offshore wind accounting for a record 10% of new installations.
- Market growth reflected surges in China and the United States in advance of policy changes, and a significant increase in Europe despite continued market contraction in Germany.
- At least 102 countries had some level of commercial wind power capacity, enough to provide an estimated 5.9% of global power generation; the highest shares of generation were in Denmark (57%), Ireland (32%), Uruguay (29.5%) and Portugal (26.4%).
- Falling prices are opening new markets, but the global transition to auctions and tenders has resulted in intense price competition, reducing the number and diversity of participants and leading to further attrition among turbine manufacturers.

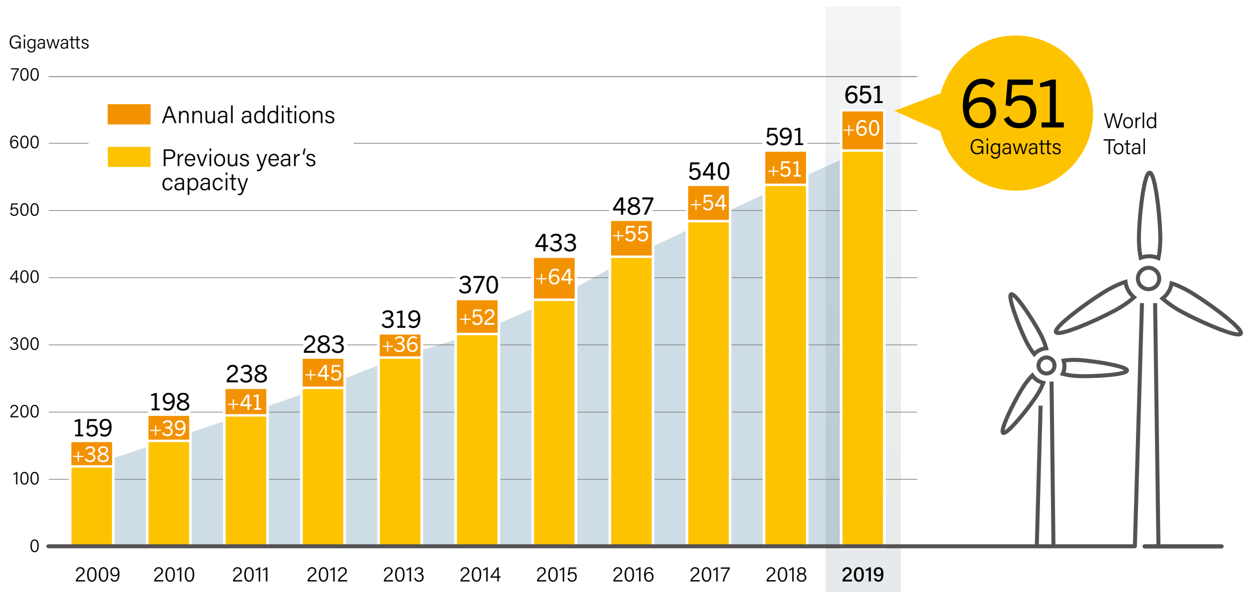
WIND POWER

WIND POWER MARKETS

The global wind power market expanded 19% in 2019, with around 60 GW of new capacity added to the world's electric grids (including more than 54 GW onshore and over 6 GW offshore).[1] This was the second largest annual increase in capacity ever, and followed three consecutive years of decline after the peak in 2015 (63.8 GW).[2] Offshore wind power plays an increasingly important role in the global market, accounting for a record one-tenth of additions in 2019.[3] The year's newly installed wind power capacity increased the global total by 10% to around 651 GW overall (621 GW onshore and the rest offshore).[4] (→ *See Figure 37.*)

The rapid growth in 2019 was due largely to surges in China and the United States in advance of policy changes and to a significant increase in Europe, despite continued market contraction in Germany.[5] Some emerging markets experienced slowdowns due to delays in public tenders and stop-and-go policies, which have deterred investment, although several markets in Africa, Latin America, the Middle East and Southeast Asia saw notable growth relative to 2018.[6] New wind farms reached full commercial operation in at least 55 countries during 2019, up from 47 in 2018, and at least one country, Senegal, brought online its first commercial project.[7] By year's end, the number of countries with some level of commercial wind power capacity exceeded 102, and 35 countries – representing every region – had more than 1 GW in operation.[8]

FIGURE 37. Wind Power Global Capacity and Annual Additions, 2009-2019



Note: Totals may not add up due to rounding.

Source: GWEC. See endnote 4 for this section.

Rapidly falling costs per kilowatt-hour (both onshore and offshore) have made wind energy ever more competitive and allowed onshore wind power to compete head-to-head with fossil fuel generation in a large and growing number of markets around the world, often without financial support.[9] The economics of wind energy have become the primary driver for new installations.[10] Outside of China (which has a feed-in tariff, or FIT, for wind power) and the United States (which offers tax credits and state renewable portfolio standards, or RPS), global demand for wind power in 2019 was driven largely by other policy mechanisms including auctions (or tendering), which have exerted a downward pressure on prices.[11] In some mature markets – such as in North America (around 80% of the global market) and northern Europe – corporate power purchase agreements (PPAs) are playing an ever more important role; worldwide, newly signed PPAs during 2019 were up an estimated 30% compared with 2018.[12]

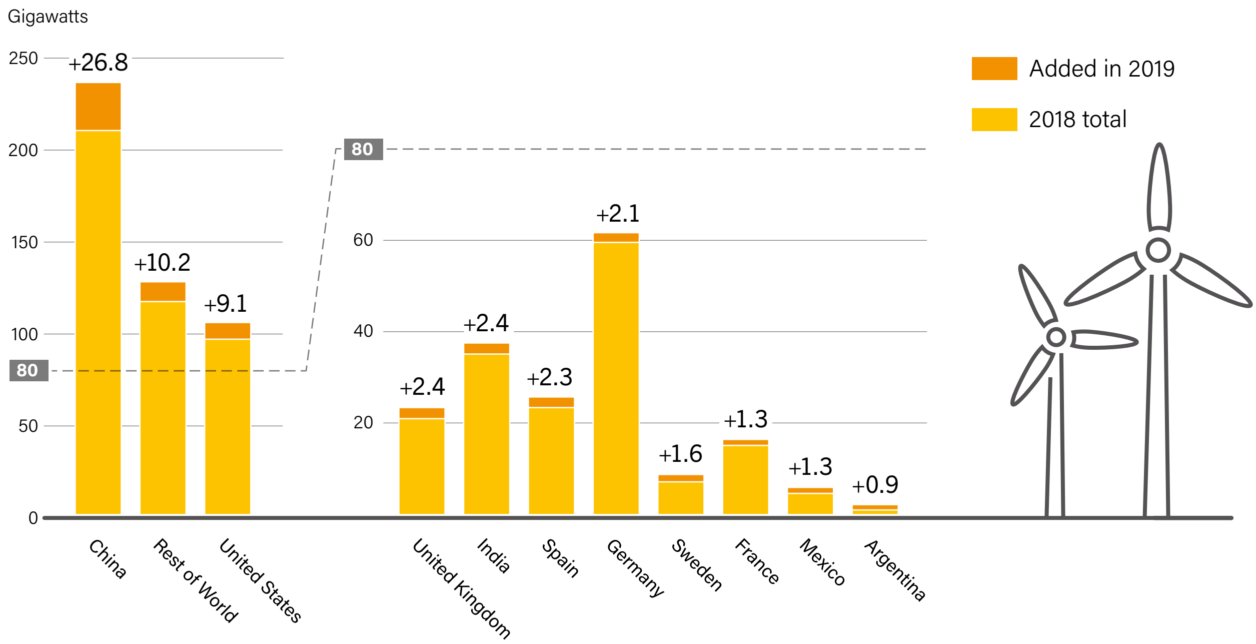
Wind power provides a substantial share of electricity in a growing number of countries.

Wind power provides a substantial share of electricity in a growing number of countries. In 2019, wind energy generated enough to provide an estimated 15% of the EU's annual electricity consumption, and equal or higher shares in at least seven individual Member States.[13] Wind energy met an estimated 47% of Denmark's electricity demand in 2019 and accounted for nearly 57%[i] of the country's total generation.[14] Other countries in Europe with wind generation shares above 20% for all of 2019 included Ireland (32%), Portugal (26.4%), Germany (21.8%) and Spain (20.9%).[15] Uruguay (29.5%), Nicaragua (17.4%) and Costa Rica (15.8%) also achieved high shares of generation from wind energy in 2019, and shares were high at the sub-national level in several countries.[16] By year's end, wind power capacity in operation worldwide was enough to provide an estimated 5.9% of total global electricity generation.[17]

For the 11th consecutive year, Asia was the largest regional market, representing more than 50% (down from 52% in 2018) of added capacity, with a total exceeding 292 GW by the end of 2019.[18] Europe (24%), North America (16%) and Latin America and the Caribbean (6%) accounted for most of the rest of the year's installations.[19] China retained its lead for new capacity (both onshore and offshore) and was followed distantly by the United States, the United Kingdom and India (both adding almost equal amounts) and Spain; together, these five countries accounted for 70% of annual installations.[20] Other countries in the top 10 for total capacity additions were Germany, Sweden, France, Mexico and Argentina.[21] For cumulative capacity, the top 10 countries were unchanged from 2018.[22] (→ *See Figure 38* and ***Reference Table R19***.)

i The difference between generation (electricity produced within a country's borders) and consumption is due to imports and exports of electricity and to transmission losses.

FIGURE 38. Wind Power Capacity and Additions, Top 10 Countries, 2019



Note: Additions are net of decommissioning.

Source: See endnote 22 for this section.

China again saw an increase in new installations (up 22%) during 2019, adding around 26.8 GW (24.3 GW onshore and 2.5 GW offshore) for a total of 236.3 GW installed.[23] More than 25.7 GW (23.8 GW onshore and nearly 2 GW offshore) of wind power capacity was integrated into the national grid in 2019, with just over 210 GW[i] considered officially grid-connected by year's end.[24]

China's support through the FIT (and its looming expiration), as well as the country's first wind power auction, drove the domestic market in 2019.[25] In May, the national government announced that, starting in 2021, FITs for onshore wind generation will no longer exceed those provided for coal-fired generation.[26] The government also published an initial list of approved projects (totalling 5.7 GW) to be built without direct financial support.[27] The policy changes result from a belief that the wind energy sector is mature enough to proceed without direct government support, as well as the need to clear a backlog of outstanding FIT payments for existing projects.[28]

Although the northern and western provinces were still home to the majority of China's cumulative capacity by year's end, the top provinces for official grid-connected additions in 2019 were Henan (nearly 3.3 GW), Hebei (2.5 GW), and Shanxi and Shandong (2.1 GW each), with Jiangsu in the lead for offshore installations – all of which are relatively close to demand centres and where curtailment rates were relatively low.[29] Overall, an estimated 16.9 TWh of potential wind energy was curtailed in China – a national average of 4% for the year, down from 7% (27.7 TWh) in 2018, and below the national government's targeted cap (10%) for 2019.[30] Curtailment remained concentrated mainly in Xinjiang, Gansu and Inner Mongolia, but all three provinces saw substantial reductions relative to 2018.[31] China's generation from wind energy was up nearly 11% (to 405.7 TWh), and wind energy's share of total generation continued its steady rise, reaching 5.5% in 2019 (up from 5.2% in 2018).[32]

India was the only other Asian country to rank among the top 10 for installations of wind power capacity in 2019, placing fourth globally for additions and for total capacity.[33] The country's additions increased 8.5% over 2018, when installations fell nearly 50% from their record high in 2017, as India shifted from FITs to reverse auctions.[34] India added 2.4 GW in 2019, bringing the year-end total to 37.5 GW.[35] Another 8.6 GW was in the active pipeline at year's end, but many wind (and other) power projects have been delayed by problems obtaining land and accessing transmission lines.[36]

Although the issuance of tenders remained strong in India during 2019, many were cancelled or undersubscribed, and projects that were already tendered faced delays (due to efforts to renegotiate for lower tariffs or to outright withdrawal of existing PPAs), which have held up turbine deliveries and put significant pressure on the domestic manufacturing industry.[37] Among the many challenges deterring investment have been policy uncertainties, India's slowing economy, aggressive bidding, low ceiling tariffs for auctions, curtailment and infrastructure constraints, delayed payments for generation, lack of low-cost financial resources, lack of available land in good wind areas (where developers want to be, due to low wind energy tariffs) and duties and tariffs on imports.[38] The number and diversity of local investors has declined since the shift to auctions, while installations have become more concentrated geographically.[39]

Elsewhere in Asia, Turkey's annual installations increased relative to 2018, with nearly 0.7 GW added for a total exceeding 8.1 GW.[40] Wind energy accounted for 7.4% of Turkey's electricity generation in 2019.[41] Thailand placed fourth in the region (added 0.3 GW for a total of 1.5 GW), although its market contracted after a significant drop in FIT rates dampened investor confidence.[42] Other Asian countries that added capacity included Japan (adding nearly 0.3 GW for a total of 3.9 GW), the Republic of Korea, Pakistan and Vietnam.[43] Vietnam's capacity increased 70% (to 388 MW) in a rush to complete projects before generous FIT rates were reduced, and wind power projects competed with solar PV and conventional power projects for space on the country's grid networks.[44] In much of Southeast Asia, policy uncertainty and subsidies to fossil fuels continued to curb deployment.[45]

After Asia, Europe installed the most capacity of any region during 2019. All of Europe added nearly 14.7 GW of new wind power capacity, bringing the total to 196.8 GW.[46] Most of this was in the EU-28[ii], which installed roughly 13.2 GW (9.6 GW onshore and 3.6 GW offshore), or net additions of 13 GW (accounting for decommissioning), for a year-end total of 192.2 GW (170.2 GW onshore and 22.1 GW offshore[iii]).[47]

Net EU additions, although below the all-time high in 2017, were up 34% over 2018.[48] The sharp increase was due mainly to strong growth in Greece (added a record 0.7 GW), Spain and Sweden – which more than doubled its additions relative to 2018, installing 1.6 GW for a total of 9 GW.[49] In total, 19 EU countries added capacity during 2019, up from 16 countries in 2018.[50]

i Statistics differ among Chinese organisations and agencies as a result of what they count and when. For more details, see endnote 24 for this section.

ii Here, the EU refers to the EU-28, including the United Kingdom. The EU-27 added nearly 10.8 GW during the year and had 169 GW of capacity at end-2019. See endnote 47 for this section.

iii Numbers do not add up to total of 192.2 GW due to rounding.

Net installations of wind power capacity in the EU-28 were up 34% over 2018.

However, the market was again fairly concentrated, with the top five countries – the United Kingdom, Spain, Germany, Sweden and France – accounting for almost 75% of net additions, even though markets in France and Germany contracted for the second consecutive year.[51] The leading EU countries for cumulative capacity were Germany, Spain, the United Kingdom, France and Italy.[52]

The United Kingdom was the region's top installer in 2019, adding 2.4 GW, three-quarters of which is operating offshore, for a total of 23.5 GW.[53] Most new onshore capacity (0.6 GW) was added in Scotland and Wales, and was awarded under Contracts for Difference[i] (CfD) in 2015.[54] Elsewhere in the United Kingdom, wind energy projects rely on merchant options such as PPAs.[55] The country saw historic lows for generation from coal (less than 1% for the second quarter of 2019), due largely to the rise of wind power, which accounted for nearly 20% of domestic electricity generation during the year.[56]

Spain, which ranked second in the region and fifth globally for installations, had its best year in a decade. The country added 2.3 GW (all onshore) – more than five times its 2018 installations – to end 2019 with 25.8 GW.[57] While most of this capacity was awarded in auctions held in 2016 and 2017, Spain also led the region for investments in new onshore capacity.[58] In late 2019, to mitigate regulatory uncertainty regarding future revenue from renewable power plants, the national government introduced a series of measures in an effort to guarantee a stable economic and regulatory framework to encourage further investment in renewable energy projects.[59]

Although still among the EU's top installers, Germany saw a sharp decline in annual additions (as well as in investment in new projects), ceding its first-place ranking in Europe, held since 2011.[60] Germany added 2.2 GW (nearly 2.1 GW net, including almost 1 GW onshore and 1.1 GW offshore) in 2019 for a cumulative 61.4 GW (53.9 GW onshore and more than 7.4 GW offshore).[61] Onshore installations have declined markedly since the 2014-2017 period (to 16% of the volume in 2017, when the auction model was introduced), due mainly to long, complex permitting processes and policy uncertainty.[62]

As of late 2019, more than 10 GW of wind power projects was stuck in Germany's permitting process, which has lengthened from around 10 months just a few years ago to more than two years.[63] The largest permitting barriers relate to aviation and the military; in addition, rising public opposition and a proposed setback distance of 1,000 metres for wind turbines have ruled out several prime locations.[64] (→ *See Feature chapter.*)

Growing economic risk, the increased complexity associated with tenders, permitting challenges and the threat of legal action have deterred potential investors, including community wind energy actors, and the removal of some privileges for community projects has reduced the number and diversity of participants in auctions.[65] Of the total 3.7 GW of onshore capacity auctioned in 2019, only 1.8 GW was awarded – far below the volume envisioned in Germany's expansion plan.[66] The number of companies active in the domestic wind power industry has declined with new installations, affecting the entire local value chain.[67]

Germany's gross generation from wind energy was up 12% onshore and 27% offshore, reaching a total of 126 TWh, or 21.8% of electricity generation in 2019.[68] Much of this electricity is produced in northern Germany, and a lack of grid capability hinders the transmission of excess electricity to load centres in the country's south, resulting in curtailment of wind energy and challenges for neighbouring countries due to electricity exports.[69] Curtailment in Germany has declined since 2017, however, as have exports, and the country has completed the first 1,300 kilometres of 7,700 kilometres of new transmission lines planned by 2030.[70] In Germany and elsewhere, interest in the use of excess renewable generation for electric heating, cooling and transport as well as for hydrogen production is quickly gaining ground.[71] (→ *See Systems Integration chapter.*)

For the EU as a whole, onshore wind energy met around 12.2% of total electricity demand, and offshore wind energy met 2.3%, with an estimated total of 417 TWh of wind generated electricity.[72] The one percentage point share increase relative to 2018 resulted from additional capacity and from windy conditions during the year throughout the region.[73]

Outside the EU-28, Norway was again the largest installer in Europe (adding 0.8 GW) in 2019.[74] However, Norway's plans for future installations were put on hold due to local opposition across the country sparked by environment and tourism concerns.[75] Ukraine saw a nearly 10-fold increase in installations relative to 2018 (adding 0.6 GW), more than doubling its capacity to 1.2 GW in advance of a transition from attractive FITs to auctions in 2020.[76] Throughout all of Europe, 2.1 GW of wind power PPAs were signed, and 10 countries held auctions in which wind energy secured contracts, including 8.6 GW onshore and 6.8 GW offshore.[77]

Across the Atlantic, the Americas added 13.4 GW (up 13% over 2018) and accounted for more than one-fifth of the world's newly installed capacity in 2019.[78] The United States installed 68% of the region's total and had its third biggest year[ii].[79] US additions were up 20% over 2018, to 9.1 GW, for a total of 105.6 GW across

i The CfD is the UK government's primary mechanism for supporting renewable electricity generation. Developers that win contracts at auction are paid the difference between the strike price (which reflects the cost of investing in the particular technology) and the reference price (a measure of the average market price for electricity).

ii The year 2019 saw the third highest installations of new capacity after 2009 and 2012, when the US production tax credit was due to expire and then was extended retroactively.

41 states and 2 territories.[80] At year's end, another 22.1 GW was under construction.[81] The rush of new installations was driven mainly by the phase-out of the federal production tax credit (PTC), which was granted a one-year extension[i] in late 2019.[82] Demand from utilities to meet customer preferences, sustainability goals and mandates under state RPS laws as well as demand from corporations also played a role.[83] Wind power PPAs achieved a new record (8.7 GW) in 2019, with utilities contracting 5.1 GW; at year's end, almost half of the project pipeline had a PPA in place, with 27% of these owned by utilities.[84]

The state of Texas (nearly 4 GW) again led for annual installations and, along with Iowa (1.7 GW), set new records for capacity additions.[85] Six US states ended the year with more than 5 GW in operation – including Texas, with more than 28.8 GW.[86] In Texas and much of the rest of the country, wind power set short-term generation records, exceeding 66% in the US central region, and grid operators were reliably managing such high penetration levels.[87] Tests by the California Independent System Operator during 2019 found that wind turbines equipped with inverter-based smart controllers can provide grid services similar to those provided by natural gas power plants.[88] (→ *See Systems Integration chapter.*)

For the full year, utility-scale wind power facilities accounted for more than 30% of electricity generation in 3 US states – with Iowa (in the lead at 42%) passing Kansas (41.4%) – and accounted for more than 16% of annual generation in 13 states.[89] In total, wind power accounted for 7.3% of US utility-scale electricity generation (up from 6.5% in 2018).[90] As an indication of how big wind power has become in the United States, it exceeded hydropower for generation in 2019, having already surpassed it for capacity three years earlier.[91]

Latin America and the Caribbean added 3.7 GW of capacity in 2019, with two countries – Mexico and Argentina – ranking among the top 10 globally.[92] The slight decline relative to 2018 was due mainly to a significant drop in Brazil that was nearly offset by increases elsewhere.[93] The region ended the year with around 29.2 GW of wind power capacity operating in at least 26 countries.[94] The top installers were Mexico (nearly 1.3 GW) and Argentina (0.9 GW), which both surpassed Brazil (0.7 GW) in annual additions for the first time, followed by Chile (0.5 GW).[95] Colombia held its first successful renewable energy auction, in which wind power was awarded nearly 1.2 GW.[96] More than 80% of the non-hydro renewable power capacity operating across the region (mostly wind power) at year's end was driven by public tenders and auctions, and PPAs also were becoming increasingly important.[97]

Mexico was again among the world's top 10 installers, ranking ninth for additions ahead of Argentina, and ending the year with 6.2 GW.[98] The country cancelled planned auctions and revised its renewable energy support scheme, and annual installations (up 38% over 2018) were due mainly to bilateral PPAs.[99] Argentina's market also has been affected by on-and-off policies but, thanks to awarded capacity from auctions launched between 2016 and 2018, the country more than doubled its capacity to end the year with 1.6 GW.[100] Argentina's largest wind farm (220 MW) was completed in 2019; the project has an average capacity factor of 51%, and is expected to supply enough electricity for more than 330,000 homes.[101]

Brazil added its lowest amount of wind power capacity since 2011, due to a break in the country's auction schedule during the recent national economic crisis; even so, by one account, more wind power than thermal power capacity was installed in 2019.[102] Brazil's free market[ii] has expanded in recent years, and in 2019 more than 2 GW of new wind power capacity was sold into the free market compared to 1.1 GW via public auctions.[103] At year's end, with almost 15.5 GW of capacity in operation, Brazil remained home to more than half of the total capacity operating in Latin America and the Caribbean.[104] Wind power accounted for 9.4% of Brazil's electricity generation (up from 8.3% in 2018).[105]

Canada again added a modest 0.6 GW, bringing total capacity to 13.4 GW.[106] Wind power has been the country's largest source of new electricity generation over the past decade, driven by environmental concerns and by the relatively low price of wind-generated electricity.[107] The leading provinces for cumulative capacity were Ontario (5.4 GW), Quebec (3.9 GW) and Alberta (1.7 GW).[108] Wind power accounted for 6.5% of Canada's electricity generation in 2019, up from 5.8% in 2018.[109]

i The PTC gives wind energy generators a tax credit of roughly USD 0.02 per kWh for electricity fed into the grid. Starting in 2021, the credit will decline steadily until it ends in 2025.

ii Brazil's power sector is undergoing a transition that encourages the development of a free market, in which power buyers, sellers and traders can negotiate PPAs directly. See endnote 103 for this section.

Wind energy is also playing a growing role in Australia, which again saw records for both installations and output in 2019.[110] The country brought online more than 0.8 GW of capacity for a total approaching 6.3 GW.[111] Wind power surpassed hydropower in 2019 to become Australia's largest renewable source of electricity, producing 19.5 TWh, or 8.5% of the country's total generation.[112] Far higher shares were achieved in several states, including in South Australia (29%), Victoria (28%) and New South Wales (22.6%).[113] The rapid increase in the number and capacity of large wind (and solar) power projects in Australia continued to challenge the grid, resulting in project delays.[114] (→ *See Solar PV section in this chapter.*) By year's end, more than 5.5 GW of additional capacity was under construction or financially committed.[115] Other parts of Oceania were quiet, with little wind power activity observed in 2019.[116]

Africa and the Middle East together added about 2.6% less capacity than they did in 2018, with around 0.9 GW brought online in 2019.[117] At year's end, 13 countries in Africa and 6 in the Middle East had a cumulative 6.7 GW of wind power capacity (all onshore), with most of it in South Africa (2.1 GW), Egypt (1.5 GW) and Morocco (1.2 GW).[118] Challenges in both regions included uncertain or unsupportive policy and power market frameworks, bottlenecks in transmission infrastructure and off-taker risk.[119]

In Africa, the leaders[i] for new installations were Egypt (262 MW), Morocco (216 MW) and Ethiopia (120 MW).[120] Egypt's additions were in a single project, the country's largest and first privately owned wind farm.[121] Despite being among the top three on the continent for additions and total capacity, Egypt remained far short of its target of 7 GW by 2022, but the country had a project pipeline of 4 GW as of early 2020.[122] Senegal also added capacity: its first utility-scale wind farm (159 MW) began delivering electricity to the grid in December, with full commissioning planned for 2020.[123]

Jordan (0.2 GW) and Iran (50 MW) led the Middle East for new installations during 2019.[124] Saudi Arabia's government contracted for the country's first large-scale wind power plant, a 0.4 GW facility with an expected operation date of early 2022.[125] The Saudi government aims to free up for export much of the oil used to generate electricity.[126]

In the **offshore wind power segment**, five countries in Europe and three in Asia connected a record 6.1 GW in 2019 (up 35.5% over 2018), increasing cumulative global capacity to more than 29 GW.[127] Wind turbines operating offshore represented less than 5% of total global wind power capacity at year's end, but offshore additions accounted for 10% of all newly installed capacity (up from 5% in 2015), and 2019 was a record year for investment in future offshore capacity.[128] Europe accounted for 59% of new installations and Asia for 41%.[129]

China again led the sector, completing nearly 2.4 GW of capacity for a total of 6.8 GW, and easily surpassing a national target of 5 GW by 2020.[130] Record installations were driven by policy changes: for the first time, China announced reductions to the FIT for offshore wind power for 2019, and further cuts in 2020, and several new projects were initiated to take advantage of the policy before it expires.[131] Although the country has no long-term targets for offshore capacity, coastal provinces have targets and development plans, including Guangdong (30 GW by 2030), Jiangsu (15 GW) and Zhejiang (6.5 GW).[132] At year's end, more than 10 GW was under construction and an additional 30 GW had received approval.[133]

Elsewhere in Asia, Chinese Taipei commissioned its first offshore utility-scale (120 MW) project and announced that, in addition to its target of 5.7 GW by 2025, the country aims for a further 10 GW between 2026 and 2036.[134] Japan launched 3 MW of floating capacity to end the year with nearly 66 MW of offshore capacity and 14 GW in the pipeline; Vietnam had 0.1 GW of intertidal capacity with several projects under construction; and India launched a tender process for offshore wind power.[135]

Offshore wind power additions accounted for **10%** of all newly installed capacity, up from 5% in 2015.

i Kenya's 310 MW Lake Turkana wind power project remained the largest in Africa at the end of 2019. Several sources note that it started operations in 2019; however, the project began supplying electricity to the national grid in 2018, and Vestas announced the project's completion that year, so it was included with 2018 data in GSR 2019. See endnote 120 for this section.

Europe continued to be home to most of the world's offshore capacity. In 2019, the region added more than 3.6 GW (up 36% from 2018), a new high, bringing the regional total close to 22.1 GW.[136] Installations came online in the United Kingdom (1.8 GW), Germany (1.1 GW), Denmark (374 MW), Belgium (370 MW) and Portugal (8 MW); all but Germany set new records.[137] The United Kingdom accounted for about half of Europe's offshore installations and reached a year-end total of 9.9 GW offshore.[138] All turbines were grid-connected for the UK's 1.2 GW Hornsea One, making it the world's largest offshore wind farm as well as the farthest from shore.[139] Germany added more capacity offshore than on land, for the first time, and exceeded the national offshore target for 2020.[140]

Several European governments also increased targets for offshore wind power, driven at least in part by falling prices, raising the region's total targeted capacity by 2030 from 76 GW to 100 GW.[141] France, the Netherlands and the United Kingdom all held auctions for offshore capacity during 2019, including the world's largest-ever offshore auction – 5.5 GW was awarded by the UK government.[142] An additional five offshore corporate PPAs were signed, following the first in 2018, totalling more than 360 MW of future capacity.[143] In Sweden, however, a proposed 300 MW offshore wind farm that was permitted in 2012 was cancelled after the national military rejected revised plans.[144]

The US offshore capacity remained at 30 MW, but targets for state procurement increased from 9.1 GW in 2018 to 25.4 GW in 2019.[145] Vineyard Wind, a 0.8 GW project off the Massachusetts coast, was scheduled to begin construction in 2019, but was delayed repeatedly for further government study of the broader impacts of offshore wind farms[i] on commercial fisheries.[146] The project is the first in a long pipeline of large wind farms along the country's east coast, and the delay has caused wider uncertainty in the US offshore market.[147] However, construction did begin on a 12 MW project off Virginia's shores, and by year's end an estimated 7.5 GW was in advanced development[ii] along the US east coast.[148] During the year, six east coast states procured capacity, approved projects or passed legislation[iii], and a new coalition was launched to push for at least 10 GW off the California coast by 2040.[149] At year's end, a Maine utility announced that it was the anchor buyer in a PPA for the first US floating wind power project, a 12 MW facility off the state's coast.[150]

By the end of 2019, 18 countries (12 in Europe[iv], 5 in Asia and 1 in North America) had offshore wind capacity in operation.[151] The United Kingdom maintained its lead for total capacity (9.9 GW), followed by Germany (7.5 GW), China (6.8 GW), Denmark (1.7 GW) and Belgium (1.6 GW).[152] Europe was home to about 75% of global offshore capacity (down from 79% in 2018), with Asia accounting for nearly all the rest.[153] (→ *See Figure 39.*)

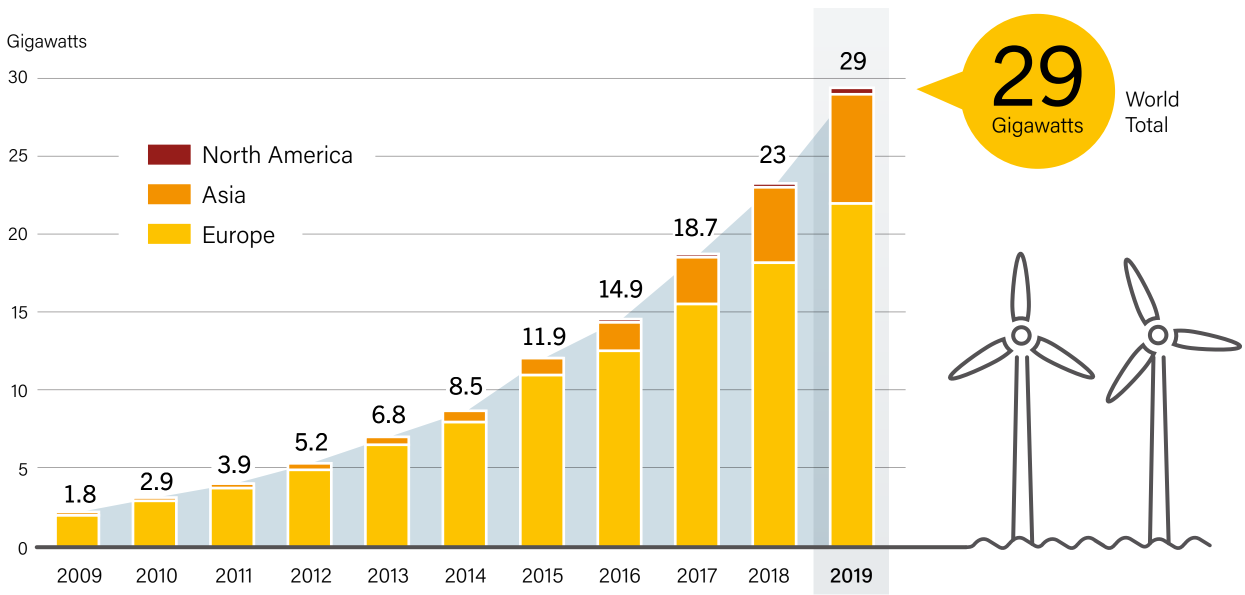
i Opposition that resulted in the failure of the proposed Cape Wind project in 2017 led developers and regulators to locate leases farther out from shore, pushing them into vessel routes and commercial fishing areas. See endnote 146 for this section.

ii Advanced development means that projects have a signed PPA, a firm turbine order or are proceeding under utility ownership. See endnote 148 for this section.

iii Connecticut committed to solicit 2 GW by 2030, enough to meet 30% of the state's electricity demand; Maryland raised its Renewable Portfolio Standard (RPS) to 50% by 2030, with incentives for deployment of 1.2 GW offshore capacity; and New Jersey more than doubled its offshore wind capacity target from 3.5 GW by 2030 to 7.5 GW by 2035. See endnote 149 for this section.

iv By year's end, all of the offshore capacity in France, Norway and Spain was in demonstration projects; all other European countries with offshore wind power capacity also had demonstration projects in place. See endnote 151 for this section.

FIGURE 39. Wind Power Offshore Global Capacity by Region, 2009-2019



Source: See endnote 153 for this section.

Additional countries were studying the feasibility of offshore wind or starting project development in 2019, and the World Bank Group announced a new programme to speed the deployment of offshore wind power in emerging markets, many of which have strong offshore wind resources.[154]

Cost reductions in new wind power projects have resulted from a combination of lower capital costs and improved performance.

Offshore and (mostly) onshore, wind turbines of various sizes, totalling an estimated 0.4 GW of capacity in nine countries, were decommissioned in 2019.[155] The United States took the lead, decommissioning about 195 MW of capacity.[156] In Europe, around 170 MW of capacity was decommissioned (down from 451 MW in 2018), led by Germany (97 MW), with turbines also decommissioned in Austria, Denmark, France and the United Kingdom.[157] Some of the decommissioned projects were repowered. (→ *See Industry section.*)

WIND POWER INDUSTRY

Wind energy has emerged as one of the most economical ways to add new generating capacity.[158] Yet, while falling prices are helping to move wind power into new markets and are pushing up sales, the global transition from FITs to auctions and tenders has resulted in intense price competition in some countries, challenging wind developers and causing attrition among turbine manufacturers.[159] Even as progress is made, new challenges have emerged in some markets, such as poorly designed tenders, permitting delays and lack of available land and grid access, as well as the inherent limitations of power systems and markets that were designed and optimised for centralised, large-scale fossil power.[160] (→ *See Systems Integration chapter.*) Meanwhile, the industry is working to meet each new challenge with improved technologies (including larger and more efficient turbines) and other advances (such as supply chain efficiencies) that are helping to further reduce the cost of energy and to better integrate wind energy with existing electricity grids.[161]

By one estimate, from 2018 to 2019 the global benchmark levelised cost of energy (LCOE) from new wind power projects declined 10% onshore (to an average USD 48.5 per MWh) and 28% offshore (USD 83.50 per MWh).[162] Cost reductions have resulted from a combination of lower capital costs and improved performance.[163]

Auctioned capacity in 2019 was more than double the 2018 total, with 25 GW auctioned onshore and 15.8 GW offshore in at least 18 countries (including wind-specific and technology-neutral/renewable energy auctions[i]).[164] Auction results vary widely depending on local conditions and costs[ii], project scale, expected commissioning date and other factors.[165] While declining costs and fierce competition have driven average bid prices down in many markets, bids have been rising in others, such as Germany.[166]

Some of the lowest winning bids (excluding China) in 2019 were seen in Brazil (USD 20.8 per MWh) and Denmark (USD 22.8 per MWh).[167] Saudi Arabia's first commercial wind farm, the 400 MW Dumat Al Jandal project, reached financial close in July at USD 19.9 per MWh.[168] In Latin America and the Caribbean, the surge in public auctions helped to drive down the region's average price for wind energy by 46% from 2016 to 2019.[169] Colombia's first successful renewable energy auction brought low average winning prices (for both wind and solar energy) of USD 28 per MWh in 2019.[170]

Across Europe, more than 14 GW of new wind power capacity was awarded (about 7.6 GW onshore and 6.8 GW offshore) through auctions in 2019.[171] The region's largest onshore auction was held in Poland, where 2.2 GW of capacity was awarded at an average price of EUR 49 (USD 55) per MWh.[172] Europe's winning onshore bids were in the range of EUR 21 to EUR 67.2 (USD 23.5 to USD 75.3) per MWh.[173] However, while average awarded bid prices continued to fall in Denmark and

i Unless noted otherwise, mentions of auctions and tenders as support mechanisms presume wind technology-specific tenders or those specific to renewables in general. Technology-neutral tenders (open to non-renewables) do not constitute a support mechanism, although such tenders can and do draw successful bids from renewable energy developers.

ii Note that bid levels do not necessarily equate with costs. Also, energy costs vary widely according to wind resource, project and turbine size, regulatory and fiscal framework, the cost of capital and other local influences. Bid levels differ from market to market due to varying auction designs, policies and risks, among other factors. See endnote 165 for this section.

Greece, for example, they increased further in Germany (above the statutory tariffs under the old FIT), where five of the six onshore wind power auctions in 2019 were undersubscribed.[174]

Offshore in Europe, prices in auctions (in France, the Netherlands and the United Kingdom) continued to fall due in part to technology innovations and economies of scale.[175] The United Kingdom awarded 5.5 GW of capacity offshore in a single auction, for projects to be commissioned between 2023 and 2026, with strike prices 30% below those of the 2017 auction.[176] The Netherlands held its second offshore wind tender for which the winning project (due online by 2023) will receive only the wholesale price of electricity and will pay an annual rent for seabed rights.[177]

In the United States, while average contract lengths shortened, wind PPA prices[i] remained level or even rose throughout 2019, following historic lows in 2018, in anticipation of the PTC phase-out and further exacerbated by tariffs.[178] Vestas blamed its rising execution costs and falling margins in the United States (the company's most important market) on trade conflicts and tariffs, which had cascading effects on the global supply chain.[179] US tariffs on steel and aluminium, which make up 70-90% of wind turbines, as well as tariffs on permanent magnets, have put pressure on the US network of suppliers.[180] By one estimate, US tariffs on Chinese imports increased the costs of US wind projects by as much as 20%.[181] Several other countries also have introduced new trade barriers on wind-related commodities and components, which affects the flexibility of supply chains, even as local content rules push for localisation of manufacture.[182] (→ *See Sidebar 3.*)

While the shift from FITs to other instruments such as tenders and auctions has helped push down the cost of energy, it also has helped create a race to the bottom on price.[183] This intense competition (combined with trade tariffs in some cases) has challenged the sustainability of the entire supply chain, squeezing the margins of turbine manufacturers, developers and operations and maintenance (O&M) suppliers.[184] For a variety of reasons, including tender design and unrelenting competitive pressures, the diversity (in size and geography) and the number of auction participants has dropped sharply in some countries, including Germany and India, with only a handful of large international corporations submitting bids.[185]

The wind industry has seen more than 100 turbine suppliers over the years, with a peak of 63 suppliers reporting installations during 2013, but the number has declined rapidly since 2015; in 2019, four companies (three in China and one in India) had no new installations.[186] While 33 manufacturers delivered wind turbines to the global market during the year, the top 10 companies captured 85.5% of the capacity installed (up from 85% in 2018, 80% in 2017 and 75% in 2016).[187] The leading four companies – Vestas (Denmark), Siemens Gamesa (Spain), Goldwind (China) and GE Renewable Energy (United States) – were responsible for about 55% of capacity installed during 2019.[188] Vestas stayed on top but lost the most market share; Siemens Gamesa jumped from fourth to second (and led the offshore market); GE benefited from the healthy US market; and Goldwind continued to dominate in China while also increasing its presence in the Asia-Pacific region and beyond.[189] China-based Envision also remained in the top five globally.[190] Germany's Nordex-Acciona and Enercon (despite a significant decline in market share) took the seventh and eighth spots, and the remaining companies among the top 10 (all Chinese – Ming Yang, Windey and Dongfang) moved up in ranking thanks to a strong domestic market.[191]

By contrast, Senvion (Germany) and India's Suzlon – both of which were among the top 10 in 2017 – suffered severely as a result of declining home markets, as did Enercon, despite

i Prices in the United States reflect the US production tax credit, which applies to commercial wind power systems.

remaining among the top 10 (80% of the company's installations were outside of Germany).[192] After two years of dramatic decline in the German onshore market, Enercon cut thousands of jobs at home and abroad, ended co-operation with domestic production partners and reported significant losses.[193] Senvion, once a leading innovator in the global industry, filed for insolvency in 2019; Siemens Gamesa took over some of Senvion's key European assets and businesses.[194] In early 2020, Suzlon disclosed outstanding debt of about USD 1.8 billion and started debt restructuring.[195]

Even the top manufacturers suffered losses, closed factories and laid off workers in 2019, despite record turbine orders (globally and for individual companies) and increased revenues, due to rising costs that included trade-related tariffs.[196] But some companies opened new facilities as well, driven by the need to reduce transport costs and to access new revenue sources, as well as by local content requirements.[197] For example, Vestas opened a new turbine factory in Brazil, and MHI Vestas Offshore Wind (Denmark) signed a contract for blade materials in Chinese Taipei; Nordex opened a rotor blade factory in Mexico; Siemens Gamesa completed Turkey's first nacelle factory, a condition of Turkey's first wind tender in 2017, and confirmed plans for a nacelle assembly plant in Chinese Taipei; and GE started constructing a factory in China for its 12 MW Haliade-X.[198]

Many wind turbine manufacturers and project developers were pulling together teams to expand into solar PV, and many were developing hybrid projects during 2019.[199] In Australia, China, India, the United States and several European countries, wind power projects have been co-located with solar and/or storage projects to reduce energy prices while mitigating the impacts of variability and expanding revenue opportunities.[200] Some companies have taken this a step further. In 2019, Acciona (Spain) was studying the use on its turbine towers of flexible solar PV thin films made of carbon to power auxiliary systems.[201] Also during the year, a 2 MW hybrid project in Minnesota was the first in the United States to combine solar and wind power at the same interconnection, using a GE turbine that routes solar and wind energy through a shared inverter.[202] Pairing technologies not only side-by-side but at the same interconnection reduces costs of equipment, siting, grid connection, financing, and operations and maintenance compared to separate projects, while also increasing capacity factors.[203] The Minnesota project, for example, expects a capacity factor of 65-70%.[204]

Both the number and size of large projects continued to increase in 2019, especially onshore in China and the United States and offshore in the United Kingdom.[205] By year's end, the largest projects in operation were the East Anglia (0.7 GW) and Hornsea One (1.2 GW) off the UK coast.[206] Particularly offshore, the rapid increase in project and turbine size has helped to reduce costs through scale and standardisation – as project size increases, the costs of capital and the per MW costs of planning and balance-of-plant all typically decline.[207]

The trend also continued towards larger machines (including longer blades, larger rotor size and higher hub heights, and therefore higher power rating) for both onshore and offshore use, as turbine manufacturers aimed to boost output and to gain or maintain market share.[208] The average size of turbines delivered to market was 12% larger than in 2018 (2.45 MW), at 2.76 MW (2.6 MW onshore and nearing 5.7 MW offshore) in 2019.[209] Onshore, the largest country averages were seen in Morocco (4.2 MW), Finland (almost 4.2 MW) and Norway (3.8 MW), with averages exceeding 2 MW in all other established markets – including Brazil (2.6 MW), the United States (2.5 MW) and China (nearly 2.4 MW).[210] Offshore, the highest average power ratings were in Belgium and Portugal (both 8.4 MW), and in Denmark (8.3 MW).[211] Across Europe, the average per unit capacity of newly installed turbines offshore in 2019 was 7.2 MW, up from 6.8 MW in 2018.[212]

The world's **largest turbine,** at 12 GW, started generating electricity in November, and serial production was scheduled to begin in 2021.

Turbines are set to get only bigger. Siemens Gamesa launched a 10 MW offshore turbine in January 2019 and presented an upgraded 11 MW model late in the year; the company plans to have the machine on the market in 2022.[213] MHI Vestas also had a 10 MW turbine under way in 2019.[214] Chinese manufacturers are in competition to develop machines that match these capacities, and both Dongfang (prototype) and CSIC Haizhuang (plan only) unveiled 10 MW machines in 2019.[215] GE installed its first Haliade-X (12 MW) prototype at the Port of Rotterdam; the world's largest turbine to date started generating electricity in November, and serial production was scheduled to begin in 2021.[216] The machines blades are the longest ever made, at 107 metres, about the length of a football pitch (soccer field), and a single turbine is expected to generate enough electricity for 16,000 European homes.[217] Other turbine and generator companies are working on the next generation, envisioning unit capacities of 20 GW.[218]

Offshore developers are taking advantage of larger turbines as soon as they become available, with several orders placed for these mega-turbines during 2019.[219] Larger turbines mean that fewer foundations, converters, cables, less labour and other resources are required for the same output, translating into faster project development, reduced risk, lower grid-connection and O&M costs, and overall greater yield.[220]

At the same time, increasing machine size (whether for onshore or offshore use), large projects and developments farther out to sea have required that suppliers adapt designs to minimise the logistical challenges of manufacture, transport, installation as well as O&M.[221] GE, for example, developed a two-part blade that can be assembled on-site for its largest onshore turbine (5.3 MW).[222] Drones already have been used to inspect blades, reducing outage time from hours to minutes and reducing the required numbers of vessel trips.[223] In 2019, Vestas unveiled a research partnership to develop drone technology to support blade installation, and Siemens Gamesa, Ørsted (Denmark) and Esvagt (Danish vessels supplier) were exploring how to use drones to transport spare parts to offshore wind projects.[224] Some operators have begun to pool resources at centralised facilities or to expand operations hubs at sea that can house technicians for weeks at a time.[225]

The offshore industry also made advances in the segment of floating turbines, which offer the potential to expand the areas where offshore wind energy is viable and economically attractive because they can be placed where winds are strongest and most consistent, rather than where the sea-floor topography is suitable.[226] Several configurations for floating substructures continue to be developed and demonstrated in Europe and elsewhere, and the technology is becoming increasingly cost-competitive.[227]

During 2019, Portugal installed the first platform of WindFloat Atlantic, and the first of three 8.4 MW turbines began feeding the grid, while Spain tested the first multi-turbine floating platform.[228] Innogy SE (Germany), Shell (Netherlands) and Steisdal Offshore Technologies (SOT, Denmark) announced the final investment decision to build a demonstration project off Norway using SOT's modular floating foundation concept, which can be fully industrialised and deployed without installation vessels.[229] By year's end, Europe's floating fleet reached 45 MW, and an estimated 80.5 MW was operating offshore around the world.[230]

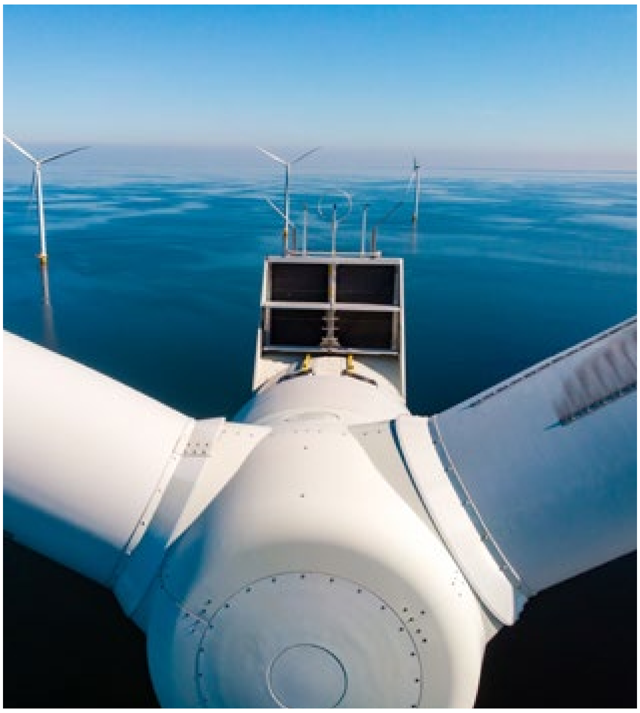
The low centre of mass of vertical-axis wind turbines and their potential for use with a floating platform has revitalised interest in the concept.[231] Several attempts, often unsuccessful, have been made in the past to develop these turbines for offshore use.[232] In 2019 and early 2020, Swedish company SeaTwirl, which is developing a floating vertical-axis turbine, announced that it had secured patents in China, Europe and the United States.[233] In September the firm launched a two-year project with the ultimate aim to commercialise its 1 MW turbine.[234] Vertical-axis designs have the potential to greatly reduce costs by eliminating the need for a number of components, enabling the use of cheaper platforms, improving stability and requiring easier and less costly maintenance compared to horizontal-axis turbines.[235]

In Europe, major offshore wind power developers advanced efforts to produce hydrogen from excess wind energy for greater grid flexibility or for use in transport and industry.[236] In 2019, Ørsted (Denmark), the world's largest offshore wind developer, announced plans to use electricity from wind farms being built off the Dutch coast to produce hydrogen for sale to industrial customers.[237] Siemens joined a partnership to develop a hybrid solar PV-wind power project in Australia for hydrogen production, and partnered with Shell (Netherlands) and grid operator TenneT (Netherlands/Germany) to propose a joint offshore wind power and hydrogen tender in Germany.[238] (→ *See Systems Integration chapter.*)

As offshore wind power has advanced, particularly floating technologies, Shell and other major oil companies have become interested in the sector.[239] Developments in 2019 included: Italy's oil and gas contractor Saipem unveiled a new substructure that can be a foundation for a range of turbine sizes; US-based ExxonMobil was researching the use of floating turbines to enhance oil production; and Equinor (Norway), which built the world's first floating offshore wind project (Hywind Scotland), entered the Chinese offshore market and committed to constructing a project to supply oil and gas facilities by 2022, aiming to reduce costs 40% compared to Hywind Scotland.[240]

New offshore markets still face challenges that Europe and China have addressed, including developing supply chains, a trained workforce and associated infrastructure such as ports, rail links and installation vessels, as well as grid infrastructure and technology for electrical connections.[241] Much of the Asian market also lacks viable finance solutions and co-operation among the relevant countries.[242] However, several countries – including India, Turkey and Vietnam – were collaborating with Denmark in 2019 to develop roadmaps and build technical capacity.[243]

In the United States, states are collaborating to establish an efficient supply chain and are investing in grid infrastructure.[244]



US utilities and project developers are partnering with Europe's largest offshore wind developers to set up manufacturing hubs and build projects, while also working with US government agencies, environmental organisations and the fishing industry to study and address the potential impacts of offshore wind power on fisheries and wildlife.[245]

Around the world, and particularly onshore, major manufacturers are focused increasingly on the repowering segment.[246] Historically, repowering has involved the replacement of old turbines with fewer, larger, taller, and more-efficient and reliable machines at the same site, but increasingly operators are switching even relatively new machines for larger and upgraded turbines (including software improvements) or are replacing specific components, such as blades (partial repowering).[247] Such partial repowering can extend turbine lifetime while greatly increasing a wind farm's performance.[248] Nearly every major turbine manufacturer offers various upgrading services.[249]

In the United States, project owners partially repowered a total of 2.8 GW at existing projects, up from 1.2 GW in 2018.[250] Despite the rising number of ageing turbines in some European countries, repowering was down relative to 2018 due to permitting challenges, lack of regulatory support and high wholesale electricity prices[i].[251] An estimated 185 MW of European capacity was repowered, mostly in Germany but also in Austria, Greece and the United Kingdom.[252] Repowering in China has been limited to date.[253]

As the earliest fleets of wind turbines reach retirement age, concerns are increasing about what to do with turbines at the end of their life. Although most of a turbine can be used on another wind farm or recycled, blades are made of materials that are difficult and expensive to recycle.[254] Developments in 2019 that were aimed at addressing this challenge included a partnership in Europe among wind power and chemical industries to advance recycling efforts for composite wind turbine blades; plans by the Danish company Miljoskarm to grind blades into small pieces and use them in recycled plastic casing as noise barriers; and the construction by US-based Global Fiberglass Solutions of a recycling plant that will break down blades and turn them into water-resistant pellets or panels for use as flooring and walls.[255] In addition, US researchers were working to develop blades from a thermoplastic resin system, which has the potential to reduce the energy, time and cost involved in manufacturing while also allowing for blades to be recycled at the end of their life.[256]

Also in 2019, GE Renewable Energy announced that it would make its operations 100% carbon neutral by the end of 2020.[257] Siemens Gamesa committed to becoming a carbon-neutral company by, for example, switching all operations to renewable energy-based electricity sources, and in early 2020 it turned its attention to its international supply chain.[258] Also in early 2020, Vestas (which achieved 100% renewable electricity in 2013) joined RE100 and set a target to become carbon-neutral by 2030 through its own corporate actions. Vestas also announced plans to eliminate non-recyclable waste from manufacturing, operating and decommissioning of its wind turbines by 2040.[259]

→ *See Box 1 for developments in the small-scale wind power sector. Also see Sidebar 5 and Figure 40 on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.*[260]

i Old wind turbines that are no longer receiving FIT payments can operate in the open market or contract under PPAs (with similar prices). As long as wholesale prices are high enough to more than cover rising O&M costs, operators have a business case for continuing to operate the old turbines. See endnote 251 for this section.

Around the world, major manufacturers are focused increasingly on the **repowering segment.**

BOX 1. Small-scale Wind Power

Small-scale[i] (up to 100 kW) wind turbines are used for a variety of on- and off-grid applications, including defence, rural electrification, water pumping and desalination, battery charging, telecommunications and to displace diesel in remote locations. The annual global market continued to shrink in 2018 (latest data available) in response to unfavourable policy changes and ongoing competition from relatively low-cost solar PV.

By one estimate, 47 MW of new small-scale wind power capacity was installed in seven countries during 2018, down from an estimated 114 MW[ii] in 2017. China continued to be the largest market, with an estimated nearly 31 MW installed in 2018, a slight increase from 2017 but a substantial decline relative to previous years. The United States deployed an estimated 1.5 MW (2,661 units) in 2018, a 12% annual reduction that continued the country's downwards trend in small-scale turbines. The UK market also fell further from its 2014 peak, in step with FIT changes.

Japan and Denmark, by contrast, both saw significant increases during 2018. Japan added an estimated 12.9 MW (up from 2.85 MW in 2017) and had another 153 MW in the FIT-approved queue by year's end. Worldwide, more than 1 million small-scale turbines (totalling at least 1.7 GW) were estimated to be operating at the end of 2018.

In response to shrinking markets in recent years, the number of producers of small-scale wind turbines in China and the United States has declined sharply, with manufacturers relying heavily on export markets, which also are in decline. US-manufactured exports, for example, fell from 5.5 MW (USD 42 million) in 2017 to less than 1 MW (USD 4.6 million) in 2018. The number of small-scale wind turbine manufacturers that reported sales in the United States fell from 31 in 2012 to 8 in 2018, and several manufacturers reported that costs were affected during 2018 by tariffs on materials imported from China.

At least in the United States, however, things were looking up in 2019 with evidence that a 2018 extension of the US investment tax credit for small-scale wind power, combined with public research and development funding, could enable small and distributed wind power technology to turn the corner in the country. In addition, US R&D efforts were under way to make wind power a plug-and-play component in hybrid systems and microgrids, among other options.

Also in 2019, a small-scale turbine made by Hi-VAWT (Chinese Taipei) became the first vertical-axis turbine to achieve certification under the Small Wind Certification Council's Small Wind Turbine Program.

i Small-scale wind systems generally are considered to include turbines that produce enough power for a single home, farm or small business (keeping in mind that consumption levels vary considerably across countries). The International Electrotechnical Commission sets a limit at approximately 50 kW, and the World Wind Energy Association and the American Wind Energy Association as well as the US government define "small-scale" as up to 100 kW, which is the range also used in the GSR; however, size varies according to the needs and/or laws of a country or state/province, and there is no globally recognised definition or size limit. See endnote 260 for this section.

ii The significant reduction in reported deployment between 2017 and 2018 could be due in part to differences in data availability, from US Department of Energy, Office of Energy Efficiency and Renewable Energy, *2017 Distributed Wind Market Report* (Washington, DC: 2018), p. 12, https://www.energy.gov/sites/prod/files/2018/09/f55/2017-DWMR-091918-final.pdf.

Source: See endnote 260 for this section.

SIDEBAR 5. Renewable Electricity Generation Costs in 2019

Renewable power generation is increasingly becoming the default source of least-cost new power generation. The global weighted average levelised cost of electricity (LCOE)[i] from solar and wind power technologies again declined in 2019, with utility-scale solar PV down 13%, onshore and offshore wind both down 9%, and concentrating solar thermal power (CSP) down 1% compared with 2018[ii].

The 13% decline in the global weighted average LCOE of solar PV in 2019 – which was slightly below the 15% reduction in 2018 – was driven by declines in module prices and balance-of-system costs. The 9% decline in onshore wind costs was only slightly below the 10% reduction in 2018; however, the LCOE of offshore wind fell by three times the 3% decline of 2018. These cost decreases are due in part to technology improvements and to reductions in total installed costs, but also to increasing market competition. For example, major suppliers of turbines and associated technology for solar PV noted strong and increasing competition in the global marketplace, contracting sales, and declining or even negative margins. (→ *See Market and Industry chapter.*)

Because the LCOE of different technologies can vary greatly by country and region, the global weighted average LCOE is an imperfect measure; however, trends in this metric give a sense of overall movement and comparison with costs of generation from conventional fuels. In 2019, mature renewable electricity generation technologies – hydropower, bio-power and geothermal power – remained cost competitive with fossil-fuelled power technologies. The global weighted average LCOEs of solar and wind power technologies show that they continue to become more cost competitive with fossil fuels.

In particular, costs for solar PV and CSP as well as onshore and offshore wind have fallen sharply over the past decade. (→ *See Figure 40.*) Global average hydropower costs have risen since 2010 as more challenging sites are exploited, but nine-tenths of the new hydropower capacity added in 2019 still had lower costs than the cheapest fossil fuel-fired source of new electricity.

i All references to LCOE in this sidebar exclude the impact of any financial support policies, so the cost to final consumers will be lower than quoted here in markets where this support is material. The other key assumption is that the weighted average cost of capital is 7.5% in member countries of the Organisation for Economic Co-operation and Development (OECD) and in China, compared with 10% (adjusting for inflation) elsewhere. LCOE numbers presented here are therefore conservative given the low interest rate environment in 2019. Note also that costs are very location- and project-specific, and cost ranges can be substantial; the LCOEs presented here should be considered in the context of the country- and region-specific project cost ranges provided in International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2019* (Abu Dhabi: 2020), which also provides further details on the LCOE methodology.

ii All data in this sidebar are from the IRENA Renewable Cost Database 2020, which contains cost data on more than 17,000 renewable power generation projects, accounting for around half of all deployment to 2019. All cost data are expressed in USD_{2019}.

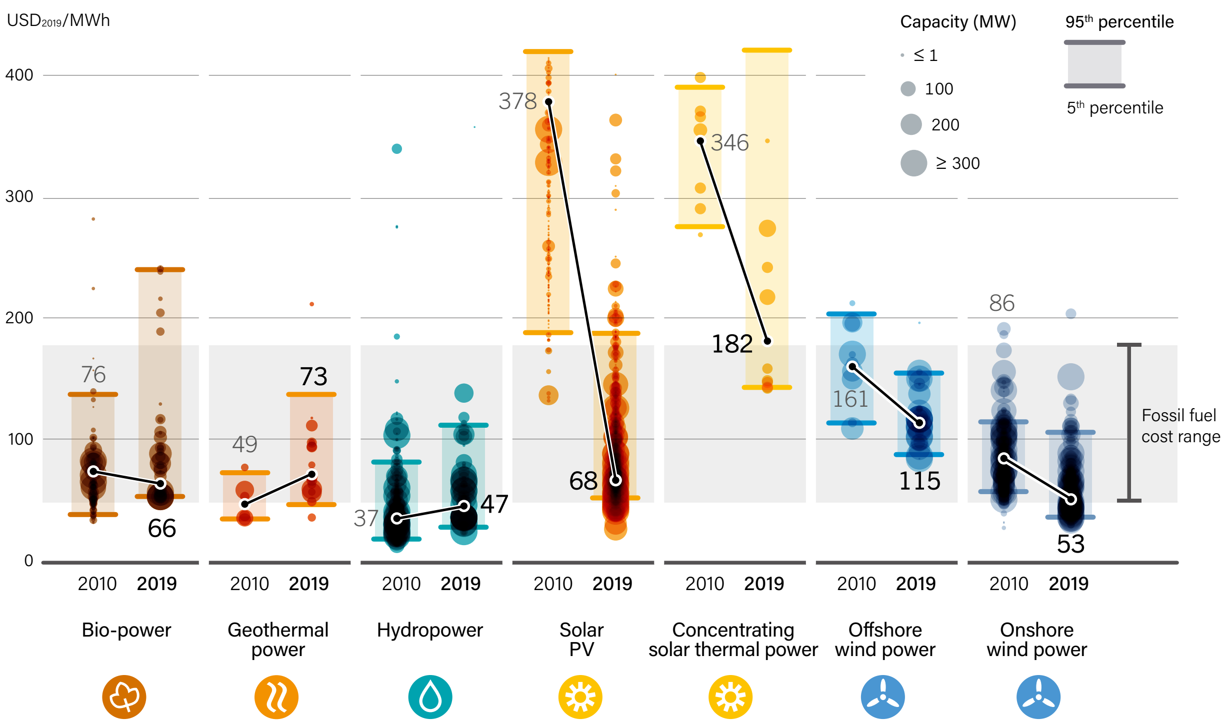
Source: IRENA. See endnote 260 of Wind Power section in this chapter.

Between 2010 and 2019, the global weighted average LCOE of commissioned projects fell 13% for bio-power, 29% for offshore wind power, 39% for onshore wind power, 47% for CSP and a precipitous 82% for solar PV. The global weighted average LCOE of geothermal projects increased to USD 73 per MWh in 2019, reflecting the higher volatility of the thin geothermal market.

The global weighted average LCOE of utility-scale solar PV for newly commissioned projects fell from USD 378 per MWh in 2010 to USD 68 per MWh in 2019. This reduction was driven mainly by the decline in module prices – which have fallen around 90% since 2010 – and by the reduction in balance-of-system costs, which together resulted in a nearly four-fifths decrease in the total installed costs of utility-scale solar PV between 2010 and 2019.

The global weighted average cost of electricity from onshore wind power projects fell 39% between 2010 and 2019, from USD 86 per MWh to USD 53 per MWh. This decline was driven by reductions in total installed costs, technology improvements in wind turbines (which increased capacity factors) and lower operations and maintenance costs. Wind turbine prices have fallen around 55-60% since 2010, with the global weighted average total installed cost declining more slowly at 24%. For onshore wind power, the key cost reductions from technology improvements have been through larger turbines, as their higher hub heights and swept areas collect more energy than older turbines.

FIGURE 40. Global Levelised Cost of Electricity from Newly Commissioned, Utility-scale Renewable Power Generation Technologies, 2010 and 2019

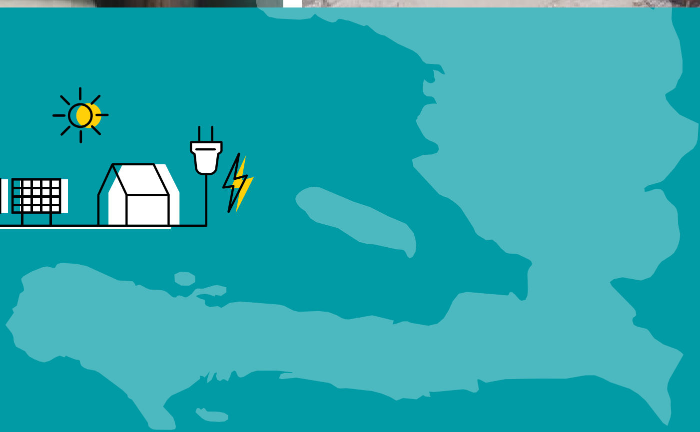


Note: These data are for the year of commissioning. The diameter of the circle represents the size of the project, with its centre being the value for the cost of each project on the y-axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

Source: IRENA.
See endnote 260 of Wind Power section in this chapter.

04

WORKING WITH COMMUNITIES TO REDUCE ENERGY POVERTY, HAITI



The social enterprise EarthSpark International is reducing energy poverty in Haiti by scaling and multiplying the delivery of clean energy technology, ranging from mini-grids to solar lanterns and energy-efficient cook stoves. EarthSpark began by helping a community organisation in the rural town of Les Anglais develop a store to supply clean energy technologies, education and training. In 2019, Earthspark worked with community members in the small fishing town of Tiburon to launch a community power solar mini-grid, which will serve 500 homes and businesses with 24/7 electricity.

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

KEY FACTS

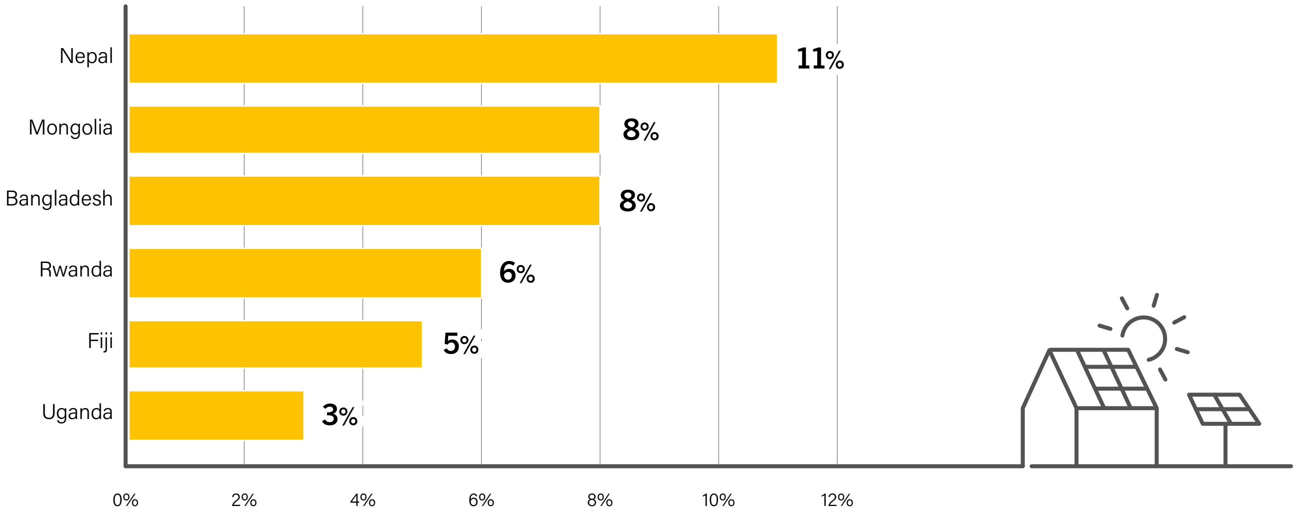
- By the end of 2018, the global population without access to electricity fell to 860 million, while 2.65 billion people lived without access to clean cooking facilities.
- The market for solar lighting systems and solar home systems grew 13% in 2019 – the highest growth of the past five years – with sales totalling some 35 million units.
- Solar PV and solar hybrid mini-grids, which accounted for just under 10% of the total installed mini-grids, continued to gain momentum and were increasingly positioned as the technology of choice.
- With a smaller number of advanced start-ups, investment in the off-grid solar sector dropped 42%, highlighting a shift from equity to debt financing.
- Investments in mini-grid start-ups more than doubled to a record USD 113 million. Clean cooking attracted less than 1% of the USD 4.4 billion investment required annually to achieve universal access in the sector.

Distributed renewables for energy access (DREA)[i] systems are renewable-based systems (stand-alone off-grid systems as well as mini-grids) that can generate and distribute energy independently of a centralised electricity grid. DREA systems provide a wide range of services – including for lighting, consumer and productive appliances, cooking, space heating and cooling – in both urban and rural areas of the developing world. They represent a key solution for fulfilling modern energy needs and improving the livelihoods of hundreds of millions of people presently lacking access to electricity or clean cooking solutions. For example, mini-grids and stand-alone systems are considered to be the least-cost option for providing electricity access to nearly half of the population in sub-Saharan Africa by 2030.[1]

DREA systems already provide electricity access to more than 14% of the combined populations of Bangladesh, Cambodia, Ethiopia, Kenya, Myanmar and Rwanda.[2] In 2017, the countries with the highest rates of electricity access from off-grid solar were Nepal (at around 11%), Mongolia (8%), Bangladesh (8%) and Rwanda (6%).[3] (→ *See Figure 41.*) Around 60% of the population in Papua New Guinea, and 35% in Vanuatu, relied on off-grid solar lighting systems that year.[4]

i See Sidebar 9 in GSR 2014 for more on the definition and conceptualisation of DREA. Note that since 2018 the GSR has used the acronym DREA to distinguish from distributed renewable energy (DRE) that has no link to providing energy access.

FIGURE 41. Top 6 Countries with Highest Electricity Access Rate from Off-grid Solar Solutions (Tier 1+), 2017



Note: Data in figure include solar home systems and mini-grids but exclude solar lights. Data are rounded to the nearest ones. Tier 1+ access technologies include small solar home systems (11-50 W), large solar home systems (>50 W) and mini-grids.

Source: World Bank. See endnote 3 for this chapter.

Because of their improved reliability, lower technology costs and the emergence of innovative financial schemes that improve accessibility, DREA systems are increasingly being considered as either a complement to, or in some situations a substitute for, traditional centralised approaches. Several countries, such as Ethiopia, Kenya and Rwanda, have developed integrated electrification strategies around both grid-based and DREA systems in their efforts to reach universal access in a cost-effective and timely manner.[5] Similarly, many countries, such as India, Indonesia and Nepal, are adopting key policy measures to accelerate the transition to clean cooking fuels and technologies.[6]

Beyond the opportunity to accelerate energy access in many regions of the world, DREA systems offer social, environmental and economic co-benefits, such as:

- reduced chronic and acute health effects, especially for women[i] and children;
- improved lighting quality for households;
- increased income and resilience for rural livelihood enterprises, including small and medium-sized businesses;
- improved delivery of public services such as health care and education; and
- reduced negative impacts on forests.[7]

In South Asia, 94% of off-grid solar customers reported improvements in their quality of life, and 11% of households using the systems saw about a 10% increase in their monthly incomes.[8] In East Africa, 89% of off-grid solar customers reported improved health, and for 28% of customers their monthly incomes increased (by 14% on average).[9] Among students using off-grid solar lighting in East Africa, the majority reported having much more time to dedicate to their education after the school day, as a result of longer and more reliable lighting hours.[10]

The DREA sector is a **significant employer** in emerging economies and has wide, positive impact through formal, informal and productive use jobs.

The rapid deployment of DREA systems has had a positive effect on job creation in many countries. The DREA sector accounted for some 95,000 formal jobs in India, 10,000 in Kenya and 4,000 in Nigeria.[11] Overall, in East, West and Central Africa, as well as in South Asia, an estimated 370,000 people work full-time in the off-grid solar sector.[12] (→ *See Sidebar 2.*)

This chapter reviews the current status of and trends in the DREA sector in developing countries and presents an overview of the major programmes and initiatives launched or operational in 2019.

i See Sidebar 9 in GSR 2015 on women and distributed renewables for energy access.

OVERVIEW OF ENERGY ACCESS

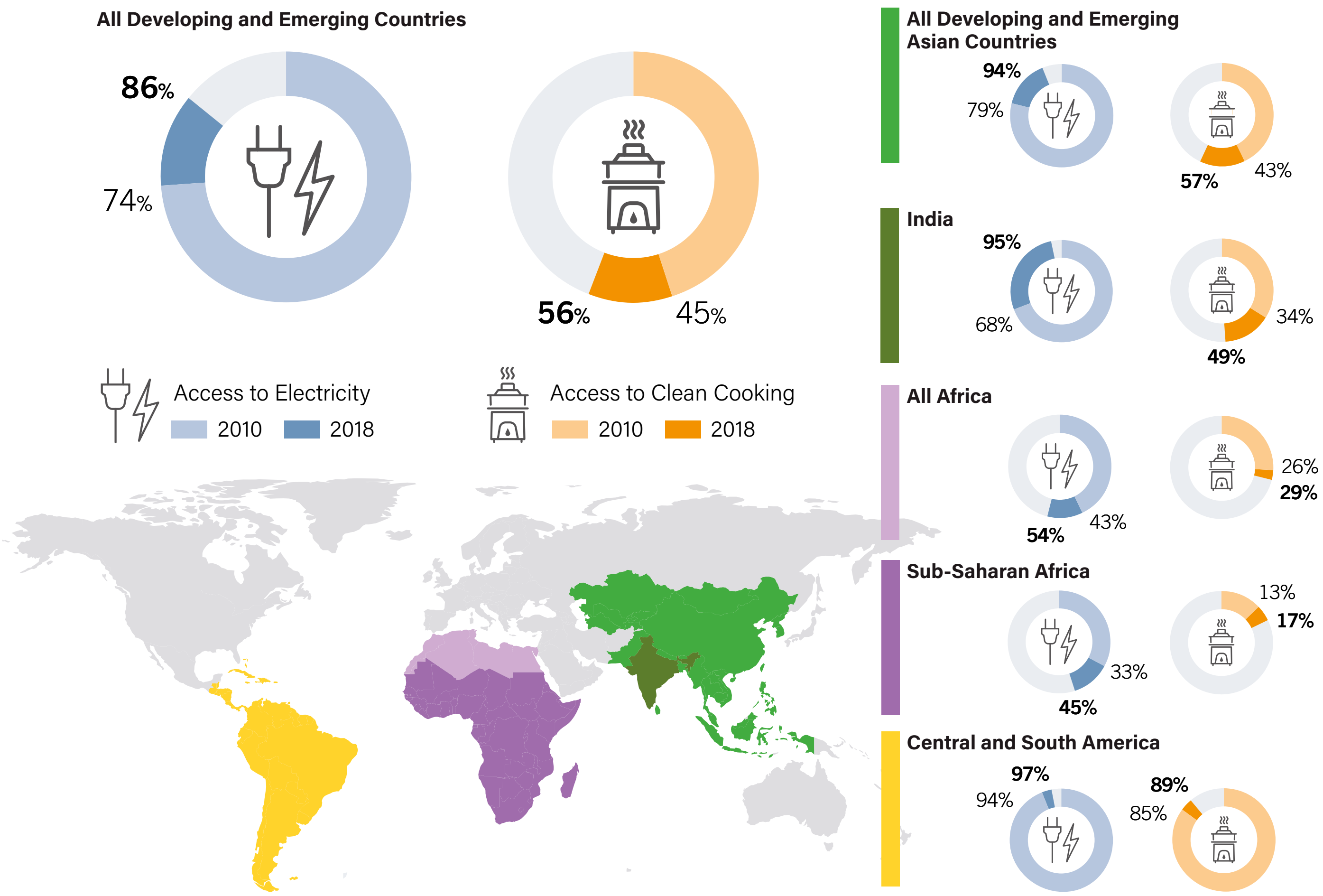
Worldwide, the number of people lacking access to electricity dropped to 860 million (11% of the population) in 2018, down from a reported 1 billion (13%) in 2017.[13] Meanwhile, an estimated 2.65 billion people (35% of the global population and 44% of the population in developing countries) were living without clean[i] cooking facilities in 2018, down from 2.7 billion in 2017 (36% of the global population and 46% of the population in developing countries).[14] (→ *See Figure 42.*)

With 153 million additional people gaining **access to electricity** every year, significant progress has been made in many regions.[15] However, this progress remains uneven. Around 80% of the 800 million people who gained access to electricity between 2010 and 2018 were in developing Asia, while more than two-thirds of the people without electricity access in 2018 were living in sub-Saharan Africa.[16] (→ *See Figure 42 and* ***Reference Table R20***.)

Some 20 million people in sub-Saharan Africa gained access to electricity between 2014 and 2018, and the region's electrification rate increased from 49% in 2015 to 54% in 2018.[17] Progress has been notable in East Africa, where Kenya, Ethiopia and Tanzania together accounted for more than half of the increase in the number of people with electricity access in the region.[18] In North Africa, access rates have neared 100%.[19] However, in 10 countries across the African continent more than 80% of the population still lacked access to electricity in 2018, with the highest shares in South Sudan (more than 99%, or 12.3 million people), the Central African Republic (more than 95%; 4.6 million), Chad (91%; 13.9 million) and the Democratic Republic of the Congo (91%; 76.9 million).[20]

i As per the methodology of the World Bank (Multi-Tier Framework), access to clean cooking facilities means access to (and primary use of) modern fuels and technologies, including natural gas, liquefied petroleum gas (LPG), electricity and biogas, or improved biomass cook stoves that have considerably lower emissions and higher efficiencies than traditional three-stone fires for cooking.

FIGURE 42. Access to Electricity and Clean Cooking by Region, 2010 and 2018



Source: IEA. See endnote 14 for this chapter.

In developing Asia, 94% of the population had electricity access in 2018.[21] For specific countries, the rates reached 95% in India and Indonesia and 85% in Bangladesh (up from only 47% in 2010).[22] Even so, a large number of people, mainly in rural and remote areas of developing Asia, still lacked electricity access in 2018, including 73.7 million in India (5% of the population)[i], 46.3 million in Pakistan (23%), 30.6 million in Myanmar (57%) and 25.1 million in Bangladesh (15%).[23]

In Central and South America, 97% of the population had access to grid electricity in 2018.[24] However, several countries still had high shares of people without access, including Haiti (61% of the population; 6.8 million people), Honduras (21%; 2 million) and Guatemala (7%; less than 1.2 million).[25] In the Middle East, 93% of the population had electricity access in 2018.[26] Yemen continued to lag, however, with 53% of its population (15.4 million people) lacking access to electricity.[27]

In the area of **clean cooking**, although millions of people have gained access to clean cooking facilities in recent years (including 450 million in India and China since 2010), progress continued to be uneven both within and across regions, and was often outpaced by population growth.[28] In 2018, 63.1% of people without access to clean cooking energy lived in developing Asia, and 34.1% lived in sub-Saharan Africa.[29] (→ *See **Reference Table R21**.*)

Across Africa, nearly 910 million people (71% of the population) lacked access to clean cooking facilities in 2018, with 853 million of them (83%) living in the sub-Saharan region.[30] Only 25 million people in sub-Saharan Africa gained access to clean cooking facilities between 2015 and 2018, and in about 22 countries in the region more than 90% of the population still relies on the traditional use of biomass[ii], coal or kerosene for cooking.[31] These countries include Nigeria (142 million people without access to clean cooking), Ethiopia (99 million) and the Democratic Republic of the Congo (81 million).[32]

In Asia, where most of the progress in clean cooking has occurred, some 1.7 billion people (43% of the population) still lacked access to clean cooking facilities in 2018.[33] In China and India, the share of the population without access dropped 15 points on average between 2010 and 2018 (falling from 45% to 28% in China and from 66% to 51% in India).[34] The number of people relying on the traditional use of biomass, coal or kerosene to meet household cooking needs in 2018 totalled more than 688 million (51% of the population) in India, 242 million (28%) in China, 135 million (81%) in Bangladesh, 108 million (54%) in Pakistan and 785 million (32%) in Indonesia.[35]

Around 57 million people in Central and South America (11% of the population) did not have access to clean forms of cooking in 2018.[36] In Haiti, 94% of the population (10 million people) depended on traditional cooking fuels and devices, and in Guatemala, Honduras and Nicaragua less than 60% of the population had access to clean cooking (9 million, 4 million and 3 million people, respectively).[37]

In the Middle East, where 96% of the population had access to clean cooking facilities in 2018, Yemen lagged with an estimated 34% of its population (10 million people) lacking access to modern cooking fuels and technologies.[38]

TECHNOLOGIES AND MARKETS

DREA solutions are an effective, established solution for providing energy access and served some 150 million people around the world in 2019.[39] The number of people obtaining electricity access through DREA systems increased an estimated three-fold between 2010 and 2017.[40] In 2017, DREA systems provided electricity access to more than 60% of the rural populations in both Ethiopia and Myanmar.[41]

Depending on a country's infrastructure and market readiness, a range of DREA technologies are being deployed to provide energy access. Populations that are not served through grid connections or extensions can obtain access to electricity through DREA solutions such as solar PV, bio-power, and hydropower mini-grids and stand-alone solar PV systems. DREA systems also are increasingly being used in grid-connected areas to address the unreliability of existing electricity infrastructure. For clean cooking, DREA systems use biomass, biogas, solar and ethanol.

150
million people
worldwide benefited from energy access through DREA systems in 2019.

i India announced in 2019 that it had provided access to all willing households after connecting 26 million households since October 2017 through its Saubhagya scheme. Efforts are being undertaken to provide a reliable, 24/7 supply of electricity to these populations.

ii See Glossary.

ACCESS TO ELECTRICITY

Off-grid solar solutions (solar lighting systems and solar home systems) accounted for nearly 85% of DREA systems worldwide in 2019, and since 2010 more than 180 million off-grid solar units have been sold, including 150 million pico solar products[i] and 30 million solar home systems.[42] In at least 10 countries or territories – Benin, Burkina Faso, Fiji, Jordan, Kenya, Papua New Guinea, Rwanda, Samoa, Tanzania and Vanuatu – at least 9% of the population has benefited from off-grid solar lighting systems.[43]

The market for off-grid solar systems grew 13% in 2019 – the highest growth of the past five years – with sales totalling some 35 million units, up from 31 million units in 2018.[44] (→ *See Figure 43.*) This increase is attributed mainly to a higher-than-expected decline in solar PV prices and to gains in the efficiency and commercial viability of off-grid systems, which have made them more economically attractive.[45] In addition, the availability of proven, viable and affordable consumer financing models, specifically the "pay-as-you-go" (PAYGo) model, has been instrumental in expanding the off-grid solar market.[46]

A record 8.5 million units of affiliated[ii] off-grid solar products were sold in 2019, up 12% from 2018.[47] (→ *See Figure 43.*) Pico solar systems continued to dominate, with around 7 million units sold in 2019 and 4.5% growth in sales (by volume) compared to the previous year.[48] However, the market share of solar home systems[iii] expanded – from 13% in 2018 to 18% in 2019 – due to the greater affordability of these systems and the rising demand for off-grid appliances – and sales jumped 66.6% to 1.5 million units.[49] (→ *See Box 1.*) The total installed capacity of off-grid solar products grew to 94.1 MW in 2019, up from 58.8 MW in 2018.[50]

The main regional markets for affiliated off-grid solar systems – together accounting for nearly three-quarters of the total sales volume – continued to be East Africa (49% of total sales in 2019; led by Kenya) and South Asia (23%; led by India).[51] After declining in 2018, sales of affiliated products in the East African market recovered in 2019, increasing 41%, whereas sales in South Asia fell 28%.[52] Sales also continued to grow in the Middle East and North Africa (up 57%, with the products used mainly to meet humanitarian needs) as well as in Central Africa (up 32%) and West Africa (up 27%).[53]

The top five markets for affiliated off-grid solar systems in 2019 (by sales volume) were Kenya, India, Ethiopia, Uganda and Nigeria.[54] Sales expanded the most in Ethiopia (up 108% to 1.01 million units) and Kenya (up 55% to 1.97 million units).[55] (→ *See Figure 44.*) The growth in Kenya is attributed mainly to rising customer demand for solar home systems and to the country's conducive sales environment, resulting from an adequate regulatory framework and from the impetus provided by the ongoing World Bank-funded Kenya Off-Grid Solar Access Project (KOSAP).[56]

i Pico solar systems/products refer to off-grid solar systems rated up to 10 watts-peak (W_p), that are used primarilly for lighting and mobile charging purposes.

ii Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members, companies selling products that meet Lighting Global Quality Standards, and appliance companies that participated in the Global LEAP Awards, or are engaging with the Low Energy Inclusive Appliances (LEIA) programme.

iii Solar home systems are off-grid solar systems, rated at 11 W_p and above, that can be used for lighting purposes and to power electrical appliances.

BOX 1. Energy-Efficient Appliances

The adoption of energy-efficient appliances continues to expand with the growth of distributed renewable solutions for energy access and increasing focus on productive uses of energy.

Global sales of off-grid consumer appliances, such as fans, televisions and refrigerators, have increased 50% to 80% annually since 2014. In 2019, an estimated 1.2 million off-grid appliances were sold, with the majority being televisions and fans. In addition, the demand for packaged off-grid solar solutions and appliances has grown, and up to 80% of solar home systems now include an appliance such as a fan, radio or television. Electric cooking also is increasingly in demand, and the 2020 Global LEAP Awards administered by CLASP provided grants to appliance manufacturers and off-grid solar distributors for efficient electric pressure cookers for use in off-grid and weak-grid settings.

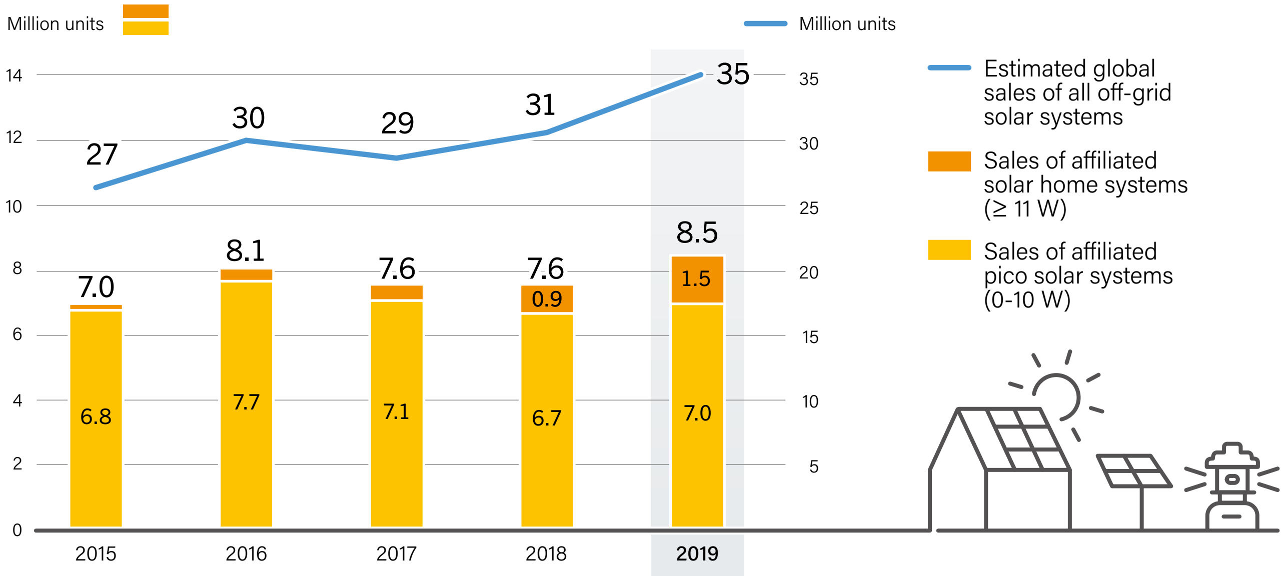
Interest in productive end-use appliances powered by distributed renewables is rising as well. Existing applications include water pumps, cold storage and agro-processing. However, the market remains in its infancy, and appropriate delivery models continue to be tested to reach commercial viability and scale.

High-risk funding is required to support research and development, pilot initiatives, consumer research and capacity building. Some of the programmes that have supported the development of appliances and ecosystems for productive uses of energy include the 2019 Global LEAP Awards (with a focus on solar water pumps and off-grid refrigerators), the Efficiency for Access Research and Development Fund and the CEEW-Villgro Powering Livelihoods initiative.

Unlocking the market for off-grid appliances requires wider availability of products for consumers and improved access to financing. In some contexts, service-based delivery models allow consumers to access products on a pay-per-use basis.

Source: See endnote 49 for this chapter.

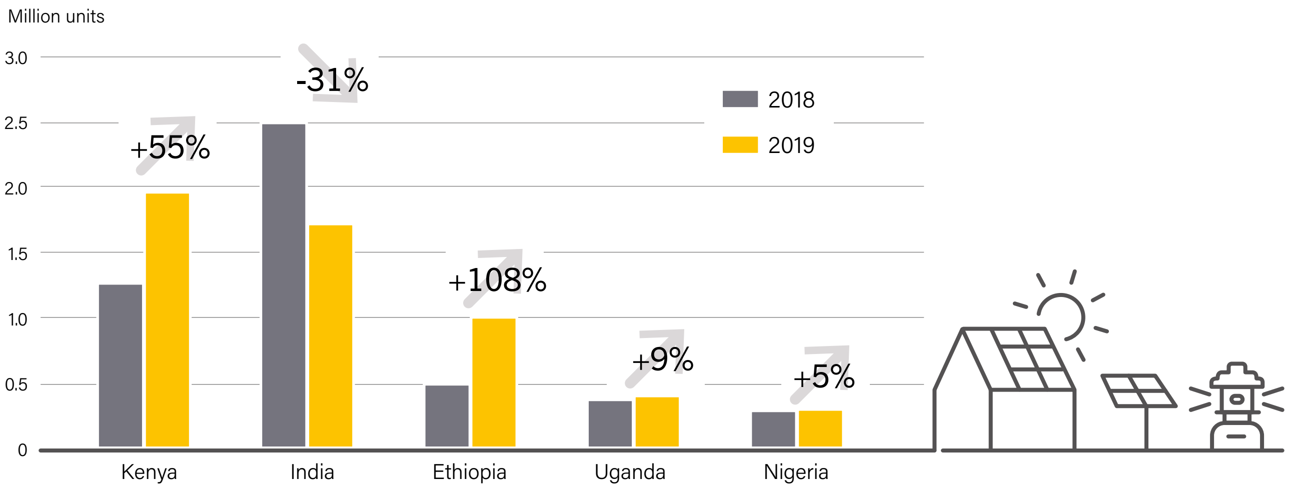
FIGURE 43. Global Sales Volumes of Off-Grid Solar Systems, 2015-2019



Note: Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members and companies selling products that meet Lighting Global Quality Standards.

Source: IFC and GOGLA. See endnote 44 for this chapter.

FIGURE 44. Sales Volumes of Affiliated Off-Grid Solar Systems in Top 5 Countries, 2018 and 2019



Note: Figure includes only countries that provided data for more than three companies. Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members and companies selling products that meet Lighting Global Quality Standards.

Source: GOGLA. See endnote 55 for this chapter.

In Ethiopia, three key policy interventions catalysed the boost in sales in 2019: the provision of adequate foreign currency to facilitate imports of off-grid solar products, implementation of quality standards for these products and the development of an appropriate ecosystem for PAYGo companies to operate.[57] Sales also increased in Uganda (up 9%) and Nigeria (up 5%).[58] In contrast, the sales volume in India fell nearly 31% due to policy uncertainties, the limited funding availability of microfinance institutions, and rising imports and sales of non-solar portable lanterns in the country.[59]

Cash-based sales continued to dominate the market for affiliated off-grid solar products. Of the total volume of affiliated products sold in 2019, 75% of the transactions were made in cash and 25% through the PAYGo model.[60] Cash sales of affiliated off-grid solar products were more prominent in South Asia than in the African sub-regions – representing nearly 99% of sales in South Asia but just over 60% in sub-Saharan Africa.[61]

A key driver of sales in East, West and Central Africa has been the availability of the PAYGo model for the commercialisation of off-grid solar products. In 2019, PAYGo sales accounted for 39%, 47% and 22% of the total sales of affiliated products in these regions, respectively.[62] For affiliated solar home systems, nearly 70% of the sales were completed using the PAYGo model, whereas for pico solar products, 81% of sales were conducted on a cash basis.[63]

Renewable energy-based mini-grids continued to gain momentum as more projects were developed across Africa and Asia. Worldwide, an estimated 19,000 mini-grids had been installed by the end of 2019, serving some 47 million people.[64] Around half of these mini-grids were based entirely or partially on renewables, with most supplied by hydropower. Solar PV and solar hybrid systems, which accounted for just under 10% of the installed mini-grids, are increasingly being positioned as the technology of choice, with solar installations growing 100% between the 2009-2013 period and the 2014-2018 period.[65] The shift to solar PV has been enabled by the drop in prices for PV technologies and the emergence of innovations such as smart meters and remote monitoring.

An estimated 354 MW of solar mini-grid capacity was added globally in 2018, providing more than 3 million people with electricity access.[66] Around 77% of the systems were in Africa and only 16% in Asia.[67] (→ *See Figure 45.*) In 2019, some 150 mini-grid projects were completed, another 1,600 projects were announced, and around 7,500 projects were either in planning or under development, mainly in India, Nigeria and Senegal.[68]

Africa continued to be a major testing ground for mini-grid projects during the year. In Nigeria, one of the most promising markets for mini-grids under a public-private partnership model, projects were commissioned in several states.[69] As part of Nigeria's national Energizing Education Program, mini-grids with capacities ranging from 2.8 MW to 7.1 MW were commissioned at four universities.[70] In Sierra Leone, some 24 solar hybrid mini-grids totalling 1.2 MW were installed across small towns and villages to increase energy access.[71]

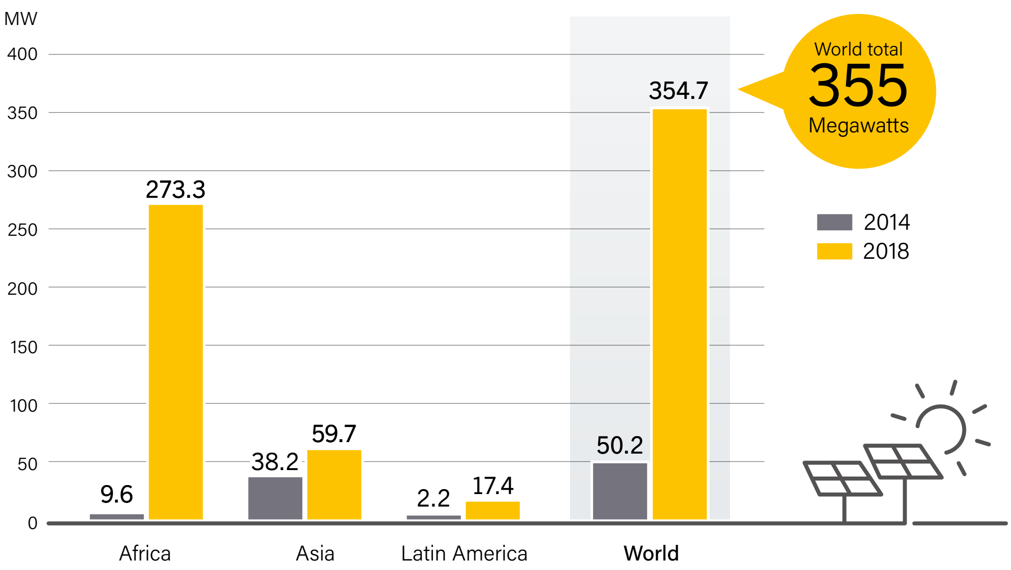
Solar PV mini-grids

are increasingly the preferred technology for providing electricity access across Africa and Asia.

In Tanzania, 11 solar mini-grids were commissioned on 10 different islands on Lake Victoria as part of the first phase of the Micro Power Economy Tanzania Roll-out project, co-funded by the European Union.[72] Solar mini-grids of 42 kW capacity were deployed in Mali to provide electricity access to 20 villages.[73] In Zambia, ENGIE (France) and Huawei (China) completed mini-grid installations in the districts of Chitandika and Mwinilunga, respectively.[74] Late in the year, Burkina Faso, Ethiopia and Togo all launched tenders for mini-grid deployments.[75]

Countries in Asia – including Afghanistan, Myanmar, India and Nepal – installed the highest numbers of mini-grids in 2019.[76] Myanmar, which has a long track-record of micro-hydro and biomass-based mini-grids, added around 100 solar hybrid mini-grids during 2017-2019.[77] Under the Rural Development Department's mini-grid programme, which aims to electrify every household in Myanmar by 2030, the country commissioned its largest solar mini-grid in 2019.[78] On the Philippine islands of Palawan, WEnergy (Singapore) installed a 2.4 MW solar hybrid mini-grid in Sabang and began building a second (662 kW_p) solar hybrid mini-grid in Panlaitan.[79]

FIGURE 45. Installed Capacity of Solar PV Mini-Grids, Selected Regions and World, 2014 and 2018



Note: World total may not add up due to rounding.

Source: IRENA. See endnote 67 for this chapter.

In addition to meeting basic power needs for lighting, television and mobile charging, the provision of energy access has the potential to catalyse income-generating activities and trigger wider economic development in rural and remote areas.[80] Activities that generate income, increase productivity, enhance diversity and create economic value in these areas are known as **"productive uses of energy"**.[81] They may include:

- local activities such as agriculture, livestock and fishing;
- light mechanical works such as welding, carpentry and water pumping;
- small retail and commercial activities such as tailoring, printing, catering and entertainment; and
- small and medium-scale production such as agro-processing (grinding, milling and husking), refrigeration and cold storage, drying, preserving and smoking.[82]

DREA systems can greatly increase the productivity of livelihood activities[i].[83] In India, the use of mini-grids has helped reduce irrigation costs 70% and improved crop productivity 50%.[84] Through the adoption of specific DREA systems, the average annual revenue of Indian micro-enterprises has increased an estimated 13%.[85] In Kenya, the uptake of solar-powered water pumps has helped to increase farmers' crop yields 2-5 times and their incomes 5-10 times.[86]

The availability of off-grid solar and mini-grid technologies, coupled with new business models that make productive uses of energy affordable, have accelerated the demand for such applications in recent years.[87] In sub-Saharan Africa (mainly East Africa), an estimated 10,000 systems for productive uses of energy – including solar-powered irrigation pumps as well as units for agro-processing and cooling/refrigeration – have been sold.[88] In India, more than 150,000 units have been sold, and in Bangladesh some 1,500 solar pumps were deployed between 2013 and 2019 under the IDCOL Solar Irrigation Program.[89]

ACCESS TO CLEAN COOKING FACILITIES

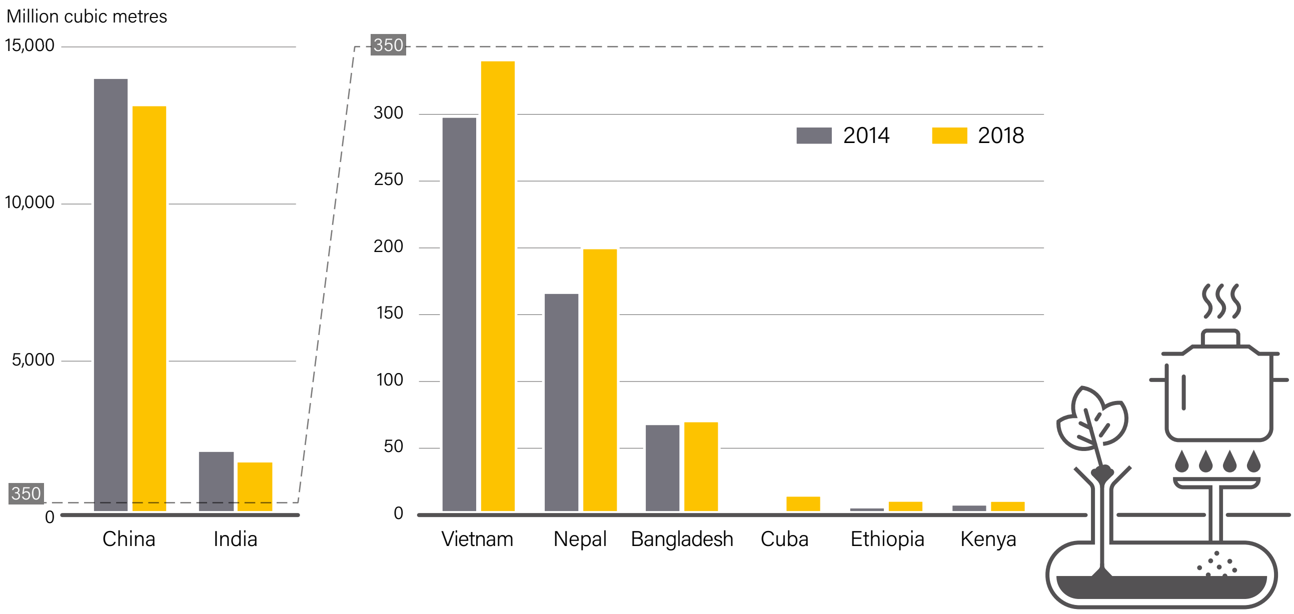
Although liquefied petroleum gas (LPG) continued to dominate the market for clean cooking solutions, other technologies such as biomass cook stoves, biogas and solar cookers, and electric cooking were being deployed and piloted in many developing countries. In Rwanda, an estimated 30,000 biomass improved cook stoves have been distributed under the National Cookstoves Programme.[90] In South Africa, biomass briquettes and pellets accounted for a reported 33% of the fuels used in clean cookstoves as of 2018.[91]

An estimated 125 million people worldwide used biogas for cooking in 2018 (latest data available), most of them in Asia (including 111 million in China and 9 million in India).[92] In total, around 15.5 billion cubic metres of biogas were produced for cooking purposes during the year, mainly in China (13.1 billion cubic metres) and India (1.6 billion cubic metres).[93] However, the demand for biogas for cooking decreased in these two dominant markets between 2014 and 2018, while surging in other Asian countries such as Bangladesh, Nepal and Vietnam.[94] (→ *See Figure 46.*) Hivos and Energia distributed around 120,000 biogas digesters through their respective programmes in Cambodia and Indonesia.[95]

Biogas production in Africa increased nearly 40% during 2014-2018 to around 46 million cubic metres, mainly in the five countries engaged in the Africa Biogas Partnership Programme: Burkina Faso, Ethiopia, Kenya, Tanzania and Uganda.[96] Under the first two phases of this programme, around 70,000 biogas digesters were installed across East Africa, providing clean cooking solutions to some 500,000 people.[97]

i As many as 65 different productive use and livelihood applications enabled by DREA systems have been documented in India. See endnote 83 for this chapter.

FIGURE 46. Production of Biogas for Cooking in Selected Countries, 2014 and 2018



Source: IRENA. See endnote 94 for this chapter.

By the end of 2019, more than 3.9 million concentrating solar cookers were estimated to have been distributed worldwide, providing clean cooking solutions to around 14 million people.[98] In addition, solar PV electric cooking gained attention after studies showed that electricity from solar PV mini-grids and solar home systems can be cost-competitive with other cooking alternatives.[99] In 2019, SUNSPOT (United States) partnered with EarthSpark International (United States) to pilot the introduction of solar-powered induction cook stoves in Haiti.[100]

BUSINESS MODELS

Innovations in business models have been critical for the successful deployment of DREA systems, mobilising the financing necessary to achieve universal energy access by 2030. DREA-specific business models vary widely in their complexity as well as in their target consumers, delivery approaches, economics and use of digital technologies. Whereas some models are as simple as cash sales of locally manufactured, off-the-shelf products, others rely on outsourced manufacturing and global supply chains, diversified sales channels, complex customer data analytics and digital finance.

One of the most successful business models for the deployment of **off-grid solutions**, and particularly off-grid solar products, in recent years has been "pay-as-you-go". The PAYGo model allows customers to pay for off-grid solutions in instalments rather than providing capital upfront, an approach that has made DREA systems more affordable to millions of people around the world. In 2019, a quarter of the global sales volume of off-grid solar products was conducted using the PAYGo model.[101] In East Africa, one of the main markets for off-grid solar products, PAYGo accounted for around 40% of the total sales volume.[102] In West Africa, also a growing market for off-grid solar, nearly 50% of sales were PAYGo.[103]

As both the off-grid sector and PAYGo mature, off-grid solar start-ups have shifted increasingly from a business development model based on growth to one focused on profitability, in order to sustain their operations over time and also to expand their activities.[104] In 2019, several companies were bundling their energy services with other financial offerings (loans, insurance or microfinance) and consumer products (TV, refrigerators, etc.).[105] These companies aimed to generate other revenue streams through their existing platforms and networks by providing a bundle of energy products and services to populations either off the grid or connected to unreliable grids.[106]

In Kenya, the PAYGo start-up Angaza (United States) partnered with JUA Energy (Kenya) to offer customers PAYGo LCD televisions and developed a PAYGo laptop together with Endless Solutions.[107] Azuri Technologies (United Kingdom), a leader in PAYGo solutions, launched a PAYGo bundle in Zambia consisting of a solar home system, a satellite television and a lighting system.[108] In Uganda, the company was promoting a PAYGo solar irrigation solution bundled with an insurance scheme that provides cover for unexpected crop loss.[109] Also in Uganda, Fenix International (Uganda) was providing loans for school fees to more than 40,000 rural families and was experimenting with bundling agricultural loans and health insurance with the company's solar home systems.[110] The PAYGo start-ups Baobab+ (France) and BrightLife (Uganda) also continued to offer microfinance products to their customers in partnership with microfinance institutions.[111]

Continuing a recent trend, some PAYGo companies established partnerships with telecommunications companies to expand their customer base and also penetrate new markets. In Afghanistan, d.light (United States) collaborated with the Afghan Wireless Communications Company to supply small-scale solar PV systems to homeowners.[112] In Africa, Greenlight Planet (United States) partnered with the mobile operators Orange in Burkina Faso, Telma in Madagascar and Vodacom in Tanzania to promote its PAYGo solar system.[113]

Beyond the PAYGo model, the concept of peer-to-peer electricity trading or "swarm electrification" was being tested among rural households in Bangladesh. Through swarm electrification, households that have a solar home system are able to connect to a low-voltage distribution system and sell their excess electricity to neighbouring households that may or may not have their own solar home system in place.[114] The government of Bangladesh, SOLshare (Bangladesh) and the national grid operator kicked off a pilot project in 2019 to trial the concept, which could enable more households to connect to electricity.[115]

Innovative business models also were being used to boost the deployment of **clean cooking facilities** worldwide, leveraging on mobile payment technologies. Cambodia-based ATEC Biodigesters launched the first PAYGo scheme for biogas, enabling farmers who cannot afford the upfront cost of a biodigester to pay monthly instalments via mobile money schemes.[116] By the end of 2019, more than 1,500 of the units had been sold in Cambodia, providing renewable gas for cooking (of which 250 sold through the PAYGo scheme).[117] In Rwanda, BBOXX (United Kingdom) launched its PAYGo cooking solution, with the goal of providing clean cooking services using biogas and LPG to some 5,000 households by 2020.[118]

A growing number of solar home system companies and mini-grid developers and operators have adapted their business models to enable **productive uses of energy**. This market segment offers a unique opportunity to provide energy start-ups with a new revenue stream, while also giving rural households the ability to boost their incomes.[119] Several companies have structured their business models to offer pay-per-use productive use of energy services – such as solar irrigation, cooling and agro-processing products – to off-grid populations.[120]

This model has helped to address the barrier of the high upfront cost of productive uses of energy products. In 2019, Oorja (India) offered a PAYGo solar irrigation service for small farmers whereby the company installs, operates and maintains the solar pumps for the community, and the farmers pay only for the irrigation services.[121] M-PAYG (Denmark) has engineered a product aimed at reducing food waste by providing local fishermen in Kenya with a solar-powered cooling system that keeps the catch cool while still on the boat.[122] ColdHubs (Nigeria) was providing solar-powered cold storage facilities to farmers using a pay-as-you-store model whereby farmers pay only a daily fee per crate of food stored.[123]

INVESTMENT AND FINANCING

ACCESS TO ELECTRICITY

Despite the multiple benefits that access to electricity provides, total investment in the DREA sector is well below the level needed to achieve universal access by 2030. Of the estimated USD 51 billion required annually to achieve universal electricity access in the 20 "high-impact countries"[i] by 2030, around USD 36 billion was invested in 2017 – and of this, only one-third, or USD 12.6 billion, is estimated to have provided residential access, and only 1.2% flowed towards DREA systems.[124]

Investment in DREA companies has increased substantially in recent years, with the sector raising a cumulative USD 2.1 billion in corporate-level investment[ii] since 2010.[125] In 2019, corporate-level investments in the DREA sector totalled around USD 468 million, down 8.5% from the USD 512 million invested in 2018.[126] (→ *See Figure 47.*) This decline is attributed mainly to a strategy of greater diversification by DREA investors, as they direct more financing towards energy access funds and financial instruments rather than to DREA companies.[127]

Investments in mini-grid start-ups more than doubled to a record USD 113 million in 2019.

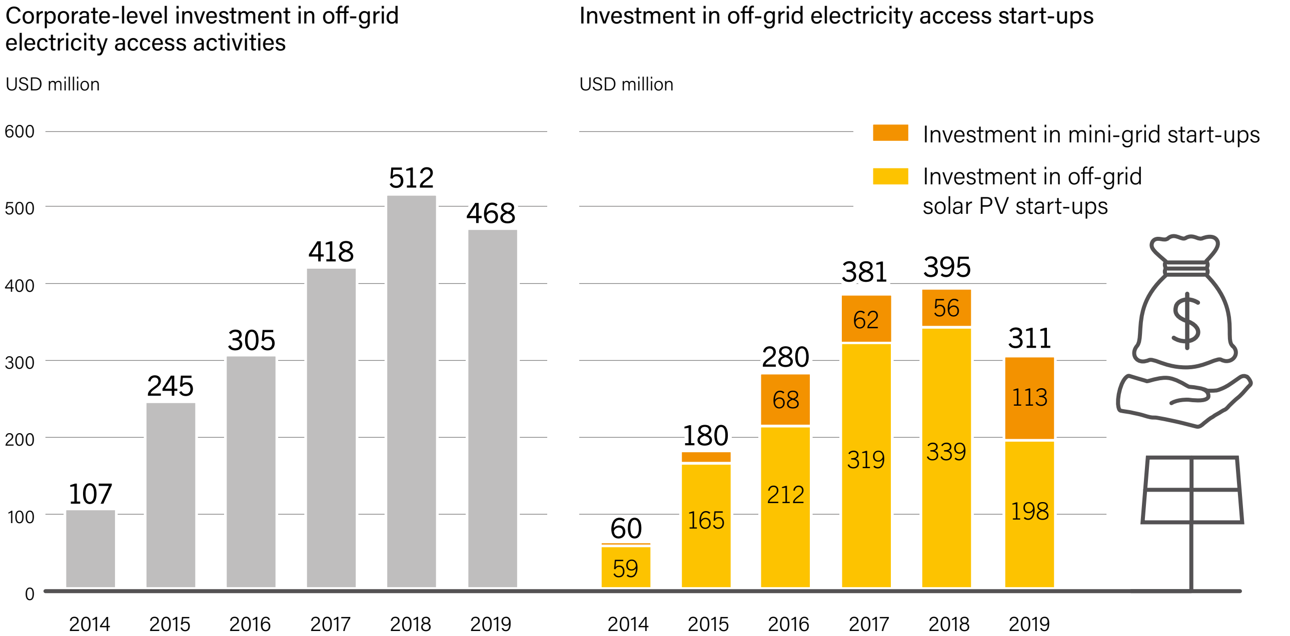
Off-grid electricity access start-ups[iii] have been one of the main actors in the deployment of DREA systems in recent years and a major recipient of DREA-related investments. These start-ups attracted an estimated USD 311 million in capital flows in 2019, down 20.1% from the USD 389 million raised in 2018.[128] (→ *See Figure 47.*) Investments in off-grid solar start-ups dropped 41.6%, whereas capital flows in mini-grid start-ups more than doubled to a record USD 113 million in 2019.[129]

i These 20 countries account for more than two-thirds of the people living without electricity and four-fifths of the people who rely on traditional biomass for cooking and heating. For electricity access, the high-impact countries, as identified in the IEA and World Bank's *Global Tracking Framework 2015* report, are Afghanistan, Angola, Bangladesh, Burkina Faso, the Democratic Republic of the Congo, Ethiopia, India, Kenya, the Democratic People's Republic of Korea, Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, the Philippines, Sudan, Tanzania, Uganda and Yemen.

ii Corporate-level investments refer to investments in off-grid energy access companies by strategic investors. These include grants, direct investments (debt and equity), mergers and acquisitions, and blended finance, among others.

iii Off-grid electricity access start-ups refer to start-ups providing electricity access through off-grid systems (off-grid solar systems and mini-grids). Mini-grids refer to systems (100 kWp or more) that provide energy access to multiple users. Mini-grid systems may be powered by more than one source of energy, with at least one renewable energy source (solar, hydropower or wind) and include energy storage.

FIGURE 47. Global Investment in Off-Grid Electricity Access Activities, 2014-2019



Note: Corporate-level investment encompasses off-grid and off-grid-related energy access activities by strategic investors such as oil and gas majors, utilities and independent power producers, and global original equipment manufacturers (OEMs), as well as by market leaders from the technology, telecommunications and fast-moving consumer goods sectors. This includes direct investment (debt and equity), mergers and acquisitions, commercial partnerships and joint ventures, and investment through funds and financial intermediaries. Investment in energy access start-ups refers to investment through debt and equity mainly in start-ups providing electricity access through off-grid systems. Mini-grids refer to systems of more than 100 kW for energy access activities only. These systems may have more than one source of energy, with at least one renewable energy source.

Source: See endnote 126 for this chapter.

The decline in investment in off-grid solar start-ups may be attributed to the high concentration of investments in a small number of start-ups and to recent acquisitions by large corporations.[130] Since 2012, just 10 start-ups[i] have raised 78% of the total investment in the off-grid solar sector.[131] With less of an appetite for equity financing and successful debt financing campaigns in 2017 and 2018, these companies were less involved in mobilising investment in 2019.[132] In addition, several of the major start-ups – such as d.light, Fenix International, Mobisol (Kenya) and Simpa Networks (India) – have since been acquired by larger corporations and no longer rely heavily on external investment.[133]

East Africa, and to a lesser extent West Africa, continued to be the main recipients of off-grid solar investment in 2019, due to the high penetration of mobile money services in these regions.[134] Since 2012, off-grid solar companies in East Africa have attracted an estimated 60% of investments in the sector, and West Africa has mobilised around 17%, as more companies start or expand operations in the region.[135] In 2019, notable investment deals in East and West Africa included a USD 50 million investment by Mitsubishi (Japan) in BBOXX and a USD 26 million equity investment by Marubeni (Japan) in Azuri Technologies.[136]

In addition, PEG Africa (Ghana) secured USD 46.5 million in debt and equity to develop new markets in West Africa, where it already served some 400,000 people in Côte d'Ivoire, Ghana and Senegal, while d.light mobilised USD 18 million to expand operations on the continent.[137] Companies operating in Central and Southern Africa also mobilised investments during the year: upOwa (Cameroon) raised USD 2.8 million to support its PAYGo solar home systems operations, and Solarworks (South Africa) mobilised some USD 6 million to expand its off-grid solar operations in Mozambique.[138]

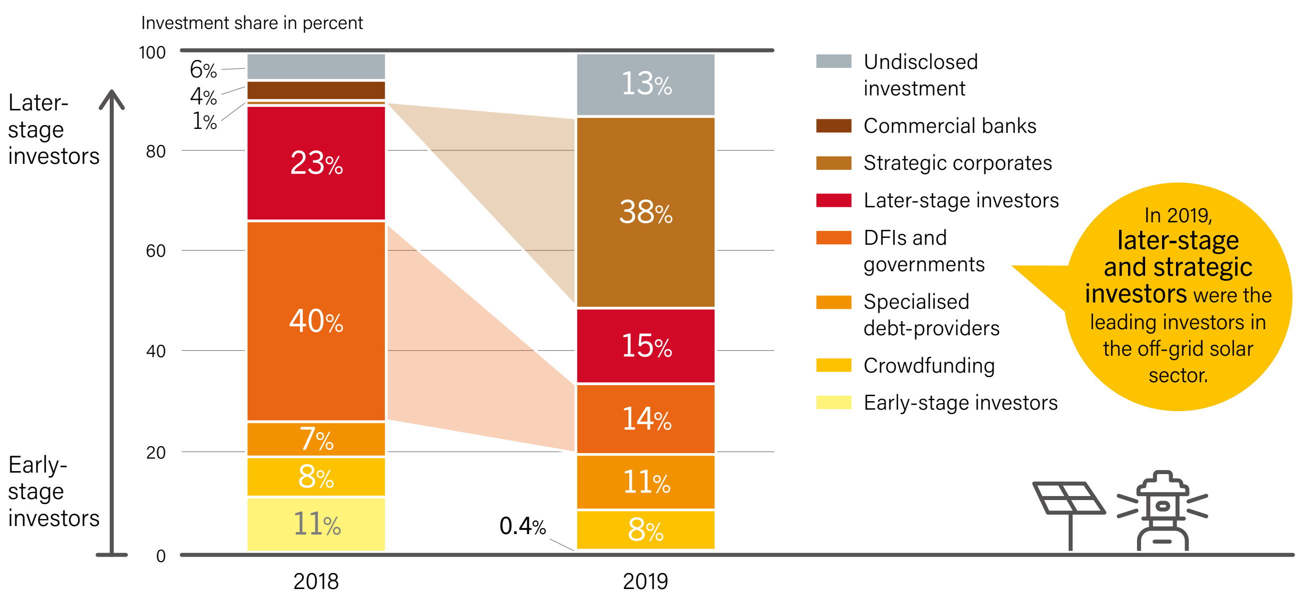
Off-grid solar companies in Asia, traditionally operating on cash sales rather than using the capital-intensive PAYGo model, mobilised relatively low investment in 2019.[139] Despite the uncertainty in the Asian off-grid solar market, SolarHome (Singapore), a PAYGo solar start-up, secured USD 1 million to provide off-grid electricity access in Myanmar through its solar home systems solution.[140] Orb Energy (India) obtained equity investments from Shell New Energies to support its growth in India.[141]

Building on the momentum of recent years and on the emergence of new business and financing models, investments in mini-grid start-ups more than doubled in 2019 to exceed USD 100 million for the first time.[142] Investments continued to flow in Asia, which had the most mini-grids installed by year's end, with Yoma Micro Power (Myanmar) mobilising USD 30 million to develop solar mini-grids in Myanmar.[143] In Africa, where investment in mini-grid start-ups also continued, Cross-Boundary Energy Access made a first USD 5.5 million investment in PowerGen (Kenya) to deploy 60 mini-grids to provide electricity to some 34,000 people in Tanzania.[144] PowerGen also secured USD 6.9 million from Infraco to deploy mini-grids in Sierra Leone.[145] In addition, Powerhive (United States) raised USD 9.3 million from the clean energy investment company Kouros (United States) to expand rural mini-grid operations in Kenya.[146]

The type of investors in DREA markets shifted notably in 2019. Strategic corporate investors accounted for nearly 38% of total capital flows in the sector – up from less than 1% in 2018 – while the share of total investments in off-grid solar companies by development finance institutions (DFIs) and governments fell to 13.5%, down from 40.1% in 2018.[147] (→ *See Figure 48.*) This shift is attributed mainly to the growing maturity of the sector and to the new growth strategy being adopted by the first generation of off-grid solar start-ups.[148] A major illustration of the rising role of strategic corporate investors was ENGIE's acquisition of Mobisol, a leader in East Africa's PAYGo market.[149] DFIs and governments, however, continued to be the main investors in mini-grid start-ups in 2019.

i The 10 start-ups are Zola Electric, d.light, M-KOPA SOLAR, BBOXX, Mobisol, Nova Lumos, Greenlight Planet, Azuri Technologies, Kingo and SolarNow.

FIGURE 48. Share of Investment in Off-Grid Solar PV Companies, by Type of Investor, 2018 and 2019



Note: Early-stage investors include impact investors, individuals such as business angels, and venture capital funds; later-stage investors include private equity and asset management funds; DFI = development finance institution.

Source: IFC. See endnote 147 for this chapter.

Crowdfunding remained an important source of working capital for off-grid solar companies, with some USD 22 million in investment mobilised in 2019; through the Trine crowdfunding site, BBOXX raised around USD 6.6 million from more than 4,400 investors to finance its off-grid activities in Africa.[150] Greenlight Planet secured some USD 2 million through Trine to finance its growth in India's off-grid solar market.[151]

ACCESS TO CLEAN COOKING FACILITIES

Despite recent calls for action, less than 1% (USD 32 million) of the USD 4.4 billion required annually to achieve universal access to clean cooking facilities by 2030 is being invested in the sector.[152] In 2019, Sistema.bio (Mexico) secured USD 12 million in investment to expand its biodigester activities in India, Kenya, Mexico and South America.[153] In addition, ATEC Biodigesters raised USD 1.6 million to roll out the world's first PAYGo model for biodigesters and to expand its operations from Cambodia to Bangladesh.[154]

Clean cooking attracted **less than 1%** of the USD 4.4 billion investment required annually to achieve universal access in the sector.

POLICY DEVELOPMENTS

With the rapid deployment of off-grid energy solutions in recent years and stronger recognition of the added value and potential of DREA in providing energy access, governments are increasingly prioritising the adoption of policy and regulatory frameworks promoting the uptake of DREA systems.[155] Between 2010 and 2017, four of the top five fast-moving policies for electricity access among countries that have deficits in energy access were DREA related.[156] These included programmes as well as fiscal and financial incentives to promote the development of mini-grids and stand-alone systems.[157] (→ *See Tables 4 and 5 at the end of this chapter.*)

Although many countries had electricity access targets in 2019 (in line with the goals of the United Nations' Sustainable Development Goal 7 on affordable, reliable, sustainable and modern energy for all), only a few had targets specific to DREA technologies. India, in particular, has introduced various schemes for DREA deployment in recent years, with specific targets for off-grid technologies such as solar home systems, solar streetlights and solar PV pumps.[158] In Africa, the Rural Electrification Agency of Nigeria announced in late 2017 its aim to develop 10,000 mini-grids, and the government of Rwanda, in its 2018 Energy Sector Strategic Plan, outlined a pathway for DREA systems to serve 48% of the population by 2024.[159] The Angolan government announced plans in 2019 to install 30,000 off-grid solar systems with a total capacity of 600 MW by 2022.[160]

Governments continued to develop policy frameworks to enable the deployment of DREA systems and the mobilisation of investments in the sector. In 2019, the most common policy-based approaches for accelerating the deployment of DREA included product quality standards for solar systems and cook stoves, as well as regulations for the licensing, tariff setting, grid-interconnection and technical performance of mini-grids. Fiscal and financial instruments such as tax and import duty reductions and waivers, capital subsidies and results-based financing also were widely used. In addition, more countries have been developing integrated electrification plans that consider DREA systems, and several countries have adopted competitive tenders as an instrument for deploying the systems.[161]

In 2019, Guatemala launched a new electrification policy that aims to extend electricity access to 1.5 million people through alternative sources including off-grid and mini-grid systems.[162] By year's end, five countries – Ethiopia, Kenya, Myanmar, Nepal and Togo – had adopted integrated electrification plans that incorporate approaches and policies that support energy access using grid-based, mini-grid and off-grid solutions, and Namibia and the Republic of the Congo were developing such plans.[163] In the area of clean cooking, Kenya announced plans to provide clean cooking solutions to 100% of the population by 2028.[164]

Competitive processes to deploy DREA systems were launched in several African countries. The government of Togo, through its CIZO programme, launched a tender procedure for the supply, installation and maintenance of off-grid solar systems on a PAYGo basis.[165] Mali launched a tender procedure for two mini-grid systems totalling 1.3 MW as part of its rural electrification programme.[166] Ethiopia launched its first tender for the deployment of solar mini-grids in 25 villages.[167] In addition, Nigeria began signing grant agreements with companies selected to deploy mini-grids, following a competitive process under the World Bank-backed Nigeria Electrification Project.[168] Algeria launched tenders for the installation of solar-diesel hybrid mini-grids in 2019.[169]

Also during the year, policy makers continued to develop regulatory frameworks and to enact policies to attract private sector investment in DREA systems in their countries. Nigeria launched a minimum subsidy tender, a performance-based grant and a mini-grid acceleration scheme to support mini-grid deployment.[170] India announced plans to adopt guidelines for distribution companies on the interconnection of decentralised solar plants with capacities above 2 MW, which will potentially facilitate the development of larger mini-grids.[171]

Fiscal and financial incentives – including grants, subsidies, and exemptions on value-added tax, import duties and custom tariffs – play an important role in addressing the financial barriers to the deployment of off-grid systems in many countries. India, building on the success of its electrification programme, launched a financing scheme[i] in 2019 that encourages farmers to replace their diesel and grid-connected water pumps with solar PV pumps.[172] In East Africa, analysis found that a 20% increase in import tariffs (currently at 0%) could reduce sales of off-grid solar systems by an estimated 18-32%, depending on the size of the systems.[173]

With the expansion of DREA markets, a growing number of governments and policy makers have explored approaches for setting up the proper regulatory frameworks needed to ensure the quality of off-grid solutions in their countries. Among the measures that governments have introduced to keep poor-quality products out of the market and to protect customers are the adoption of international standards; the implementation of quality assurance through product testing, inspections and market surveillance; and product bans.

Several countries took steps in 2019 to enhance their policy frameworks around product quality. In the East Africa region, Ethiopia, Kenya, Tanzania and Uganda introduced pre-export verification of compliance to standards for stand-alone solar systems.[174] Under this procedure, DREA systems such as solar lights or solar home systems must be inspected prior to import by an accredited entity in the country of origin. A similar system of pre-inspection was put in place in Pakistan.[175] The Nigerian government started work on a framework to adopt the IEC Global standards for solar energy, and China marked an important milestone by adopting the IEC test methods for stand-alone solar systems.[176] In the areas of cooking and heating, Ethiopia's National Standardisation Council endorsed a clean cook stove and clean cooking solution standard aligned with the International Organization for Standardization's ISO19867-1.[177]

i The full name of the subsidy scheme is Pradhan Mantri Kisan Urja Suraksha evem Utthan Mahabhiyan (PM KUSUM).

NEW PROGRAMMES AND INITIATIVES

A variety of programmes and initiatives were launched in 2019 to support global efforts to advance energy access. These activities, established by international organisations, development partners, philanthropic foundations and non-governmental actors, aimed primarily at creating the right enabling environment, promoting a co-ordinated and integrated approach, and unlocking the level of financing required to achieve the 2030 target of universal energy access.

Several countries have developed **integrated electrification** strategies that include both grid-based and distributed renewable solutions to reach universal access.

ACCESS TO ELECTRICITY

In 2019, development finance institutions continued to provide financial and technical support to the off-grid energy sector through various programmes and mechanisms. DFIs committed an estimated USD 1 billion[i] to off-grid electricity access programmes and projects during the year (around 12% of total commitments in the energy sector).[178] For example, the World Bank approved the Regional Off-Grid Electrification Project for West Africa[ii] (ROGEP), a USD 200 million programme that aims to improve the policy landscape and the business and investment climate for off-grid energy businesses in the region.[179] The Bank also allocated USD 5.6 million for the development of mini-grids in Nepal.[180]

The African Development Bank (AfDB) launched a USD 50 million multinational financing programme to provide guarantees to off-grid energy service companies in sub-Saharan Africa, seeking capital from local banks or financial intermediaries.[181] Through its Sustainable Energy Fund for Africa, the AfDB also committed USD 500,000 to support the development and launch of the Nigeria Energy Access Fund, a new private equity fund investing in off-grid and mini-grid projects in the country.[182] The Green Climate Fund approved support of around USD 28 million for the Mali rural electrification programme.[183]

In addition, several donor governments launched bilateral initiatives to support off-grid electricity access in 2019. The Dutch government launched the SDG 7 Results Facility programme to provide grants up to EUR 2.5 million (USD 2.8 million), through a competitive process, for energy access projects in 17 countries[iii,184] The UK government, together with the Shell Foundation, established the Catalysing Agriculture by Scaling Energy Ecosystems initiative to provide energy access to smallholder farms in South Asia and sub-Saharan Africa.[185] The United Kingdom also increased its support to several of its programmes including the Transforming Energy Access programme, the UK Energy Catalyst fund and the Africa Clean Energy programme.[186]

Under a joint Papua New Guinea Electrification Partnership, the governments of Australia, Japan, New Zealand and the United States committed USD 25 million to provide electricity access to 70% of the country's population.[187] The US government, through its Power Africa initiative and the US Agency for International Development, also launched a USD 5 million Solar Home System Kick-Starter Programme to provide financing and technical support to solar home system companies in Malawi.[188] The Swedish International Development Cooperation Agency expanded its USD 50 million Beyond the Grid Fund for Africa Facility to provide electricity access to 5-15 million people in Burkina Faso, Liberia and Mozambique.[189] The Italian government signed a USD 9 million extension of its 10-year-long partnership on clean energy access with the International Finance Corporation, which will help support continuation of the Lighting Global programme.[190]

i Includes commitments from the Abu Dhabi Fund for Development, the Asian Development Bank, the Asian Infrastructure Development Bank, the African Development Bank, the European Bank for Reconstruction and Development, FMO, the Green Climate Fund, Proparco and the World Bank Group.

ii Beneficiary countries include the 15 countries in the Economic Community of West African States (ECOWAS) region as well as Cameroon, the Central African Republic, Chad and Mauritania.

iii The 17 countries are: Bangladesh, Burkina Faso, Chad, Ethiopia, the Gambia, India, Kenya, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, South Sudan, Sudan, Tanzania and Uganda.

Also in 2019, several partnerships between philanthropic foundations, corporations and financial intermediaries were established to support energy access activities in Africa and Asia. The Rockefeller Foundation joined forces with Tata Power (India) to create an enterprise to set up 10,000 mini-grids and provide power to 5 million households in India by 2026.[191] The Rockefeller Foundation also partnered with All On, a Shell-backed off-grid energy impact investment company, to launch a facility to support off-grid entrepreneurs in Nigeria.[192]Schneider Electric collaborated with Amundi, EDFI and Norfund to create the Schneider Electric Energy Access Asia Impact Fund, which aims to provide energy access to some 350 million people in Bangladesh, India, Indonesia, Myanmar and the Philippines.[193] In addition to its partnership with the UK government, the Shell Foundation launched the USD 120 million Energy Entrepreneurs Growth Fund (along with the Dutch Development Bank (FMO) and other investment firms), to provide catalytic financing for early- to growth-stage energy access companies in sub-Saharan Africa.[194]

Various actors launched initiatives aimed at providing key market, policy and technical information to entrepreneurs, investors and policy markets. For example, building on the experience of the Africa-EU Renewable Energy Cooperation Programme, the European Union launched together with Austria, Germany, the Netherlands and Sweden the GET.invest programme to provide market information and to catalyse financing for sustainable energy and DREA projects, primarily in Africa.[195]

Similarly, the World Bank launched the Global Electrification Platform, an open-access, interactive, online platform that offers practitioners and policy makers an overview of electrification investment scenarios and pathways for achieving universal electricity access in selected developing countries.[196]

In the same vein, Swedfund, in collaboration with the Alliance for Rural Electrification, the Africa Minigrid Developers Association and Smart Power India, launched a comprehensive set of Consumer Protection Principles for Clean Energy Mini-Grids that are aimed at guaranteeing a minimum standard of service to consumers connected to mini-grids.[197]

The Global Commission to End Energy Poverty (GCEEP) also was launched during the year. The GCEEP comprises heads of development banks, utilities, DREA companies, academics and investors, and aims to develop a co-ordinated approach to address energy access challenges.[198]

Efforts during 2019 also sought to advance the use of renewables in humanitarian situations. The UN refugee agency UNHCR launched a new Global Strategy for Sustainable Energy that promotes the transition to clean and renewable energy at refugee settlements and other facilities that host migrants, in part as a means to boost energy access for these populations.[199] The strategy builds on, among others, the existing Renewable Energy for Refugees (RE4R) partnership between IKEA Foundation, UNHCR and Practical Action, which aims to deliver renewable energy solutions to 60,000 people in humanitarian settings in Jordan and Rwanda.[200] A key achievement of the partnership in 2019 was the deployment of DREA systems to 1,500 households in refugee settlements in Rwanda.[201]

ACCESS TO CLEAN COOKING FACILITIES

Various development partners established financing programmes and instruments to catalyse investments in the clean cooking sector during 2019. The World Bank launched a USD 500 million Clean Cooking Fund[i] to scale up public and private investment in the clean cooking sector, in collaboration with United Nations organisations and other DFIs.[202] The UK Department for International Development launched the Modern Energy Cooking Services initiative, a USD 50 million research and innovation programme to facilitate the transition from traditional use of biomass to modern cooking solutions.[203]

To mobilise the international community and improve co-operation between the health and energy sectors, several organisations (the Clean Cooking Alliance, the International Renewable Energy Agency, Sustainable Energy for All, the United Nations Development Programme (UNDP), the United Nations Foundation, the World Bank and the World Health Organisation (WHO)) launched the Health and Energy Platform of Action in 2019.[204] The platform will focus initially on clean cooking and healthcare facilities. In addition, a High-Level Coalition of Leaders for Clean Cooking, Energy and Health was convened by the WHO, UNDP, the UN Department of Economics and Social Affairs and the World Bank to catalyse potential synergies at the ministerial level among the health, energy and finance sectors to address access to clean cooking.[205] The Clean Cooking Alliance also launched a global advocacy campaign, "Clean Cooking Is …", to create awareness and support for clean cooking solutions.[206]

i The main donors to the Clean Cooking Fund are Denmark, the Netherlands, Norway and the United Kingdom, and the recipient countries to be engaged are Burundi, Ghana, Niger, Rwanda, Uganda and Zambia.

TABLE 4. Distributed Renewables Policies for Electricity Access, Selected Countries, 2019

Country	National Plans and Targets			Regulatory Policies			Non-Regulatory Policies		
	Distributed renewables for energy access targets	Distributed renewables for energy access in INDC or NDC	Integration of distributed renewables in energy access plan/strategy	Grid arrival plan/strategy	Administrative and legal provisions (connection codes, tariff, licensing, etc.)	Tendering, call for proposals or competitive process	Quality/ Technical frameworks and standards	Public financing (loans, grants, subsidies, guarantees, etc.)	Fiscal incentives (import duty, VAT, etc.)
Africa									
▲ **Angola**	★		●		●	●			
Benin	●				●	●	●		●
Botswana						●			
▲ **Burkina Faso**	●		●	●	●	●		●	●
Burundi									●
Cameroon		●	●						
Central African Republic									
Chad									●
Comoros									
▲ **Congo, Democratic Republic of the**			●						●
Côte d'Ivoire	●		●	●	●	●			●
Djibouti			●		●				
Equatorial Guinea									
Eritrea			●						
Eswatini		●							
▲ **Ethiopia**	●		●		●	★, ○	★	●	●
Gabon									
Gambia	●		●		●				
Ghana	●	●	●		●	●			●
Guinea									●
Guinea-Bissau	●								
▲ **Kenya**	●		●		●	●	★	●	●
Lesotho									
Liberia	●		●						●
▲ **Madagascar**	●		●		●	●	●	●	●
▲ **Malawi**	●								●
Mali	●					○		●	●
Mauritania		●							
▲ **Mozambique**	●		●		●				●
Namibia	●				●			●	
▲ **Niger**	●	●	●		●				●
▲ **Nigeria**	●	●	●	●	●	★, ○		●	
Rwanda	●	●	●	●	●	●	●	●	●
São Tomé and Príncipe		●							
Senegal	●	●	●		●			●	●
Sierra Leone	●			●	●	●			●
Somalia		●							
South Africa									●
South Sudan	●								
▲ **Sudan**	●	●							
▲ **Tanzania**			●	●	●		★	●	●
Togo	●		●			★, ○	●		●
▲ **Uganda**	●	●	●		●		★	●	●
Zambia							●		●
Zimbabwe		●			●				●
Asia									
▲ **Bangladesh**		●	●		●	●	●	●	●
Cambodia		●		●	●		●	●	
▲ **India**	●		●	●	●	●	●	●	●
▲ **Korea, Democratic People's Republic**									
Lao PDR	●	●			●				●
Mongolia	●				●				
▲ **Myanmar**	●	●	●		●	●	●	●	●
Nepal	●	●			●	●	●	●	●
Pakistan		●					★		●
▲ **Philippines**			●		●			●	

Note: Please see key on the next page.

TABLE 4. Distributed Renewables Policies for Electricity Access, Selected Countries, 2019 (continued)

Country	National Plans and Targets			Regulatory Policies			Non-Regulatory Policies		
	Distributed renewables for energy access targets	Distributed renewables for energy access in INDC or NDC	Integration of distributed renewables in energy access plan/strategy	Grid arrival plan/strategy	Administrative and legal provisions (connection codes, tariff, licensing, etc.)	Tendering, call for proposals or competitive process	Quality/Technical frameworks and standards	Public financing (loans, grants, subsidies, guarantees, etc.)	Fiscal incentives (import duty, VAT, etc.)
Central and South America									
Bolivia									
Guatemala			★						●
Haiti									
Honduras									●
Nicaragua									
Panama									
Peru			●		●	●		●	
Middle East									
Syria									
▲ **Yemen**	●	●	●						

Note: The list includes only countries that had an electrification rate below 95% according to the IEA World Economic Outlook 2019 Electricity Access Database. For more on the electrification rates of these countries, see Reference Table R20. High-impact countries are the 20 countries with the highest absolute gaps in access to electricity and/or clean fuels and technologies for cooking, measured by population as identified in the IEA and World Bank's *Global Tracking Framework 2015* report. For electricity access, the countries are: Afghanistan, Angola, Bangladesh, Burkina Faso, the Democratic Republic of the Congo, Ethiopia, India, Kenya, the Democratic People's Republic of Korea, Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, the Philippines, Sudan, Tanzania, Uganda and Yemen.

INDC and NDC refers to countries' (Intended) Nationally Determined Contributions to reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: See endnote 157 for this chapter.

- ● Existing national policy or tender framework
- ★ New (one or more policies of this type)
- ○ National tender held in 2019
- ▲ High-impact countries

TABLE 5. Distributed Renewables Policies for Clean Cooking Access, Selected Countries, 2019

Country	National Plans and Targets			Regulatory Policies		Non-Regulatory Policies		
	Clean cooking targets	Clean cooking in INDC or NDC	Integration of clean cooking in energy access plan/strategy	Administrative and legal provisions	Tendering, call for proposals or competitive process	Quality/Technical frameworks and standards	Public financing (loans, grants, subsidies, etc.)	Fiscal incentives (import duty, VAT, etc.)
Africa								
▲ **Ethiopia**	●	●	●			●		
Ghana	●	●	●			●		
▲ **Kenya**	●		●			●		●
Rwanda	●	●	●			●		
▲ **Uganda**	●	●	●					●
Asia								
▲ **Bangladesh**	●	●	●			●		●
▲ **China**	●	●	●					
▲ **India**	●	●	●				●	
▲ **Nepal**	●	●	●			●	●	●
Central and South America								
Guatemala		●	●					

Note: High-impact countries are the 20 countries with the highest absolute gaps in access to electricity and/or clean fuels and technologies for cooking, measured by population as identified in the IEA and World Bank's *Global Tracking Framework 2015* report. For clean cooking access, the countries are: Afghanistan, Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, India, Indonesia, Kenya, the Democratic People's Republic of Korea, Madagascar, Mozambique, Myanmar, Nepal, Nigeria, Pakistan, the Philippines, Sudan, Tanzania, Uganda and Vietnam.

INDC and NDC refers to countries' (Intended) Nationally Determined Contributions to reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: Clean Cooking Alliance. See endnote 157 for this chapter.

- ● Existing national policy or tender framework
- ★ New (one or more policies of this type)
- ○ National tender held in 2019
- ▲ High-impact countries

05

SOCIO-ECONOMIC BENEFITS OF CSP, SOUTH AFRICA

The KaXu Solar One project in South Africa is the first privately developed large-scale concentrating solar thermal power (CSP) plant with storage to operate in an emerging market. The project has stimulated local economic growth and generated around 1,780 jobs in the Northern Cape, an impoverished province with one of the world's highest rates of youth unemployment. Thanks to a unique ownership structure that includes minority shareholding by the local community, the project can directly support long-term education and economic development initiatives in the area.

05 INVESTMENT FLOWS

KEY FACTS

- Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) totalled USD 301.7 billion, up 5% from 2018.
- Dollar investment in new renewable power capacity (including all hydropower) was three times the total committed to new coal, natural gas and nuclear power generating capacity.
- Developing and emerging economies surpassed developed countries in renewable energy capacity investment for the fifth year running, reaching USD 152 billion.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 megawatts, MW) totalled USD 301.7 billion in 2019, as estimated by BloombergNEF[i]. This was a 5% increase from 2018, due in part to greater spending on small-scale solar PV systems. Investment in renewable power and fuels has exceeded USD 200 billion annually since 2010.

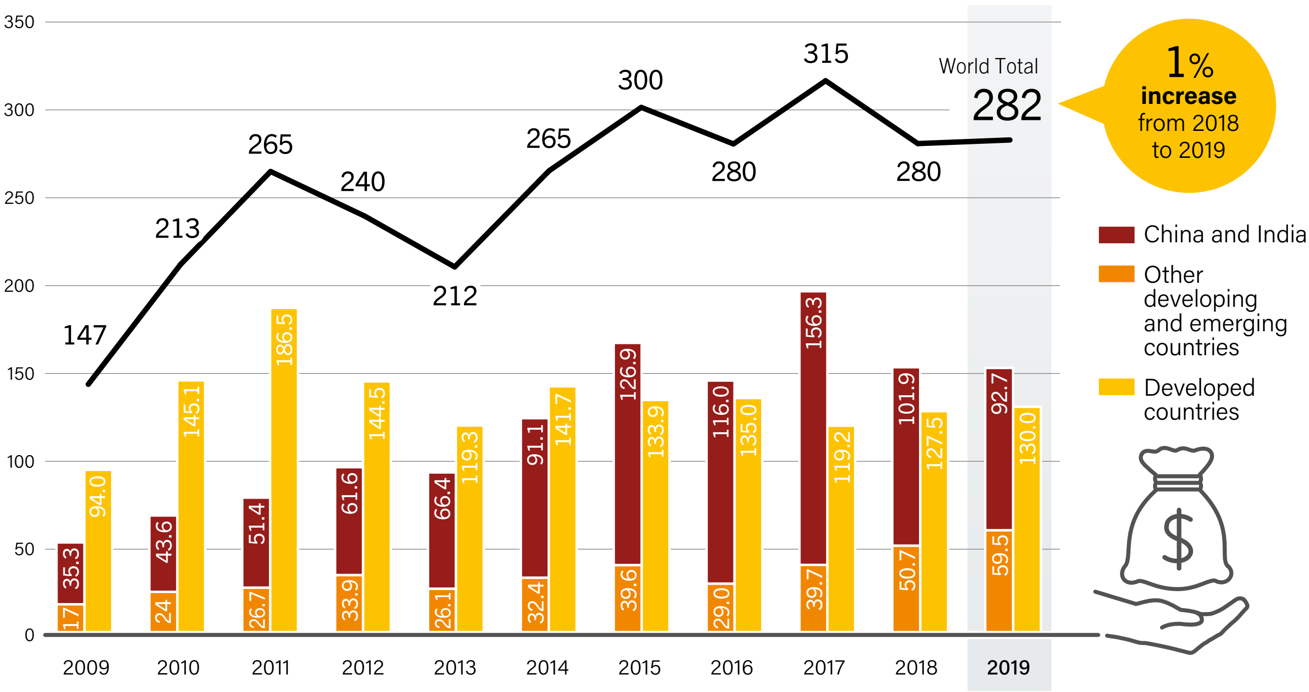
Investment in renewable power and fuel capacity accounted for much of the 2019 total, at USD 282.2 billion, up 1% from 2018. (→ *See Figure 49 and* ***Reference Table 22***.) Investment in hydropower projects larger than 50 MW added an estimated USD 15 billion to the global total in 2019[ii],[1]

These estimates do not include investment in renewable heating and cooling technologies, for which data are not collected systematically.

i This chapter is derived from the United Nations Environment Programme's *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020), the sister publication to the GSR, prepared by the Frankfurt School–UNEP Collaborating Centre for Climate and Sustainable Energy Finance (FS-UNEP Centre) in co-operation with BloombergNEF. Data are based on the output of the Desktop database of BloombergNEF, unless otherwise noted, and reflect the timing of investment decisions. The following renewable energy projects are included: all biomass and waste-to-energy, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with solar PV projects less than 1 MW estimated separately and referred to as small-scale projects or small-scale distributed capacity; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more. For more information, see the FS-UNEP Centre and BloombergNEF *Global Trends* report. Where totals do not add up, the difference is due to rounding. Capacity investment values include asset finance volume adjusted for re-invested equity as well as small distributed capacity investment for solar power. Total investment values include capacity investment values and estimates for undisclosed deals as well as R&D and company investment (venture capital, private equity and public market new equity).

ii Investment in large-scale hydropower (>50 MW) is not included in the overall total for investment in renewable energy. Similarly, investment in large-scale hydropower is not included in the figures throughout this chapter, unless otherwise noted.

FIGURE 49. Global Investment in Renewable Power and Fuel Capacity in Developed, Emerging and Developing Countries, 2009-2019



Note: Figure does not include investment in hydropower projects larger than 50 MW. Investment totals have been rounded to nearest billion.

Source: BloombergNEF.

Investment in new renewable power capacity (excluding large hydropower) was almost three times the level of investment in fossil fuel generating capacity and accounted for a remarkable 71% of the total amount committed to new power generating capacity (including coal, natural gas and nuclear) in 2019.

Investment in renewable energy continued to be dominated by wind power and solar photovoltaics (PV). Asset finance of utility-scale[i] projects, such as wind farms and solar parks, dominated investment at USD 230.1 billion worldwide. Small-scale solar PV installations (less than 1 MW in size) accounted for USD 52.1 billion.

Investment in renewable power capacity was **three times** the level of investment in coal, natural gas and nuclear generating capacity combined in 2019.

i "Utility-scale" here refers to wind farms, solar parks and other renewable power installations of 1 MW or more in size, and to biofuel production facilities with capacity exceeding 1 million litres.

INVESTMENT BY ECONOMY

Developments in renewable energy investment varied by region[i], rising in the Americas, including the United States and Brazil, but falling in all other world regions including China, Europe, India, and the Middle East and Africa. (→ *See Figure 50.*)

Developing and emerging economies outweighed developed countries in renewable energy capacity investment for the fifth year running, accounting for 54% of the total in 2019, due largely to China. Investment in developing countries (including China and India) totalled USD 152.2 billion for the year, down slightly from 2018. Although renewable energy capacity investment declined in both China and India, outside these two countries it rose 17% in developing countries to a record USD 59.5 billion.

Renewable energy capacity investment in developed countries[ii] as a group rose 2% in 2019. Sharp increases in the Netherlands, Poland, Spain and the United States were balanced by declines in Australia, Belgium, Germany and the United Kingdom.

China continued to account for the largest share of global investment in renewable energy capacity (excluding hydropower larger than 50 MW), at 30%, followed by the United States (20%), Europe (19%) and Asia-Oceania (excluding China and India; 16%). The Middle East and Africa accounted for 5%, the Americas (excluding Brazil and the United States) 4%, India 3% and Brazil 2%.

The top 10 countries with the most renewable energy capacity investment comprised six developed countries and four developing or emerging countries. In addition to China and the United States, the top five countries were Japan, India and Chinese Taipei, and the next five were Spain, Brazil, Australia, the Netherlands and the United Kingdom.

China's overall investment in renewable power and fuels dropped 6% in 2019 to USD 90.1 billion, continuing the downward trend started in 2018. In capacity only, China invested USD 83.4 billion – most of it in wind power (USD 55 billion), a 10% increase over 2018. Investments rose in both onshore and offshore wind power capacity. Despite the boom in solar power capacity investment in China in 2017, by 2019 wind investment overshadowed solar PV investment, which fell 33% to USD 25.7 billion. The decline reflected the government's 2018 announcement of its suspension of financial support for solar PV, which caused a so-called market freeze. Biomass and waste-to-energy investment increased 2% to USD 1.5 billion, driven by a string of incineration plants being built in the country.

Investment in European renewable power and fuels totalled USD 58.4 billion in 2019, down 4% from 2018, with a sharp contrast across technologies. In capacity only, Europe invested USD 54.6 billion, with investment in wind energy down 24% to USD 26.4 billion (reflecting the regional trend) but investment in solar PV rising 25% to USD 24.6 billion, a high not seen since 2012. The growth in solar PV resulted from the spread of low-cost projects in Spain and elsewhere, relying on tariffs set in auctions or via private sector power purchase agreements. (→ *See Policy Landscape chapter.*) In 2019, for the first time, Spain led investment in renewable energy capacity in Europe at USD 8.4 billion, up 25% from 2018. The Netherlands (at USD 5.5 billion) and the United Kingdom (at USD 5.3 billion) were in second and third place, due largely to offshore wind projects.

In the United States, which remained the largest individual investor among developed economies, investment increased 25% to USD 59.0 billion in 2019 – its highest value to date. In capacity only, the United States invested 55.5 billion. Developers pushed forward solar PV and wind power projects to enable them to qualify for the soon-to-expire federal tax credits. Investment in wind power projects increased 44% to USD 31.8 billion, and investment in solar PV projects increased 16% to USD 23.3 billion. All other renewable technologies experienced declines or stagnation.

In Asia-Oceania (excluding China and India), overall investment in renewable power and fuels fell 3% to USD 48.2 billion. In capacity only, Asia-Oceania invested USD 45.1 billion. Japan's investment in renewable capacity fell 10% to reach its lowest level since 2011, at only USD 16.5 billion. Reasons for the decline included the lower unit costs of solar PV, which reduced the dollar amount committed per megawatt, as well as grid and land constraints that held back developer activity and auction bidding. However, biomass capacity investment climbed 26% to USD 2.6 billion.

Elsewhere in the region, Chinese Taipei experienced an all-time high in capacity investment of USD 8.8 billion, up 390% from 2018. This was due largely to the financing of three large offshore wind power arrays, together worth USD 7.8 billion. Increases also occurred in Kazakhstan (up 58% to USD 0.8 billion), Pakistan (up 12% to USD 0.6 billion) and Cambodia (rising from almost zero to USD 0.6 billion). Capacity investment declined in Vietnam (down 64% to USD 2.6 billion), Indonesia (down 53% to USD 0.4 billion) and Malaysia (down 44% to USD 0.3 billion).

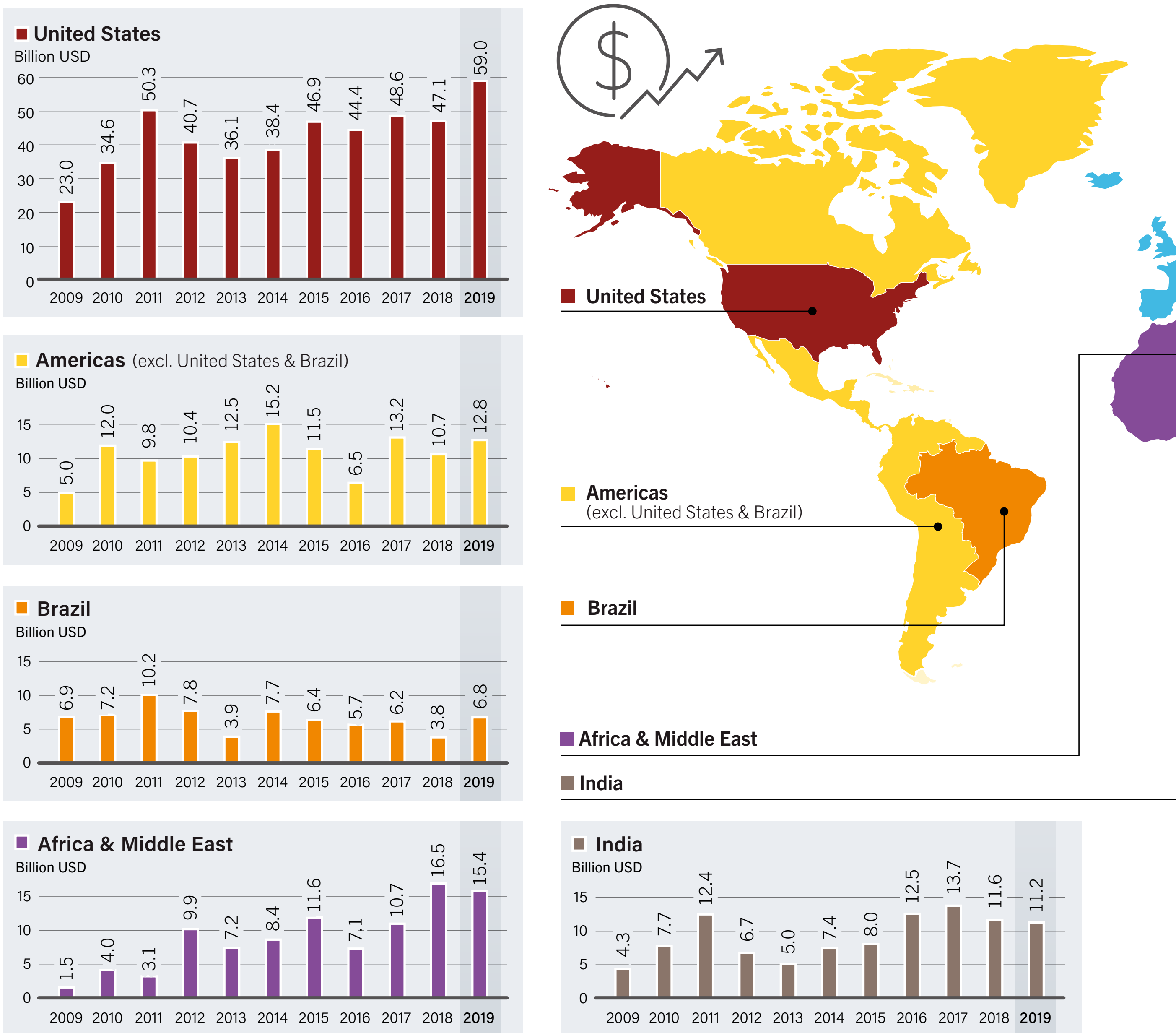
i Regions in this chapter reflect those presented in Frankfurt School-UNEP Centre and BloombergNEF's *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020) and differ from the regional definitions across the rest of the GSR, which can be found at http://www.ren21.net/GSR-Regions.

ii Developed-country volumes are based on countries in the Organisation for Economic Co-operation and Development (OECD), excluding Mexico, Chile and Turkey.

In India, total new investment in renewable power and fuels fell 4% in 2019 to USD 11.2 billion, due largely to project financing delays resulting from problems with the electricity distribution companies. In capacity only, India invested USD 9.3 billion. The decline reflected a 48% drop in wind power investment (to USD 2.2 billion) and a 32% drop in biomass and waste-to-energy investment (to USD 0.3 billion). Investment in solar PV capacity increased 8% to USD 6.6 billion.

In the Americas (beyond Brazil and the United States), investment totalled USD 12.8 billion, up 20% from 2018 but still below the 2017 high. In capacity only, investment was USD 12.6 billion. Increases in capacity investment occurred in both Chile (up 302% to USD 4.9 billion, the country's highest value yet) and Mexico (up 17% to USD 4.3 billion). Investment fell 18% in Argentina and also decreased in the Dominican Republic and in Panama (down 66% and 44%, respectively), although these countries remained comparatively small markets.

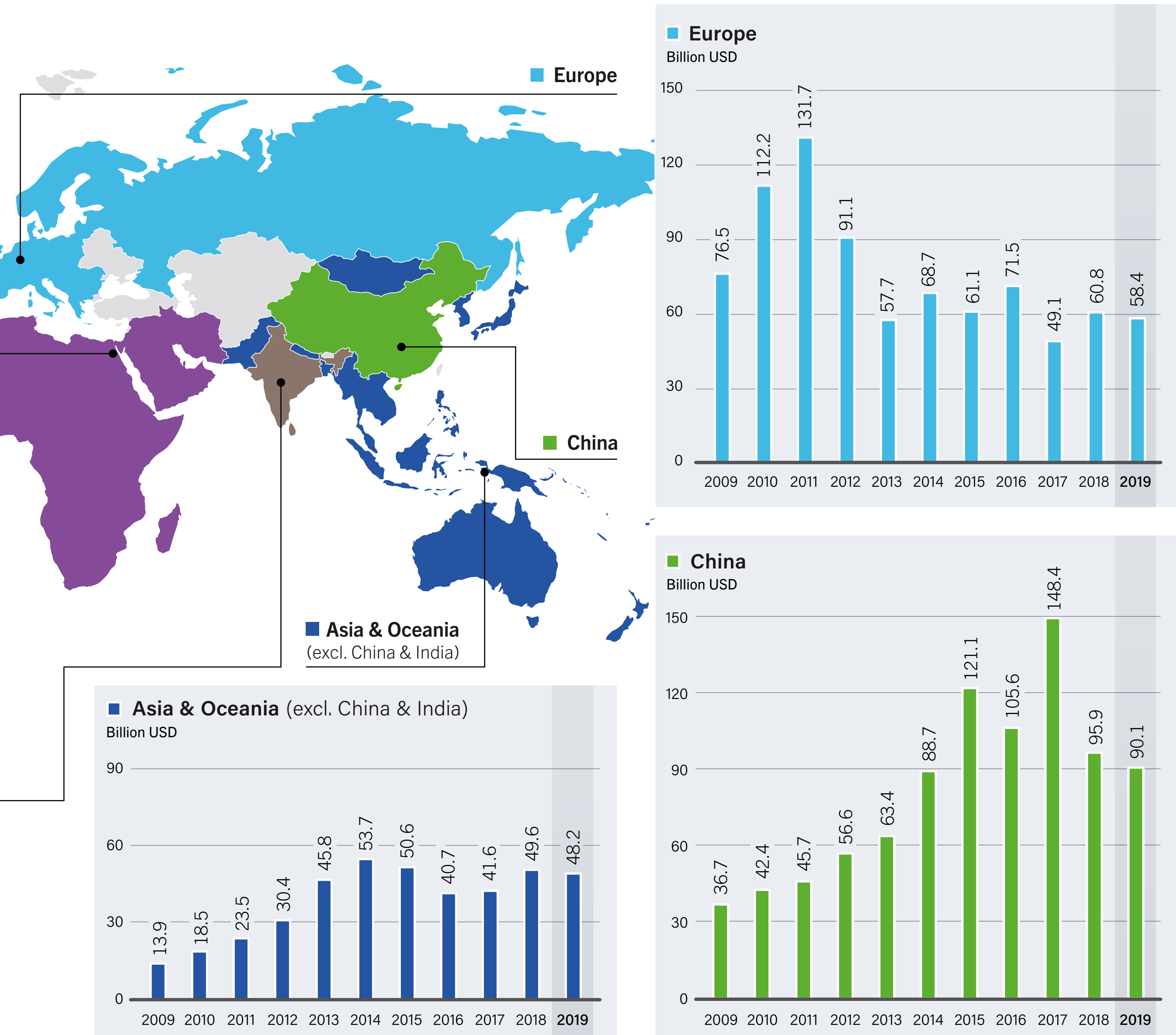
FIGURE 50. Global Investment in Renewable Power and Fuels, by Country and Region, 2009-2019



Note: Investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals.

Brazil's total investment in renewable power and fuels was USD 6.8 billion, up 78% from 2018 but still far below the peak of USD 11.1 billion in 2008, when the country's biofuel boom was in full swing. In capacity only, investment was USD 6.5 billion. Most investment was in wind power, at USD 3.4 billion (up 148% from 2018), and in solar power, which rose 30% to USD 2.5 billion.

Total investment in the Middle East and Africa region decreased 7% in 2019 to USD 15.4 billion. In capacity only, investment was USD 15.2 billion. Gaps in auction programmes were a leading factor behind the declines in capacity investments in many countries that had become prominent renewable energy investors, including South Africa (down 76% to USD 1.0 billion), Kenya (down 45% to USD 0.7 billion) and Morocco (down 83% to USD 0.5 billion). However, in the United Arab Emirates, investment rose a staggering 1,223% to USD 4.5 billion, making it the new regional leader.



Source: BloombergNEF.

INVESTMENT BY TECHNOLOGY

Wind power and solar PV continued to dominate new investment in renewable energy in 2019, each accounting for roughly 47% of the total. Wind power and small hydropower were the only technologies for which investment increased in 2019, with wind power investments rising 8% to USD 142.7 billion. Investment in wind power capacity outweighed that in solar PV for the first time since 2010, and investment in small hydropower technologies grew 6% to USD 2.5 billion. (→ *See Figure 51.*)

Although overall solar power investment slipped 2% to USD 141 billion, a sharp dichotomy was apparent between utility-scale asset finance of solar PV projects (which fell 19% due mainly to a slowdown in financing of solar PV projects in China) and money committed to small-scale solar PV systems (which jumped 37% to USD 52.1 billion). Investment in concentrating solar thermal power (CSP) capacity totalled USD 4.6 billion, up 256% from 2018.

The other renewable energy technologies struggled to attract capital spending commitments in 2019. Most dramatically, overall investment in geothermal was down 50% to USD 1.2 billion, well below its peak of USD 3.8 billion in 2011.

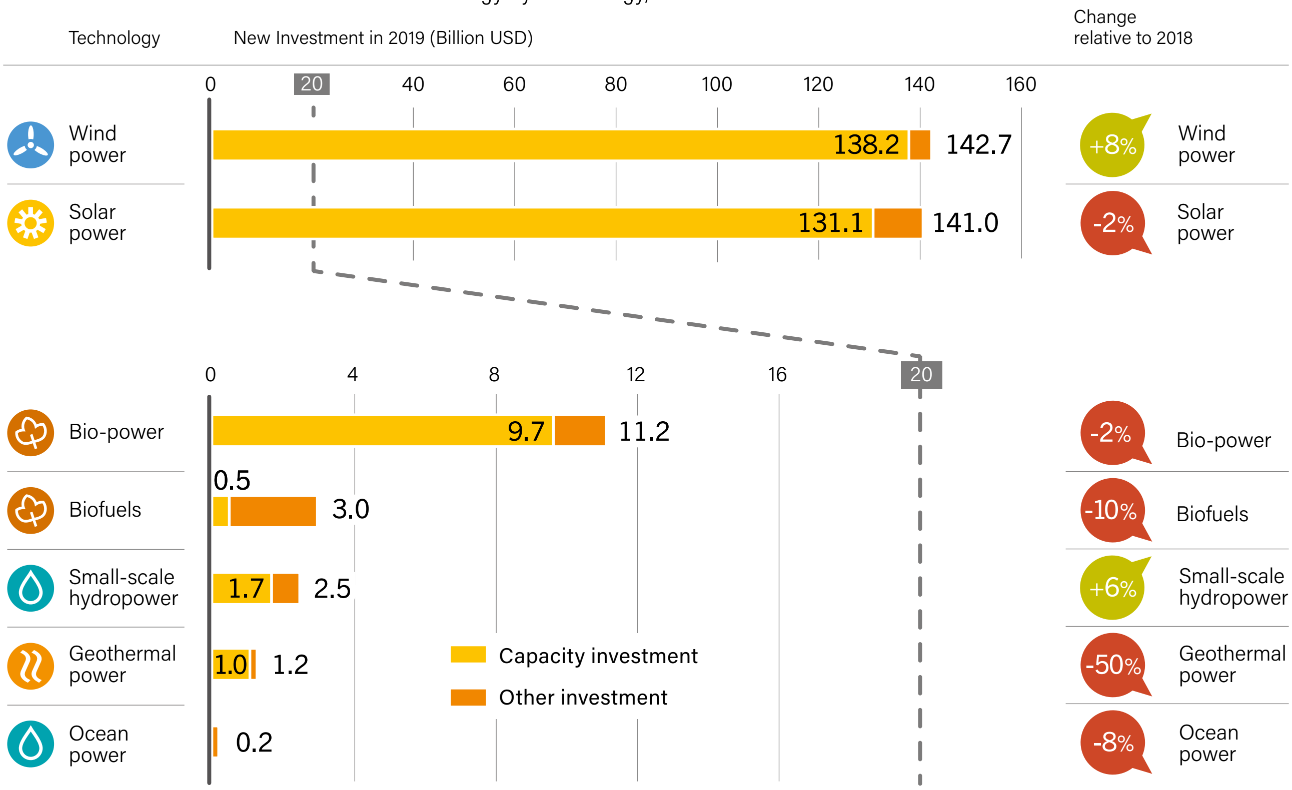
Investment in biofuels fell 10% to 3.0 billion – also far below its peak of USD 26.4 billion in 2007 – as industry stagnated without fresh government purchasing mandates. Investment in biomass and waste-to-energy[i] technologies also fell slightly (down 2%) to USD 11.2 billion.

Large-scale hydropower projects (over 50 MW) represented the third largest sector (after solar and wind power) for renewable energy investment in 2019, reaching an estimated USD 15 billion[ii].

i Includes all waste-to-power technologies, but not waste-to-gas.

ii Translating hydropower capacity additions into asset finance dollars per year is not straightforward because the average project takes four years to build. Although BloombergNEF did not track detailed statistics for large-scale hydropower projects, it estimated that asset financing for large-scale hydropower projects reaching financial go-ahead totalled around USD 15 billion in 2019, down 6% from 2018.

FIGURE 51. Global Investment in Renewable Energy by Technology, 2019



Note: Capacity investment values include asset finance volume adjusted for re-invested equity as well as small distributed capacity investment for solar power. Total investment values include estimates for undisclosed deals as well as R&D and company investment (venture capital, private equity and public market new equity).

Source: BloombergNEF.

INVESTMENT BY TYPE

Research and development[i] (R&D) spending rose 1% in 2019 to USD 13.4 billion. Government R&D edged up 4% relative to 2018, to USD 5.7 billion, while corporate R&D slipped 1% to USD 7.7 billion after three years of growth. Trends in total R&D spending were mixed across renewable energy technologies in 2019.

R&D investment in solar power – the largest recipient of such investment – increased 1% to USD 6.7 billion, while R&D spending for biofuels grew 2% to USD 1.8 billion and for geothermal rose 2% to USD 0.2 billion. Small hydropower saw the strongest growth in R&D investment, up 29% to USD 742 million.

Declines occurred in wind power (down 6% to USD 2.7 billion), biomass and waste-to-energy (down 1% to USD 1.0 billion) and ocean power technologies (down 4% to USD 0.2 billion).

Venture capital and private equity investment (VC/PE) in renewable energy increased 22% in 2019, to USD 3 billion, which was the highest level since 2015 but less than a third of its 2008 peak. The main renewable energy technologies, and the companies that manufacture them, are now mature, so there is less need for this earlier-stage financing compared with a decade ago. Solar power companies continued to attract the most VC/PE investment (up 29% to USD 1.8 billion), and wind power VC/PE investment reached USD 529 million.

India was the biggest market for VC/PE spending in 2019 – up 169% to USD 1.4 billion – followed by the United States where VC/PE investment fell 8% to USD 797 million. In the biggest VC/PE deal of the year, worth USD 824 million, India's wind, hydropower and solar developer Greenko Energy Holdings was bought by Singapore's Sovereign Wealth Fund (GIC) and the Abu Dhabi Investment Authority.

Public market investment in renewable energy companies and funds increased 11% to USD 6.6 billion, just a third of the peak reached in 2007. Because solar and wind power – the main sectors – are now dominated by well-established global companies, there is less need to tap investors. Funds raised by initial public offerings (IPOs) increased 47% to USD 2 billion but remained well below the 2007 peak. In the biggest public market deal in 2019, Greencoat UK Wind raised USD 488 million in a secondary offering.

Asset finance of utility-scale projects again accounted for the bulk of total investment in renewable energy, although it fell 5% in 2019 to USD 230.1 billion, the lowest level since 2014. The largest asset financing of the year was for a combined CSP and PV project in Dubai (United Arab Emirates) that received a USD 3.9 billion equity and debt package.

Small-scale distributed capacity investment, or investment in solar PV systems of less than 1 MW, increased 37% to USD 52.1 billion. Although the increase remained well below the 2011 peak of USD 75.1 billion, it was an encouraging upswing from the declines witnessed since that time. Small-scale investment was highest in China, at USD 9.6 billion (up 8% over 2018), followed by the United States at USD 5.3 billion (up 176%). Large increases also occurred in Brazil (up 337% to USD 2.1 billion), the Netherlands (up 93% to USD 2.9 billion) and India (up 40% to USD 1.5 billion).

Most renewable energy projects rely on balance sheet finance by a utility, an independent power producer or other investor, or on non-recourse project finance comprised mainly of debt from banks. Funds for renewable energy projects also are channelled increasingly through climate finance avenues.[2] (→ *See Box 1.*)

Acquisition activity – which is not counted as part of the USD 301.7 billion in new renewable energy investment – dropped 34% in 2019 to USD 100.7 billion, ending five years of strong growth. This was due mainly to a decline in the sale and purchase of assets such as solar farms. Corporate mergers and acquisitions (M&A), the buying and selling of companies, slipped 6% to USD 13.7 billion. Private equity buy-outs fell to USD 3.2 billion, just a fraction of the highs seen in 2017 and 2018. Asset acquisitions and refinancing fell sharply in 2019 after five years of growth, with deals worth USD 83.8 billion. European asset acquisitions and refinancing remained comparatively high at USD 44.2 billion. Activity fell sharply in both the United States (down 49% to USD 23.3 billion) and China (down 32% to USD 3.2 billion).

i See Sidebar 5 in GSR 2013 for an explanation of investment terms used in this chapter.

Corporate and government R&D	Venture capital and private equity	Public market investment	Asset finance	Small-scale distributed capacity investment	Acquisition activity
13.4 billion USD	3.0 billion USD	6.6 billion USD	230.1 billion USD	52.1 billion USD	100.7 billion USD

BOX 1. Climate Finance and Renewable Energy

Climate finance is any financing that seeks to support either mitigation actions (for example, renewable energy generation, energy efficiency or low-carbon transport[i]) or adaptation actions (for example, disaster risk management, waste and water, or resilient infrastructure) to address climate change.

Climate finance flows reached a record high of USD 612 billion in 2017 but dropped 11% in 2018 to USD 546 billion[ii], reflecting regulatory shifts in the East Asia and the Pacific region, decreases in the costs of renewable energy and the global slowdown in economic growth. Mitigation activities represented roughly 93% of the 2018 total, or around USD 508 billion. Renewable energy accounted for the largest share of mitigation-related financing flows, at 63%, with most of the rest going to low-carbon transport (26%) and energy efficiency (6%).

The landscape of climate finance flows is multifaceted, interconnected and evolving. As of 2018, private finance supplied around 56% of climate finance, and public finance – including funds provided by governments, climate funds and development finance institutions (DFIs) – supplied the remaining 44%. Although most public climate finance comes from DFIs, multilateral climate funds are an important source of capital for some of the most challenging sectors and poorest regions, providing around USD 3.2 billion in 2017/2018[iii].

The Green Climate Fund (GCF), established in 2010 within the framework of the United Nations Framework Convention on Climate Change, provided 50% of the finance from climate funds in 2018, followed by the Global Environment Facility (GEF) at 32% and the Climate Investment Funds (CIF) at 14%. The shares for renewable energy projects, however, have varied widely across funds over time. Around 37% of the GCF's USD 5.6 billion in project funding has gone to energy access or renewable energy-related projects. The GEF, since its inception in 1992, has provided USD 2.5 billion for renewable energy and energy efficiency projects. Around 69% of the CIF Clean Technology Fund's USD 4.3 billion in projects was for renewable energy.

Most climate finance is channelled as market-rate debt (through project-level or balance sheet finance), although equity and grants also are common instruments. Issuance of one type of debt instrument – climate or green bonds[iv] – reached a record high of USD 257 billion in 2019, up 51% from 2018. Most green bonds were issued in Europe (45%; led by France), followed by the Asia-Pacific region (25%; led by China) and North America (23%; led by the United States)[v]. In 2019, around 31% of green bonds were allocated to the energy sector – down from 51% in 2018 – followed by the buildings (30%) and transport (20%) sectors.

Governments in many regions have established taxonomies of assets and project types that qualify for specific climate finance and/or have the most impact. For example, China's Green Bond Endorsed Project Catalogue, first released in 2015, lists projects eligible for green bond issuance, and India, Japan and Malaysia also include lists of eligible assets in their green bond guidelines. In the European Union, a taxonomy was published in March 2020 that set performance thresholds for different economic activities that contribute to one of six environmental objectives, including climate change mitigation and adaptation. Similar models were being established in Australia and Canada.

i Low-carbon transport includes a wide range of options, from walking and cycling infrastructures to public transport and "low emission" vehicles.

ii Total estimates of climate finance flows vary depending on methodology and data quality. This figure is provided by the Climate Policy Initiative.

iii Total provided is an average of funds supplied in the two-year period 2017/2018, which is the most recent data available.

iv See Glossary for definition. In order for green bonds to qualify as a true climate finance instrument, proceeds must flow to climate beneficial infrastructure or assets, which is not always the case. More recent data (2019) are available for green bonds than for climate finance flows as a whole, which are covered only up to 2018.

v The definition of these regions may differ from the regional definitions used in the rest of the GSR, which can be found at http://www.ren21.net/GSR-Regions.

Source: See endnote 2 for this chapter.

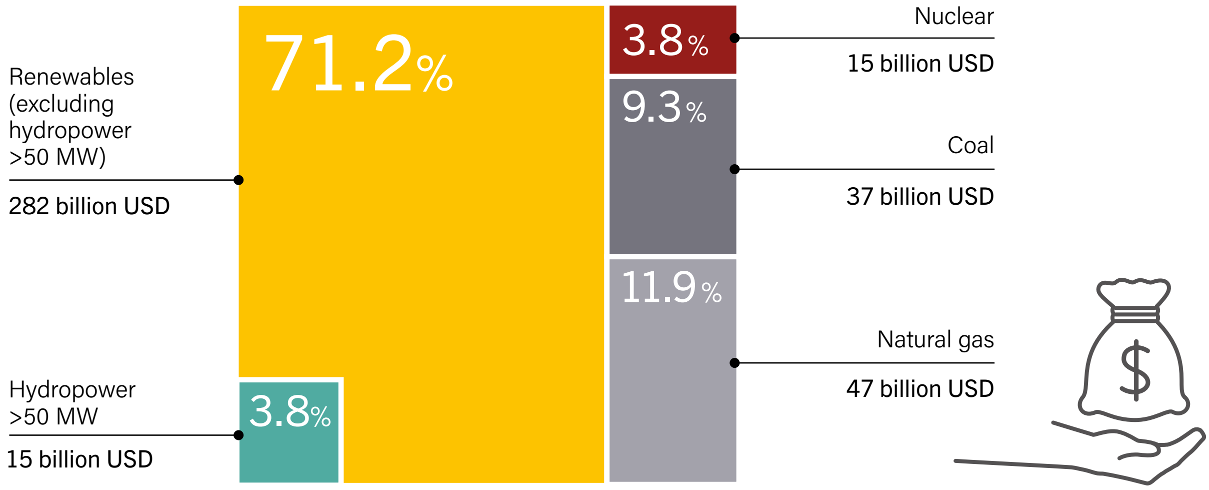
INVESTMENT IN PERSPECTIVE

In 2019, renewable power technologies continued to attract far more investment dollars than did coal, natural gas or nuclear power generating plants. An estimated USD 296.7 billion was committed to building new renewable power plants (USD 281.7 billion[i] without large-scale hydropower, plus an estimated USD 15 billion for hydropower projects above 50 MW). This compares to around USD 84 billion committed to coal and natural gas-fired generating capacity and USD 15 billion for nuclear power capacity. Dollar investment in new renewable power capacity (including all hydropower) was three times the total committed to new coal, natural gas and nuclear power generating capacity. Overall, renewable energy (including all hydropower) accounted for three times the total amount committed to new power generating capacity (including coal, natural gas and nuclear) in 2019. (→ *See Figure 52.*)

The number of institutions divesting from fossil fuels has increased globally since 2011, although the funds are not necessarily reinvested in companies associated with renewable energy.[3] (→ *See Box 2.*)

i This number is for renewable power asset finance and small-scale projects. It differs from the overall total for renewable energy investment (USD 301.7 billion) provided elsewhere in this chapter because it excludes biofuels and some types of non-capacity investment, such as equity-raising on public markets and development R&D.

FIGURE 52. Global Investment in New Power Capacity, by Type (Renewables, Coal, Gas and Nuclear Power) 2019



Note: Renewable investment data in figure exclude biofuels and some types of non-capacity investment.

Source: BloombergNEF.

BOX 2. Fossil Fuel Divestment Trends

Since 2011, institutions worldwide have increasingly divested from, or sold off their financial interests in, fossil fuel companies. By 2019, around 1,115 institutions spanning 48 countries had committed to fossil fuel divestment[i], with estimated total asset values of around USD 11 trillion. This is up from an estimated USD 7.9 trillion in 2018, a 39% increase in one calendar year.

The set of institutions committed to divestment is diverse and spans insurance companies (which account for roughly 50% of total assets under management), private and government pension funds (around 30%), banks (around 10%), as well as governments, non-governmental and faith-based organisations, health, cultural and educational institutions, and others.

Insurance companies (including at least 19 major companies worldwide) have increasingly divested from coal company equities and bonds and, in some cases, have ceased to underwrite coal projects. Company divestment policies covered around 37% of the insurance industry's global assets in 2019, up from 20% in 2018 and 13% in 2017. What began as a European phenomenon expanded in 2019 to reach the United States and Australia. Asian insurers remained reluctant to adopt divestment policies during the year.

As of the end of 2019, 158 self-managed public pension funds had committed to divesting from fossil fuels, up from 144 in 2018. This includes the pension funds of major cities such as Berlin (Germany), Copenhagen (Denmark), Dunedin (New Zealand), Paris (France) and Sydney (Australia). Norway's sovereign wealth fund, worth USD 1.1 trillion, announced that it would divest from companies dedicated solely to oil and gas exploration and production, although it will maintain stakes in refiners and other downstream firms.

Funds divested from fossil fuel companies are not necessarily reinvested in companies associated with renewable energy. However, a global network of individuals and organisations, known as DivestInvest, links the two by providing guidance to organisations and individuals through the divestment process and encouraging them to establish climate-friendly criteria for their investments (for example, in renewable energy companies, low-carbon transport[ii], or sustainable agriculture and forestry options). In addition, C40 Cities launched the the C40 Divest/Invest Forum in late 2018, forming a network of cities interested in divesting and investing in sustainable options. Further expanding the connection between divesting and investing in renewable energy, in 2019 the first major Global South divest-invest conference was held, the Financing the Future Summit.

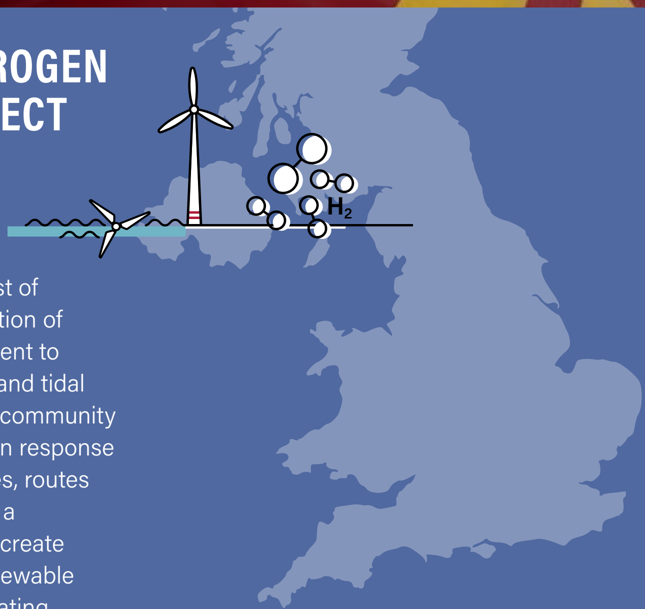
i Through fossil fuel divestment, an institution makes a binding commitment to exclude any fossil fuel company (coal, oil and natural gas) from either all or part of its managed asset classes, or to selectively exclude companies that derive a large portion of their revenue from coal and/or tar sands companies. Organisations also may commit to some form of an exclusion policy based on a different criteria, such as whether the company is aligned with the goals of the Paris Agreement.

ii Low-carbon transport includes a wide range of options, from walking and cycling infrastructures to public transport and "low emission" vehicles.

Source: See endnote 3 for this chapter.

06

RENEWABLE HYDROGEN COMMUNITY PROJECT IN SCOTLAND, UNITED KINGDOM



The Orkney islands, off the coast of Scotland, have used a combination of private and community investment to develop significant wind, wave and tidal power capacity. The innovative community project Surf 'n' Turf, developed in response to energy curtailment challenges, routes surplus renewable electricity to a 500 kW electrolyser in order to create green hydrogen. The stored renewable energy then can be used for heating, power, transport and other purposes, including agricultural fertiliser.

06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

KEY FACTS

- Rapid growth in the installed capacity and penetration of variable renewable electricity has occurred in many countries. In 2019, at least four countries met more than 30% of electricity generation from solar PV and wind power.
- To integrate higher shares of VRE, countries are drawing on a wide variety of flexibility resources including power market design, grid extension, forecasting and demand response.
- Technologies that support the integration of variable renewable electricity, such as heat pumps, electric vehicles and energy storage, have seen substantial market growth in recent years. However, key national markets for EVs and battery storage slowed in 2019.

Energy systems integration is the removal or reduction of many of the technical, physical, organisational and legal barriers to high penetration of renewable energy – including in power grids, heating and cooling systems, and transport fuelling systems. Integration includes the planning, design and implementation of supply- and demand-side technologies, infrastructure, markets and regulatory frameworks to facilitate greater use of renewables across all end-use sectors, while ensuring sustainable, secure, adequate, reliable and affordable energy services.

Renewable energy can facilitate more efficient, sustainable and economical operation of energy systems.[1] To achieve this, governments, energy utilities and other actors are working to address barriers that may slow or halt the growth of renewables.[2] As shares of renewable energy grow, energy systems that have evolved or been designed around conventional energy sources may require multifaceted restructuring to ensure that the benefits of renewables are fully realised.[3]

As such, growth in renewable energy is transforming energy systems around the world.[4] In the power sector in particular, rapid growth in the installed capacity and penetration of **variable renewable electricity** (VRE) sources – such as solar photovoltaic (PV) and wind power[i] – has occurred in many countries.[5] At the end of 2019, renewables produced an estimated 27.3% of global electricity generation, 8.7% of which was from VRE.[6] The penetration of modern renewables in the heating, cooling and transport sectors is much lower than in the power sector, however.[7] (→ *See Global Overview chapter.*)

i Defined more broadly, VRE also can include some forms of ocean power and hydropower. This chapter focuses mainly on solar PV and wind power, as these are the fastest growing VRE markets and are having the greatest impacts on energy systems. See Glossary for an extended definition of VRE.

Many of the notable advances in renewable energy integration in 2019 involved increased uptake of VRE in power systems and the use of VRE to electrify end-uses in transport, heating and cooling. These advances occurred mainly in countries or regions that have supportive policy environments or where energy markets are adapting to the uptake of VRE, including in Australia, China, Europe and North America. (→ *See Policy Landscape chapter.*)

Several technologies are supporting the integration of renewables by enabling greater flexibility in energy systems or by promoting the linking of energy supply and demand across electricity, thermal and transport applications. Among the more mature or commercialised technologies are heat pumps, electric vehicles (EVs) and certain types of energy storage. Other technologies are still emerging but may help to reach higher shares of renewable energy in all sectors – including renewable hydrogen, non-lithium-ion batteries (such as flow batteries) and novel forms of mechanical storage.[8]

ADVANCES IN THE INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

In numerous countries, the power sector has transformed rapidly in recent years, driven by the increased penetration of variable wind and solar power. At least four countries met more than 30% of their electricity generation from VRE in 2019: Denmark, Germany, Ireland and Uruguay.[9] (→ *See Figure 53.*)

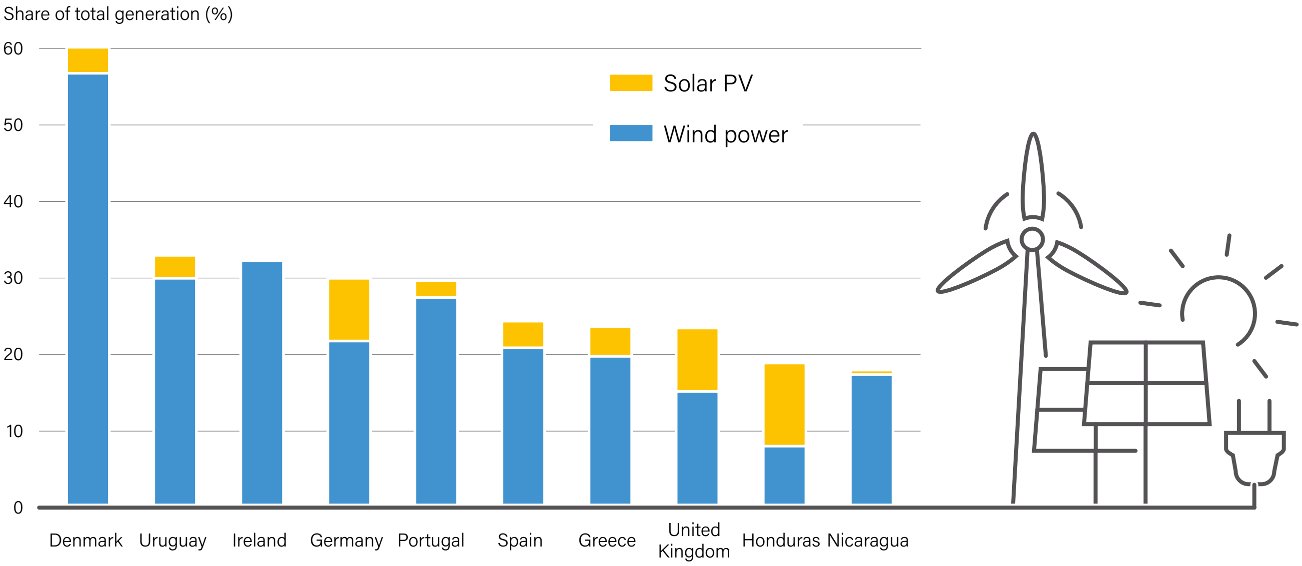
Improving **power system flexibility** is central to advancing the integration of VRE.[10] Flexibility is important in all power systems to ensure uninterrupted services while managing changes in supply and demand, allowing for safe operating conditions and minimisation of generator or transmission outages.[11] Some degree of flexibility exists in all power systems, and most systems can accommodate at least moderate shares of VRE in their generation mix before reaching significant physical or capacity-related barriers and experiencing operational challenges, such as grid imbalances and excessive or uneconomic curtailment of generation.[12]

Solar PV and wind power provided

8.7%

of global electricity in 2019, up from around 7.9% in 2018.

FIGURE 53. Share of Electricity Generation from Variable Renewable Energy, Top Countries, 2019



Note: Figure shows countries among the top 10 according to the best available data at the time of publication. However, several small-island countries with low total generation may be excluded from this list.

Source: See endnote 9 for this chapter.

Power system flexibility can be improved through a range of interventions, many of which are supported by and continue to be enhanced through advances in the digitalisation of power systems.

Four key interventions discussed here are:

- strategic market design that rewards or promotes flexibility;
- direct procurement of flexibility services from sources of generation, demand and energy storage;
- improved forecasting of electricity demand and of VRE generation and demand; and
- the implementation of physical linkages – in the form of grid infrastructure – between VRE sources and demand centres, as well as among VRE sources in different geographical locations.

MARKET DESIGN FOR FLEXIBILITY

Effective electricity market design for VRE integration promotes the accurate pricing of energy and the appropriate remuneration of grid balancing services that improve flexibility. This can be achieved by designing or re-designing short-term (day-ahead or intraday) markets to more accurately reflect the real-time value of electricity, and by procuring flexibility services from distributed sources of demand, generation and energy storage.[13]

Market design interventions in 2019 included the California Independent System Operator's (United States) announcement of a day-ahead market for renewables, which will allow utilities to better plan for and optimise the use of VRE on the grid.[14] The Italian grid operator Terna also outlined reforms of its intraday electricity markets to shorten forecast periods for VRE generators feeding into the grid, allowing for more accurate commitments of VRE capacity.[15] In Singapore, liberalisation of the retail electricity market enabled distributed energy resources to start providing flexibility services.[16]

INCREASED FLEXIBILITY FROM GENERATION, DEMAND AND STORAGE

Conventional power systems with low VRE shares obtain flexibility primarily by adjusting the output of dispatchable generators to follow demand.[17] As VRE shares increase, power system flexibility is being enhanced not only through better generation flexibility, but also through flexibility from sources of demand and energy storage.[18]

VRE generators themselves can contribute essential reliability services to power grids, including frequency control and regulation, inertial response, voltage regulation and reactive power voltage support (also known as power factor correction).[19] Apart from generation, demand flexibility also is an increasingly important enabler of higher shares of VRE, primarily through demand response initiatives that use market signals – such as time-of-use pricing, incentive payments and penalties – to influence the electricity consumption behaviours of end-users.[20]

Virtual power plants use digital technologies to co-ordinate and control energy demand, distributed generation and energy storage.

Grid operators are increasingly procuring packaged flexibility services that incorporate both demand response[i] and flexibility from the embedded generation and energy storage assets of prosumers[ii]. In Canada, the Italian firm Enel X was awarded 210 megawatts (MW) of demand response capacity to provide flexibility services to the grid by managing the demand of industrial energy users in parallel with energy storage and generation assets.[21] Several electrical utilities in the United Kingdom undertook tendering for demand and generation flexibility capacity in 2019, from both commercial and residential sources.[22] In the United States, a 14 MW contract for behind-the-meter demand response in California was awarded to a firm that aggregates fleets of home batteries.[23]

The wider aggregation of generation, demand and storage capacity is being unlocked through innovative trials and digital technologies that can control fleets of assets providing flexibility services. For example, a 2019 virtual power plant trial backed by the Australian Renewable Energy Agency aimed to use up to 50,000 distributed residential solar-plus-storage installations to deliver co-ordinated power dispatch and frequency control services.[24]

In Finland, the German technology firm Siemens, in partnership with the government, piloted an initiative that combines loads from buildings with renewable energy generators and battery storage.[25] Such systems also work in conjunction with forecasting technologies, as in Singapore where a partnership among government, industry and academia aims to complete a virtual power plant by 2022 that responds to demand forecasting based on live market data from the power grid.[26]

"Smart" digital products are being used to change consumption patterns among grid-connected customers, leading to better grid balancing during high VRE production periods and to reduced curtailment of solar and wind energy.[27] In the United Kingdom, consumers who subscribed to a pilot smart metering programme were paid to use electricity during a period of surplus VRE generation in late 2019.[28] These prosumers were effectively compensated for providing a grid balancing service.[29] Digital technologies, including artificial intelligence, also are being used for predictive maintenance of fleets of VRE generators, leading to increased reliability and reduced downtime.[30]

i Demand response initiatives or programmes make use of market signals such as time-of-use pricing, incentive payments and penalties to influence end-user electricity consumption behaviours, usually to balance electrical supply and demand within a power system. Modern demand response programmes often also aim to influence or control the behaviour of embedded generators or energy storage capacity to achieve similar ends.

ii A prosumer, in the context of the energy sector, is an individual or entity that both consumes and generates energy.

IMPROVED FORECASTING OF VARIABLE RENEWABLE ELECTRICITY GENERATION

Accurate forecasting of both power system demand and VRE generation allows system operators to anticipate VRE availability and to cost-effectively balance generation and demand in short-term energy market scheduling.[31] This reduces fuel costs, minimises curtailment of VRE and improves system flexibility and reliability.[32] Efforts continued in 2019 to improve forecasting of VRE resources to enable accurate supply and demand planning. In Australia, researchers combined neural networks and pattern sequences – techniques commonly used in artificial intelligence and language translation – to improve solar forecasting.[33] In the United Kingdom, artificial intelligence was used to evaluate up to 80 variables influencing solar generation output and to boost forecasting accuracy by one-third.[34] Solar forecasting advanced at numerous US universities and research institutes, and a company on the Indian Ocean island of Reunion (France) was combining multiple data inputs and models to offer enhanced VRE forecasting tools to solar projects around the world.[35]

For wind power, the Australian Renewable Energy Agency awarded funding to Vestas (Denmark) to develop a new wind forecasting solution for Australia.[36] In the United States, DeepMind, a subsidiary of the US multinational Alphabet, used artificial intelligence to more accurately predict generation from wind energy and the periods during which its value can be maximised in the market.[37]

INFRASTRUCTURAL LINKAGES

Grid infrastructure, including transmission and distribution equipment and technologies, can be a crucial enabler of power system flexibility. Grid infrastructure can connect regions of VRE generation with demand centres; aggregate VRE resources over larger geographic areas to mitigate the effects of variability; and link or expand electricity markets to increase market scope, choice and efficiency.[38] Conversely, with the rapid growth of VRE capacity in many markets, grid infrastructure can become a significant bottleneck for integrating rapidly increasing VRE output if power networks are not actively planned and upgraded in line with VRE uptake.[39]

Grid infrastructure upgrades to directly support VRE growth were under way or planned in most world regions in 2019. In Europe, a subsea transmission line linking Ireland and the United Kingdom to support the uptake of renewables secured private and public funding and advanced through various permitting processes.[40] In several US states, large transmission projects were under development with the aim of interconnecting regional energy markets with VRE projects.[41] Projects also were planned in Australia, where transmission infrastructure has been a barrier to ongoing deployment of wind and solar power.[42]

In Asia, the state-owned Power Grid Corporation of India announced plans for USD 1.8 billion of new transmission projects in several Indian states to support 25.4 gigawatts (GW) of planned wind and solar power projects.[43] Significant investments in enhanced transmission infrastructure have occurred in China – including the completion of 22 ultra-high-voltage transmission lines in the past decade, motivated in part by the need to accommodate more renewable generation.[44]

South Africa's public utility Eskom secured ZAR 1.5 billion (USD 107 million) in development funding for transmission projects that will couple solar and wind power plants with the national grid.[45] In Mozambique, the World Bank approved USD 420 million in grants to strengthen the transmission system and support the integration of renewable technologies in power system planning and operation.[46]

In Latin America, the Brazilian Development Bank approved a BRL 1.8 billion (USD 429 million) loan for developing transmission lines that will enable the connection of 6.5 GW of wind power projects.[47] A 55-kilometre transmission line was completed in Chile to connect 293 MW of solar capacity to the national grid.[48]

ENABLING TECHNOLOGIES FOR SYSTEMS INTEGRATION

Technologies such as heat pumps, electric vehicles and energy storage are supporting the integration of renewable energy by increasing flexibility in energy systems, and in particular power systems. These technologies also are unlocking increased demand for renewable energy, particularly VRE, by coupling renewables with end-uses across the power, transport, and heating and cooling sectors.

In many cases, these enabling technologies have been in use for decades, for applications unrelated to the integration of renewable energy. They have achieved varying levels of commercial maturity: while EVs have relatively low market shares, heat pumps are deeply embedded in many residential and industrial heating and cooling markets.[49] Important market and industry developments occurred for all of these technologies in 2019.

HEAT PUMPS

Heat pumps are a widely used and mature group of technologies that most commonly employ an electrically driven process to efficiently[i] move heat from one body of air, water or the ground to another. They are used for heating and cooling in buildings and industry. Heat pumps can increase power system flexibility by coupling generation with heating and cooling end-uses that have flexible demand characteristics.

The potential of heat pumps for increasing power system flexibility and for unlocking greater demand for VRE is significant. An estimated 75% of the global potential for demand response lies in the electrification of heat in buildings, and heat pumps could serve as much as 90% of global space and water heating demand.[50]

Heat Pump Markets

Heat pumps form a large part of the broader heating, ventilation and air conditioning (HVAC) market, which has grown rapidly in recent years, driven by rising demand for cooling in emerging economies.[51] However, accurately assessing the scale of the global heat pump market is challenging due to a lack of data and to inconsistencies among datasets[ii].

Much of the growth in the heat pump market is due to sales of reversible air conditioning units used for both cooling and heating.[52] Air-source heat pumps are particularly well suited to use solar electricity to meet large and rising global demand for cooling, since solar generation typically corresponds with increased cooling loads.[53] Much of the remaining heat pump market consists of ground-source heat pumps.[54]

As global demand for heating and cooling has expanded, growth in the heat pump market has been consistently strong.[55] Nearly 18 million households purchased heat pumps for heating and/or cooling applications in 2018 (latest data available), up nearly 30% from 2017.[56] Around 80% of these units were installed in China, Japan and the United States.[57]

Heat pumps still contribute only a small share to heating applications, servicing around 3% of global heating demand in buildings as of the end of 2018.[58] However, global sales of heat pumps for water heating grew rapidly compared with the previous decade.[59] In 2019, heat pump sales for sanitary water heating in China reached 1.5 million units.[60] Japan also is a large market for water heating applications of heat pumps, with more than 0.5 million sales in 2019 after four consecutive years of strong market growth.[61] In Europe, sales of heat pumps for sanitary hot water totalled around 0.2 million.[62]

China dominated the global market for air-source heat pumps for space heating, with sales numbering in the tens of millions in 2019.[63] In the United States, where the market has grown for a decade, more than 3.1 million air-source heat pumps were sold.[64] For the European market, 2019 was the sixth year in a row with market growth above 10%, and by year's end heat pumps met nearly 10% of space heating demand in European buildings.[65] Air was the dominant energy source, used in more than 90% of the 1.5 million heat pumps sold in Europe for residential and commercial applications.[66]

Large heat pumps are well suited to district heating and cooling applications and have been implemented in systems across Europe, including in Denmark, France, Scotland and Serbia.[67] In Denmark, 13 large heat pumps at 11 combined heat and power plants with a total capacity of 29.7 MW were installed in 2019.[68] In Serbia, a heat pump for industrial heating and residential cooling was in planning, and large heat pumps form part of the city of Belgrade's long-term district heating and cooling plan, presented in 2019.[69]

Heat Pump Industry

The year 2019 saw a range of investments by large technology companies in specialised heat pump firms, a focus on incremental cost and efficiency improvements, and the integration of heat pumps alongside renewables and energy storage using digital technologies.

The heat pump industry consists of both large manufacturers and many small and medium-sized enterprises involved in the design, manufacture, installation and maintenance of heat pumps. Large manufacturers included Bosch (Germany), Carrier (United States), Daikin (Japan), Ingersoll-Rand (Ireland), Johnson Controls (United States), Mitsubishi (Japan), Panasonic (Japan), Nibe (Sweden) and Stiebel-Eltron (Germany).

Several large technology firms invested in specialised heat pump companies during the year, often across country or regional boundaries. The air conditioning company Daikin (Japan)

i Heat pumps can typically move three to five units of heat for each unit of electricity consumed, and the output of a heat pump can be 100% renewable when it is driven by renewable electricity and makes use of a renewable heat source (such as ambient heat from the air, the ground or bodies of water). The ratio of heat energy moved over electrical energy consumed is known as the coefficient of performance of the heat pump and varies based on the technical characteristics of a given unit as well as the temperatures of the both heat source and the body where the heat is pumped to (known as the heat "sink").

ii One reason for limited and fragmented data on heat pumps may be variation in how systems are classified. In moderate climates, heat pumps generally are counted as air conditioning equipment, with a side benefit of dehumidification or provision of hot water. In cold climates, the heating service is much more important, and heat pumps thus are counted as heating equipment, with cooling and dehumidification considered welcome by-products.

acquired AHT (Austria), which specialises in the use of natural refrigerants in air conditioning and heat pump systems, and Panasonic (Japan) completed the acquisition of the heat pump business of Kauco Oy (Finland) in early 2020.[70] In Europe, the building services firm Bravida (Sweden) acquired ICS Cooling Systems (United Kingdom), a specialist in industrial heat pumps, and Swegon Group (Sweden), a ventilation and indoor heating and cooling company, acquired Klimax AS, a major heat pump distributor in Norway.[71] Also in 2019, Dalrada Financial Corporation (United States) acquired Likido (Scotland), a manufacturer of high-efficiency heat pumps, as part of a strategy to expand manufacturing and engineering services.[72]

Heat pumps are a mature technology, consisting of a basic product design that is expected to remain largely unchanged.[73] In Europe in particular, the main focus of the heat pump industry has turned to cost optimisation, and in some locations heat pumps have been subject to new standards that forced manufacturers to improve unit efficiency.[74] Several manufacturers, including Bosch, Carrier, Ingersoll-Rand and Mitsubishi, released new residential and industrial heat pump products in 2019 that offered improved efficiencies, lower costs or greater durability.[75] In Denmark, research and development (R&D) on air-to-water heat pumps was under way to increase efficiencies 5-10% and to achieve the highest possible rating under the EU energy label system.[76]

Heat pumps are being incorporated alongside renewable energy, storage and digital technologies to deliver flexible energy services in a range of pilot projects. In the United Kingdom, a demonstration project aims to couple 320 ground-source heat pumps with battery storage to supply heating for social housing.[77] Planning also is under way in the country for a pilot virtual power plant facility that will combine heat pumps (both air- and water-sourced) with solar PV, battery storage and EVs.[78] In Bedburg (Germany), a government-backed flexible district energy system plans to use heat pumps powered by wind and solar PV plants to meet heat demand.[79]

ELECTRIC VEHICLES

The use of electric vehicles[i] allows for renewable electricity to replace fossil fuels in some transport applications, to the extent that the electricity comes from renewable sources. As their market share grows, EVs also have the potential to support the integration of VRE by presenting options for demand- and supply-side response, such as through vehicle-to-grid (V2G)[ii] technology. EV uptake in individual markets is influenced greatly by the presence of supportive national and local policies.[80] (→ *See Policy Landscape chapter and* ***Reference Table R10***.) Although passenger rail is the most electrified form of transport, the largest recent advancements in electric transport have been in road vehicles.[81] Limited examples of commercialised electric marine transport exist, and electric aviation remains pre-commercial.[82] (→ *See Global Overview.*)

Electric Vehicle Markets

EV markets continued to grow quickly in 2019, with the global EV stock reaching 259 million units.[83] The vast majority were two- and three-wheelers, while around 7.2 million of the vehicles were electric cars (passenger EVs), just over half a million were electric buses, and nearly 0.4 million were light commercial vehicles.[84]

The stock of electric cars (passenger EVs) increased 40% in 2019, up more than 2 million from 2018.[85] (→ *See Figure 54.*) However, growth was lower than in 2018, when 2.2 million of the vehicles were sold and the global stock jumped 63% over the previous year.[86] In 2019, electric cars still comprised only a small share of all passenger vehicles, at just 0.6% of the global stock.[87] However, the share of electric cars in new car sales reached 2.5%, a record high.[88]

China was home to 47% of the global electric car stock by the end of 2019, followed by Europe (25%) and the United States (20%).[89] Chinese sales of new electric cars reached just over 1 million units, around 20,000 units less than in 2018.[90] Europe had the next highest sales, at 560,000 units, followed by the United States at 327,000 units.[91] Overall, global sales of electric cars were down 6% in 2019, just above the 4% decline in sales for passenger cars of all types.[92] Norway remained the leader in the share of electric cars in overall car sales, at 56%, followed by Iceland (25%), the Netherlands (15%) and Sweden (11%).[93]

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

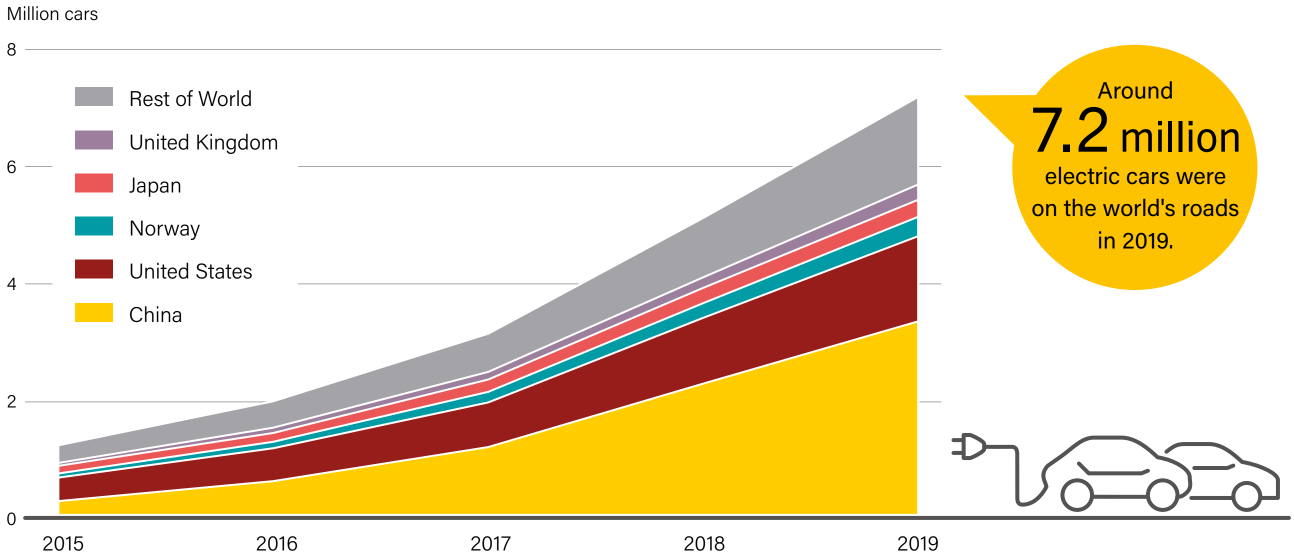
ii Vehicle-to-grid (V2G) refers to a system that allows EVs to communicate with the power grid and provide demand response services by reducing charging rates or returning electricity to the grid. A V2G system can allow EVs to store or discharge VRE if the prevailing electricity mix within a power system includes solar PV or wind power.

The global stock of electric two- and three-wheelers reached around 251 million in 2019.[94] Virtually all of these vehicles were in China.[95]

Sales of electric buses declined for the fourth consecutive year.[96] This drop reflected a 20% decrease in year-on-year sales in China – where some 71,000 new electric buses were registered, or 95% of the global total.[97] Growth was strong in other regions, but with much lower numbers.[98] India increased its stock of electric buses to around 800 units, and Europe's stock increased 60% compared with 2018, to around 4,500 units.[99] In North America, some 2,200 electric buses were in operation at the end of 2019.[100] (→ *See Figure 55.*)

Public procurement by local and national governments helped boost EV markets in 2019. In India, the government of the Delhi region approved the purchase of 1,000 electric buses, the largest such commitment outside of China.[101] A range of other policies supported EV markets during the year, including e-mobility targets, financial incentives and indirect incentives (such as free parking and preferred access). (→ *See Policy Landscape chapter.*)

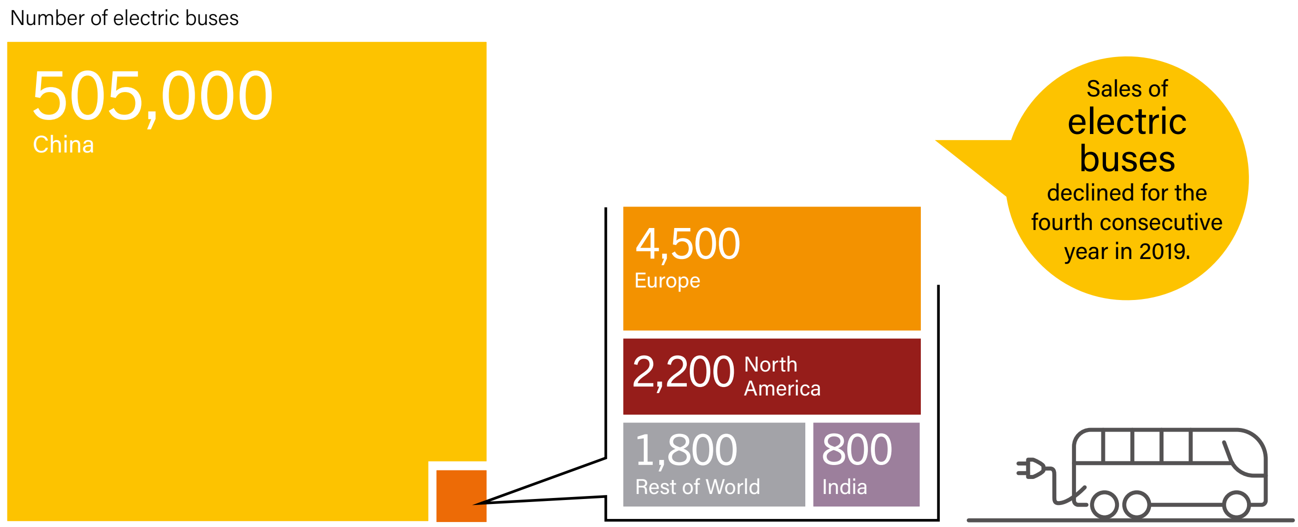
FIGURE 54. Electric Car Global Stock, Top Countries and Rest of World, 2015-2019



Note: Includes battery electric vehicles and plug-in hybrid electric vehicles. Shows countries among the top 5 according to the best available data at the time of publication.

Source: IEA. See endnote 85 for this chapter.

FIGURE 55. Electric Bus Global Stock, China and Selected Regions, 2019



Source: IEA. See endnote 100 for this chapter.

Around 2 million EV charging points were installed in 2019, increasing the global stock 40% to 7.5 million.[102] This includes both private and public, and fast and slow chargers, although nearly 90% of the total is private slow chargers.[103] The number of private chargers grew just under 40% in 2019, while the number of public chargers increased 60%.[104] China accounted for 80% of the new public fast chargers that entered the global market in 2019 and for just over half of the new public slow chargers.[105]

Passenger rail is the only form of transport that is widely electrified, and the share of electrification in the sector increased from 60% in 2000 to around 75% in early 2019.[106] The highest rates of passenger rail electrification are in Europe and Japan.[107] In the Americas, rail remains predominantly diesel-powered, and in most world markets freight rail is much less electrified than passenger rail.[108]

Electric rail can only be considered as a partially renewable form of transport depending on the prevailing shares of renewable energy in a given power supply system. Efforts have been made to directly electrify rail transport using VRE. In the United Kingdom, a trial project launched in 2019 connects solar panels to the direct current network of a rail system in south-east England.[109] Similar systems have been implemented at a small scale in several other countries.[110]

Variable renewable electricity was increasingly supplied to EV charging networks in 2019.

Electric Vehicle Industry

The electric vehicle industry in 2019 was characterised by diverse commitments and investments from both dedicated EV manufacturers and traditional automakers. The industry also was bolstered by investments from non-automotive companies and by large corporate orders for EV fleets.

In 2019, the leading manufacturers of passenger EVs (including BEVs and PHEVs) were (in order of number of units produced) Tesla (United States); BYD, BAIC and SAIC (all China); BMW and Volkswagen (both Germany), Nissan (Japan), Geely (China), Hyundai (Republic of Korea) and Toyota (Japan).[111] Tesla surpassed BYD as the global EV sales leader after it recorded strong growth in the European and Chinese markets.[112]

Many traditional vehicle manufacturers announced plans to expand their EV offerings.[113] Toyota intends to offer electric versions of all of its vehicles by 2025, and Hyundai aims to offer 44 EV models by 2025.[114] In Europe, Volvo (Sweden) plans to launch new EVs every year until 2025, and Volkswagen intends to build 22 million EVs over the next 10 years.[115] Several other traditional auto manufacturers planned to release new models in 2020 and beyond.[116]

Hydrogen fuel cell electric vehicles (FCEV) also advanced in 2019, although the upfront and running costs of the vehicles remain higher than for petrol or diesel equivalents.[117] Toyota, which launched the world's first commercial FCEV for the general market – the Mirai sedan – in 2014, unveiled a second version in 2019.[118] Hyundai planned to launch two new hydrogen FCEVs by 2025 and partnered with the diesel engine and generator manufacturer Cummins to supply hydrogen fuel cell systems to the transport and electricity sectors.[119]

Non-automotive companies have moved into the EV space, including the solar technology company SolarEdge (Israel), which announced plans to acquire SMRE, an Italian firm specialised in powertrain technology and electronics for EVs.[120] Numerous Chinese companies, including online retailer Alibaba, and the internet companies Tencent and Baidu, acquired or increased stakes in EV companies.[121]

VRE was increasingly available on EV charging networks in 2019. The largest US public fast-charging network, EVgo, was contracting 100% of its electricity from renewable sources during the year.[122] In the US state of Texas, the utility Austin Energy offered 100% electricity from wind power to EV users via its network of 800 charging points.[123] In Europe, BMW partnered with the Dutch grid operator TenneT to pilot an intelligent charging system that allows EVs to maximise their use of VRE.[124]

Numerous vehicle-to-grid initiatives were under way in 2019, enabling EVs to provide flexibility services to electric grids through the controlled export of electricity from their onboard batteries. By year's end, around 65 V2G projects and initiatives were in progress across 15 countries.[125] Several projects in the Netherlands, the Republic of Korea and the United Kingdom reached the pilot stage, and others had achieved or were nearing commercial operation in Denmark, Japan, the United Kingdom and the United States.[126]

ENERGY STORAGE

Energy storage can allow for flexible dispatch of renewable electricity and thermal energy at times of demand, and also can enable surplus or otherwise curtailed VRE to be applied to end-uses such as heating and cooling, mobility (as in EVs) and electricity generation. Energy storage includes mechanical, electrical, electro-chemical, thermal and chemical technologies, all of which can play an important role in the system integration of renewables.

Widely commercialised storage technologies relevant to the integration of renewables include pumped storage, various forms of electro-chemical storage such as lithium-ion, lead-acid and flow batteries, and certain thermal energy storage systems (including molten salt storage and hot water or ice storage). Biofuels also are a form of renewable energy storage, but in this report they are addressed as a primary form of renewable energy rather than as an enabling technology. (→ *See Bioenergy section in Market and Industry chapter.*)

Much of the development of energy storage over the past decade has focused on short-duration[i] applications. Emerging long-term or long-duration technologies, such as renewable hydrogen, flow batteries and novel forms of mechanical storage, are supported by decreasing costs and rising shares of VRE in many power systems.[127] Mature storage technologies often are less viable for longer-duration storage because of limitations relating to cost, durability, energy density or resource availability (for example, pumped storage) – a characteristic that has potential importance for wider decarbonisation of the energy sector.[128]

Energy Storage Markets

The global market for energy storage of all types reached 183 GW in 2019.[129] Mechanical storage in the form of **pumped (hydropower) storage** accounted for most of this capacity, at around 158 GW[ii], with 0.3 GW of new pumped storage capacity added during the year.[130]

Several new pumped storage facilities were under development in 2019 to directly facilitate the integration of renewables through storage and dispatch of VRE – including in Greece, the United Arab Emirates, the United States and Zimbabwe.[131] In Australia, the public utility Hydro Tasmania planned to connect the electrical grid of Victoria with up to 2.5 GW of new pumped storage capacity on Tasmania, increasing grid flexibility on mainland Australia and enabling higher VRE shares in the national electricity market.[132]

The leading markets for **battery storage** saw mixed results in 2019.[133] The United States had a record year for new capacity, adding 523 MW and 1,113 megawatt-hours (MWh), although project delays impacted the market.[134] Regulatory changes slowed growth in the Chinese battery market, with 520 MW and 855 MWh of new capacity added in 2019.[135] (→ *See Figure 56.*)

In Australia, 143 MWh of grid-scale battery capacity was installed, more than double the amount in 2018.[136] Australia added 233 MWh of new home batteries to reach 1 gigawatt-hour (GWh) of residential battery capacity.[137] In the Republic of Korea, battery installations fell 70% relative to 2018, mainly because a series of fires at battery installations triggered safety concerns.[138]

The European energy storage market (excluding pumped storage and TES) also contracted in 2019, with 1 GWh of new storage capacity added for a total of 3.7 GWh.[139] Despite around 5% growth in the behind-the-meter storage market (mostly residential), a decline in front-of-meter installations contributed to the overall market drop.[140]

Renewables-plus-storage has emerged as a major driver of battery market growth, and the direct coupling of batteries with VRE generators has become more widespread.[141] In the United States, utility-scale projects combining solar PV and storage were completed in Hawaii, Massachusetts, and Texas, and several other projects coupling solar PV or wind with batteries were under construction or planning.[142] VRE-plus-storage projects also were completed or in planning in Australia, China, the United Kingdom, and smaller or developing countries such as Mali, South Sudan and St. Kitts and Nevis.[143]

The United States is a leading market for stand-alone utility-scale batteries, many of which are being built to indirectly enable higher VRE shares or to directly provide power systems with services that increase flexibility and resilience.[144] In the state of New York, a 4.8 MW (16.4 MWh) battery was installed as part of a demand response programme, and facilities under development in Arizona and Texas planned to provide demand response and ancillary services.[145] Elsewhere in the world, a battery in South Australia entered operations to provide both frequency response and arbitrage services, and in Tonga a battery that aims to enable greater deployment of wind and solar power was expected to enter operations in mid-2020.[146]

Decentralised, behind-the-meter battery storage – including both stand-alone storage and VRE-plus-storage – showed strong growth in several markets. Germany was the leading European market for residential storage in 2019, with 369 MWh, and the number of US residential solar-plus-storage installations doubled between 2017 and 2019.[147] In the New England region of the United States, 20 MW of storage capacity – to be aggregated from around 5,000 residential systems – was approved for connection to the local grid, representing the first participation of residential solar-plus-storage in the US wholesale market.[148] Residential storage also grew strongly in South Australia, where the government's Home Battery Scheme secured 5,500 installations and orders by early 2020, equivalent to 62 MWh of storage capacity.[149]

i The terminology used to categorise energy storage by duration or discharge period varies widely in academia, industry and the media. The GSR considers "short-duration" storage to be energy storage for less than around 10 hours, and "long-duration" refers to periods of around 10 to 100 hours. "Long-term" or "seasonal" storage describes energy storage for periods in excess of 100 hours, typically for weeks, months and years. Pumped storage is a mature and widely commercialised form of long-term storage.

ii Energy storage installations are specified in terms of both rated power (measured in kilowatts (kW), MW or GW) and the energy capacity (kilowatt-hours (kWh), MWh or GWh). Where possible, information on energy storage installations is reported in terms of both the rated power and the energy capacity of the installation. In some cases, data are reported in terms of only power or energy due to a lack of available information. Energy storage data also are occasionally reported in terms of time (i.e., the number of hours at which a facility can operate at its rated power output, based on its energy storage capacity), notably in concentrating solar thermal power storage markets. In these cases, rated power and storage "hours" may be used to calculate energy capacity in kWh, MWh or GWh.

Thermal energy storage – mainly in the form of molten salts – has been commonly deployed alongside concentrating solar thermal power (CSP) to allow for greater generation flexibility. In 2019, 3.4 GWh of new TES was deployed at CSP facilities, increasing the global installed capacity nearly 20% to 21 GWh.[150] (→ *See CSP section in Market and Industry chapter.*) Other thermal storage media, including water, were in use or being developed for non-CSP applications. At least 45 cities across Africa, Asia, Europe, the Middle East and North America were using centralised water reservoirs to store hot or cold water in district heating and cooling systems.[151]

Renewable hydrogen is an emerging storage technology with long-duration and long-term applications, although virtually all hydrogen continued to be produced from fossil fuels in 2019. Renewable hydrogen is produced from water through a VRE-driven electrolysis[i] process, or alternatively from renewable feedstocks through gasification[ii]. Producing hydrogen using VRE with electrolysers can enable significant power system flexibility when surplus VRE is utilised.[152] Renewable hydrogen also can unlock demand for VRE by acting as a substitute for non-renewable hydrogen, which is produced using natural gas and is widely used in global industry.[153]

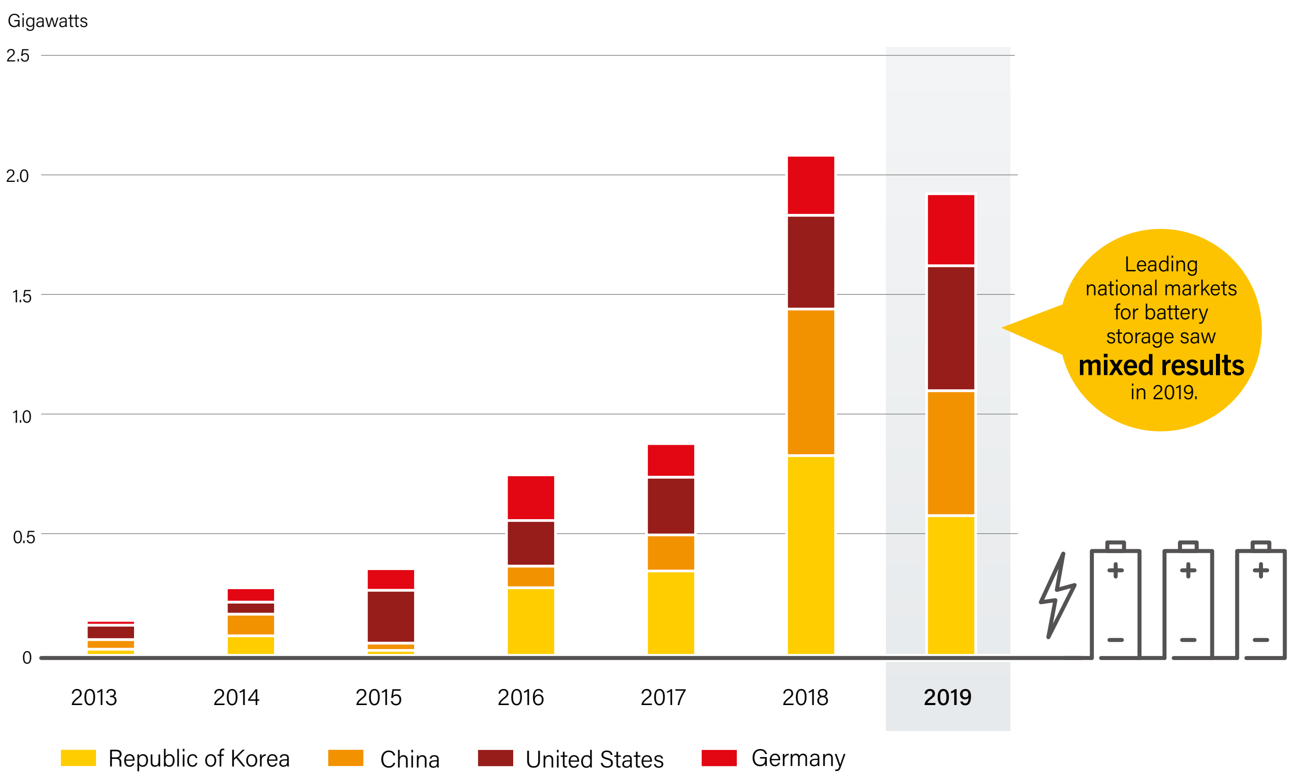
As of early 2020, more than 70 MW of hydrogen electrolyser capacity was in operation globally, with a further 45 MW under construction.[154] Efforts to scale up hydrogen production and demand received greater public support in 2019 , although not always linked to renewable energy. Japan has driven support for the global hydrogen economy by promoting hydrogen-fuelled vehicles and initiatives aimed at greatly reducing hydrogen costs.[155] Australia's National Hydrogen Strategy targeted the creation of clusters of large-scale demand for hydrogen in ports, cities and rural locations.[156] Australia also planned to export renewable hydrogen to Asian markets, and a large-scale hydrogen production facility driven by 5 GW of wind and solar power capacity was slated to open in 2028.[157] The UK government backed a plan to deploy a GBP 12 billion (USD 16 billion) offshore wind farm in the North Sea with the aim of generating renewable hydrogen.[158]

Other long-duration or long-term storage technologies advanced in 2019. For example, a 2 MW (8 MWh) vanadium redox flow battery, originally launched in 2017, became the first battery of this type to be connected to a US wholesale power market (in California).[159] A long-term 1.75 MW (10 MWh) mechanical storage facility developed in Ontario, Canada by Hydrostor (Canada) was built to use (surplus) VRE to store energy in the form of compressed air.[160] The company was developing similar facilities elsewhere.[161]

i The electrolysis of renewable hydrogen makes use of an electrical current to split water molecules into hydrogen and oxygen.

ii The gasification process exposes feedstocks (for example biomass, fossil fuels, or municipal waste) to extremely high temperatures in order to split them into their component elements, including hydrogen, oxygen, and other metallic and nonmetallic byproducts.

FIGURE 56. Battery Storage Annual Additions, Selected Countries, 2013-2019



Note: Capacity shown for selected countries according to available data at the time of publication. Does not reflect global total.

Source: See endnote 135 for this chapter.

Energy Storage Industry

The energy storage industry saw significant cost improvements, increased manufacturing capacity, large investments and ongoing R&D during 2019, with many of these activities focused on short-duration storage applications and battery technologies.

Notable cost improvements occurred for several storage technologies, particularly batteries. The average cost of a unit of lithium-ion battery capacity decreased 85% between 2010 and 2018.[162] Meanwhile, the levelised cost of electricity from lithium-ion batteries fell by half between early 2018 and early 2020.[163] In certain markets, lithium-ion battery storage coupled with VRE has become competitive with traditional, fossil fuel-based power in providing flexible, "dispatchable" power.[164] Declining lithium-ion costs are driving the increased competitiveness of EVs in relation to conventional fossil fuel-powered equivalents.[165] (→ *See Electric Vehicles section in this chapter.*)

The costs of low-carbon and renewable hydrogen produced via electrolysis fell 45% between 2015 and early 2020, but have remained high relative to non-renewable hydrogen.[166] By one estimate, the cost per kWh of renewable hydrogen produced with solar PV power was roughly two to four times that of petrol in the United States.[167] In Canada, a hydrogen producer began offering partially renewable hydrogen in early 2020 at a cost of USD 2.67 per kilogram (compared with USD 1.50 per kilogram for typical non-renewable hydrogen).[168]

The manufacturing capacity of certain types of storage has increased. For lithium-ion batteries, the global manufacturing capacity expanded from 14 GWh in 2010 to 316 GWh in early 2019, with more than 86% of this in China.[169] Large lithium-ion battery factories also were planned in Australia, India, South Africa and the United States.[170] As of mid-2019, the five largest lithium-ion manufacturers by capacity were LG Chem (Republic of Korea), CATL (China), BYD (China), Panasonic (Japan) and Tesla (United States).[171]

Global capacity for manufacturing renewable hydrogen was expected to grow strongly as of 2019, and in several countries large-scale electrolysers were either opened, under construction or nearing construction. A 6 MW electrolyser powered by renewable electricity entered operations in Austria.[172] In Germany, a project was announced for what is expected to be the world's largest electrolyser when it opens in 2023 – a 100 MW electrolyser powered by wind and solar energy.[173] A 1.25 MW electrolyser started construction in Australia, and a 20 MW electrolyser in Canada aimed to start production in 2020.[174]

Energy storage, and particularly lithium-ion batteries, attracted significant investment in 2019. Venture capital firms contributed an estimated USD 1.7 billion to battery storage companies, with 80% of the total directed at lithium-ion technologies.[175] Several notable acquisitions occurred in the energy storage sector. For example, US-based private equity firm Energy Capital Partners acquired Convergent, a developer of the largest utility-scale battery projects in North America.[176]

Oil and gas companies made strategic investments in energy storage as a way to diversify their services. Shell (Netherlands) acquired 100% of the German battery storage firm Sonnen with the aim of offering cleaner energy solutions to customers, and BP (United Kingdom) increased its stake in the solar PV and energy storage developer Lightsource.[177] In the areas of mining and battery raw material production, Wesfarmers (Australia) took a controlling stake in lithium mine developer Kidman Resources, which is involved in a lithium hydroxide project in western Australia that aims to supply the EV market.[178]

Among public investments in storage, the World Bank announced a partnership with 29 research and industry organisations aimed at advancing energy storage in developing countries.[179] In Tonga, the Asian Development Bank committed USD 44.6 million to a range of renewable-based systems and mini-grids, including battery systems.[180]

Significant investments in emerging storage technologies occurred, including in renewable hydrogen, mechanical or gravity-based energy storage, flow batteries, compressed air and cryogenic energy storage.[181] Amazon (United States) invested in Plug Power, a US company specialising in hydrogen fuel cells, and Cummins (United States) bought shares in Loop Energy (Canada), a provider of hydrogen fuel cell electric range extenders for commercial trucks.[182] Cummins also acquired the hydrogen and fuel cell technology company Hydrogenics (Canada) in 2019, the same year that Cummins made a commitment to be carbon neutral by 2050.[183]

In Sweden, the electric utility Vattenfall and the oil and fuel company Preem collaborated on designing a 20 GW renewable hydrogen facility that is expected to be Europe's largest water electrolysis facility – one of numerous "green hydrogen" initiatives that Vattenfall is involved in across the transport, power generation and industrial sectors.[184]

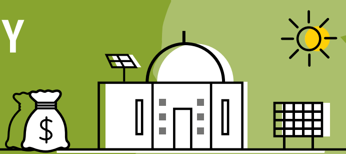
Among investments in long-term storage, SoftBank (Japan) invested USD 110 million in the mechanical storage company Energy Vault (Switzerland), and a consortium including the oil company Eni (Italy) invested USD 40 million in Form Energy (United States), a long-term chemical storage company.[185] Two long-term storage start-ups also received significant investments: ESS Inc. (United States), focused on iron-flow batteries, and Hydrostor (Canada), which is developing compressed-air storage.[186]

Wide-ranging R&D activities related to energy storage included a focus on improving battery efficiency, safety, reliability and cost.[187] The safety of lithium-ion battery storage facilities gained attention after a fire and explosion at a plant in the US state of Arizona and numerous fires in the Republic of Korea; research aimed at reducing these risks through the use of alternative electrolyte materials and other approaches.[188] Batteries also were investigated (alongside solar PV) for military applications, and the US Navy ordered two transportable solar-battery microgrids for test use.[189]

R&D in thermal energy storage included the testing of new storage media in Hamburg, Germany, where Siemens Gamesa (Spain) was piloting the use of crushed volcanic rock as the storage medium for VRE converted into heat using electrical resistance heating.[190] Novel applications of water- and ice-based thermal storage also advanced. In the US state of California, a distributed network of ice machines was being developed to produce ice during periods when electricity rates are low and to service air conditioning demand during high-rate periods.[191]

07

GOVERNMENT SUPPORT FOR ENERGY EFFICIENCY, JORDAN



The Kingdom of Jordan's Renewable Energy & Energy Efficiency Fund (JREEEF) uses a bottom-up approach to make renewable energy more accessible to citizens. The Fund covers 30% of the costs of household solar PV systems and works with local banks to provide subsidised loans to cover the rest. Across Jordan, some 138 schools and 430 mosques and churches have benefited from JREEEF's support by installing solar water heaters and PV systems, improving insulation and lighting, and reducing their energy bills.

07 ENERGY EFFICIENCY AND RENEWABLES

KEY FACTS

- Global primary energy intensity continued to fall in recent years, enabled in part by increased renewable electricity production.
- Global final energy demand has risen, despite improvements in energy intensity that have facilitated larger renewable energy shares.
- The increase in final energy demand has been driven largely by rapid economic growth and improved energy access in developing and emerging economies and a global shift towards energy-intensive transport.

International efforts to meet energy demand in a safe and reliable manner generally acknowledge the complementary nature of renewable energy deployment and energy efficiency measures.[1] Both renewables and efficiency can contribute significant benefits including lower energy costs on a national, corporate or household level, increased grid reliability, reduced environmental and climate impacts, improved air quality and public health, and increased jobs and economic growth.[2] The United Nations' Sustainable Development Goal 7[i] (SDG 7) recognises that combining renewables and efficiency provides an integrated means towards achieving sustainable energy access for all.[3]

Energy production and use account for more than two-thirds of global greenhouse gas emissions.[4] Taken together, renewable energy deployment and energy efficiency measures can potentially achieve most of the carbon reductions required to keep global temperature rise below 1.5 degrees Celsius.[5] Moreover, renewables and efficiency maximise their emissions mitigation potential when pursued together.[6]

Coalitions of governments, corporations, institutions and non-governmental organisations have boosted global energy efficiency efforts, recognising the potential to greatly reduce greenhouse gas emissions.[7] As of the end of 2019, 131 parties

i In 2015, the United Nations General Assembly adopted a set of 17 goals as part of a new global agenda on sustainable development. SDG 7 aims to ensure access to affordable, reliable, sustainable and modern energy for all – including targets to "increase substantially the share of renewable energy in the global energy mix" and to "double the global rate of improvement in energy efficiency" by 2030. See endnote 3 for this chapter.

to the Paris Agreement mentioned renewable energy in their Nationally Determined Contributions (NDCs) to reduce emissions, while 112 parties mentioned energy efficiency, and 94 mentioned both.[8] Energy efficiency was a main contributor to stabilising global greenhouse gas emissions in 2019, along with renewables.[9] (→ *See Box 1.*)

Energy intensity, which represents primary energy supply per unit of economic output[i], plays an important role in evaluating developments in energy efficiency (for example, it is a key indicator for tracking efficiency improvements under SDG 7). Energy intensity is complemented by carbon intensity, which measures the amount of carbon dioxide emitted per

i See Glossary for expanded definition and for details on why energy intensity is used as a proxy for energy efficiency. Energy intensity is an imperfect indicator for energy efficiency, as it reflects not only changes in relative energy efficiency but also structural changes in economic activity (such as a shift from heavy industry towards services and commerce). (→ See Box 2.)

BOX 1. Energy Efficiency and the Deployment of Renewables: Working Together with Limited Resources

Energy efficiency and renewables generally complement each other in an integrated approach to achieve common global goals. In some cases, however, trade-offs can occur between the two, due mainly to competing costs. Given that financial resources are inherently limited in most economies and for most actors, the relative prices for energy efficiency and renewable energy have the capacity to reduce the incentive to implement one or the other. This is not necessarily a negative phenomenon, as both efficiency and renewables serve largely the same objective.

The costs of generating electricity from renewable energy technologies continued to decline in 2019, with solar photovoltaic (PV), hydropower, onshore wind power, bioenergy and geothermal projects becoming increasingly competitive with fossil energy generation. (→ *See Sidebar 5.*) In some locations, however, renewable electricity prices for end-consumers remain higher than conventional electricity prices[i].

Meanwhile, plenty of no- or low-cost energy conservation and efficiency measures exist that can be implemented at a wide scale, such as turning off appliances that are not in use or activating "sleep" settings, switching to low-energy lighting and installing insulation films for windows. The public and private sectors are increasingly recognising how such "low-hanging fruit" can yield major energy cost savings.

Ultimately, the optimal combination of efficiency and renewables is both location- and sector-specific. Additionally, implementing efficiency measures facilitates the deployment of renewable energy either concurrently or subsequently. Integrated strategies for efficiency and renewables thus can be the most effective approach for maximising the potential of both. For example, in the Seychelles an Energy Efficiency and Renewable Energy Programme in place since 2017 aims to encourage residents to buy energy-efficient appliances and renewable energy, and Morocco's Jiha Tinou programme seeks to stimulate renewables and efficiency initiatives in cities and regions. (→ *See Policy Landscape chapter for additional developments in 2019.*)

i Some of this price discrepancy can be attributed to ongoing adjustments to variable electricity supplies in power markets and to the diverse business models of energy utilities and infrastructure operators. Conventional electricity prices are those from fossil fuel and nuclear power plants.

Source: See endnote 9 for this chapter.

unit of final energy consumed[i,10] In general, interactions between the deployment of renewable energy technologies and improvements in energy efficiency are complementary, as efficiency reduces the overall primary energy needed, while the use of renewables minimises both the primary energy needed as well as the carbon intensity.[11] (→ *See Box 2.*)

Factors behind these reductions in primary energy demand and carbon emissions include:

- **Interactions between renewables and primary energy efficiency.** Primary energy demand includes all of the energy contained in all the energy sources required to meet the final energy consumption of end-users, taking into account losses from transforming primary energy (such as oil, coal or natural gas) into secondary energy (such as electricity or oil distillates). Because the use of some sources of renewable power – particularly hydropower, solar PV and wind power technologies – reduces the overall transformation losses in generation, the uptake of renewables lessens the amount of primary energy needed to meet final energy needs, thus improving primary energy intensity.[12] Increasing the share of electricity generation from renewables also helps to reduce overall carbon intensity.

- **Interactions between renewables and final energy efficiency.** Energy efficiency measures are necessary for increasing the overall share of renewables in final energy consumption. By lowering final energy consumption, energy efficiency allows the same level of renewable energy uptake to meet a larger share of energy consumption, and also reduces the capital investment required to supply the demand through on-site and/or off-site renewables. This is particularly pertinent in light of rising energy use in developing and emerging economies, and in light of barriers that limit the speed of renewables deployment (such as land scarcity, potential opposition by local communities, etc.).[13] (→ *See Feature chapter.*)

i Energy intensity and carbon intensity are complementary because, taken together, they indicate the primary energy required per unit of GDP and the carbon dioxide emissions produced through the transformation and use of this energy.

BOX 2. Energy Optimisation: Efficiency, Conservation and Structural Changes

The term energy efficiency is often used as a proxy term for energy savings. Yet improvements in efficiency alone do not necessarily lead to energy savings. Energy reduction or optimisation is simultaneously influenced by:

- energy efficiency improvements through technology and design;
- energy conservation measures, which are related to the behaviours and habits of energy end-users; and
- structural changes, or changes in the composition of sectors or within a sector (for example, a switch to less energy-intensive or more service-oriented industries), which can be achieved through policies, investments and planning processes.

Both energy efficiency improvements and the integration of behavioural measures are necessary within energy optimisation strategies, whereas structural changes generally are kept outside of the scope.

Energy efficiency measures without behavioural awareness can lead to a "rebound effect", whereby the energy reductions generated by nominal efficiency improvements are either lower than expected or even negative. For example, in response to improved insulation in buildings, residents may opt to maintain warmer homes rather than to reduce their energy consumption – resulting in a direct rebound effect – or they may spend the cost savings on other goods and services that also require energy to provide (an indirect rebound effect).

Often, the benefits of efficiency are not "lost" but rather are redirected; thus, it is important to distinguish two types of impact of the rebound effect:

- The reduction in energy expenditure due to energy efficiency leads to wasteful energy use with no appreciable increase in utility to the consumer. This could include, for example, leaving the lights on in a vacant room because lighting is cheap.
- The reduction in energy expenditure due to energy efficiency leads to the opportunity to increase the consumer's utility, by using some or all of the energy that is otherwise saved for new or improved energy services. This could include, for example, increasing space heating to a range of comfort from a previously unhealthy state, or efficient lighting allowing for more study time during non-daylight hours.

Source: See endnote 11 for this chapter.

In addition, specific efficiency measures in end-use sectors, such as energy-efficient building codes, can be enablers for both energy efficiency and renewable energy. These efficiency measures often are coupled with measures to supply the remaining energy demand either directly with renewables (for example, bioenergy, solar thermal and geothermal heat) or indirectly with renewables-based electricity.[14] The electrification of end-use sectors, such as heating, cooling and transport, is one pathway to achieving a double benefit: electrified systems can be more energy efficient than their fossil fuel-based counterparts, and electricity demand can be sourced more readily from a wide variety of renewables.[15] (→ *See Systems Integration chapter.*)

Renewables and energy efficiency maximise their **emissions mitigation potential** when pursued together.

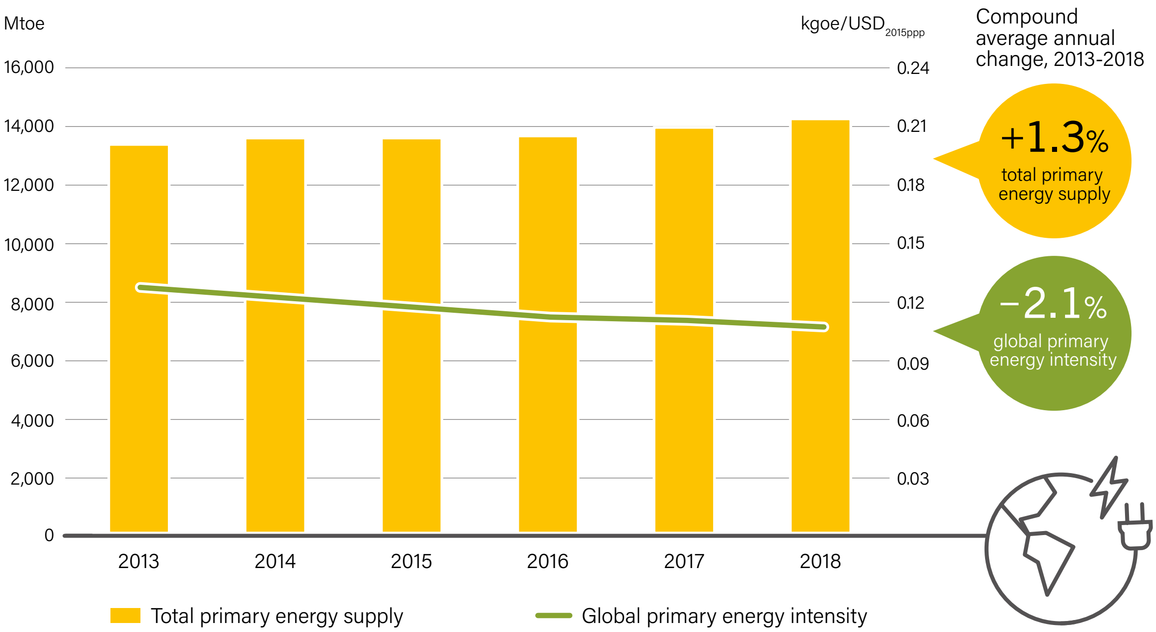
RENEWABLES AND PRIMARY ENERGY EFFICIENCY

The world's total primary energy demand increased 2.3% in 2018, the largest increase since 2010, driven by global economic growth.[16] However, improvements in primary energy intensity helped limit the growth in demand to some extent. Global primary energy intensity decreased more than 10% during the five-year period between 2013 and 2018, at an average annual rate of 2.1%.[17] (→ *See Figure 57.*) On a year-to-year basis, the improvement in energy intensity has slowed more recently, falling from 3.0% in 2015 to 1.2% in 2018.[18]

If the total primary energy demand had moved in tandem with global economic growth[i] – with no reduction in energy intensity – during 2013-2018, and considering that primary energy demand grew 6.5% over this period (average annual growth of 1.3%), total primary energy demand would have risen 19.2% over the five-year span (or 3.6% per year).[19] In the context of a growing global economy, improvements in energy intensity thus are key to curbing global growth in energy demand.

i This does not take into account unknown feedback from higher energy intensity on economic growth. In other words, global economic growth might not have been as large over the observed period if not for the benefit of more efficient use of energy in economic activity.

FIGURE 57. Global Primary Energy Intensity and Total Primary Energy Supply, 2013-2018



Note: Dollars are at constant purchasing power parities.
Mtoe = megatonnes of oil equivalent;
kgoe = kilograms of oil equivalent.

Source: Enerdata. See endnote 17 for this chapter.

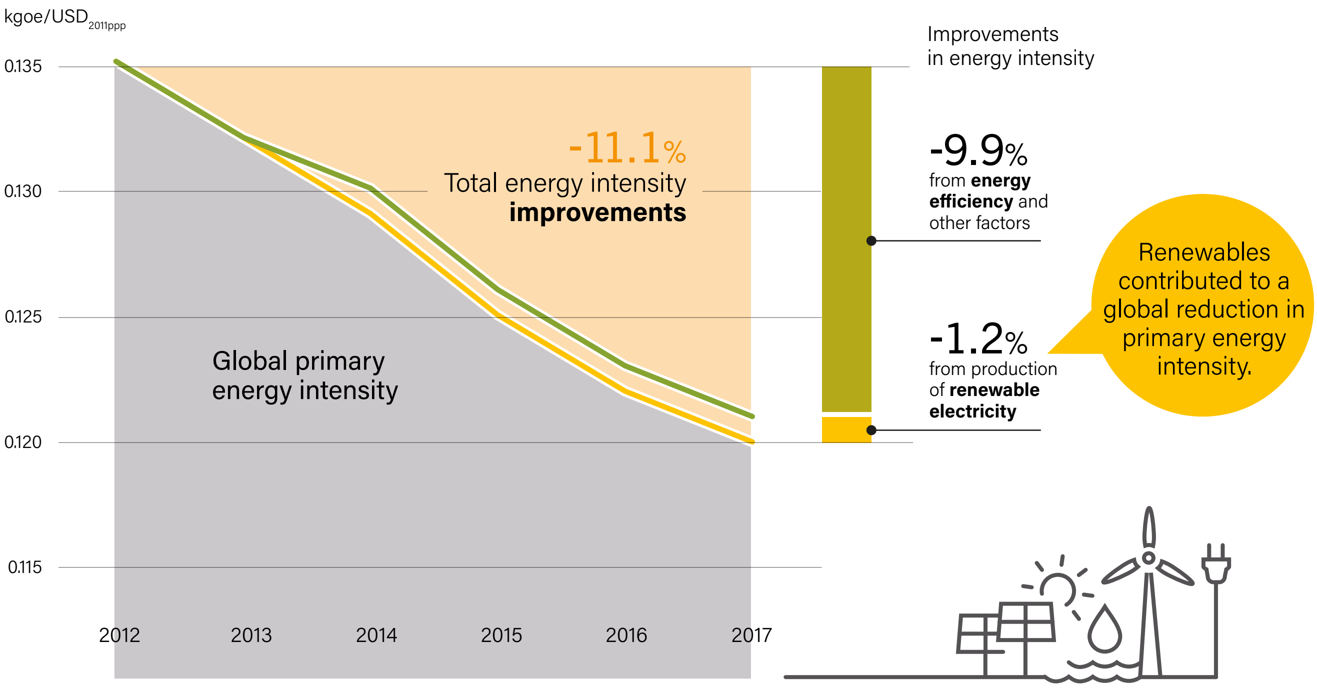
In 2017, the world's total primary energy supply was 584 exajoules (EJ).[20] Each year, more than 23% of the primary energy supply is dissipated through various transformation processes (such as conventional electricity generation).[21] The fossil fuel energy industry itself consumes another 6% of the total primary energy supply through its net demand for energy, including for operating oil refineries and mining and extracting fossil fuels.[22] Less than 2% of the total primary energy supply goes to "non-productive" losses, which occur mainly during the transmission and distribution of electricity.[23]

Looking specifically at thermal power plants (combustion only; biomass-, coal-, natural gas- and oil-fired power plants), more than half of the primary energy input is lost during the transformation process.[24] Non-thermal renewable energy technologies (such as wind power and solar PV) also have a low conversion efficiency, but in these cases the energy loss is irrelevant, because any potential energy not harnessed by these technologies is never part of the primary energy supply, unlike with fossil fuels that are extracted for electricity generation and for the production of refined fuels.[25] As a consequence, non-thermal renewables have a higher primary energy efficiency. Additionally, the dissipated energy in fossil fuel power plants (unlike "lost" solar and wind energy) manifests itself in increased emissions of greenhouse gases and other pollutants.

Based on these factors, improving primary energy efficiency (and thus reducing greenhouse gas emissions) in the power sector can be achieved in one of two ways: either by improving the efficiency of thermal power plants (through greater thermal conversion efficiency and through direct use of residual heat, or co-generation), or by reducing transformation losses through a shift to non-thermal renewable energy technologies.

Between 2012 and 2017, the increase in renewable electricity production reduced global primary energy intensity an estimated 1.2%.[26] Meanwhile, general improvements reduced global primary energy intensity an estimated 9.9%, with energy efficiency playing a role alongside fuel switching and regional shifts in energy demand, among other factors.[27] (→ *See Figure 58.*)

FIGURE 58. Estimated Impact of Increased Renewable Electricity Production on Global Primary Energy Intensity, 2012-2017



Note: The figure estimates the additional primary energy input that would have been required in the absence of the renewable electricity uptake since 2012, all else being equal. The estimation accounts for the difference in transformation losses between conventional and renewable electricity generation but does not account for potential feedback loops on the energy demand itself due to energy prices, structural changes in economic activity or similar effects. The figure is not intended to provide results of a comprehensive energy model. For further explanation of the methodology, see endnote 27 for this chapter.

Dollars are at constant purchasing power parities.
kgoe = kilograms of oil equivalent.

Source: See endnote 27 for this chapter.

RENEWABLES AND FINAL ENERGY CONSUMPTION

Total final energy consumption (TFEC) – that is, what remains of the total primary energy demand following all of the losses that occurred during the processes of transformation, energy sector use, transmission and distribution – amounted to 370 EJ in 2017.[28]

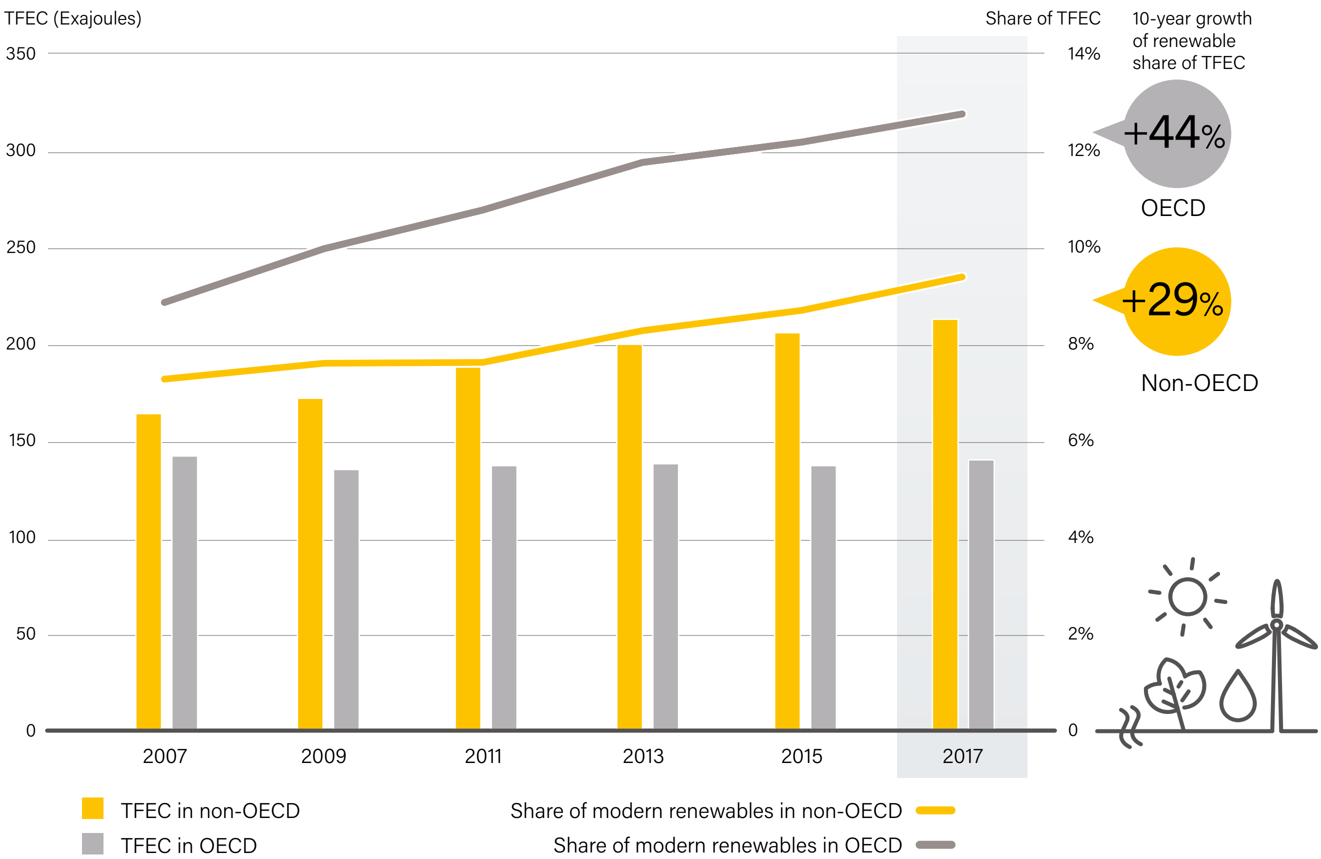
Like primary energy intensity, global final energy intensity improved during the 2012-2017 period, although by a higher margin of 13%.[29] Because of this higher improvement in final energy intensity, which reduces overall energy demand, the same renewable energy sources can supply a larger share of the world's final energy needs.[30]

Between 2007 and 2017, global TFEC increased 1.4% annually, while the share of TFEC met by modern renewables grew at an average annual rate of 3.0%.[31] Differences are evident between the member countries of the Organisation for Economic Co-operation and Development (OECD) and the countries outside of it[i].[32] (→ *See Figure 59.*)

- In **OECD countries**, contrary to the global trend, TFEC decreased 1.8% between 2007 and 2017, due in part to a 14% improvement in final energy intensity during this period.[33] This decrease facilitated larger growth in the share of consumption met by renewables: while consumption of renewable energy increased around 42% between 2007 and 2017, the share of modern renewables in TFEC increased 44% during the period.[34]
- **Non-OECD countries** experienced a large rise in energy demand (TFEC increased 30%) between 2007 and 2017, driven by rapid economic growth and improved energy access, but limited to an extent by a 20% improvement in final energy intensity.[35] This growth tempered the increase in the share of consumption met by renewable energy. While the absolute amount of renewable energy in TFEC grew at a higher rate than in OECD countries (68%) during the period, the share of renewables in TFEC increased to a lesser extent (29%).[36]

i The member states of the OECD (37 countries, as of end-2019) account for the majority of the world's gross domestic product (GDP) and are among the countries with the highest GDP per capita as well as rank near the top of the Human Development Index. They typically are classified as countries with developed economies. Non-OECD countries are normally classified as countries with developing or emerging economies, some of which have seen rapid rises in GDP per capita in recent decades.

FIGURE 59. Total Final Energy Consumption and Share of Modern Renewables in OECD and non-OECD Countries, 2007-2017



Note: TFEC = total final energy consumption.

Source: Based on IEA. See endnote 32 for this chapter.

BUILDINGS

The buildings sector accounted for around 33% of global TFEC in 2018.[37] Residential buildings consumed nearly three-quarters of this energy, and the rest was used in commercial and public buildings.[38] In 2017, electricity end-uses (for example, lighting and appliances) accounted for less than 25% of building energy demand, with various fuels (natural gas, biomass, fuel oil, coal, etc.) serving most of the remaining (mostly thermal) demand.[39] Although the overall share of renewable energy used to meet building energy demand remained low (13.6%), renewables were the fastest growing energy source in the sector.[40] (→ *See Global Overview chapter.*)

Despite the development of more-efficient appliances and improvements in building structure and construction, the energy demand of buildings rose 38% globally between 2000 and 2017.[41] In OECD countries, TFEC in the buildings sector *decreased* 2.6% between 2005 and 2017, whereas in non-OECD countries it *increased* 26% during this period.[42] Various factors explain these differences, shaping the trends in energy consumption.[43] As a consequence, issues related to the share of renewables in the sector, and how to increase it, can differ.

In **OECD countries**, the energy intensity of buildings – measured as the final energy use per unit of floor area – fell 1.3% annually between 2000 and 2018, leading to a decrease in final energy consumption.[44] Although energy use for cooling per OECD household has increased in recent years, this has been offset by a decrease in the average energy intensities of space heating and lighting.[45] Since 2010, heating and lighting have seen the highest efficiency improvements among household energy uses in OECD countries, with average annual energy intensity improvements per dwelling of 1.4% for heating and 1.7% for lighting.[46]

Electricity is the predominant energy carrier used in OECD countries, accounting for 37% of the energy consumption of residential buildings.[47] The overall improvement in the energy intensity of buildings in these countries reflects declines in the average electricity use per electrified household in Europe (down 9% since 2010), North America (down 5%) and the Pacific (down 14%).[48]

Interest in energy-efficient buildings is increasing, mainly in developed countries where the implementation and updating of energy codes, certification policies and energy performance requirements for construction and renovation at the national level are influencing energy use in the sector.[49] Numerous building standards emphasise a high commitment to energy efficiency, ensuring that the energy performance of buildings is as efficient as possible, and often interlinking efficiency with on-site and/or off-site renewable generation (mostly through solar PV) to cover residents' remaining energy use.[50] However, policy approaches to energy efficiency and renewables in the buildings sector range widely in their level of commitment. (→ *See Policy Landscape chapter.*)

Despite advances in energy efficiency, **global energy demand** in buildings has continued to rise.

The market penetration of energy-efficient buildings[i] is difficult to estimate due to varying definitions and a lack of monitoring.[51] However, a clear upward trend can be seen in the United States and Canada, where the number of zero energy housing units either in the design phase, under construction or completed increased 59% between 2017 and 2018, from 13,960 units to 22,146 units.[52] This still represents only a tiny share of the reported 1.47 million new construction starts in 2017 in the two countries.[53] In the European Union, the ZEBRA2020 project monitors the market uptake of "nearly zero-energy buildings" across 17 Member States and shows the wide variance in deployment across the region.[54]

Countries outside of the OECD have the highest growth in building energy demand, but in many instances mandatory building energy standards and policies either are not in place or cover a small portion of building energy use.[55] The average annual electricity consumption in non-OECD countries, at around 2,100 kilowatt-hours (kWh) per household, remains below the global average (some 3,500 kWh per household) and is less than one-third that of the OECD countries.[56] However, average electricity consumption increased in non-OECD countries between 2010 and 2018, mainly in Asia (up 37%) and Africa (15%) but also in Latin America (4%).[57]

The growth in electricity consumption in non-OECD countries can be explained mainly by rising wealth and increased access to energy in these countries. Many poor and lower-middle income residents have gained access to modern energy services for the first time: between 2015 and 2017, an estimated 153 million people gained electricity access worldwide.[58] (→ *See Distributed Renewables chapter.*) Consumers also are opting for larger homes, increasing the building floor area and appliance ownership per household, which ultimately expands energy use.[59] This shift, coupled with a lack of access to efficient systems and appliances due primarily to a lack of economic resources, has led to the overall rise in energy demand – despite the introduction of minimum energy performance standards in many countries.[60]

This challenge is particularly apparent in the cooling sector. While many lower- to middle-income people in developing countries are now able to purchase cooling systems, their preference for the most affordable (upfront) solution leads to greater inefficiency and impacts the rise in energy use and associated greenhouse gas emissions.[61] Efforts to implement regulations in the sector include the COOL_ME project to scale up "sustainable cooling" in the Middle East (funded through Germany's International Climate Initiative) and China's Green and High-Efficiency Cooling Action

i Such buildings are characterised by the efficient use of energy (and sometimes of water and other resources, as in "green buildings"); they can include generation from renewables to fulfil their current energy consumption (e.g., "zero energy", "zero emission" or "energy neutral" buildings), to meet their future energy consumption (e.g., "zero energy ready" buildings) or even to produce more energy than they consume (e.g., "energy positive" buildings). See Glossary for definitions.

Plan, released in 2019.[62] Ultimately, rising energy demand from increased access is related to improving quality of life, but it poses threats of long-term lock-in to fossil fuel use if the access is provided by renewables coupled with energy efficiency.

Meanwhile, the deployment of renewables and efficiency has played a major role in electrifying rural areas of developing countries, where on average 77% of the population has access to electricity.[63] The deployment of off-grid solar systems such as solar lighting and solar home systems has emerged as an important driver of rural energy access.[64] Between 2011 and 2016, the global number of people connected to off-grid renewables grew by a factor of six, to nearly 133 million, with countries in Africa and Asia accounting for most of the growth.[65] (→ *See Distributed Renewables chapter.*) In this context, the interaction between efficiency and renewables is evident, as energy-efficient appliances enable a wider spectrum of electricity services to be delivered by small-scale renewable energy systems that offer both reduced capacity and lower costs. (→ *See Box 1 in Distributed Renewables chapter.*)

INDUSTRY

The industrial sector accounts for nearly 35% of global TFEC, excluding non-energy uses of fossil fuels. Despite a 19% improvement in global industrial energy intensity between 2010 and 2017 (a 3% yearly decrease in intensity on average), industrial energy use has gradually increased, at an annual average rate of 0.9% during the period.[66]

As in the residential sector, key contributors to improved energy intensity in industry are:

- **Deployment of more-efficient technologies** and operational improvements, leading to gains in overall efficiency. This is due mainly to more-efficient heavy industrial production in emerging economies such as China and India, with a consequent greater decrease in energy intensity in the region.[67] More recently, however, the impact of annual efficiency gains in the industry and services sector has fallen, from around 4% savings in final energy demand in 2015 to just under 2% savings in 2018, a return to the trend of previous years (2012-2014).[68]
- **Structural factors,** notably the shift, primarily in developed countries, away from energy-intensive industry and towards less energy-intensive sectors of the economy (particularly services) as well as higher value-added[i] economic activities (such as automotive manufacturing, food and beverages, and textiles). However, this effect has slowed globally since 2013 as energy-intensive manufacturing has shown renewed growth.[69] As of 2017, renewable energy, including renewable electricity, supplied more than 14% of industrial energy demand.[70] This share grew only slightly between 2007 and 2017, despite increases in the use of renewables in the sector over the period.[71] (→ *See Global Overview chapter.*)

Electrification of industry can potentially play a role in increasing the share of renewables in TFEC. For example, during the 2007-2017 period the share of electricity in industrial TFEC grew from 25% to 27%.[72]

As in the buildings sector, electrification of industry generally results in gains in final energy efficiency, thereby reducing overall energy demand, and it facilitates the uptake of renewables indirectly to the extent that the electricity comes from renewable sources.[73]

TRANSPORT

Energy use in the transport sector grew 20% between 2007 and 2017 – at an average annual rate of 1.8% – and accounted for 32% of TFEC in 2017.[74] Most of the increase in energy use reflects the growing size and number of vehicles on the world's roads (and the accompanying passenger-kilometres travelled) as well as, to a lesser extent, rising air transport.[75] As of 2016, road transport continued to account for the bulk of energy demand for transport (at 75%), followed by aviation (11%), marine transport (9.6%) and rail (1.8%).[76] (→ *See Global Overview chapter.*)

In developed countries, passenger road transport data reveal a shift towards the use of light-duty vehicles and continued growth in sales of sport utility vehicles (SUVs).[77] Between 2010 and 2018, the average passenger-kilometres travelled per person for buses decreased 9%, whereas for light-duty vehicles it increased 15%.[78] However, major differences exist between countries: bus use has increased in Australia, France and Portugal (up 11%, 25% and 33% respectively) but has decreased in Belgium, the United Kingdom and the United States (down 17%, 20% and 33% respectively).[79] Considering that the average energy intensity per passenger-kilometre of a bus, at 0.89 megajoules (MJ), is about half that of a light-duty vehicle (1.71 MJ), this has led to increased, energy demand from road transport.[80] Furthermore, fuel economy standards for light-duty vehicles exist in only 37 countries, and just 5 countries have fuel economy policies for trucks. (→ *See Policy Landscape chapter.*)

The shift towards more energy-intensive transport modes is not specific to developed countries and can be observed globally. Coupled with behavioural factors and consumer preferences,

i Higher value-added sectors generate a larger margin between the final price of a good or service and the cost of the energy inputs used to produce it.

Electric vehicles show a complementarity between energy efficiency and renewable energy.

such as lower vehicle occupancy and a demand for larger cars and SUVs, this can counteract any improved efficiency of motor vehicles.[81]

The transport sector has the lowest penetration rate of renewable energy among end-use sectors, with renewables supplying only a small share of final energy (3.3%), mostly in the form of biofuels and the remaining share from renewable electricity.[82] Overall, both renewable and non-renewable electricity supply only around 1.1% of the TFEC of transport, mostly in road transport (15%) and rail (around 70%).[83]

In addition to efforts to incorporate more renewables in the transport sector (through both renewable fuels and electricity from renewable sources), renewable energy can benefit from wider initiatives to decrease energy demand in the sector, as this could help boost the renewable share. Ways to reduce energy demand include avoiding the need for motorised transport, transitioning to more-efficient transport modes such as (renewable based) public transport and rail and efforts to improve vehicle technology and fuels, such as through higher fuel efficiencies and emission standards.[84] (→ *See Global Overview chapter.*)

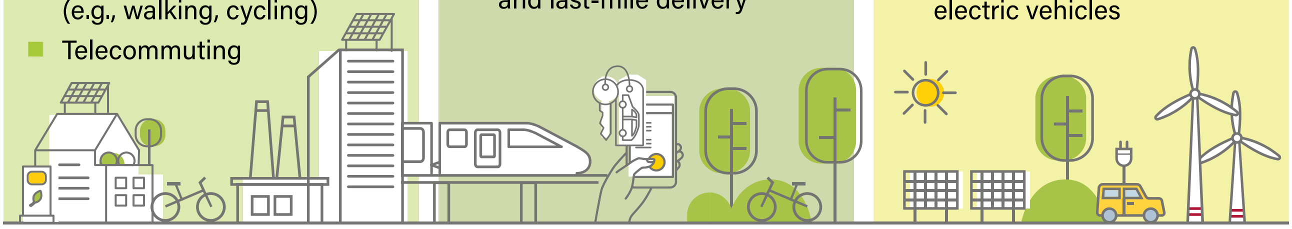
These actions, commonly referred to together as Avoid-Shift-Improve, seek to address broader policy maker concerns in the transport sector, such as environmental and health impacts (e.g., congestion, pollution, road safety) and transport security.[85] (→ *See Figure 60.*)

Electric vehicles (EVs) for passenger and freight use highlight an area where a complementarity between energy efficiency and renewable energy can clearly be seen. EVs have a higher technical efficiency than vehicles with internal combustion engines (higher kilometres travelled per unit of energy) and can be supplied easily with renewable energy, both as distributed generation with renewables rises and as electricity systems gradually integrate higher renewable energy shares.[86] (→ *See Systems Integration chapter.*) Although policy maker attention to EVs has increased in recent years, policies and targets for EVs rarely include a direct link to renewable electricity; meanwhile, the number of countries with biofuel blend mandates has levelled off in recent years (standing at 70 countries since 2017).[87]

The worldwide EV market has grown dramatically in recent years, with the global stock of passenger EVs surpassing 7 million in 2019.[88] Nevertheless, the rise in renewable energy use related to EV deployment remains a slow process, due to the need to both shift the vehicle fleet and to install charging stations that are either directly linked to renewable electricity or planned in parallel with shares of renewables in electricity generation.[89]

FIGURE 60. Avoid-Shift-Improve Framework in the Transport Sector

AVOID	SHIFT	IMPROVE
Avoid or reduce the need for motorised travel	**Shift to more efficient, less carbon-intensive modes**	**Improve efficiency, vehicle technology and fuels**
■ Transport demand management ■ Mixed-use, transit-oriented development ■ Active transport (e.g., walking, cycling) ■ Telecommuting	■ Public transport, intercity and high-speed rail, and new mobility services (powered by renewable energy) ■ Zero emission logistics and last-mile delivery	■ Fuel economy ■ Renewable fuels (e.g., sustainable biofuels, renewable electro-fuels) ■ Renewable-based electric vehicles

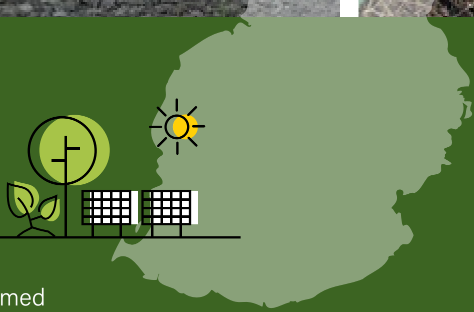


Note: Transport demand management refers to encouraging travelers to avoid trips or shift to more resource-efficient options to limit vehicle traffic. Mixed-use development refers to having more than one use or purpose within a building or development area, ranging from housing on upper floors of a building and office or commercial space on the ground floor, to comprehensive developments with multiple buildings having separate but compatible uses. Transit-oriented development refers to mixed urban development around or near a transit station to reduce the need for motorised trips.

Source: See endnote 85 for this chapter.

08

CO-OPERATIVE RENEWABLE ENERGY CAMPAIGNS, MAURITIUS



In Mauritius, a coalition of groups formed the People's Cooperative Renewable Energy Society in 2013 and launched a Power Shift Campaign to accelerate the transition to renewables. The campaign challenges the privately owned, non-renewable sector by providing co-operative solar energy alternatives that unemployed farmers can use to power greenhouses and improve local food production. The campaign's actions led to the cancellation of plans for a new coal plant, and have improved government transparency by pushing for the creation of a national commission to review Mauritius' energy policies.

08 FEATURE: PUBLIC SUPPORT FOR RENEWABLES

KEY FACTS

- The extent to which renewables gain public support and are able to attract adequate private or public investment is key to their further uptake.
- Although individuals and some groups have expressed concerns about specific renewable energy projects, opinion polls indicate strong public support for the growth of renewables.
- Governments have sought to improve public participation, strengthen regulatory control and share economic benefits with host communities to further build citizen support for renewable energy projects.

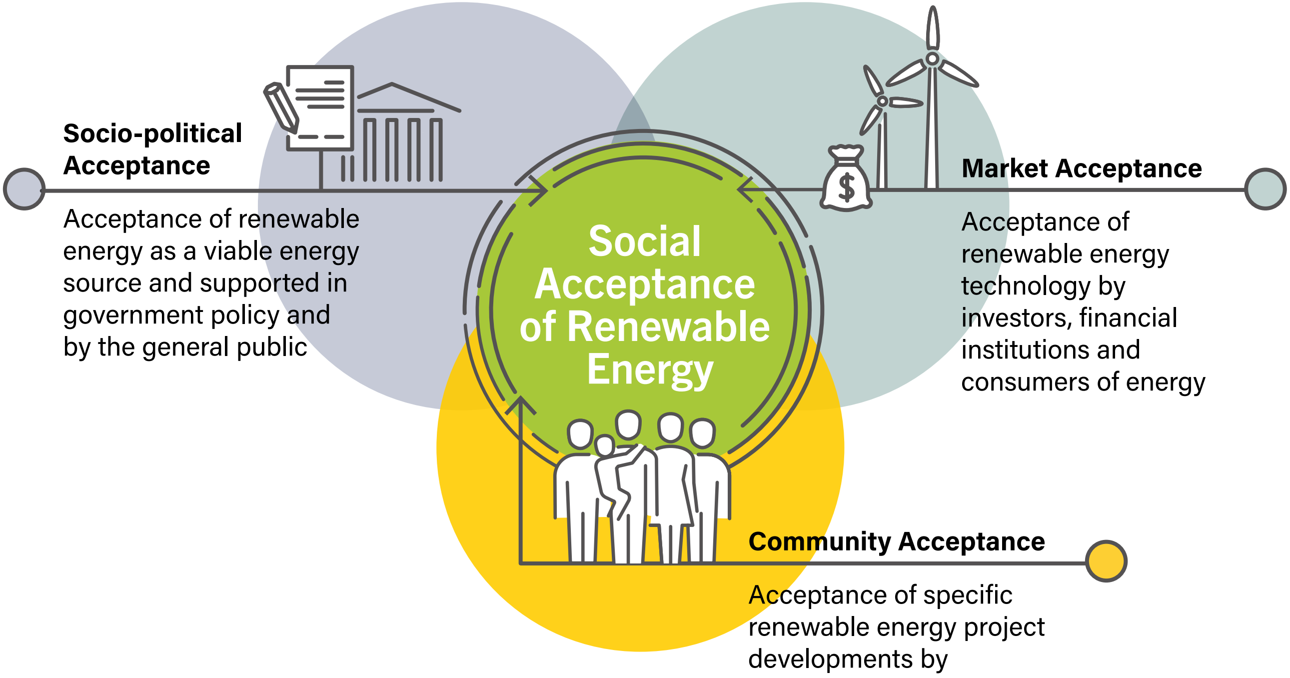
A complex array of technological, economic, environmental and social factors can affect the extent and pace of renewable energy deployment. However, also critical is how these technologies are perceived by society. In 2019, global climate strikes and opinion polls revealed rising public demand for a shift away from fossil fuels; at the same time, opposition from local communities limited the implementation of renewable energy projects in some regions. The extent to which renewables gain public support[i] and are able to attract adequate private or public investment is a key factor in increasing their deployment. Consideration of the range of reactions related to the public response to renewables can help build support for these technologies and ultimately encourage broader inclusion and participation.

Although the views of local communities are an important factor in the uptake of renewables, they are only one part of a broader condition of social acceptance of renewables that also includes market and socio-political dimensions.[1] (→ *See Figure 61.*) Each of these three dimensions can influence the overall acceptability of renewable energy, and each has the potential to stimulate a virtuous or detrimental cycle of support or opposition. Rather than looking at public support for renewables solely through the lens of concepts such as "NIMBYism"[ii] (→ *See Box 1*), a more holistic approach includes community engagement, financial measures, political leadership and market confidence.[2]

i For the purposes of this chapter, "public" is defined, in most cases, as all citizens/residents and does not include specific private or state energy interests or non-governmental organisations; the public often is distinguished from those most directly affected by energy projects, which are referred to here as "host communities".

ii NIMBY ("Not In My Backyard") and NIMBYism refer to the behaviour of a person or group of people that objects to a development project (such as a renewable energy plant) being built near to where they live.

FIGURE 61. Dimensions of Social Acceptance of Renewable Energy



Source: See endnote 1 for this chapter.

Many of the factors that shape the rate and nature of renewable energy uptake depend on local, regional and national contexts. They also include issues such as the availability of renewable resources (such as solar and wind energy), environmental constraints (such as settlement patterns or protected landscapes), political conditions, planning and environmental governance, and procurement and financial arrangements.[3] Likewise, the extent and features of public support vary depending on demographics, socio-economic characteristics and the local/national context, which can be influenced by a complex set of issues.[4]

FACTORS BEHIND PUBLIC SUPPORT FOR RENEWABLES

LANDSCAPE OF REACTIONS TOWARDS RENEWABLE ENERGY

Although individuals may express concerns about specific renewable energy projects, the public generally has shown support for renewables based on the multiple benefits that these technologies provide.[5] For example, people may recognise that renewable energy brings health improvements (through reduced pollution), greater energy reliability and resilience, increased energy security, climate change mitigation and the alleviation of energy poverty.[6] In specific locations, residents may appreciate the job creation and other economic opportunities that come from renewables, which are necessary for an inclusive and just energy transition.[7] (→ *See Sidebar 2.*)

In the past few years, opinion polls have consistently indicated strong public support for the expansion of renewables. In a 2019 survey in the European Union (EU-28), 90% of respondents agreed that the region should encourage greater investment in renewable energy, and participants showed widespread support for all renewable technologies.[8] A poll in Indonesia, Pakistan, the Philippines, South Africa, Turkey and Vietnam identified a strong preference (61-89%) for "clean energy", with solar power receiving the highest positive responses.[9] Strong preferences for renewables also are visible in Australia, Canada, France, Switzerland and the United States.[10] Meanwhile, in a 2017 survey of more than 26,000 people across 13 countries in Asia Pacific,

BOX 1. Social Acceptance and NIMBYism

Often, local disputes about proposed development projects, including new renewable energy infrastructure, are associated with the concept of NIMBY, or "Not In My Backyard". The term is used to imply that individuals opposing a development are acting out of self-interest – in other words, while they may recognise the benefits of the infrastructure (implied by societal support for technologies, climate response, etc.), they do not want projects sited close to their residences because of perceived impacts and costs to themselves.

Many studies, however, assert that the NIMBY label is unhelpful, pejorative and a myth. The concept is criticised for failing to explore the actual motivations of individuals opposing a development, the strong influence of wider institutional arrangements for regulating such developments and the value of competing concepts such as attachment to place. The term NIMBY also is "weaponised", as it implies that any objection to a proposed project is due to the irrational and selfish attitude of host communities, rather than to issues related to project design or the decision-making process. Thus, use of the term allows developers and regulators to displace responsibility for community acceptance.

In some cases, the use of "NIMBY" can increase conflict over proposed developments, as the host community often deeply resents the implication that a dispute over a project is because of them. This outcome can reduce the conditions for effective dialogue and community engagement, which have been shown to offer more effective responses to such situations.

Source: See endnote 2 for this chapter.

Europe and North America, 82% of respondents – independent of age, education and political ideology – believed that it was important to create a world "fully powered" by renewable energy.[11]

Despite this support, many individual renewable energy projects – including wind, solar, bioenergy, geothermal and hydropower plants – still face opposition from local host communities. This creates an apparent **"social gap"** between strong overall support for renewables and the disapproval with specific proposed projects expressed at a local level.[12] Although the social gap varies depending on the context, project scale and type of technology being deployed, policy makers are faced with the challenge of developing an appropriate response to this gap. To better understand the nature of public support for (or opposition to) renewable energy projects at the local, national and global levels, the public's reaction has to be considered within the wider context of public engagement with energy and related issues, including climate action.[13]

Public engagement with renewables reflects a broad continuum – from collective mass movements to individual action – and it can either align or conflict with wider energy objectives. The landscape of social responses to renewables illustrates a wide range of aspirations and motivations, including concerns about technologies, projects or processes; visions for the future; and/or inertia and resistance to change. Reactions can range from apathy to "strongly against" or "strongly in favour", and can occur at scales from a societal level (for example, global climate action) to a local level (relating to individual projects).

At a **societal level**, global climate strikes and litigation often are aligned with implicit support for renewable energy. During 2019, millions of people participated in international strikes and protests in more than 4,500 locations across 150 countries, demanding political action on climate change.[14] In addition, more than 1,300 climate lawsuits were filed around the world between 1990 and 2019 to oppose the ongoing reliance on fossil fuels, representing civil society efforts to hold companies and governments accountable for supporting activities that exacerbate the climate challenge.[15] Most of these disputes – which arose not just in the United States (where they have been most common) but increasingly in Asia, Europe and Latin America – target national governments, but some also target private companies for their contribution to climate change.[16]

At the same time, public reactions at a societal level can hinder the development of renewables, particularly when perceptions of unfairness or a lack of transparency lead people to oppose these technologies. In France and Iran, protests emerged in late 2018 and 2019, respectively, against government energy policies that disproportionately impacted lower-income households and adversely affected living standards.[17] Fuel taxation efforts in France, for example, may have stimulated negative public perception of environmentally driven policies and projects, a response that manifested in the so-called yellow vest protests.[18] In Canada, the implementation of carbon taxes (which generally lead to net economic benefits) also triggered ideological opposition, resulting in the election of provincial governments that rejected renewable energy policies and projects.[19]

Opinion polls have consistently indicated **strong public support** for the expansion of renewables.

Industry actions can lead to opposition to renewables as well, for example if companies lack transparency or engage in real or perceived violations of human rights, labour rights, (indigenous) land rights and others.[20] The neglect of socially responsible and ethical practices in renewable energy manufacturing and project development could result in broad societal opposition to the industry, diminishing the prospects of renewables in certain regions as well as globally.[21]

At the **local level**, movements for energy sufficiency and conservation[i] have spread around the world since the early 2000s, as both community energy projects and the number of prosumers[ii] continue to grow. In Australia, Europe, and North America, and increasingly in Asia and Latin America, communities have established "transition towns" aimed at boosting energy self-sufficiency (often through renewables) to counter the effects of climate change and economic instability.[22]

Although community energy initiatives have existed since the mid-19th century, it was not until the late 1970s that these efforts became more associated with modern renewables, beginning in Denmark. (→ *See Feature chapter in GSR 2016.*) On the Danish island of Samsø, for example, community financial participation has played a major role in the development of renewable energy sources.[23]

At the same time, host communities may be sceptical of, or oppose, certain forms of infrastructure development (transport, commercial and even residential) because of the perceived

impacts on the character of a neighbourhood or landscape.[24] Renewable energy projects in particular may trigger concerns because of their proposed locations – for example, wind projects sited on relatively untouched landscapes, or the presence of multiple dispersed renewable energy projects within a host community (as opposed to a single large, thermal (e.g., fossil fuel) power station that is typically out of sight).

The term "NIMBYism" has been used to depict opposition by individuals or grassroots organisations to local renewable energy projects; however, this type of dissent commonly reflects ineffective consent-building and project development processes, rather than any ideological objection by locals.[25] Still, such opposition has taken root against many different types of renewable energy projects, including geothermal, wind, solar, hydropower and production of biofuels.[26] Over the last decade, there has been a growing recognition that effectively engaging local communities around renewable energy projects is critical for gaining sufficient public support, and necessary for larger objectives of decarbonising the energy supply.

INFLUENCING FACTORS AND THE ROLE OF STAKEHOLDERS

A wide range of complex and inter-related **factors** can influence the public's perception of local or regional renewable energy projects, often based on different perceptions of justice.[27] These could be generalised as follows:

- *Concerns about health and environmental impacts.* Potential impacts include the noise or shadow flicker from wind energy projects, emissions from bioenergy or geothermal plants, the disruption of landscapes, land acquisitions and impacts on biodiversity. To respond to concerns about environmental justice, some of these impacts can be ameliorated through effective project design, planning regulations and other environmental safeguards.
- *Perceptions of the distribution of economic costs and benefits.* Some local communities have expressed concerns that renewable energy project developers are securing economic gain at the expense of local amenities, farming or fishing assets, or residential property values. Reponses to these concerns have included the creation of community benefit funds, local procurement and employment policies, and encouraging community investment in a project to create a sense of distributive justice.
- *Perceived fairness of the consenting process.* Some communities have argued that decision making for renewable energy projects has not been transparent or that public engagement has not been appropriate. In such cases, more effective community engagement, information giving and openness can help to create a better atmosphere of trust and generate a sense of procedural justice.

i See Energy Efficiency chapter and Glossary.

ii A prosumer, in the context of the energy sector, is an individual or entity that both generates and consumes energy. Many different categories of prosumers exist, including residential, commercial and industrial scale, but the most common is homeowners who install solar PV on their rooftops. See Systems Integration chapter and Glossary.

These factors are managed and perceived differently by the range of key **stakeholders** in the energy system. Among the stakeholders that have crucial roles in the social acceptance of renewable energy are national governments, cities and municipal regulatory bodies, developers, energy trade bodies and host communities.

- *National governments* are responsible for meeting overall energy goals, including renewable energy targets. They are central to fostering socio-political and market acceptance of renewables by being primarily responsible for setting strategic policy directions, aligning energy policy with other objectives, and deploying financial instruments to support renewable energy and enabling technology uptake. National governments also frame the standards and regulatory arrangements around renewable energy projects, which play a critical role in community acceptance. In some countries, state or provincial governments can have a similar supporting role.
- *Municipalities and other regulatory* bodies often are responsible for local consenting permits (such as planning permissions) and planning policy, and for ensuring that the environmental and socio-economic impacts of projects are minimised. In some cases, these bodies have the capacity to develop economic instruments, which some have used to bring energy under local democratic control.[28]
- *Developers* have the ability to propose high-quality projects at appropriate sites and to act with transparency and integrity towards host communities.
- *Energy trade bodies* have a critical role in ensuring effective standards across the renewable energy sector, issuing guidance and protocol, and sharing best practices.
- *Host communities* can be given the capacity to participate appropriately in consenting and engagement processes. Through such engagement, they can articulate their concerns about projects in their communities and better ensure that their perspectives and needs are taken into account.

LEVERS TO BUILD PUBLIC SUPPORT AND ENCOURAGE ACTION

As governments have become aware of the impacts that community concerns can have on renewable energy development, they have sought to pursue more effective responses. These include improving public participation, strengthening regulatory control (such as through more detailed planning policy) and making efforts to better share the economic benefits with host communities (for example, through benefit funds, local share offers and community-run energy projects).

Around the world, a wide range of initiatives seek to advance citizen support for renewables, including awareness campaigns, policy and regulatory measures, and new approaches to participation, control and ownership[i].

AWARENESS CAMPAIGNS

Campaigns to **raise awareness about renewable energy technologies** are important measures to build citizen support and have been employed widely in recent years, often at the national level. Such campaigns typically aim not just to increase awareness, but also to **encourage changes in energy use** and "climate-friendly" behaviour. For example, a national energy transition awareness project in Mauritius aims to increase the presence of women in the renewable energy sector, and the Netherlands' Save Energy Now! campaign encourages residents to increase energy efficiency at home and to install rooftop solar PV and other domestic renewables.[29] Some campaigns target a global audience: for example, the Global Bioenergy Partnership aims to both facilitate the development of bioenergy and raise awareness of the technology worldwide.[30]

Governments also can raise awareness of the benefits of renewables and energy efficiency by making **declarations on the "climate emergency"** or "climate crisis". Such declarations have become more frequent in recent years and often are combined with efforts to reduce reliance on fossil fuels. In November 2019, the EU declared a climate emergency and emphasised the need to reduce greenhouse gas emissions and phase out fossil fuel subsidies in the region by 2050.[31] As of April 2020, at least 1,490 jurisdictions in 29 countries worldwide, covering a total population of 822 million, had issued climate emergency declarations.[32]

In addition, many non-governmental organisations have initiated campaigns to raise awareness about climate change, stressing the urgent need for a renewable energy transition. Numerous student-led groups and other campaigns have called on corporations, governments and others to divest from fossil fuels.[33] In late 2019, Greenpeace Australia launched REenergise, one of its biggest campaigns yet, to address carbon dioxide emissions in Australia and to urge the country's largest energy-consuming companies to switch to 100% renewable electricity use.[34]

i This chapter provides examples of only a small selection of initiatives; a more extensive list can be found in the GSR 2020 data pack at www.ren21.net/GSR.

POLICIES IMPACTING PUBLIC ENGAGEMENT WITH RENEWABLES

A range of public bodies have adopted policies and other regulatory measures that enable civic and market actors to engage in the development and procurement of renewable energy. These include efforts designed to encourage energy efficiency, new forms of energy ownership and "green consumerism"[i] to help achieve national, state and local climate and energy targets, based on complex market incentives and measures to encourage grassroots development of renewables.

Feed-in tariff (FIT) schemes have been conducive to renewable energy development not only at a large scale but also at the community and residential levels.[35] Such efforts have involved households, small and medium-sized businesses, energy co-operatives and municipalities, with benefits for energy democracy, citizen participation and social acceptance of renewables.[36] Since the early 2010s, however, interest has shifted away from FITs and towards competitive tendering schemes such as auctions, as a way to improve cost effectiveness and increase control over renewable capacity levels, although FITs remain in place in 87 countries.[37] (→ *See Policy Landscape chapter.*) The introduction of auctions has tended to favour large-scale developers and to disadvantage citizen-driven initiatives seeking to participate in ongoing decarbonisation efforts.[38]

Both Ireland and Germany have put in place measures to encourage **community ownership** of renewable energy as a means to retain stakeholder diversity, wider public engagement and citizen support.[39] Similarly, governments can enable the growth of renewable energy **prosumers** through grid integration, peer-to-peer models and prosumer community groups.[40] Consumers also can be encouraged to purchase renewable energy as part of more conventional **electricity contracts**: "green power programmes" are now offered in Australia, Canada, Denmark, Finland, France, Germany, the Netherlands, Slovenia, Sweden and the United States, among others, and "green electricity" certification schemes are offered by many companies, such as Blue Energy (Slovenia), Eesti Energi (Estonia), EKOenergy (Finland), Green-e (United States) and Nanoenergies (Czech Republic).[41]

By necessity, a transition towards more renewable energy means phasing out high-carbon industries that rely on fossil fuels, including coal mining and oil and gas extraction. However, this shift may impact regional economies and communities that depend heavily on such industries, resulting in opposition to initiatives and projects – such as renewable energy developments – that displace these sectors. **Ensuring a "just" energy transition** is central to the wider objectives of a sustainable economy.[42] The EU's Green Deal, for example, includes a Just Transition Fund aimed at guaranteeing a fair allocation of impacts and equitable distribution of benefits of its climate plans; similar efforts have emerged in Spain, Ireland and among US philanthropic institutions.[43]

In some countries, it has become common for developers to establish some form of **benefits package for local communities**, whether through a fund for local community projects, education bursaries or discounts on electricity bills. The United Kingdom's Coastal Communities Funds give a percentage of state royalties from offshore wind energy to adjacent coastal areas.[44] These "passive" forms of financial participation are becoming increasingly formalised and institutionalised.[45] For example, Scotland has a searchable register of community benefits packages associated with wind power projects, with the aim of increasing fairness and transparency, and in 2009 Denmark introduced a compulsory option-to-purchase share scheme that requires developers of wind energy projects to offer a proportion of investment in the project to the local community.[46]

Awareness campaigns, supporting policies, and new forms of participation, control and ownership further **build citizen support** for renewables.

i Green consumerism refers to the willingness of consumers to purchase goods that have been produced in a manner that protects the natural environment, such as from renewable energy.

PUBLIC PARTICIPATION, CONTROL AND OWNERSHIP

The distributed nature of many new renewable energy projects has shifted the scale and geography of energy generation, creating new opportunities for more dispersed patterns of ownership and control of energy production.[47] This has given rise to the concept of **energy democracy**, which covers different aspects of renewable energy – from "good governance" and public consultation in policy making (such as Citizen Assemblies or civil society movements for decarbonisation, for example the Mauritian Power Shift Plan) to more widespread civil society ownership and control of energy infrastructure.[48]

Greater democratic engagement in energy systems increases social acceptance and can lead to more equitable socio-economic outcomes.[49] The movement for energy democracy has many disparate and contested goals and instruments.[50] In developing countries, for example, narratives remain focused on issues such as energy justice or energy sovereignty.[51]

The opportunities for community participation in renewable energy have been expressed in many different ways. For example, efforts to ensure stakeholder engagement throughout the life cycle of a renewable energy project are considered best practice as part of environmental impact assessments (EIAs) or environmental and social impact assessments (ESIAs)[i]. Examples of **extended participation processes** include the Stakeholder Engagement Plans for the Baikonur Solar Power plant in Kazakhstan and the Sebzor Hydropower Plant Project in Tajikistan.[52] In many jurisdictions, stakeholder engagement is mandatory: Ireland's proposed Renewable Electricity Support Scheme includes provisions on how communities should be consulted during project development, and in Victoria, Australia proof of community engagement is required as part of the 2017 renewable energy auction scheme.[53]

Although the private sector plays a strong role in driving renewable energy projects in many parts of the world, public bodies, particularly municipalities, have assumed more direct involvement in energy projects. In some cases, public ownership is considered an instrument for energy democratisation, because of the accountability that elected officials have towards citizens and their mandate to protect the public interest. Between 2005 and 2019, some 374 processes to re-municipalise energy generation and supply were undertaken across 19 countries.[54]

Re-municipalisation[ii] often is a result of grassroots activity and engagement.[55] Communities also have become more directly engaged in the ownership of energy. **Community ownership** implies a high level of control and allows local residents to maximise economic benefits. Locally owned energy co-operatives involve various technologies and have burgeoned across diverse geographies, from the El Cuá community hydropower project in Nicaragua to the Aran Islands Energy Co-operative in Ireland.[56]

Some models of ownership have wider definitions of community. In Japan, more than 200 open shareholder models, which are not restricted to a specific geographic area, provide over 70 megawatts of renewable power.[57] In Costa Rica, four regional co-operatives distribute and transmit electricity to rural areas that were not being serviced by the state or private companies, covering a geographical area representing 9% of the national territory.[58]

i EIAs/ESIAs are usually required under legislation before consent is granted for construction and are sometimes a condition attached to receipt of project finance from financial institutions; however, the quality of engagement and consultation varies widely in practice.

ii Re-municipalisation refers to efforts by citizens or cities to reverse the privatisation of local services such as water provision, waste collection and management services, and energy generation and distribution through local or municipally owned utility companies. See REN21's *Renewables in Cities 2019 Global Status Report* at www.ren21.net/cities.

TABLE R1. Global Renewable Electricity Capacity, Heat Demand and Biofuel Production, 2019

Power Capacity (GW)	Change in 2019	Existing at End-2019
Bio-power	8.3	139
Geothermal power	0.7	13.9
Hydropower	15.6	1,150
Ocean power	~0	0.5
Solar PV[a]	115	627
Concentrating solar thermal power (CSP)	0.6	6.2
Wind power	60	651

Heat Demand (EJ)	Change in 2019	Consumption in 2019
Modern bio-heat	0.2	14.1
Geothermal direct use[b]	<0.1	0.4
Solar hot water[c]	~0	1.4

Transport Fuel Production (billion litres per year)	Change in 2019	Production in 2019
Ethanol	3	114
Biodiesel (FAME)	1.4	47
Biodiesel (HVO)	0.5	6.5

[a] Solar PV data are provided in direct current (DC).

[b] Data do not include heat pumps.

[c] Data do not include air, PV-thermal or concentrating collectors.

Note: Annual capacity additions are net. Values are rounded to the nearest full number, with the exceptions of numbers <15, which are rounded to the first decimal point, and transport fuels; where totals do not add up, the difference is due to rounding. Rounding is to account for uncertainties and inconsistencies in available data. Capacity amounts of <50 MW (including pilot projects) and heat consumption <0.01 EJ are designated by "~0". FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil. For more precise data, see Reference Tables R13-R19, Market and Industry chapter and related endnotes.

Source: See endnote 1 for this section.

TABLE R2. Renewable Power Capacity, World and Top Regions/Countries[a], 2019

Technology	World Total	BRICS[b]	EU-28	China	United States	India	Germany	Japan	United Kingdom
	GW			GW					
Bio-power	139	48	44	22.5	16.0	10.8	8.9	4.3	7.9
Geothermal power	13.9	0.1	0.9	~0	2.5	0	~0	0.6	0
Hydropower	1,150	530	131	326	80	45	5.6	22	1.9
Ocean power	0.5	0	0.2	0	0	0	0	0	~0
Solar PV[c]	627	256	132	205	76	43	49	63	13.4
Concentrating solar thermal power (CSP)	6.2	1.1	2.3	0.4	1.7	0.2	0	0	0
Wind power	651	292	192	236	106	38	61	3.9	24
Total renewable power capacity (including hydropower)	**2,588**	**1,127**	**502**	**790**	**282**	**137**	**124**	**94**	**47**
Total renewable power capacity (not including hydropower)	**1,438**	**597**	**371**	**464**	**202**	**92**	**119**	**72**	**45**
Per capita capacity (kilowatts per inhabitant, not including hydropower)	0.2	0.2	0.7	0.3	0.6	0.1	1.4	0.6	0.7

[a] Table shows the top six countries by total renewable power capacity not including hydropower; if hydropower were included, countries and rankings would differ (the top six would be China, the United States, Brazil, India, Germany and Canada).

[b] The five BRICS countries are Brazil, the Russian Federation, India, China and South Africa.

[c] Solar PV data are in direct current (DC). See Solar PV section in Market and Industry chapter and Methodological Notes for more information.

Note: Global total reflects additional countries not shown. Numbers are based on the best data available at the time of production. To account for uncertainties and inconsistencies in available data, numbers are rounded to the nearest 1 GW, with the exception of the following: capacity totals below 20 GW and per capita totals are rounded to the nearest decimal point. Where totals do not add up, the difference is due to rounding. Capacity amounts of <50 MW (including pilot projects) are designated by "~0". For more precise capacity data, see Global Overview and Market and Industry chapters and related endnotes. Numbers should not be compared with prior versions of this table to obtain year-by-year increases, as some adjustments are due to improved or adjusted data rather than to actual capacity changes. Hydropower totals, and therefore the total world renewable capacity (and totals for some countries), reflect an effort to omit pure pumped storage capacity. For more information on hydropower and pumped storage, see Methodological Notes.

Source: See endnote 2 for this section.

■ TABLE R3. Renewable Energy Shares of Primary and Final Energy, Targets as of End-2019 and Status in 2018

Note: Text in **bold** indicates new/revised in 2019, and text in italics indicates mandates adopted at the state/provincial level.

Country	Primary Energy		Final Energy	
	Target	Status in 2018[a]	Target	Status in 2018[a]
EU-28		13.3%	→ 20% by 2020 → 32% by 2030	18.9%
Afghanistan			→ 10%[b]	8.8%
Albania	→ 18% by 2020	34.4%	→ 38% by 2020	34.9%
Angola	→ 7.5% by 2025			4.4%
Armenia	→ 21% by 2020 → 26% by 2025	12.4%		6.4%
Austria[c]		30.1%	→ 45% by 2020	33.4%
Bangladesh		24.8%	→ 10% by 2020[d]	0.2%
Belarus		5.5%	→ 32% by 2020	6.8%
Belgium	→ 9.7% by 2020	6.7%	→ 13% by 2020	9.4%
Wallonia			→ *20% by 2020*	
Benin		59.6%	→ 25% by 2025[d]	8.8%
Bosnia and Herzegovina		24.9%	→ 40% by 2020	8.9%
Brazil		40.3%	→ 45% by 2030 → 81% by 2029	43.3%
Brunei Darussalam			→ 10% by 2035	0.1%
Bulgaria[c]		10.7%	→ 16% by 2020 → 27% by 2030	20.5%
Burundi			→ 2.1% by 2020	2.6%
Canada		17.4% (2016)		17.4% (2016)
China[e]	→ 15% by 2020 → 20% by 2030	8.4%		7.8%
Chile			→ 20% by 2024[d]	21%
Côte d'Ivoire	→ 15% by 2020 → 20% by 2030	3%		7.6%
Croatia		23.3%	→ 20% by 2020 → **36.4% by 2030**	28%
Cuba				19.3%
Cyprus		7.3%	→ 13% by 2020	13.9%
Czech Republic[c]		10.5%	→ 13.5% by 2020	15.1%
Denmark		30%	→ 35% by 2020 → 100% by 2050	36.1%
Djibouti	→ 17% by 2035			
Egypt	→ 14% by 2020	3.8%	→ 25% by 2020	4%
Estonia		17.6%	→ 25% by 2020	30%
Fiji			→ 23% by 2030	30.1%
Finland		31.2%	→ 38% by 2020 → 40% by 2025[c]	41.2%
France		9.6%	→ 23% by 2020 → 33% by 2030	16.6%
Gabon		76.7%	→ 80% by 2020	60.1%
Germany[c]		13.8%	→ 18% by 2020 → 30% by 2030 → 45% by 2030 → **65% by 2030**	16.5%
Ghana		42.5%	→ Increase 10% by 2030 (base year 2010)	13.5%

■ TABLE R3. Renewable Energy Shares of Primary and Final Energy, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, and text in italics indicates mandates adopted at the state/provincial level.

Country	Primary Energy		Final Energy	
	Target	Status in 2018[a]	Target	Status in 2018[a]
Greece[c]		12.1%	→ 20% by 2020 → **35% by 2030**	18%
Grenada	→ 20% by 2020			0.7%
Guatemala		63%		
Guinea			→ 30% by 2030	2.4%
Guinea-Bissau				7.8%
Guyana			→ 20% by 2025	20.8%
Hungary[c]		11.5%	→ 14.65% by 2020	12.5%
Iceland		89.5%	→ 64% by 2020	77%
India			→ 40% by 2030	9.9%
Indonesia	→ 23% by 2025 → 31% by 2050	13%		6.2%
Ireland		7.9%	→ 16% by 2020	11.1%
Israel		2.4%	→ 13% by 2025 → 17% by 2030	3.7%
Italy		17.4%	→ 17% by 2020	17.8%
Jamaica		18.6%	→ 20% by 2030	7.5%
Jordan	→ 10% by 2020	16%	→ 15% by 2025	2.8%
Korea, Republic of	→ 6.1% by 2020 → 11% by 2030	1.7%		2.7%
Kosovo[f]			→ 25% by 2020	24.9%
Lao PDR		80%	→ 30% by 2025[d]	23.4%
Latvia		39.1%	→ 40% by 2020	40.3%
Lebanon			→ 12% by 2020 → 15% by 2030	1.6%
Liberia	→ 30% by 2030	5%	→ 10% by 2030	73.8%
Libya	→ 10% by 2020			
Lithuania	→ 20% by 2025	19.6%	→ **45% by 2030**	24.4%
Luxembourg		5.6%	→ 11% by 2020	9.1%
Macedonia, North		15.7%	→ 28% by 2020	18.1%
Madagascar			→ 54% by 2020[d]	38.6%
Malawi	→ 7% by 2020			47.3%
Mali	→ 15% by 2020			4.3%
Malta		3.2%	→ 10% by 2020	8%
Mauritania	→ 20% by 2020			1.1%
Moldova	→ 20% by 2020	10.3%	→ 17% by 2020	14.3%
Mongolia	→ 20-25% by 2020	3.2%		1.4%
Montenegro		30.6%	→ 33% by 2020	38.8%
Nepal	→ 10% by 2030[d]	84.1%		6.4%
Netherlands[c]		4.9%	→ 14% by 2020	7.4%
Niger	→ 10% by 2020[d]	74.7%		
Norway		49.2%	→ 67.5% by 2020	72.8%
Palau	→ 20% by 2020			
Palestine, State of	→ 20% by 2020		→ 25% by 2020	4.4%
Panama	→ 30% by 2050	21.1%		16.4%
Philippines		30%		

REFERENCE TABLES

TABLE R3. Renewable Energy Shares of Primary and Final Energy, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, and text in italics indicates mandates adopted at the state/provincial level.

Country	Primary Energy		Final Energy	
	Target	Status in 2018[a]	Target	Status in 2018[a]
Poland	→ 12% by 2020	8.5%	→ 15% by 2020	11.3%
Portugal		26.8%	→ 31% by 2020 → 47% by 2030	30.3%
Qatar			→ 25% by 2030	
Romania		18.7%	→ 24% by 2020	23.9%
Rwanda				8.2%
Samoa	→ 20% by 2030			4.8%
Serbia		13.1%	→ 27% by 2020	20.3%
Slovak Republic		9.7%	→ 14% by 2020	11.9%
Slovenia		16.8%	→ 25% by 2020	21.1%
Spain[c]		14.6%	→ 20% by 2020	17.4%
Sudan	→ 20% by 2020			24.7%
Sweden[c]			→ 49% by 2020	54.6%
Tajikistan		37%	→ 50% by 2020	44.6%
Tanzania	→ 24% by 2020	22.3%		19.8%
Thailand		19.2%	→ 25% by 2021 → 40% by 2035	14.4%
Togo		78.9%	→ 4%[b]	12.7%
Tonga				0.8%
Tunisia		78.9%		1.3%
Ukraine	→ 18% by 2030	3%	→ 11% by 2020 → 25% by 2035	1.9%
United Arab Emirates			→ 44% by 2050	
United Kingdom		8.2%	→ 15% by 2020	11%
Vanuatu			→ 65% by 2020	11%
Vietnam	→ 5% by 2020 → 8% by 2025 → 11% by 2050	0.28%		13.3%

[a] Status data are for 2018 unless otherwise noted.

[b] No date given.

[c] Final energy targets by 2020 for all EU-28 countries are set under EU Directive 2009/28/EC. The governments of Austria, the Czech Republic, Germany, Greece, Hungary, Spain and Sweden have set higher targets, which are shown in this table. The government of the Netherlands has reduced its more ambitious target to the level set in the EU Directive.

[d] Targets may exclude large-scale hydropower and/or traditional biomass. Large-scale hydropower generally is defined as more than 10 MW of installed capacity, but the definition may vary by country.

[e] The Chinese target is for share of "non-fossil" energy. All targets include nuclear power.

[f] Kosovo is not a member of the United Nations.

Note: Traditional biomass has been removed from share of final energy. Actual percentages are rounded to the nearest whole decimal for numbers over 10% except where associated targets are expressed differently. Historical targets have been added as they are identified by REN21. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable energy for the country. Some countries shown have other types of targets (→ See Reference Tables R4-R8). Some targets shown may be non-binding.

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

TABLE R4. Renewable Heating and Cooling, Targets as of End-2019 and Status in 2017

Note: Text in **bold** indicates new/revised in 2019.

Country	Target	Status in 2017[a]
EU-28	**1.3% annual increase in the share of renewable heat through 2030**	19.5%
Albania		24.9%
Austria	33% by 2020	32%
Belgium	11.9% by 2020	8.1%
Bhutan	Solar thermal: 3 MW equivalent by 2025	
Bulgaria	24% by 2020	30%
China	Solar thermal: 800 million m^2 by 2020	462.9 million m^2 (2016)
Croatia	19.6% by 2020	36.6%
Cyprus	23.5% by 2020	24.5%
Czech Republic	14.1% by 2020	19.7%
Denmark	39.8% by 2020	46.5%
	100% by 2050	
Estonia	38% by 2020	51.6%
Finland	47% by 2020	54.8%
	10% of heating for construction machines and fitted motors from bio-based light fuel oil starting in 2021	
France	38% by 2030	21.4%
Germany	14% by 2020	13.7%
Greece	20% by 2020	26.6%
	30% by 2030 (60% domestic hot water from solar thermal systems)	
Hungary	18.9% by 2020	19.6%
India	Solar water heating: 14 GW_{th} (20 million m^2) by 2022	6.7 GW_{th} (2016)
Ireland	15% by 2020	6.8%
Italy	17.1% by 2020	20%
	Bioenergy: 5,670 ktoe by 2020	6,320 ktoe
	Geothermal: 300 ktoe by 2020	207 ktoe (2016)
	Solar water and space heating: 1,586 ktoe by 2020	231.3 ktoe (2016)
Jordan	Solar water heating: 30% of households by 2020	882 MW_{th} of solar thermal (2015)
Kenya	Solar water heating: 60% of annual demand for buildings that use more than 100 litres of hot water per day (voluntary/no date)	
Kosovo[b]	45.6% by 2020	50.5%
Latvia	53.4% by 2020	54.6%
Lebanon	15% renewables in gross final consumption in power and heating by 2030	
Libya	Solar water heating: 80 MW_{th} by 2015; 250 MW_{th} by 2020	
Lithuania	90% of district heating and cooling by 2030	46.5%
	80% of household-based heating and cooling by 2030	
Luxembourg	8.5% of gross final heating and cooling use by 2020	8.1%
Macedonia, North	11% by 2020	36.4%
Malawi	Solar water heating: produce 2,000 solar water heaters; increase total installed to 20,000 by 2030	
Malaysia	B10 in industrial sector by 2020[c]	

TABLE R4. Renewable Heating and Cooling, Targets as of End-2019 and Status in 2017 (continued)

Note: Text in **bold** indicates new/revised in 2019.

Country	Target	Status in 2017[a]
Malta	6.2% by 2020	19.8%
Mexico	Solar water heating: 18.2 million m^2 of collectors by 2027	3.4 million m^2
Moldova	27% by 2020	
Montenegro	38.2% by 2020	67.5%
Morocco	Solar water heating: 1.2 GW_{th} (1.7 million m^2) by 2020	316 MW_{th} (2015)
Mozambique	Solar water and space heating: 100,000 rural systems (no date)	1 MW_{th} of solar thermal (2015)
Netherlands	8.7% by 2020	5.9%
Poland	17% by 2020; emission standards for heating appliances in single-family homes banning use of coal and wood in 11 of 16 regions, 2022-2027	14.5%
Portugal	34% by 2020	41%
	38% by 2030	
	69-72% by 2050	
Romania	22% by 2020	26.6%
Serbia	30% by 2020	24.4%
Sierra Leone	Solar water heating: 2% in hotels, guest houses and restaurants by 2020, and 5% by 2030; 1% in the residential sector by 2030	
Slovak Republic	14.6% by 2020	9.8%
Slovenia	30.8% by 2020	33.2%
Spain	17.3% by 2020	17.5%
Sweden	62.1% by 2020	69%
Thailand	Bioenergy: 8,200 ktoe by 2022	6,573 ktoe
	Biogas: 1,000 ktoe by 2022	495 ktoe
	Organic municipal solid waste[d]: 35 ktoe by 2022	88 ktoe
	Solar water heating: 100 ktoe and 300,000 systems in operation by 2022	11.3 ktoe (2016)
Ukraine	12.4% by 2020	
United Kingdom	12% by 2020	7.5%
Uruguay	50% solar thermal water heating in certain types of non-residential buildings/refurbishments after 2014	

[a] Status data are for 2017 unless otherwise noted. Status and targets are for overall share of renewable heat unless otherwise noted.

[b] Kosovo is not a member of the United Nations.

[c] The Malaysia target is mandated for industry in general, not specifically for heating.

[d] It is not always possible to determine whether municipal solid waste (MSW) data include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

Note: Targets and status refer to share of renewable heating and cooling in total energy supply unless otherwise noted. Historical targets have been added as they are identified by REN21. A number of countries have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable heat. Because calculation of heating and cooling shares is not standardised across countries, the table presents a variety of targets for the purpose of general comparison.

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

TABLE R5. Renewable Transport, Targets as of End-2019 and Status in 2017

Note: Text in **bold** indicates new/revised in 2019 and text in italics indicates policies adopted at the state/provincial level.

Country	Target	Status in 2017[a]
EU-28	→ 10% of transport final energy demand by 2020 → 14% minimum share of renewable fuels for transport energy by 2030 (7% cap on share from conventional food and feed-based biofuels)	8.3%
Albania	→ 10% by 2020	13.4%
Austria	→ 11.4% by 2020	9.7%
Belgium	→ 10% by 2020	6.6%
Wallonia	→ 10.14% by 2020	
Bulgaria	→ 11% by 2020	7.2%
Croatia	→ 10% by 2020	1.2%
Cyprus	→ 10% by 2020	2.6%
Czech Republic	→ 10.8% by 2020	6.6%
Denmark	→ 10% by 2020	6.8%
	→ 100% by 2050	
Estonia	→ 10% by 2020	0.4%
Finland	→ 40% by 2030	18.8%
France	→ 15% by 2020	9.1%
Germany	→ 10% by 2020	7%
Greece	→ 10.1% by 2020	14%
Hungary	→ 10% by 2020	6.8%
Iceland	→ 10% by 2020	7.2%
India	→ 20% by 2030	
Ireland	→ 10% by 2020	7.4%
Italy	→ 10.1% (2,899 ktoe) by 2020	6.5%
Latvia	→ 10% by 2020	2.5%
Liberia	→ 5% palm oil blends in transport fuel by 2030	
Lithuania	→ 10% by 2020 → 15% by 2030	3.6%
Luxembourg	→ 10% by 2020	6.4%
Macedonia, North	→ 2% by 2020	0.1%
Malta	→ 10.7% by 2020	6.8%
Moldova	→ 20% by 2020	
Montenegro	→ 10.2% by 2020	1%
Netherlands	→ 10% by 2020	5.9%
Norway	→ 20% by 2020	19.7%
Poland	→ 20% by 2020	4.2%
Portugal	→ 10% by 2020	7.9%
	→ 13% by 2025	
	→ 20% by 2030[b]	
Qatar	→ 10% by 2020	
Romania	→ 10% by 2020	6.6%
Serbia	→ 10% by 2020	1.2%
Slovak Republic	→ 10% by 2020	7%
Slovenia	→ 10.5% by 2020	2.7%
Spain	→ 10% by 2020	5.9%
Sri Lanka	→ 20% biofuels by 2020	
Sweden	→ Vehicle fleet independent from fossil fuels by 2030	38.6%
Thailand	→ 9 million litres per day ethanol consumption by 2022	
	→ 6 million litres per day bio-diesel consumption by 2022	
	→ 25 million litres per day advanced biofuel production by 2022	
Ukraine	→ 10% by 2020	
United Kingdom	→ 10.3% by 2020	5.1%
Vietnam	→ 5% of transport petroleum energy demand replaced by 2025	

[a] Status data are for 2017 unless otherwise noted.

[b] Excluding aviation and shipping

Note: Targets refer to share of renewable transport in total energy supply unless otherwise noted. Historical targets have been added as they are identified by REN21. A number of countries have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable energy for the country.

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

TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018[a]
EU-28	→ 57% by 2030	32.1%
Afghanistan[b]	→ 100% by 2050	86.1%
Algeria	→ 27% by 2030 → 22 GW by 2030	2% of installed capacity (2012)
Antigua and Barbuda	→ 10% by 2020 → 15% by 2030	
Argentina	→ 12% by 2019 → 16% by 2021 → 18% by 2023 → 20% by 2025	2%
Armenia	→ 40% by 2025	12%
Aruba	→ 100% by 2020	
Australia	→ 23% by 2020	19%
Tasmania		*90% (2017)*
Australian Capital Territory	*→ 100% by 2025*	
Northern Territory	*→ 50% by 2030*	
Queensland	*→ 50% by 2030*	
Victoria	*→ 25% by 2020* *→ 40% by 2025* *→ 50% by 2030*	
Austria	→ 70.6% by 2020	77%
Azerbaijan	→ 20% by 2020	
Bahamas, The	→ 15% by 2020 → 30% by 2030	
Bahrain	→ 5% by 2025 → 700 MW by 2030 → 10% by 2035	
Bangladesh[b]	→ 10% by 2020 → 100% by 2050	
Barbados[b]	→ 65% by 2030 → 100% by 2050	
Belgium	→ 21% by 2020	20% (2018)
Belize	→ 85% by 2030	91%
Benin	→ 50% by 2025 (off-grid and rural)	
Bhutan[b]	→ 100% by 2050	
Bolivia	→ 79% by 2030	
Brazil[c]	→ 87% by 2026	83.3%
Brunei Darussalam	→ 10% by 2035	
Bulgaria	→ 16.7% by 2020	17%
Burkina Faso[b]	→ 50% by 2025 → 100% by 2050	
Cambodia	→ 100% by 2025 [100% by 2035] [50% by 2020]	
Cameroon	→ 25% by 2035	
Canada	→ no national target	65.19%[d]
Alberta	*→ 30% by 2030*	
British Columbia	*→ 93% (no date)*	
New Brunswick	*→ 40% by 2020*	
Nova Scotia	*→ 40% by 2020*	
Saskatchewan	*→ 50% by 2030*	
Cabo Verde	→ 100% by 2025	25%
Chile	→ 70% by 2030	22.8% (2019)
China	→ 35% by 2030	26.7%
Hainan Province	*→ 80% by 2030[e]*	*23% (2019)*
Chinese Taipei	→ 9% by 2020 → 20% by 2025	4.5%
Colombia[b]	→ 70% by 2030 → 100% by 2050	
Comoros[b]	→ 43% by 2030 → 100% by 2050	
Congo, Democratic Republic of the[b]	→ 100% by 2050	
Congo, Republic of	→ 85% by 2025	
Costa Rica	→ 100% by 2030	99.62% (2019)
Côte d'Ivoire	→ 42% by 2020	
Croatia	→ 39% by 2020	71%
Cuba	→ 24% by 2030	4%
Cyprus	→ 16% by 2020	8%
Czech Republic	→ 14.3% by 2020	13.7% (2018)
Denmark[f]	→ 50% by 2020 → 100% by 2050	76%
Djibouti	→ 100% by 2020	
Dominica	→ 100% (no date)	
Dominican Republic[b]	→ 25% by 2025 → 70% by 2030 → 100% by 2050	12%
Egypt	→ 20% by 2022 → 37-42% by 2035	
Eritrea	→ [50% (no date)] → 70% by 2030	
Estonia	→ 17.6% by 2020	14%
Ethiopia[b]	→ 100% by 2050	
Fiji	→ 100% by 2030	
Finland	→ 33% by 2020	44%
France	→ 40% by 2030	20%
Gabon	→ 70% by 2020 → 80% by 2025	
Gambia[b]	→ 35% by 2020 → 100% by 2050	
Germany	→ 40-45% by 2025 → 55-60% by 2030 → 80% by 2050	38%
Ghana[b]	→ 10% by 2020 → 100% by 2050	
Greece	→ 34.3% by 2020 → 63.54% by 2030	32%
Grenada[b]	→ 100% by 2050	
Guatemala[b]	→ 80% by 2030 → 100% by 2050	59%

TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018[a]
Guyana	→ 90% (no date)	
Haiti[b]	→ 70% by 2030 → 100% by 2050	
Honduras[b]	→ 60% by 2022 → 70% by 2030 → 80% by 2038 → 100% by 2050	60% (2017)
Hungary	→ 10.9% by 2020	
Iceland	→ 100% by 2020	
India[g]	→ 10% by 2022	9.2%
Indonesia	→ 23% by 2020 → 26% by 2025	12% (2017)
Iraq	→ 10% by 2020	
Ireland	→ 42.5% by 2020 → 70% by 2030	29%
Israel	→ 10% by 2020 → 17% by 2030	2%
Italy	→ 26% by 2020	39%
Jamaica	→ 50% by 2030	
Japan	→ 24% by 2030	17.84%
Jordan	→ 20% by 2020 → 1.8 GW by 2020 → 30% by 2030	
Kazakhstan	→ 3% by 2020 → 50% by 2030	2.3%
Kenya[b]	→ 100% by 2050	
Kiribati[b]	→ 3% by 2020 → 100% by 2050	
Korea, Republic of	→ 6% by 2019 → 7% by 2020 → 20% by 2030 → 35% by 2040	6% (2017)
Kuwait	→ 15% by 2030 4.5 GW by 2030	
Latvia	→ 60% by 2020	50%
Lebanon[b]	→ 12% by 2020 → 30% by 2030 → 100% by 2050	
Lesotho	→ 35% by 2020 (off-grid and rural)	
Liberia	→ 30% by 2021	
Libya	→ 7% by 2020 → 10% by 2025 → 22% by 2030	
Lithuania	→ 45% by 2030 → 100% by 2050	83%
Luxembourg	→ 11.8% by 2020	58%
Macedonia, North	→ 24.7% by 2020	24.8%
Madagascar[b]	→ 85% by 2030 → 100% by 2050	
Malawi[b]	→ 100% by 2050	
Malaysia	→ 9% by 2020 → 20% by 2030	2%
Maldives[b]	→ 100% by 2050	
Mali[h]	→ 25% by 2033	
Malta	→ 3.8% by 2020	16%
Marshall Islands[b]	→ 20% by 2020 → 100% by 2050	
Mauritania	→ 60% by 2020	
Mauritius	→ 35% by 2025	22% (2019)
Mexico	→ 30% by 2021 → 35% by 2024 → 38% by 2030 → 40% by 2035 → 50% by 2050	11.5% (2013)
Micronesia, Federated States of	→ 10% in urban centres and 50% in rural areas by 2020	
Moldova	→ 10% by 2020	
Mongolia[b]	→ 20% by 2020 → 30% by 2030 → 100% by 2050	
Montenegro	→ 51.4% by 2020	
Morocco	→ 42% by 2020 → 52% by 2030 → 11 GW by 2030 → 100% by 2050	
Namibia	→ 70% by 2030	
Nepal[b]	→ 100% by 2050	100%
Netherlands	→ 37% by 2020	15%
New Zealand	→ 90% by 2025	83.21%
Cook Islands	→ *100% by 2020*	
Niue	→ *100% by 2020*	
Tokelau	→ *100% (no date)*	
Nicaragua	→ 90% by 2027	50%
Niger[b]	→ 100% by 2050	
Nigeria[i]	→ 10% by 2020	
Norway		99% (2016)
Oman	→ 10% by 2020 → 2.6 GW by 2025	
Palau[b]	→ 100% by 2050	
Palestine, State of[b]	→ 10% by 2020 → 100% by 2050	
Papua New Guinea	→ 100% by 2030	
Paraguay	→ 60% increase 2014-2030	
Peru	→ 70% by 2030	59.44% (2017)
Philippines[b]	→ 40% by 2020 → 100% by 2050	24.56% (2017)
Poland	→ 19.3% by 2020	14%
Portugal	→ 59.6% by 2020 → 80% by 2030 → 100% by 2050	52.2%

TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018[a]
Qatar	→ 2% by 2020 → 20% by 2030	
Romania	→ 43% by 2020	41%
Russian Federation[j]	→ 20% by 2024 (including large hydro)	18%
Altai Republic	→ *80% by 2020*	
Rwanda[b]	→ 100% by 2050	
Samoa	→ 100% by 2030	
São Tomé and Príncipe	→ 47% (no date)	
Saudi Arabia	→ 9.6 GW by 2023 → 30% by 2030	
Senegal[b]	→ 100% by 2050	
Serbia	→ 37% by 2020	28.7%
Seychelles	→ 5% by 2020 → 15% by 2030	
Sierra Leone	→ 33% by 2020 → 36% by 2030	
Singapore	→ 8% (no date)	
Slovak Republic	→ 24% by 2020	23%
Slovenia	→ 39.3% by 2020	32%
Solomon Islands	→ 100% by 2030	
South Africa	→ 9% by 2030	3.11%
South Sudan[b]	→ 100% by 2050	
Spain	→ 39% by 2020 → 70% by 2030 → 100% by 2050	38%
Sri Lanka[b]	→ 20% by 2020 → 100% by 2050	
St. Lucia[b]	→ 35% by 2020 → 100% by 2050	
St. Vincent and the Grenadines	→ 60% by 2020	
Sudan[b]	→ 11% by 2031 → 100% by 2050	
Sweden	→ 100% by 2040	55%
Syria	→ 4.3% by 2030	
Tajikistan	→ 10% (no date)	
Tanzania[b]	→ 100% by 2050	
Thailand[k]	→ 20% by 2036	
Timor-Leste[b]	→ 50% by 2020 → 100% by 2050	
Togo	→ 15% by 2020	
Tonga	→ 50% by 2020	

Country	Target	Status in 2018[a]
Trinidad and Tobago	→ 5% of peak demand (or 60 MW) by 2020	
Tunisia[b]	→ 30% by 2030 → 4.7 GW by 2030 → 100% by 2050	
Turkey	→ 65% by 2023	64%
Tuvalu	→ 100% by 2020	
Ukraine	→ 11% by 2020 → 20% by 2030 → 25% by 2035	5.68%
United Arab Emirates	→ 44% by 2050	0.59% (2017)
Abu Dhabi	→ *7% by 2020*	
Dubai	→ *25% by 2030*	
United Kingdom	→ no national target	34%
Scotland	→ *100% by 2020*	
Wales	→ *70% by 2030*	
United States[l]	→ no national target	18.2% (2019)
Arizona	→ *15% by 2025*	
California	→ *33% by 2020* → *60% by 2030*	
Colorado	→ *30% by 2020*[m]	
Connecticut	→ *27% by 2020* → *40% by 2030*	
Delaware	→ *25% by 2026*	
Hawaii	→ *25% by 2020* → *40% by 2030* → *100% by 2045*	
Illinois	→ *25% by 2026*	
Maine	→ *100% by 2050*	
Maryland	→ *25% by 2020* → *50% by 2030*	
Massachusetts	→ *40% by 2030* → *100% by 2090*	
Michigan	→ *15% by 2021*	
Minnesota	→ *31.5% by 2020 Xcel Energy (utility) [25% by 2025 (other utilities)]* → *26.5% by 2025 (IOUs)*[l]	
Missouri	→ *15% by 2021*[l]	
Nevada	→ *25% by 2025*	23% (2015)
New Hampshire	→ *24.8% by 2025*	
New Jersey	→ *20.38% by 2020* → *4.1% solar by 2027* → *50% by 2030*	

TABLE R6. Renewable Share of Electricity Generation, Targets as of End-2019 and Status in 2018 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Target	Status in 2018[a]
New Mexico[n]	→ *50% by 2030* → *80% by 2040*	
New York	→ *70% by 2030*	
North Carolina	→ *12.5% by 2021*	
Ohio	→ *12.5% by 2026*	
Oregon	→ *50% by 2040 [25% by 2025 (utilities with 3% or more of state's load); 10% by 2025 (utilities with 1.5-3% of state's load); 5% by 2025 (utilities with less than 1.5% of state's load)]*	
Pennsylvania	→ *18% by 2021*	
Rhode Island	→ *38.5% by 2035*	
Vermont	→ *Increasing by 4% every three years until reaching 75% by 2032*	
Washington, DC	→ *15% by 2020* → *100% by 2032*	
Washington State	→ *100% by 2045*	
District of Columbia	→ *100% by 2032*	
Puerto Rico	→ *20% by 2035* → *100% by 2050*	
U.S. Virgin Islands	→ *30% by 2025*	
Uzbekistan	→ 19.7% by 2025	12.6%
Vanuatu	→ 65% by 2020 → 100% by 2030	
Vietnam[b]	→ 7% by 2020 → 10% by 2030 → 100% by 2050	
Yemen[b]	→ 15% by 2025 → 100% by 2050	

[a] Status data are for 2018 unless otherwise noted.

[b] 100% by 2050 target established by the Climate Vulnerable Forum.

[c] Brazil's target excludes all hydropower.

[d] Canada's share excludes all hydropower.

[e] Hainan's share of 80% is from both renewables and nuclear energy.

[f] In March 2012, Denmark set a target of 50% electricity consumption supplied by wind power by 2020.

[g] India does not classify hydropower installations larger than 25 MW as renewable energy sources, so hydropower >25 MW is excluded from national targets. De facto sub-national targets have been set through existing RPS policies.

[h] Mali's target excludes large-scale hydropower.

[i] Nigeria's target excludes hydropower plants >30 MW.

[j] The Russian Federation's targets exclude hydropower plants >25 MW.

[k] Thailand does not classify hydropower installations larger than 6 MW as renewable energy sources, so hydropower >6 MW is excluded from national shares and targets.

[l] The United States does not have a national renewable electricity target. De facto state-level targets have been set through RPS policies.

[m] RPS mandate for Investor-owned utilities (IOUs), which operate under private control rather than government or co-operative operation.

[n] RPS mandate for co-operative utilities.

Note: Unless otherwise noted, all targets and corresponding shares represent all renewables, including hydropower. A number of state/provincial and local jurisdictions have additional targets not listed here. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2019. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable electricity for the country. Some countries shown have other types of targets (→ See Tables R3-R8). See Policy Landscape chapter for more information about sub-national targets. Existing shares are indicative and may need adjusting if more accurate national statistics are published. Sources for reported data often do not specify the accounting method used; therefore, shares of electricity are likely to include a mixture of different accounting methods and thus are not directly comparable or consistent across countries. Where shares sourced from EUROSTAT differed from those provided to REN21 by country contributors, the former was given preference.

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

TABLE R7. Renewable Power, Targets for Technology-Specific Share of Electricity Generation as of End-2019

Note: Text in **bold** indicates new/revised in 2019, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Technology	Target
Denmark	Wind power	50% by 2020
Eritrea	Wind power	50% (no date)
Egypt	Wind power	12% by 2020
Germany	Solar power	**17% by 2030**
Guinea	Solar power	6% by 2025
	Wind power	2% by 2025
Haiti	Bio-power	5.6% by 2030
	Hydropower	24.5% by 2030
	Solar power	7.55% by 2030
	Wind power	9.4% by 2030
India[a]		
Bihar	*Solar power*	*1.75% by 2018-19; 2% by 2019-20; 2.5% by 2020-21; 3% by 2012-22*
Himachal Pradesh	*Solar power*	*0.75% by 2018-19; 1% by 2019-20; 2% by 2020-21; 3% by 2021-22*
Kerala	*Solar power*	*0.25% by 2021-22*
Japan	Bio-power	3.7-4.6% by 2030
	Geothermal power	1% to 1.1% by 2030
	Hydropower	8.8-9.2% by 2030
	Solar PV	7% by 2030
	Wind power	1.7% by 2030
United Kingdom	Wind power (offshore)	33% by 2030

[a] India has established state-specific solar power purchase obligations.

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

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation as of End-2019

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Algeria	Electricity	4.5 GW by 2020; 22 GW by 2030
	Bio-power from waste-to-energy	360 MW by 2020; 1 GW by 2030
	Geothermal power	5 MW by 2020; 15 MW by 2030
	Solar PV	3 GW by 2020; 13.5 GW by 2030
	CSP	2 GW by 2030
	Wind power	1 GW by 2020; 5 GW by 2030
Antigua and Barbuda	Electricity	5 MW by 2030
Armenia	Hydropower (small-scale)	377 MW by 2020; 397 MW by 2025
	Geothermal power	50 MW by 2020; 100 MW by 2025
	Solar PV	40 MW by 2020; 80 MW by 2025
	Wind power	50 MW by 2020; 100 MW by 2025
Austria	Bio-power from solid biomass and biogas	200 MW added 2010-2020
	Hydropower	1 GW added 2010-2020
	Solar PV	1.2 GW added 2010-2020
	Wind power	2 GW added 2010-2020
Australia	Electricity	33,000 GWh by 2020
Azerbaijan	Electricity	1 GW by 2020
Bahrain	Electricity	255 MW by 2020; 710 MW by 2030
	Bio-power	5 MW by 2025; 10 MW by 2035
	Solar power (PV and CSP)	200 MW by 2025; 400 MW by 2035
	Wind power	50 MW by 2025; 300 MW by 2035
Bangladesh	Bio-power	7 MW by 2021
	Biogas power	7 MW by 2021
	Waste-to-energy	40 MW by 2021
	Hydropower	4 MW by 2021
	Solar power	1,676 MW by 2021
	Wind power	1,370 MW by 2021
Belarus	Electricity	2.6 billion kWh through 2035
Belgium		no national target
Flanders	*Solar PV*	*Increase production 30% by 2020*
Wallonia	*Electricity*	*8 TWh per year by 2020*
Bhutan	Electricity	20 MW by 2025
	Bio-power from solid biomass	5 MW by 2025
	Solar PV	5 MW by 2025
	Wind power	5 MW by 2025
Bolivia	Electricity	160 MW capacity added 2015-2025
Bosnia and Herzegovina	Hydropower	120 MW by 2030
	Solar PV	4 MW by 2030
	Wind power	175 MW by 2030
Burundi	Bio-power from solid biomass	4 MW (no date)
	Hydropower	212 MW (no date)
	Solar PV	40 MW (no date)
	Wind power	10 MW (no date)
Canada		no national target
Ontario	*Electricity*	*20 GW by 2025 supplied by a mix of technologies, including:*
	Hydropower	*9.3 GW by 2025*

TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Canada (continued)		
Ontario	*Solar PV*	*40 MW by 2025*
	Wind power	*5 GW by 2025*
Prince Edward Island	*Wind power*	*30 MW increase by 2030 (base year 2011)*
China	Electricity	680 GW non-fossil generation capacity by 2020
	Bio-power	15 GW by 2020
	Hydropower	340 GW by 2020
	Solar power	110 GW by 2020; 5 GW solar thermal power by 2020
	Wind power	210 GW by 2020 (including 5 GW grid-connected offshore wind)
Chinese Taipei	Electricity	10.9 GW by 2020; 27.4 GW by 2025
	Geothermal power	150 MW by 2020; 200 MW by 2025
	Solar PV	6.5 GW by 2020; 20 GW by 2025
	Wind power (onshore)	814 MW by 2020; 1.2 GW by 2025
	Wind power (offshore)	520 MW by 2020; 3-5.7 GW by 2025
Croatia	Hydropower	1,655 MW by 2020
Cuba	Electricity	2.1 GW biomass, wind, solar and hydropower capacity by 2030
Djibouti	Electricity	1 GW by 2035
	Geothermal power	500 MW by 2035
	Solar power (PV and CSP)	200 MW by 2035
	Wind power	300 MW by 2035
Egypt	Hydropower	2.8 GW by 2020
	Solar PV	17.3 GW by 2035
	CSP	1.1 GW by 2020; 11 GW by 2035
	Wind power	7.2 GW by 2022; 21 GW by 2035
Ethiopia	Bio-power from bagasse	103.5 MW (no date)
	Hydropower	22 GW by 2030
	Wind power	7 GW by 2030
Finland	Bio-power	13.2 GW by 2020
	Hydropower	14.6 GW by 2020
	Wind power	884 MW by 2020
France	Hydropower	0.1 to 2 GW by 2023
	Ocean power	380 MW by 2020
	Solar power	18.2-20.2 GW by 2023; [8 GW by 2020]; 45 GW by 2030
	Wind power (offshore)	1 GW per year; 2.4 GW by 2023; 4.7 to 5.2 GW by 2028
	Wind power (onshore)	21.8 to 26 GW by 2023
Germany	Bio-power	100 MW added per year
	Solar PV	**2.5 GW added per year; 98 GW by 2030**
	Wind power (onshore)	2.8 GW tendered per year through 2019; 2.9 GW per year after 2019
	Wind power (offshore)	**20 GW added by 2030**
	Wind power (total)	**67 to 71 GW by 2030**
Greece	Solar PV	2.2 GW by 2030
Grenada	Geothermal power	15 MW (no date)
	Solar power	10 MW (no date)
	Wind power	2 MW (no date)

■ TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
India	Electricity	**175 GW by 2022; 450 GW by 2030**
	Bio-power	10 GW by 2022
	Hydropower (small-scale)[a]	5 GW by 2022
	Solar PV	20 million solar lighting systems added 2010-2022
	Solar PV and CSP	100 GW by 2022
	Wind power	60 GW by 2022
Andhra Pradesh	*Electricity*	*18 GW capacity added by 2020-21*
Delhi	*Solar PV*	*5,000 MW added 2015-2020*
	Solar power	*1 GW by 2020; 2 GW by 2025*
Rajasthan	*Hybrid (solar PV and wind)*	***3.5 GW by 2024-2025***
	Wind	***2 GW by 2024-2025***
	Solar power[b]	***25 GW by 2020*** ***30 GW by 2024-2025***
Jharkhand	*Solar PV*	*2,650 MW installed by 2019-2020*
Indonesia	Geothermal power	12.6 GW by 2025
	Hydropower	2 GW by 2025, including 0.43 GW micro-hydro
	Pumped storage[c]	3 GW by 2025
	Solar power	5 GW by 2020 [156.8 MW solar PV by 2025]
	Wind power	100 MW by 2025
Iraq	Solar PV	2.24 GW by 2020
Iran	Solar power and wind power	5 GW by 2020
Italy	Bio-power	19,780 GWh per year generation from 2.8 GW capacity by 2020
	Geothermal power	6,759 GWh per year generation from 920 MW capacity by 2020
	Hydropower	42,000 GWh per year generation from 17.8 GW capacity by 2020
	Solar PV	50 GW by 2030
	Wind power (onshore)	18,000 GWh per year generation and 12 GW capacity by 2020
	Wind power (offshore)	2,000 GWh per year generation and 680 MW capacity by 2020
Japan	Ocean power (wave and tidal)	1.5 GW by 2030
Jordan	Electricity	1.8 GW by 2020; 3.22 GW by 2025
	Bio-power	50 MW by 2025
	Solar PV	1 GW by 2020; 2.5 GW by 2025
	Wind power	1.2 GW by 2020
Kazakhstan	Bio-power	15.05 MW at three stations by 2020
	Hydropower	539 MW at 41 stations by 2020
	Solar power	713.5 MW at 28 plants by 2020
	Wind power	1,787 MW at 34 stations by 2020
Kenya	Geothermal power	5 GW by 2030
Korea, Republic of	Electricity	13,016 GWh per year; 21,977 GWh per year (4.7%) by 2020; 39,517 GWh per year (7.7%) by 2030 supplied by a mix of technologies, including:
	Bio-power from solid biomass	2,628 GWh per year by 2030
	Bio-power from biogas	161 GWh per year by 2030
	Bio-power from landfill gas	1,340 GWh per year by 2030
	Geothermal power	2,046 GWh per year by 2030
	Hydropower (large-scale)	3,860 GWh per year by 2030
	Hydropower (small-scale)	1,926 GWh per year by 2030
	Ocean power	6,159 GWh per year by 2030
	Solar PV	2,046 GWh per year by 2030
	CSP	1,971 GWh per year by 2030
	Wind power	16,619 GWh per year by 2030
	Wind power (offshore)	2.5 GW by 2019

TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Kosovo[d]	Hydropower	140 MW by 2020
Kuwait	Solar PV	3.5 GW by 2030
	CSP	1.1 GW by 2030
	Wind power	3.1 GW by 2030
Lebanon	Wind power	400-500 MW by 2020
Lesotho	Electricity	260 MW by 2030
Libya	Solar PV	300 MW by 2020; 800 MW by 2025, 3.35 GW by 2030
	CSP	150 MW by 2020; 400 MW by 2025; 400 MW by 2030
	Wind power	600 MW by 2020; 1 GW by 2025
Macedonia, North	Bio-power from solid biomass	50 GWh by 2020
	Bio-power from biogas	20 GWh by 2020
	Hydropower (small-scale)	216 GWh by 2020
	Solar PV	14 GWh by 2020
	Wind power	300 GWh by 2020
Malaysia	Electricity	2.1 GW (excluding large-scale hydro), 11.2 TWh per year, or 10% of national supply (no date given); 11% by 2020; 14% by 2030; 36% by 2050
	Solar power	1 GW capacity added by 2020
Mauritania	Electricity	60 MW by 2020
Morocco	Electricity	6GW by 2020; 11 GW by 2030
	Hydropower	2 GW by 2020
	Solar PV and CSP	2 GW by 2020; 4.56 GW by 2030
	Wind power	2 GW by 2020; 4.2 GW by 2030
Mozambique	Bio-digesters for biogas	1,000 systems installed (no date)
	Hydropower, solar PV, wind power	2 GW each (no date)
	Solar PV	82,000 solar home systems installed (no date)
	Wind turbines for water pumping	3,000 stations installed (no date)
	Renewable energy-based productive systems	5,000 systems installed (no date)
Myanmar	Renewable power	27% of installed power capacity by 2030
Nigeria	Bio-power	400 MW by 2025
	Hydropower (small-scale)	2 GW by 2025[e]
	Solar PV (large-scale, >1 MW)	500 MW by 2025
	CSP	5 MW by 2025
	Wind power	40 MW by 2025
Norway	Electricity	26.4 TWh common electricity certificate market with Sweden by 2020
Palestine, State of	Bio-power	21 MW by 2020
	Solar PV	45 MW by 2020
	CSP	20 MW by 2020
	Wind power	44 MW by 2020
Philippines	Electricity	Triple the 2010 capacity by 2030
	Bio-power	277 MW added 2010-2030
	Geothermal power	1.5 GW added 2010-2030
	Hydropower	5,398 MW added 2010-2030
	Ocean power	75 MW added 2010-2030
	Solar PV	284 MW added 2010-2030
	Wind power	2.3 GW added 2010-2030
Poland	Wind power (offshore)	10 GW by 2040

TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Portugal	Electricity	14.7 GW by 2020; 27.9 GW by 2030
	Hydropower	7 GW by 2020; 8.7 GW by 2030
	Wind power	5.4 GW by 2020; 9.3 GW by 2030
	Solar	1.9 GW by 2020; 9 GW by 2030
	Other (biopower, geothermal and wave)	0.5 GW by 2020; 0.6 GW by 2030
Qatar	Electricity	500 MW by 2030
	Bio-power	50 MW by 2030
	Solar power	400 MW by 2030
	Wind power	50 MW by 2030
Russian Federation[f]	Electricity	5.5 GW by 2024
	Hydropower (small-scale)	425.4 MW by 2024
	Solar PV	1.8 GW by 2024
	Wind power	3.4 GW by 2024
Altai Republic	*Solar PV*	*150 MW by 2021*
Saudi Arabia	Electricity	27.3 GW by 2023; 58.7 GW by 2030
	Geothermal, bio-power (waste-to-energy)[g], wind power	13 GW combined by 2040
	Solar PV	20 GW by 2023; 40 GW by 2030
	CSP	300 MW by 2023; 2.7 MW by 2030
	Wind	7 GW by 2023; 16 GW by 2030
Serbia	Wind power	1.4 GW (no date)
Sierra Leone	Electricity	1 GW (no date)
Singapore	Solar PV	350 MW by 2020
Solomon Islands	Geothermal power	20 to 40 MW (no date)
	Hydropower	3.77 MW (no date)
	Solar power	3.2 MW (no date)
South Africa	Electricity	17.8 GW by 2030; 42% of new capacity installed 2010-2030
Spain	Solar	77 GW by 2030
Sudan	Electricity	16 GW by 2031
	Bio-power from solid biomass	54 MW by 2031
	Bio-power from biogas	68 MW by 2031
	Hydropower	54 MW by 2031
	Solar PV	750 MW by 2031
	CSP	50 MW by 2031
	Wind power	680 MW by 2031
Sweden	Electricity	25 TWh more renewable electricity annually by 2020 (base year 2002)
	Electricity	26.4 TWh common electricity certificate market with Norway by 2020
Switzerland	Electricity	12 TWh per year by 2035; 24.2 TWh per year by 2050
	Hydropower	43 TWh per year by 2035
Syria	Bio-power	140 MW by 2020; 260 MW by 2025; 400 MW by 2030
	Solar PV	380 MW by 2020; 1.1 GW by 2025; 1.8 GW by 2030
	CSP	50 MW by 2025; 1.3 GW by 2030
	Wind power	1 GW by 2020; 1.5 GW by 2025; 2 GW by 2030
Tajikistan	Hydropower (small-scale)	100 MW by 2020
Thailand	Bio-power from solid biomass	4.8 GW by 2021
	Bio-power from biogas	600 MW by 2021
	Bio-power from organic MSW[g]	400 MW by 2021
	Geothermal power	1 MW by 2021

TABLE R8. Renewable Power, Targets for Specific Amount of Installed Capacity or Generation, 2019 (continued)

Note: Text in **bold** indicates new/revised in 2019 and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Thailand (continued)	Hydropower	6.1 GW by 2021
	Ocean power (wave and tidal)	2 MW by 2021
	Solar PV	3 GW by 2021; 6 GW by 2036
	Wind power	1.8 GW by 2021
Trinidad and Tobago	Wind power	100 MW (no date)
Tunisia	Electricity	4.7 GW by 2030
	Bio-power from solid biomass	300 MW by 2030
	Solar power	10 GW by 2030
	Wind power	16 GW by 2030
Turkey	Bio-power from solid biomass	1 GW by 2023
	Geothermal power	1 GW by 2023
	Hydropower	34 GW by 2023
	Solar PV	5 GW by 2023
	Wind power	20 GW by 2023
United Kingdom	Wind power (offshore)	39 GW by 2030, one-third of electricity by 2030
United States		no national target
Iowa	*Electricity*	*105 MW generating capacity for IOUs*[h]
Massachusetts	*Wind power (offshore)*	*1.6 GW by 2027; additional 1.6 GW by 2035*
	Wind power (total)	*2,000 MW by 2020*
	Solar power	*1600 MW by 2020*
New York	*Energy storage*	*1.5 GW of energy storage by 2025 and 3 GW by 2030*
Texas	*Electricity*	*5,880 MW*
Uzbekistan	Solar PV	157.7 MW installed by 2019; 382.5 by 2020; 601.9 by 2021; 1.24 GW by 2025
	Wind power	102 MW installed by 2021; 302 MW installed by 2025
Venezuela	Electricity	613 MW new capacity installed 2013-2019, including:
	Wind power	500 MW new capacity installed 2013-2019
Vietnam	Hydropower	21.6 GW by 2020; 24.6 GW by 2025; 27.8 GW by 2030
	Solar power	850 MW by 2020; 4 GW by 2025; 12 GW by 2030
	Wind power	800 MW by 2020; 2 GW by 2025; 6 GW by 2030
Yemen	Electricity	714.25 MW by 2025
	Bio-power	6 MW by 2025
	Geothermal power	200 MW by 2025
	Solar PV	8.25MW by 2025
	CSP	100 MW by 2025
	Wind power	400 MW by 2025

[a] India does not classify hydropower installations larger than 25 MW as renewable energy sources. Therefore, national targets and data for India do not include hydropower facilities >25 MW.
[b] Utility or grid-scale solar parks are to account for 24 GW, distributed generation for 4 GW, solar rooftops for 1 GW and solar pumps for the remaining 1 GW.
[c] Pumped storage plants are not energy sources but a means of energy storage. As such, they involve conversion losses and are powered by renewable or non-renewable electricity. Pumped storage is included here because it can play an important role as balancing power, particularly for variable renewable resources.
[d] Kosovo is not a member of the United Nations.
[e] Nigeria's target excludes hydropower plants >30 MW.
[f] The Russian Federation's targets exclude hydropower plants >25 MW.
[g] It is not always possible to determine whether municipal solid waste (MSW) data include non-organic waste (plastics, metal, etc.) or only the organic biomass share.
[h] Investor-owned utilities (IOUs) are those operating under private control rather than government or co-operative operation.

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

TABLE R9. Renewable Heating and Cooling Policies, as of End-2019

Note: Text in **bold** indicates new/revised in 2019.

Country	Financial Support Policies						Bans/Mandates	
	Investment subsidy/grants	Rebates	Tax credits	Tax deductions and exemptions	Loans	Feed-in tariff	Targeted fossil fuel bans in buildings/industry	Renewable heat mandates
Argentina			I/C	I/C	I/C			●
Armenia[c]	I/C				R/C			
Australia	R/C							●
Austria	C			I	R		●	
Belgium				C				
Brazil								●
Bulgaria	R/I/P							
Canada	I/C		C	C				
Chile	R			C				
China	I							●
Costa Rica				I				
Croatia						I		
Cyprus	R/C							
Czech Republic	R/C			I				
Denmark				I	I	I	●	
Egypt				I				
Estonia	R							
Finland	I/C							
France	R/I/C/P		R	**R/C**	**R**			●
Georgia[c]					R/C			
Germany	R/C/P				I/C			●
Greece	R/I			R/I/C		I		●
Hungary	R/C/P							
India	R/I/C/P	I						●[a]
Ireland	R/I/C/P			C		I/C/P		●
Israel								●
Italy	R	R/C/P	R/I/C					●[a]
Japan	I							
Jordan	R							●
Korea, Republic of	R							●
Latvia				C				
Lebanon					R/I/C			
Lithuania	R			I	**R**	I		
Luxembourg	R/C/P							
Macedonia, North	R							
Malawi								●
Malta		R						
Mexico	R							
Morocco	I							
Namibia								●

TABLE R9. Renewable Heating and Cooling Policies, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019.

Country	Financial Support Policies						Bans/Mandates	
	Investment subsidy/grants	Rebates	Tax credits	Tax deductions and exemptions	Loans	Feed-in tariff	Targeted fossil fuel bans in buildings/industry	Renewable heat mandates
Netherlands			**I/C**			R/I/C/P		
New Zealand	I							
Norway	C/P	R					●	●
Philippines	I							
Poland	R				R/C/P		●	
Portugal	R/I/C							●
Romania	R/I/C[b]/P							
Slovak Republic	I							
Slovenia	R				R			
South Africa	R/I/C							●
Spain	I/C			I	R/C			●
Sweden				R/C				
Switzerland	R							●[a]
Thailand	I/C							
Tunisia	R/C							
Turkey	I					I		
Ukraine					R			
United Arab Emirates								●
United Kingdom	R/I/C/P					R/C/P	●	
United States	R/I/C/P		R					●
Uruguay	R							●

R Residential
I Industrial
C Commercial
P Public facilities

[a] City level
[b] Agricultural renewable heat installation subsidies financed by the European Agricultural Fund for Rural Development (EAFRD).
[c] Incentives provided by the European Bank for Reconstruction and Development under the Caucuses Energy Efficiency Program II.

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

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
EU					0.2% by 2022, 1% by 2025; 3.5% by 2030		13 million zero- or low-emission vehicles by 2025
Angola		10%					
Argentina	10%	12%					
Australia							
New South Wales	*2%*	*7%*					
Queensland	*1%*	*3%*					
Austria	6.3%	3.4%	5.75%	8.75% by 2020	0.5% of total transport energy from 2020		
Belgium	6% [4%]	8.5% [4%]			0.1% total transport energy by 2020		
Brazil	**11% [10%]**	27%		**15% biodiesel by 2022 and 30% by 2030; 10% biokerosene in aviation fuel by 2030**			
Bulgaria	6%	8%			1% of total transport fuel		
Cabo Verde							35% EVs by 2025; 70% by 2030; 100% by 2035
Canada	2%	5%					Ban on sale of new petrol or diesel vehicles by 2040; 10% ZEV sales by 2025, 30% by 2030; 825,000 ZEVs by 2025, 2.7 million by 2030, 14 million by 2040
Alberta	*2%*	*5%*					
British Columbia	*4%*	*5%*					*Ban on most gasoline and diesel cars after 2040*
Manitoba	*2%*	*9%*					
Ontario	*4%*	*5%*		*10% ethanol in gasoline by 2020*			
Quebec				***10% ethanol and 2% biodiesel by 2021; 15% ethanol and 4% biodiesel by 2025***			
Saskatchewan	*2%*	*8%*					
Chile							40% EVs in vehicle stock by 2050
China[a]		10%					20% of total car sales to be hybrid and electric vehicles by 2025; 2 million annual EV sales by 2020
Hainan Province							***ICE ban (sales) by 2030***
Chinese Taipei	1%						Ban on sales of ICE vehicles by 2040; zero-emission two-wheelers by 2035

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Colombia	10%	10% [8%]					10% ZEVs by 2025; 600,000 EVs by 2030
Costa Rica	20%	7%					25% of vehicles, 70% of buses and taxis to be zero emission by 2035; 100% of vehicle sales, 60% of vehicles and 100% of buses to be zero emission by 2050
Croatia	5.75%	0.97%	6.92%		0.1% second-generation biofuels[b]		
Czech Republic	6%	4.1%			0.5% of transport energy in 2020		
Denmark			5.75%		0.9% of transport energy from 2020		Ban on sale of new petrol or diesel vehicles by 2030
Ecuador	5%	10%					
Estonia	3.1%			10% by 2020	At least 0.5% in diesel fuel from 2019		
Ethiopia		10%					
Finland			15%	30% by 2029; **30% in aviation by 2030**	0.5% in total transport by 2020; 10% by 2030		250,000 BEVs/PHEVs by 2030
France		7.5%	**7.9% biofuels in motor fuel**	**8.2% in motor fuel by 2020**	2.3% of diesel and 3.4% of petrol from advanced biofuels by 2023		Sales of all diesel and petrol cars and vans banned by 2040
Germany					Minimum 0.05% market share from 2020 for companies that supplied more than 20 PJ of fuel in the previous year; increase to 0.5% by 2025.		100,000 public EV charging stations by 2020; 7-10 million BEVs/FCEVs by 2030
Greece			7%				
Guatemala		5%					
Hungary	4.9%	4.9%					
Iceland							No new registrations of diesel and gasoline cars by 2030
India	20%	10%					Ban on sale of new petrol or diesel vehicles by 2030; EVs to be 15% of all sales by 2025 and 30% by 2030
Delhi							***20% of all vehicle parking in residential and commercial parking complexes to be EV ready; all leased or hired cars used for government commuting to transition to electric by the end of 2020***

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Indonesia	**30%** [20%]	3%		30% biodiesel from 2025; 20% ethanol from 2025; 5% biofuel in aviation fuel by 2025. **Increase the portion of diesel blended with crude palm oil (CPO) from the current 20% (B20) to 30% (B30) starting January next year and to 50% (B50) by the end of 2020.**[e]		B20 blending mandate expanded from road transport to rail-roads and power plants	2200 EVs by 2025
Ireland	10%			11% from 2020; **10% in petrol and 12% in diesel by 2030**	0.25% of transport energy in 2020		**950,000 EVs by 2030**
Israel					6.7% cap on conventional biofuels by 2022		100% EV or natural gas vehicle sales by 2030; 177,000 EVs by 2025, 1.4 million by 2030
Italy			7%		0.9% by 2020; 1.85% by 2022		6 million EVs by 2030 (including 1.6 million BEVs)
Jamaica		10%					
Japan							Ban on sales of ICE vehicles by 2050
Korea, Republic of	3%						30% of all new car sales in the country to be electric by 2020; 1,000 hydrogen buses by 2022 (from natural gas)
Lithuania					0.5% by 2020		
Malawi		10%					
Malaysia	10%	10%		**20% from 2020**			100,000 EVs by 2030
Malta					0.5% by 2020		
Mexico[c]		10% [5.8%]					5% ZEV sales by 2030, 50% by 2040
Mozambique		15%		20% ethanol from 2021			
Nepal							Increase EV share to 20% by 2020 (2010 base year)
Netherlands			16.4% [8.5%]	16.4% from 2020	1% by 2020		100% sales of hydrogen and electric cars by 2030
New Zealand	7%		Max. 3% methanol blend				64,000 EVs by 2021
Norway	4%			20% ethanol by 2020	0.5% in aviation by 2020 and 30% by 2030		Ban on sale of new petrol or diesel vehicles by 2025

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Pakistan							30% EV sales by 2030
Panama		10%				30% of new vehicle purchases for public fleets to be flex-fuel (no date)	
Paraguay	1%	25%					
Peru	2%	8%					
Philippines	2%	10%					
Poland			7.5%	8.5% by 2020	0.1% by 2020		1 million EVs by 2025
Portugal			9%				
Romania	6.5%	8%		10% by 2020			
Slovak Republic			5.8%		0.5% in 2020-2024; 0.75% in 2025-2030		
Slovenia			7.5%	100% biodiesel for heavy-duty trucks by 2030	0.5% in 2020		Ban on sale of new petrol or diesel vehicles by 2030; 12% of vans and trucks to be electric by 2030
South Africa	5%	2%					
Spain			6%		0.1% from 2020		
Balearic Islands							***Ban on sale of new petrol or diesel vehicles by 2035***
Sri Lanka							Ban on sale of new petrol or diesel vehicles by 2040
Sudan		5%					
Sweden							**Ban on sale of cars with petrol or diesel engines after 2030;** all buses and government vehicles to be electric by 2030
Thailand	7%	5%		4.1 billion litres of ethanol and 5.1 billion litres of biodiesel by 2036	25 million litres per day by 2022		1.2 million EVs by 2036
Turkey		2%					
Ukraine		7%					

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	**Existing Biodiesel Blend Mandate** (% Biodiesel)	**Existing Ethanol Blend Mandate** (% Ethanol)	**Unspecified/ Overall Blend Mandate**	**Biofuel Mandate by Future Year**	**Advanced Biofuel Mandate by Future Year**	**Other Renewable Transport Mandates**	**Other Transport Mandates by Future Year** (not necessarily linked to renewables)
United Kingdom			7.25%	**9.75% from 2020**	3.1% by 2032		50% to 70% of new car sales and 40% of van sales to be ultra-low emission by 2030, and 25% of the government fleet to be ultra-low emission by 2022; **ban on sale of new petrol, diesel or hybrid cars by 2035 [2040]**
Scotland							*Ban on sales of all diesel and petrol cars and vans by 2032; USD 1.7 million to promote e-bikes*
United States				Energy Independence and Security Act of 2007 mandatory target: 113.5 billion litres by 2020, 125 billion litres by 2021, 136.2 billion litres by 2022.[d]	18.6 billion litres in 2019; 19.3 billion litres by 2020	Renewable Fuel Standard (RFS) 2019 standards: 75.4 billion litres total renewable fuels, including 1.6 billion litres cellulosic biofuel, 9.2 billion litres biomass-based diesel and a cap of 56.7 billion litres for conventional biofuels.[d]	
California							*5 million ZEVs on the road by 2030; 250,000 vehicle charging stations by 2025, 200 hydrogen refuelling stations by 2025; all-electric buses by 2040*
California, Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont							*California Air Resources Board (CARB) programme target of 3.3 million ZEVs (PHEV, BEV, FCEV) by 2025, also adopted by 10 other states*
Hawaii, Missouri and Montana		*10%*					
Louisiana	*2%*	*2%*					
Massachusetts	*5%*						
Minnesota	*10%*	*20% [10%]*					
New Mexico	*5%*						

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, as of End-2019 (continued)

Note: Text in **bold** indicates new/revised in 2019, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	Advanced Biofuel Mandate by Future Year	Other Renewable Transport Mandates	Other Transport Mandates by Future Year (not necessarily linked to renewables)
Oregon	*5%*	*10%*					
Pennsylvania						*E10 one year after 1.3 billion litres produced; B5 one year after 379 million litres produced, B10 one year after 757 million litres produced, and B20 one year after 1.5 billion litres produced*[d]	
Washington	*2%*	*2%*				*B5 180 days after in-state feedstock and oil-seed crushing capacity can meet 3% requirement*	
Uruguay	5%	5%					
Vietnam		5%					
Zimbabwe		20% [15%]					

[a] China's E10 mandate was extended to cover 15 regions.

[b] Blending mandate of 0.1% for second-generation biofuels, which may increase in 2019 depending on available supplies.

[c] Mexico's E10 maximum blend was subsequently halted in response to several court cases challenging the increase.

[d] Original target(s) set in gallons and converted to litres for consistency.

[e] Not yet enforced.

Note: ZEV = zero emission vehicle; EV = electric vehicle; ICE = internal combustion engine

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

TABLE R11. Feed-in Electricity Policies, Cumulative Number of Countries/States/Provinces and 2019 Revisions

Note: Text in **bold** indicates new/revised in 2019, and text with a ~~strikethrough~~ indicates discontinuation and text in *italics* indicates policies adopted at the state/provincial level.

Year	Cumulative[a] #	Countries/States/Provinces Added That Year
1978	1	~~United States~~[b]
1988	2	~~Portugal~~
1990	3	**Germany**
1991	4	Switzerland
1992	5	Italy[c]
1993	7	Denmark; India
1994	10	**Luxembourg**; ~~Spain~~; Greece
1997	11	Sri Lanka
1998	12	~~Sweden~~
1999	14	~~Norway; Slovenia~~
2000	14	[none identified]
2001	17	Armenia; France; Latvia
2002	23	Algeria; Austria; ~~Brazil~~; Czech Republic; Indonesia; Lithuania
2003	29	Cyprus; Estonia; Hungary; Slovak Republic; ~~Republic of Korea~~; *Maharashtra (India)*
2004	34	Israel; Nicaragua; *Prince Edward Island (Canada); Andhra Pradesh and Madhya Pradesh (India)*
2005	41	**China**[d]; Ecuador; Ireland; Turkey; *Karnataka, Uttar Pradesh and Uttarakhand (India)*
2006	46	Argentina; Pakistan; Thailand; ~~*Ontario (Canada)*~~; *Kerala (India)*
2007	55	Albania; Bulgaria; Croatia; ~~Dominican Republic~~; Finland; North Macedonia; Moldova; Mongolia; *South Australia (Australia)*
2008	70	Iran; Kenya[e]; Liechtenstein; Philippines; San Marino; Tanzania; **Queensland (Australia)**; *Chhattisgarh, Gujarat, Haryana, Punjab, Rajasthan, Tamil Nadu and West Bengal (India); California (United States)*
2009	81	Japan; Serbia; ~~South Africa~~; **Ukraine**; *Australian Capital Territory, New South Wales and Victoria (Australia);* **Chinese Taipei**; *Hawaii, Oregon and Vermont (United States)*
2010	87	Belarus; Bosnia and Herzegovina; Malaysia; Malta; ~~Mauritius~~; ~~**United Kingdom**~~
2011	95	Ghana; **Montenegro**; Netherlands; Syria; Vietnam; *Nova Scotia (Canada)*[f]; *Rhode Island (United States);* Angola[g]
2012	101	Jordan; Nigeria; State of Palestine; Rwanda; Uganda; Malawi[h]
2013	103	Kazakhstan; Pakistan
2014	107	Egypt; Vanuatu; *Virgin Islands (United States);* Mozambique[i]
2015	107	[none identified]
2016	108	Czech Republic (reinstated); Chile
2017	111	Zambia; Vietnam; *Massachusetts (United States)*
2018	113	Senegal; **Bermuda (UK)**
2019	113	[none identified]
Unknown year	126	Andorra; Honduras; Maldives; Panama; Peru; Poland; Russian Federation; Tajikistan; *Bihar, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Odisha (India)*
Total Removed	**13**	
Total Existing	**113**	

2019 FIT Policy Adjustments	
Australia – Queensland	*Solar FIT reduced*
Bermuda	FIT increased for solar PV power generators
China	New solar FIT policy
Chinese Taipei	FIT reduced for offshore wind projects
Germany	Cap removed on solar FIT programme
Luxembourg	FIT increased for solar PV power generators
Montenegro	FIT surcharge abolished
Ukraine	FIT for new wind and solar power projects commissioned after 2020 to be reduced. FIT for biomass and biogas to remain at current level until 2030.
United Kingdom	FITs for solar energy replaced with new Small Export Guarantee obligating electricity suppliers to offer a tariff (came into force 1 January 2020)

[a] "Cumulative number" refers to number of jurisdictions that had enacted feed-in policies as of the given year.

[b] The US PURPA policy (1978) is an early version of the FIT, which has since evolved.

[c] The FIT for solar PV in Italy ended in 2013.

[d] The FIT for CSP in China ended in 2016.

[e] Kenya planned to replace its FIT system with an energy auction tariff.

[f] Nova Scotia's community FIT (COMFIT) was removed in 2015, the same year that the province's Developmental Tidal Feed-in Tariff Program was introduced.

[g] Angola's policy was adopted but had not yet been enacted as of end-2019.

[h] The FIT was in use but had not yet been not formally approved by the Ministry and Malawi Energy Regulatory Authority.

[i] Although the decree was available, injection of power into the grid could not yet happen pending the approval of regulation.

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

TABLE R12. Renewable Power Tenders Held at the National/State/Provincial Levels, 2019

Country	Technology	Description
Australia	Solar PV, energy storage	250 MW solar PV and 20 MW / 40 MWh battery energy storage system announced
Belgium	Wind power (offshore)	At least 1.7 GW after 2020 announced
Brazil	Mix of technologies (including bio-power, hydropower, solar PV, wind power)	401.6 MW awarded
	Technology-neutral among renewable and non-renewable technologies	1.04 GW wind power awarded 530 MW solar PV awarded 445 MW hydropower 229.62 MW biomass awarded 734.13 MW natural gas awarded
Burkina Faso	Solar PV	30 MW announced
Cabo Verde	Solar PV	5 MW announced
	Wind power	10 MW announced
Cambodia	Solar PV	60 MW awarded
China	Solar PV	22.78 GW of ground-mounted and distributed generation awarded
Colombia	Solar power and wind power	1,374 MW awarded
Denmark	Solar PV	83 MW awarded
	Solar power and wind power (hybrid)	93 MW solar-wind hybrid facilities awarded (including 34.1 MW solar PV capacity)
Ethiopia	Solar PV	250 MW awarded
	Solar PV	750 MW announced
	Solar PV	Design, supply and commissioning of solar mini-grid projects in 25 rural towns and villages announced
France	Wind power (offshore)	600 MW awarded
	Solar PV (ground-mounted)	855 MW awarded
	Solar PV (ground-mounted)	858 MW awarded
Gambia	Solar PV and storage	Utility-scale solar PV park with 150 MW battery storage announced
Ghana	Solar PV	12 MWp announced
Germany	Solar PV	153 MW awarded
	Solar PV	501 MW awarded
	Wind power (onshore)	500 MW awarded
Greece	Solar power and wind power (joint auction)	437.78 MW awarded
	Solar PV	143 MW awarded
	Solar power	105.09 MW awarded
	Wind power	179.5 MW awarded
	Wind power	224 MW awarded
Guinea Bissau	Solar PV	22 MWp ground-mounted solar power plant and 30 kV transmission line announced
India	Solar PV	30 GW announced
	Transmission line supply and reactor package installation	Installation of reactor packages and supply of transmission lines announced
	Solar PV (floating)	70 MW announced
	Wind power (offshore)	Undisclosed capacity announced
Iraq	Solar PV	755 MW offered
Ireland	Technology-neutral among renewable technologies	13,500 GWh announced
	Energy storage	110 MW awarded
Italy	Solar power, wind power	4.8 GW announced (650 MW combined solar and wind, 600 MW rooftop PV)

TABLE R12. Renewable Power Tenders Held at the National/State/Provincial Levels, 2019 (continued)

Country	Technology	Description
Japan	Solar power	195.8 MW awarded
Lithuania	Technology-neutral among renewable technologies	300 GWh allocated
Mali	Solar PV + storage	1.3 MW with 1.5 MW/2 MWh storage announced
	Solar PV-diesel hybrid	Four 80 kWp mini-grids announced
Malaysia	Solar power	491 MW large-scale solar projects awarded
Mauritius	Energy storage	14 MW for a pre-existing solar plant announced
Mexico	Geothermal power	Additional drilling at the Los Azufres geothermal field announced
Netherlands	Wind power	760 MW awarded
Nigeria	Solar PV + storage	15 MW ground-mounted solar with 5 MW battery system offered
Poland	Wind power (onshore)	2.5 GW awarded
Portugal	Solar power	1.3 GW awarded
	Energy storage	50-100 MW announced
	Solar PV (floating)	50 MW offered
Russian Federation	Wind power	78 MW awarded
Seychelles	Solar PV (floating)	4 MW awarded
Togo	Solar PV	Tender announced for the development, operation and maintenance of solar PV based mini-grids in 317 localities
Tonga	Solar PV	6 MW awarded
Tunisia	Solar power	500 MW offered
Turkey	Wind power	1 GW awarded
United Arab Emirates	Solar power	900 MW awarded
United Kingdom	Wind power (offshore)	5.47 GW awarded
	Wind power (onshore)	330 MW awarded
Vietnam	Solar PV (floating)	400 MW announced in pilot auctions
Zambia	Hydropower (small-scale)	100 MW announced
	Solar PV	120 MW awarded
	Solar PV	100 MW announced
Zimbabwe	Solar PV, energy storage	19.65 MWp announced

State/Provincial Renewable Energy Auctions Held in 2019

Country	State	Technology	Description
India	Chhattisgarh	Solar power	Supply and installation of 5,000 small solar irrigation pumps and 700 solar trees awarded
	Kerala	Solar power	Construction and supply of three solar-powered boats offered
	Maharashtra	Bio-power	50 MW of power from bagasse-based co-generation announced
	Rajasthan	Solar PV	750 kW of grid-connected solar PV announced for electric vehicle charging stations at selected highways/cities

Note: This table provides an overview of identified renewable energy tenders in 2019 and may not constitute a comprehensive picture of all capacity offered through tenders during the year.

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

TABLE R13. Biofuels Global Production, Top 15 Countries and EU-28, 2019

Country	Ethanol	Biodiesel (FAME)	Biodiesel (HVO)	Change Relative to 2018
	Billion litres			
United States	59.7	4.0	2.5	-1.7
Brazil	35.3	5.9	0.0	2.9
Indonesia	0.0	7.9	0.0	3.9
China	4.0	0.6	0.0	0.7
Germany	0.8	3.8	0.0	0.0
France	0.9	2.8	0.2	-0.3
Argentina	1.1	2.5	0.0	-0.2
Thailand	1.6	1.7	0.0	0.3
Spain	0.5	2.0	0.0	0.1
Netherlands	0.4	1.0	1.1	0.1
Canada	2.0	0.3	0.0	0.3
India	2.1	0.2	0.0	0.5
Malaysia	0.0	1.6	0.0	0.7
Poland	0.2	1.0	0.0	0.1
Italy	0.0	0.8	0.2	0.2
EU-28	**4.7**	**12.4**	**2.9**	**-0.1**
World Total	**113.7**	**40.9**	**6.5**	**7.8**

Note: Production levels are rounded to the nearest 0.1 billion litres. Rounding is to account for uncertainties in available data. Countries are ranked according to total biofuel production in 2019. FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil.

Source: See endnote 13 for this section.

TABLE R14. Geothermal Power Global Capacity and Additions, Top 10 Countries, 2019.

Country	Added 2019	Total End-2019
	MW	GW
Top Countries by Additions		
Turkey	232	1.5
Indonesia	182	2.1
Kenya	160	0.8
Costa Rica	55	0.3
Japan	54	0.6
Mexico	27	0.9
United States	15	2.5
Germany	6	0.05
Top Countries by Total Capacity		
United States	15	2.5
Indonesia	182	2.1
Philippines	–	1.9
Turkey	232	1.5
New Zealand	–	1.0
Mexico	27	0.9
Italy	–	0.8
Iceland	–	0.8
Kenya	160	0.8
Japan	54	0.6
World Total	**728**	**13.9**

Note: Capacity additions are rounded to the nearest 1 MW, and totals are rounded to the nearest 0.1 GW, with the exception of Germany, which is rounded to the nearest 0.01 GW. Rounding is to account for uncertainties and inconsistencies in available data. Table reflects known new capacity and capacity increases at existing facilities but does not indicate known capacity decommissioning or derating of existing facilities, although those may be reflected (at least partially) in total capacity values. For more information and statistics, see Geothermal section in Market and Industry chapter and related endnotes.

Source: See endnote 14 for this section.

TABLE R15. Hydropower Global Capacity and Additions, Top 10 Countries, 2019

Country	Added 2019	Total End-2019
	GW	
Top Countries by Additions		
Brazil	4.9	109
China	3.9	326
Lao PDR	1.9	7.2
Bhutan	0.7	2.3
Tajikistan	0.6	6.4
Russian Federation	0.5	48
Angola	0.3	3.4
Uganda	0.3	1.0
Ethiopia	0.3	4.1
Turkey	0.2	29
Top Countries by Total Capacity		
China	3.9	326
Brazil	4.9	109
Canada	–	81
United States	~0	80
Russian Federation	0.5	48
India	0.2	45
Norway	0.1	31
Turkey	0.2	29
Japan	–	22
France	~0	20
World Total	**16**	**1,150**

Note: Capacity additions are rounded to the nearest 0.1 GW, and totals are rounded to the nearest 1 GW except when totals are less than 10 GW. Rounding is to account for uncertainties and inconsistencies in available data. Capacity amounts of less than 50 MW are designated by "~0". For more information and statistics, see Hydropower section in Market and Industry chapter and related endnotes.

Source: See endnote 15 for this section.

TABLE R16. Solar PV Global Capacity and Additions, Top 10 Countries, 2019

	Total End-2018	Added 2019	Total End-2019
		GW	
Top Countries by Additions			
China	175.4	30.1	204.7
United States	62.7	13.3	76
India	32.9	9.9	42.8
Japan	56	7	63
Vietnam	0.1	4.8	4.9
Spain	5.2	4.8	9.9
Germany	45.2	3.8	49
Australia	11	3.7	14.7
Ukraine	1.3	3.5	4.8
Republic of Korea	8.1	3.1	11.2
Top Countries by Total Capacity			
China	175.4	30.1	204
United States	62.7	13.3	76
Japan	56	7	63
Germany	45.2	3.8	49
India	32.9	9.9	42.8
Italy	20.1	0.7	20.8
Australia	11	3.7	14.7
United Kingdom	13.1	0.3	13.4
Republic of Korea	8.1	3.1	11.2
Spain	5.2	4.8	9.9
World Total	**512**	**115**	**627**

Note: Country data are rounded to the nearest 0.1 GW, and world totals are rounded to the nearest 1 GW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding. Data are provided in direct current (DC); data for India, Japan and the United States were converted from official data reported in alternating current (AC) into DC by sources listed for this table. Data are from a variety of sources, some of which differ significantly because of variations in accounting or methodology. For more information, see Solar PV section in Market and Industry chapter and related endnotes.

Source: See endnote 16 for this section.

TABLE R17. Concentrating Solar Thermal Power (CSP) Global Capacity and Additions, 2019

Country	Total End-2018	Added 2019	Total End-2019
		MW	
Spain	2,304	–	2,304
United States	1,738	–	1,738
Morocco	516	–	516
South Africa	400	100	500
China	220	200	420
Israel	–	240	240
India	225	–	225
United Arab Emirates	100	–	100
Saudi Arabia	50	–	50
Kuwait	–	50	50
Algeria	20	–	20
Egypt	20	–	20
Iran	17	–	17
France	–	9	9
World Total	**5,610**	**600**	**6,210**

Note: Table includes all countries with operating commercial CSP capacity at end-2019. Pilot and demonstration facilities and facilities with capacities of 5 MW or less are excluded from the table. Additional countries that had small (5 MW or less) pilot or demonstration plants in operation by year's end include Australia (4.1 MW), Denmark (4 MW), Canada (1.1 MW), France (0.25 MW), Germany (1.5 MW), Italy (6 MW), Oman (7 MW), Thailand (5 MW) and Turkey (5 MW). National data are rounded to the nearest MW, and world totals are rounded to the nearest 5 MW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding. Capacity data reflect net capacity; where it is not possible to verify if reported capacity reflects net or gross capacity, capacity is assumed to be net. For more information, see CSP section in Market and Industry chapter and related endnotes.

Source: See endnote 17 for this section.

TABLE R18. Solar Water Heating Collectors and Total Capacity End-2018 and Newly Installed Capacity 2019, Top 20 Countries

	Total End-2018 GW$_{th}$			Gross Additions 2019 MW$_{th}$		
Country	**Glazed**	**Unglazed**	**Total**	**Glazed**	**Unglazed**	**Total**
China	337.6	–	337.6	22,750	–	22,750
Turkey	17.6	–	17.6	1,320	–	1,320
India	9.5	–	9.5	1,270	–	1,270
Brazil	7.1	4.2	11.3	461	464	925
United States	2.2	15.7	17.9	112	487	600
Australia	2.6	3.9	6.5	122	266	388
Germany	13.5	0.4	13.9	358	–	358
Mexico	2.0	1.0	3.0	203	83	286
Greece	3.3	–	3.3	253	–	253
Israel	3.3	–	3.4	252	–	252
Poland	1.8	–	1.8	184	–	184
Spain	2.9	0.1	3.0	143	2	145
Denmark	1.2	–	1.2	137	–	137
South Africa	0.7	0.9	1.5	70	42	112
Italy	3.3	–	3.3	106	–	106
Austria	3.3	0.2	3.6	63	–	64
Cyprus	0.6	1.5	2.1	49	–	49
Tunisia	0.7	–	0.7	44	–	44
Palestine, State of	1.3	–	1.3	32	–	32
Switzerland	1.1	0.1	1.2	28	3	32
Total Top 20 Countries	415.4	28.1	443.5	27,957	1,348	29,305
World Total	**452**	**30**	**482**	**29,840**	**1,455**	**31,295**

Note: Countries are ranked according to newly installed glazed collector capacity in 2019. Data are for glazed and unglazed water collectors excluding air collectors, which added at least 1.1 GW$_{th}$ to the year-end world total for 2018, and excluding concentrating collectors, which achieved 364 MW$_{th}$ at the end of 2018. End-2018 data for individual countries and Total 20 Top Countries are rounded to the nearest 0.1 GW$_{th}$; end-2018 World Total data are rounded to the nearest GW$_{th}$; additions for individual countries and Total 20 Top Countries are rounded to the nearest 1 MW$_{th}$. Where totals do not add up, the difference is due to rounding. By accepted convention, 1 million square metres = 0.7 GW$_{th}$. The year 2018 is the most recent one for which firm global data on total capacity in operation were available. However, 479 GW$_{th}$ of solar thermal capacity (water and non-concentrating collectors only) was estimated to be in operation worldwide by end-2019. For details and source information on 2019 additions, see Solar Thermal section in Market and Industry chapter and related endnotes.

Source: See endnote 18 for this section.

■ TABLE R19. Wind Power Global Capacity and Additions, Top 10 Countries, 2019

Country	Total End-2018	Added 2019	Total End-2019
		GW	
Top Countries by Additions			
China[a]	184.2/209.5	25.7/26.8	210/236.3
United States	96.5	9.1	105.6
United Kingdom	21.1	2.4	23.5
India	35.1	2.4	37.5
Spain	23.5	2.3	25.8
Germany	59.3	2.1	61.4
Sweden	7.4	1.6	9.0
France	15.3	1.3	16.6
Mexico	4.9	1.3	6.2
Argentina	0.7	0.9	1.6
Top Countries by Total Capacity			
China[a]	184.2/209.5	25.7/26.8	210/236.3
United States	96.5	9.1	105.6
Germany	59.3	2.1	61.4
India	35.1	2.4	37.5
Spain	23.5	2.3	25.8
United Kingdom	21.1	2.4	23.5
France	15.3	1.3	16.6
Brazil	14.7	0.7	15.5
Canada	12.8	0.6	13.4
Italy	10.1	0.5	10.5
World Total	**591**	**60**	**651**

[a] For China, data to the left of the "/" are the amounts officially classified as connected to the grid and operational (receiving FIT premium) by year's end; data to the right are total installed capacity, most, if not all, of which was connected to substations by year's end. The world totals include the higher numbers for China. See Wind Power section in Market and Industry chapter and related endnotes for more details.

Note: Country data are rounded to the nearest 0.1 GW; world data are rounded to the nearest GW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding or to repowering/removal of existing projects. Several countries repowered or decommissioned existing capacity during the year, which is reflected in the table to the extent possible. Data are from a variety of sources, some of which differ significantly because of variations in accounting or methodology. For more information, see Wind Power section in Market and Industry chapter and related endnotes.

Source: See endnote 19 for this section.

TABLE R20. Electricity Access by Region and Country, Status in 2018 and Targets

World/Region/Country	Population with Electricity Access in 2018	Population Without Electricity Access in 2018	Target
	Share of population with access	Millions	Share of population with electricity access
World[a]	**89%**	**861**	
All Developing Countries	**86%**	**861**	
Africa	**54%**	**601**	
North Africa	**>99%**	**<1**	
Sub-Saharan Africa	**45%**	**600**	
Developing Asia	**94%**	**226**	
Central and South America	**97%**	**16**	
Middle East	**93%**	**18**	
Africa			
Angola	45%	17	→ 100% by 2030
Benin	35%	8	→ 95% by 2025 (urban) → 65% by 2025 (rural)
Botswana	59%	<1	→ 100% by 2030
Burkina Faso	20%	16	→ 100 by 2025
Burundi	11%	10	→ 25% by 2025
Cameroon	70%	7	
Central African Republic	<5%	5	→ 50% by 2030
Chad	9%	14	
Congo, Democratic Republic of the	9%	77	→ 60% by 2025
Congo, Republic of	69%	2	
Côte d'Ivoire	63%	9	→ 100% by 2025
Djibouti	42%	<1	→ 100% by 2035
Egypt	>95%	<1	
Equatorial Guinea	83%	<1	
Eritrea	49%	3	
Eswatini	87%	<1	→ 75% by 2018 → 85% by 2020 → 100% by 2025
Ethiopia	45%	59	→ 100% by 2030
Gabon	92%	<1	
Gambia	47%	1	→ 100% by 2030
Ghana	84%	5	→ 100% by 2020
Guinea	17%	10	→ 100% by 2030
Guinea-Bissau	10%	2	→ 80% by 2030
Kenya	75%	13	→ 100% by 2022
Lesotho	36%	<1	→ 40% by 2020
Liberia	11%	4	→ 100% by 2030
Madagascar	25%	20	
Malawi	15%	16	→ 30% by 2020
Mali	40%	12	→ 87% by 2030
Mauritania	30%	3	
Morocco	>95%	<1	
Mozambique	29%	22	→ 100% by 2025

TABLE R20. Electricity Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Electricity Access in 2018	Population Without Electricity Access in 2018	Target
	Share of population with access	Millions	Share of population with electricity access
Africa (continued)			
Namibia	56%	1.1	
Niger	12%	19	→ 65% by 2030
Nigeria	60%	78	→ 75% by 2020 → 90% by 2030
Rwanda	49%	6	→ 100% by 2030
Senegal	69%	5	→ 100% by 2025
Sierra Leone	25%	6	→ 100% by 2025
Somalia	18%	13	
South Africa	95%	3	→ 100% by 2019
South Sudan	<5%	12	
Sudan	47%	22	
Tanzania	37%	37	→ 75% by 2030
Togo	43%	5	→ 82% by 2030
Uganda	23%	34	→ 98% by 2030
Zambia	37%	11	→ 66% by 2030
Zimbabwe	34%	11	→ 66% by 2030 → 90% by 2030 (urban) → 51% by 2030 (rural)
Developing Asia			
Bangladesh	85%	25	→ 100% by 2021
Brunei Darussalam	>95%	<1	
Cambodia	72%	5	→ 70% by 2030 (rural)
India	95%	74	→ 100% by 2019
Indonesia	98%	5	
Korea, Democratic People's Republic	27%	19	→ 90% by 2017
Lao PDR	95%	<1	
Mongolia	91%	<1	
Myanmar	43%	31	→ 87% by 2030
Nepal	94%	2	
Pakistan	77%	46	
Philippines	>95%	5	
Vietnam	>95%	<1	
Central and South America			
Argentina	>95%	<1	
Bolivia	92%	<1	→ 100% by 2025 (rural)
Brazil	>95%	<1	
Colombia	>95%	2	→ 97.45% by 2017
Costa Rica	>95%	<1	
Cuba	>95%	<1	
Dominican Republic	>95%	<1	
Ecuador	>95%	<1	→ 98.9% by 2022 (urban) → 96.3% by 2022 (rural)
El Salvador	>95%	<1	

TABLE R20. Electricity Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Electricity Access in 2018	Population Without Electricity Access in 2018	Target
	Share of population with access	Millions	Share of population with electricity access
Central and South America (continued)			
Guatemala	93%	1	
Haiti	39%	7	→ 50% by 2020
Honduras	79%	2	
Jamaica	>95%	<1	
Nicaragua	>95%	<1	
Panama	93%	<1	
Paraguay	>95%	<1	
Peru	>95%	1	
Trinidad and Tobago	>95%	<1	
Uruguay	>95%	<1	
Venezuela	>95%	<1	
Middle East			
Bahrain	>95%	<1	
Iran	>95%	<1	
Iraq	>95%	<1	
Jordan	>95%	<1	
Kuwait	>95%	<1	
Lebanon	>95%	<1	
Oman	>95%	<1	
Saudi Arabia	>95%	<1	
Syria	>95%	1	
Qatar	>95%	<1	
United Arab Emirates	>95%	<1	
Yemen	47%	15	
Oceania			
Federated States of Micronesia[b]	80%	<1	→ 90% by 2020 (rural)

Disclaimer: The tracking of data related to energy access and DREA systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

[a] Includes countries in the OECD and economies in transition.

[b] For the Federated States of Micronesia, rural electrification rate is defined by electrification of all islands outside of the four that host the state capital (which is considered urban).

Source: See endnote 20 for this section.

TABLE R21. Clean Cooking Access by Region and Country, Status in 2018 and Targets

World/Region/Country	Population with Access to Clean Cooking in 2018	Population Without Access to Clean Cooking in 2018	Target
	Share of population	Millions	Share of population with access to clean cooking
World[a]	**65%**	**2,651**	
All Developing Countries	**56%**	**2,651**	
Africa	**29%**	**910**	
Sub-Saharan Africa	**17%**	**905**	
North Africa	**98%**	**1.1**	
Developing Asia	**57%**	**1,674**	
Central and South America	**89%**	**57**	
Middle East	**96%**	**10**	
Africa			
Algeria	92%	4	
Angola	50%	15	→ 100% by 2030
Benin	5%	11	
Botswana	66%	<1	
Burkina Faso	14%	17	→ 100% by 2030 (urban) → 65% by 2030 (rural)
Burundi	<5%	11	
Cabo Verde	83%	<1	→ 100% by 2020
Cameroon	25%	19	
Central African Republic	<5%	5	
Chad	7%	14	
Comoros	12%	<1	
Congo, Democratic Republic of the	<5%	81	
Congo, Republic of	26%	4	
Côte d'Ivoire	30%	18	
Djibouti	13%	<1	
Egypt	>95%	<1	
Equatorial Guinea	37%	<1	
Eritrea	18%	4	
Eswatini	52%	<1	→ 100% by 2030
Ethiopia	7%	100	→ 100% by 2025
Gabon	80%	<1	
Gambia	11%	2	→ 100% by 2030
Ghana	25%	22	→ 100% by 2030
Guinea	<5%	13	→ 50% by 2025
Guinea-Bissau	5%	2	→ 75% by 2030
Kenya	15%	43	→ 100% by 2022
Lesotho	37%	1	
Liberia	<5%	5	→ 100% by 2030
Libya	>95%	<1	
Madagascar	<5%	26	
Malawi	<5%	18	
Mali	<5%	19	→ 100% by 2030
Mauritania	48%	2	

TABLE R21. Clean Cooking Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Access to Clean Cooking in 2018	Population Without Access to Clean Cooking in 2018	Target
	Share of population	Millions	Share of population with access to clean cooking
Africa			
Mauritius	93%	<1	
Morocco	>95%	<1	
Mozambique	6%	29	
Namibia	43%	2	
Niger	<5%	21	→ 100% by 2030 (urban) → 60% by 2030 (rural)
Nigeria	9%	178	
Rwanda	<5%	12	→ 100% by 2030
São Tomé and Príncipe	16%	<1	
Senegal	30%	12	
Seychelles	91%	<1	
Sierra Leone	<5%	8	
Somalia	6%	14	
South Africa	87%	8	
South Sudan	<5%	12	
Sudan	46%	23	
Tanzania	6%	56	→ 75% by 2030
Togo	8%	7	→ 80% by 2030
Tunisia	>95%	<1	
Uganda	6%	42	→ 99% by 2030
Zambia	17%	15	
Zimbabwe	31%	12	
Developing Asia			
Bangladesh	19%	135	
Brunei Darussalam	>95%	<1	
Cambodia	20%	13	
China	72%	399	
India	49%	688	
Indonesia	68%	85	
Korea, Democratic People's Republic	12%	23	
Lao PDR	6%	7	
Malaysia	>95%	<1	
Mongolia	46%	2	
Myanmar	21%	43	
Nepal	30%	21	
Pakistan	46%	108	
Philippines	44%	59	
Singapore	>95%	<1	
Sri Lanka	28%	16	
Thailand	76%	17	
Vietnam	73%	26	

TABLE R21. Clean Cooking Access by Region and Country, Status in 2018 and Targets (continued)

World/Region/Country	Population with Access to Clean Cooking in 2018	Population Without Access to Clean Cooking in 2018	Target
	Share of population	Millions	Share of population with access to clean cooking
Central and South America			
Argentina	>95%	<1	
Bolivia	82%	2	
Brazil	>95%	9	
Chile[b]	92%	1.5	
Colombia	93%	4	
Costa Rica	94%	<1	
Cuba	80%	2	
Dominican Republic	91%	<1	
Ecuador	>95%	<1	
El Salvador	88%	<1	
Guatemala	46%	9	
Haiti	6%	10	
Honduras	55%	4	
Jamaica	92%	<1	
Mexico[a]	85%	19	
Nicaragua	55%	3	
Panama	90%	<1	
Paraguay	69%	2	
Peru	78%	7	
Trinidad and Tobago	>95%	<1	
Uruguay	>95%	<1	
Venezuela	>95%	<1	
Middle East			
Bahrain	>95%	<1	
Iran	>95%	<1	
Iraq	>95%	<1	
Jordan	>95%	<1	
Kuwait	>95%	<1	
Lebanon	>95%	<1	
Oman	>95%	<1	
Saudi Arabia	>95%	<1	
Qatar	>95%	<1	
United Arab Emirates	>95%	<1	
Yemen	66%	10	

Disclaimer: The tracking of data related to energy access and DREA systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

[a] Includes countries in the OECD and economies in transition.

[b] Based on 2016 data

Source: See endnote 21 for this section.

TABLE R22. Global Trends in Renewable Energy Investment, 2009–2019

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Billion USD										
New Investment by Stage											
Technology Research and Start-up											
Government R&D	5.4	4.9	4.8	4.7	5.2	4.5	4.4	5.1	5.1	5.5	5.7
Corporate R&D	3.3	3.8	4.3	4.1	4.0	4.3	4.1	4.3	6.9	7.8	7.7
Venture capital	1.6	2.6	2.6	2.4	0.8	1.0	1.4	0.8	0.8	0.2	1.2
Scale-up											
Public markets	11.7	10.6	9.9	3.8	9.8	14.9	12.0	6.2	5.6	6.0	6.6
Private equity expansion capital	3.0	5.3	2.4	1.6	1.3	1.7	1.8	1.7	0.7	2.2	1.8
Projects											
Asset finance	111.8	152.2	189.6	170.1	171.5	228.4	267.7	247.5	272.6	242.0	230.1
(re-invested equity)	-3.7	-1.8	-2.1	-2.9	-1.2	-3.5	-6.7	-4.1	-2.9	-5.8	-3.4
Small-scale distributed capacity	34.7	60.9	75.1	69.9	40.2	36.7	32.6	32.5	42.5	38.2	52.1
Total New Investment	**167.8**	**238.5**	**286.6**	**253.7**	**231.7**	**288.1**	**317.3**	**293.9**	**331.4**	**296.0**	**301.7**
Merger & Acquisition Transactions											
	61.5	57.3	75.0	65.7	67.0	88.8	108.1	133.9	146.2	151.5	100.7
Total Transactions	**229.3**	**295.8**	**361.6**	**319.3**	**298.7**	**376.9**	**425.4**	**427.8**	**477.7**	**447.5**	**402.4**
New Investment by Technology											
Wind power	72.5	97.8	83.3	78.3	83.3	111.1	119.7	123.5	133.4	132.7	142.7
Solar power	63.6	102.0	160.1	144.0	120.4	147.8	176.6	145.9	180.8	143.5	141.0
Biomass and waste-to-energy	13.4	17.3	20.9	15.4	14.6	13.1	10.4	15.2	7.4	11.5	11.2
Biofuels	9.4	10.1	10.5	7.7	5.1	5.5	3.6	2.1	3.3	3.3	3.0
Hydropower <50 MW	6.0	8.2	7.7	6.3	5.7	7.4	4.2	4.3	4.0	2.3	2.5
Geothermal	2.5	2.8	3.8	1.7	2.4	2.9	2.5	2.7	2.4	2.5	1.2
Ocean power	0.3	0.3	0.3	0.3	0.2	0.4	0.2	0.2	0.2	0.2	0.2
Total New Investment	**167.8**	**238.5**	**286.6**	**253.7**	**231.7**	**288.1**	**317.3**	**293.9**	**331.4**	**296.0**	**301.7**

Note: Excludes large hydropower projects of more than 50 MW.

Source: See endnote 22 for this section.

ENERGY UNITS AND CONVERSION FACTORS

METRIC PREFIXES

kilo	(k)	=	10^3
mega	(M)	=	10^6
giga	(G)	=	10^9
tera	(T)	=	10^{12}
peta	(P)	=	10^{15}
exa	(E)	=	10^{18}

VOLUME

1 m^3	=	1,000 litres (l)
1 US gallon	=	3.785412 l
1 Imperial gallon	=	4.546090 l

Example: 1 TJ = 1,000 GJ = 1,000,000 MJ = 1,000,000,000 kJ = 1,000,000,000,000 J

ENERGY UNIT CONVERSION

Multiply by:	GJ	Toe	MBtu	MWh
GJ	1	0.024	0.948	0.278
Toe	41.868	1	39.683	11.630
MBtu	1.055	0.025	1	0.293
MWh	3.600	0.086	3.412	1

Toe = tonnes (metric) of oil equivalent

1 Mtoe = 41.9 PJ

Example: 1 MWh x 3.600 = 3.6 GJ

BIOFUELS CONVERSION

Ethanol: 21.4 MJ/l

Biodiesel (FAME): 32.7 MJ/l

Biodiesel (HVO): 34.4 MJ/l

Petrol: 36 MJ/l

Diesel: 41 MJ/l

SOLAR THERMAL HEAT SYSTEMS

1 million m^2 = 0.7 GW_{th}

Used where solar thermal heat data have been converted from square metres (m^2) into gigawatts thermal (GW_{th}), by accepted convention.

Note on Biofuels:

1) These values can vary with fuel and temperature.

2) Around 1.7 litres of ethanol is energy equivalent to 1 litre of petrol, and around 1.2 litres of biodiesel (FAME) is energy equivalent to 1 litre of diesel.

3) Energy values from http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Tonnes_of_oil_equivalent_(toe) except HVO, which is from *Neste Renewable Diesel Handbook*, p. 15, https://www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf.

DATA COLLECTION AND VALIDATION

REN21 has developed a unique renewable energy reporting culture, allowing it to become recognised as a neutral data and knowledge broker that provides credible and widely accepted information. **Transparency is at the heart** of the REN21 data and reporting culture, and the following text explains some of the GSR's key processes for data collection and validation.

DATA COLLECTION

Production of REN21's GSR is a continuous process occurring on an annual basis. The data collection process begins following the launch of the previous year's report with an Expression of Interest form to mobilise REN21's GSR contributors. During this time, the GSR team also prepares the questionnaires that will be filled in by contributors. The questionnaires are updated each year with emerging and relevant topics as identified by the REN21 Secretariat.

REN21 collects data in seven main ways:

1. **Country questionnaire.** In the country questionnaire, contributors from around the world submit data on renewable energy in their respective countries or countries of interest. This covers information about market trends, policy developments and local perspectives. Each data point is provided with a source and verified independently by the GSR team. Data collection with the country questionnaire typically begins in October.
2. **DREA questionnaire.** The Distributed Renewables for Energy Access (DREA) questionnaire collects data related to energy access from contributors around the world and focuses on developing and emerging countries. This covers information about the status of electrification and clean cooking in a certain country or region, as well as policies and programmes for energy access and markets for distributed renewables.
3. **Technology questionnaire.** The technology questionnaire functions similarly to the country questionnaire, but the input focuses specifically on annual developments for certain renewable energy technologies. As in the country questionnaire, all submitted data are validated with reliable, primary sources.
4. **Peer review.** To further collect data and project examples and to ensure that significant developments have not been overlooked, GSR contributors and reviewers participate in an open peer review process that takes place twice during each report cycle. The first round typically occurs in January and includes Round 1 chapters such as Policy Landscape, while the second round is held typically in March/April and includes Round 2 chapters such as Global Overview and Market and Industry Trends. Peer review is open to all interested experts.
5. **Expert interviews.** REN21's global community consists of a wide range of professionals who provide their expert input on renewable energy trends in the target year through interviews and personal communication with the REN21 GSR team and chapter authors. The vast majority of the information is backed up by primary sources.
6. **Desk research.** To fill in remaining gaps in the GSR and to pursue new topics, the REN21 GSR team and chapter authors conduct extensive desk research. Topics of research vary widely between GSR years and depend on emerging topics, important trends and annual availability of formal or informal data in the target sector.
7. **Data sharing agreements.** REN21 holds several data sharing agreements with some of the largest and most reliable data providers/aggregators in the energy sector. These formal data are used exclusively in some cases or, in others, form the foundation of calculations and estimations presented in the GSR.

DATA VALIDATION

REN21 ensures the accuracy and reliability of its reports by conducting data validation and fact-checking as a continuous process. Beginning during the first submission of the country questionnaires, data are continually verified up through the design period and until the final report is published. **All data provided by contributors, whether written or verbal, are validated by primary sources, which are published alongside the full report.**

METHODOLOGICAL NOTES

This 2020 report is the 15th edition of the *Renewables Global Status Report* (GSR), which has been produced annually since 2005 (with the exception of 2008). Readers are directed to the previous GSR editions for historical details.

Most 2019 data[i] for national and global capacity, output, growth and investment provided in this report are preliminary. Where necessary, information and data that are conflicting, partial or older are reconciled by using reasoned expert judgment. Endnotes provide additional details, including references, supporting information and assumptions where relevant.

Each edition draws from thousands of published and unpublished references, including: official government sources; reports from international organisations and industry associations; input from the GSR community via hundreds of questionnaires submitted by country, regional and technology contributors as well as feedback from several rounds of formal and informal reviews; additional personal communications with scores of international experts; and a variety of electronic newsletters, news media and other sources.

Much of the data found in the GSR is built from the ground up by the authors with the aid of these resources. This often involves extrapolation of older data, based on recent changes in key countries within a sector or based on recent growth rates and global trends. Other data, often very specific and narrow in scope, come more-or-less prepared from third parties. The GSR attempts to synthesise these data points into a collective whole for the focus year.

The GSR endeavours to provide the best data available in each successive edition; as such, data should not be compared with previous versions of this report to ascertain year-by-year changes.

NOTE ON ESTABLISHING RENEWABLE ENERGY SHARES OF TOTAL FINAL ENERGY CONSUMPTION (TFEC)

Assumptions Related to Renewable Electricity Shares of TFEC

When estimating electricity consumption from renewable sources, the GSR must make certain assumptions about how much of the estimated gross output from renewable electricity generating resources actually reaches energy consumers, as part of total final energy consumption.

The International Energy Agency's (IEA) *World Energy Statistics and Balances* reports electricity output by individual technology. However, it does not report electricity consumption by technology – only total consumption of electricity.

The difference between gross output and final consumption is determined by:

- The energy industry's own-use, including electricity used for internal operations at power plants. This includes the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants, and other uses such as electricity use in coal mining and fossil fuel refining.
- Transmission and distribution losses that occur as electricity finds its way to consumers.

Industry's own-use. The common method is to assume that the proportion of consumption by technology is equal to the proportion of output by technology. This is problematic because logic dictates that industry's own-use cannot be proportionally the same for every generating technology. Further, industry's own-use must be somewhat lower for some renewable generating technologies (particularly non-thermal renewables such as hydropower, solar PV and wind power) than is the case for fossil fuel and nuclear power technologies. Such thermal power plants consume significant amounts of electricity to meet their own internal energy requirements (see above).

Therefore, the GSR has opted to apply differentiated "industry own-use" by generating technology. This differentiation is based on explicit technology-specific own-use (such as pumping at hydropower facilities) as well as on the apportioning of various categories of own-use by technology as deemed appropriate. For example, industry own-use of electricity at coal mines and oil refineries is attributed to fossil fuel generation.

Differentiated own-uses by technology, combined with global average losses, are as follows: solar PV, ocean energy and wind power (8.2%); hydropower (10.1%); concentrating solar thermal power (CSP) (14.2%); and bio-power (15.2%). For comparison, the undifferentiated (universal) combined losses and industry own-use would be 16.7% of gross generation. Estimated technology-specific industry own-use of electricity from renewable sources is based on data for 2016 from IEA, *World Energy Statistics and Balances, 2019 edition* (Paris: 2019).

Transmission and distribution losses. Such losses may differ (on average) by generating technology. For example, hydropower plants often are located far from load centres, incurring higher than average transmission losses, whereas some solar PV generation may occur near to (or at) the point of consumption, incurring little (or zero) transmission losses. However, specific information by technology on a global scale is not available.

Therefore, the GSR has opted to apply a global average for transmission and distribution losses. Global average electricity losses are based on data for 2017 from IEA, *World Energy Statistics and Balances, 2019 edition* (Paris: 2019).

NOTES ON RENEWABLE ENERGY IN TOTAL FINAL ENERGY CONSUMPTION, BY ENERGY USE

GSR 2020 presents an illustration of the share of renewable energy in total final energy consumption (TFEC) by sector in 2017. (→ *See Figure 3 in Global Overview chapter.*) The share of TFEC consumed in each sector is provided as follows: thermal (51%), transport (32%) and electricity (17%). There are three important points about this figure and about how the GSR treats end-use TFEC in general:

i For information on renewable energy data and related challenges, see Sidebar 4 in GSR 2015 and Sidebar 1 in GSR 2014.

1. Definition of Heating and Cooling and Thermal Applications

In the GSR, the term "heating and cooling" refers to applications of thermal energy including space and water heating, space cooling, refrigeration, drying and industrial process heat, as well as any use of energy other than electricity that is used for motive power in any application other than transport. In other words, thermal demand refers to all end-uses of energy that cannot be classified as electricity demand or transport.

2. Sectoral Shares of TFEC

In Figure 3, each sectoral share of TFEC portrays the energy demand for all end-uses within the sector. The shares of TFEC allocated to thermal and to transport also account for the electricity consumed in these sectors – that is, electricity for space heating and space cooling, industrial process heat, etc., and electricity for transport. These amounts have been reallocated from final demand in the electricity sector. Therefore, the share of TFEC allocated to the electricity sector comprises all final end-uses of electricity that are not used for heating, cooling or transport. This is a methodological change from GSR 2018 that is intended to strengthen the accuracy of the representation. In total, the final energy consumption of all electrical energy accounted for 20.8% of TFEC in 2017.

3. Shares of Non-renewable Electricity

Figure 3 illustrates the share of non-renewable electricity in thermal and in transport to emphasise that electricity demand is being allocated to each sector. The share of non-renewable electricity is not critical to the figure content, so the percentage value of non-renewable electricity in each sector is not explicitly shown, but it is included in this note. In 2017, all electricity for heating and cooling met 7.2% of final energy demand in the sector (1.9% renewable and 5.3% non-renewable electricity). All electricity for transport met 1.1% of final energy demand in the sector (0.3% renewable and 0.8% non-renewable electricity).

NOTES ON RENEWABLE ENERGY CAPACITIES AND ENERGY OUTPUT

A number of issues arise when counting renewable energy capacities and energy output. Some of these are discussed below:

1. Capacity versus Energy Data

The GSR aims to give accurate estimates of capacity additions and totals, as well as of electricity, heat and transport fuel production in the focus year. These measures are subject to some uncertainty, which varies by technology. The Market and Industry chapter includes estimates for energy produced where possible, but it focuses mainly on power or heat capacity data. This is because capacity data generally can be estimated with a greater degree of confidence than generation data. Official heat and electricity generation data often are not available for the target year within the production time frame of the GSR.

2. Constructed Capacity versus Connected Capacity and Operational Capacity

Over a number of years in the past decade, the solar PV and wind power markets saw increasing amounts of capacity that was connected to the grid but not yet deemed officially operational, or constructed capacity that was not connected to the grid by year's end. Therefore, since the 2012 edition the GSR has aimed to count only capacity additions that were grid-connected or that otherwise went into service (e.g., capacity intended for off-grid use) during the previous calendar (focus) year. However, it appears that this phenomenon is no longer an issue, with the exception of wind power installations in China, where it has been particularly evident over the period 2009-2019. For details on the situation in China and on the reasoning for capacity data used in this GSR, see endnote 24 in the Wind Power section of the Market and Industry chapter.

3. Retirements and Replacements

Data on capacity retirements and replacements (re-powering) are incomplete for many technologies, although data on several technologies do attempt to account for these directly. It is not uncommon for reported new capacity installations to exceed the implied net increase in cumulative capacity; in some instances, this is explained by revisions to data on installed capacity, while in others it is due to capacity retirements and replacements. Where data are available, they are provided in the text or relevant endnotes.

4. Bioenergy Data

Given existing complexities and constraints (→ *see Figure 6 in GSR 2015 and Sidebar 2 in GSR 2012*), the GSR strives to provide the best and latest data available regarding biomass energy developments. The reporting of biomass-fired combined heat and power (CHP) systems varies among countries; this adds to the challenges experienced when assessing total heat and electricity capacities and total bioenergy outputs.

Wherever possible, the bio-power data presented include capacity and generation from both electricity-only and CHP systems using solid biomass, landfill gas, biogas and liquid biofuels. Electricity generation and capacity numbers are based on national data for the focus year in the major producing countries and on forecast data for remaining countries for the focus year from the IEA.

The methodology is similar for biofuels production data, with data for most countries (not major producers) from the IEA; however, data for hydrotreated vegetable oil (HVO) are estimated based on production statistics for the (relatively few) major producers. Bio-heat data are based on an extrapolation of the latest data available from the IEA based on recent growth trends. (→ *See Bioenergy section in Market and Industry chapter.*)

5. Hydropower Data and Treatment of Pumped Storage

Starting with the 2012 edition, the GSR has made an effort to report hydropower generating capacity without including pure pumped storage capacity (the capacity used solely for shifting water between reservoirs for storage purposes). The distinction is made because pumped storage is not an energy source but rather a means of energy storage. It involves conversion losses and can be fed by all forms of electricity, renewable and non-renewable.

Some conventional hydropower facilities do have pumping capability that is not separate from, or additional to, their normal generating capability. These facilities are referred to as "mixed" plants and are included, to the extent possible, with conventional hydropower data. It is the aim of the GSR to distinguish and separate only the pure (or incremental) pumped storage component.

Where the GSR presents data for renewable power capacity not including hydropower, the distinction is made because hydropower remains the largest single component by far of renewable power capacity, and thus can mask developments in other renewable energy technologies if included. Investments and jobs data separate out large-scale hydropower where original sources use different methodologies for tracking or estimating values. Footnotes and endnotes provide additional details.

6. Solar PV Capacity Data[i]

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[ii].

The GSR attempts to report all solar PV capacity data on the basis of DC output (where data are known to be provided in AC, this is specified) for consistency across countries. Some countries (for example, Canada, Chile, India, Japan, Malaysia, Spain, Sweden and the United States) report official capacity data on the basis of output in AC; these capacity data were converted to DC output by data providers (see relevant endnotes) for the sake of consistency. Global renewable power capacity totals in this report include solar PV data in DC; as with all statistics in this report, they should be considered as indicative of global capacity and trends rather than as exact statistics.

7. Concentrating Solar Thermal Power (CSP) Data

Global CSP data are based on commercial facilities only. Demonstration and pilot facilities as well as facilities of 5 MW or less are excluded from capacity data, with the exception of certain plants in China that are described as "demonstration" plants by government but are nonetheless large- (utility-) scale, grid-connected plants that are operating or will operate commercially. Discrepancies between REN21 data and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals. The GSR aims to report net CSP capacities for specific CSP plants that are included. In certain cases, it may not be possible to verify if the reported capacity of a given CSP plant is net or gross capacity. In these cases net capacity is assumed.

8. Solar Thermal Heat Data

Starting with GSR 2014, the GSR includes all solar thermal collectors that use water as the heat transfer medium (or heat carrier) in global capacity data and the ranking of top countries. Previous GSRs focused primarily on glazed water collectors (both flat plate and evacuated tube); the GSR now also includes unglazed water collectors, which are used predominantly for swimming pool heating. Since the GSR 2018, data for concentrating collectors are available. These include new installations overall as well as in key markets and total in operation by year's end. The market for solar air collectors (solar thermal collectors that use air as the heat carrier) and hybrid or PV-thermal technologies (elements that produce both electricity and heat) is small and the data rather uncertain. All three collector types – air, concentrating and hybrid collectors – are included where specified.

Estimates for 2019 additions in China were based on produced collector area and included export volumes in the national statistics for 2019 and earlier years. The export volumes for previous years were not known at the time of publication, and to the extent possible GSR 2021 will reflect corrected statistics.

OTHER NOTES

Editorial content of this report closed by 29 May 2020 for technology data, and by 15 May 2020 or earlier for other content.

Growth rates in the GSR are calculated as compound annual growth rates (CAGR) rather than as an average of annual growth rates.

All exchange rates in this report are as of 31 December 2019 and are calculated using the OANDA currency converter (http://www.oanda.com/currency/converter).

Corporate domicile, where noted, is determined by the location of headquarters.

i Based largely on information drawn from the following: IEA Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global PV Markets 2020* (Paris: April 2020), p. 11, https://iea-pvps.org/wp-content/uploads/2020/04/IEA_PVPS_Snapshot_2020.pdf; IEA PVPS, *Trends in Photovoltaic Applications 2019* (Paris: 2019), p. 9, https://iea-pvps.org/trends_reports/2019-edition; G. Masson, Becquerel Institute and IEA PVPS, personal communication with REN21, May 2017; D. Renné, International Solar Energy Society, personal communication with REN21, March 2017; M. Schmela, SolarPower Europe, personal communication with REN21, 11 May 2019; Becquerel Institute, personal communication with REN21, April 2020.

ii See IEA PVPS, *Trends in Photovoltaic Applications 2019*, p. 9, and IEA PVPS, *Snapshot of Global PV Markets 2020*, p. 11.

GLOSSARY

Absorption chillers. Chillers that use heat energy from any source (solar, biomass, waste heat, etc.) to drive air conditioning or refrigeration systems. The heat source replaces the electric power consumption of a mechanical compressor. Absorption chillers differ from conventional (vapour compression) cooling systems in two ways: 1) the absorption process is thermochemical in nature rather than mechanical, and 2) the substance that is circulated as a refrigerant is water rather than chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), also called Freon. The chillers generally are supplied with district heat, waste heat or heat from co-generation, and they can operate with heat from geothermal, solar or biomass resources.

Adsorption chillers. Chillers that use heat energy from any source to drive air conditioning or refrigeration systems. They differ from absorption chillers in that the adsorption process is based on the interaction between gases and solids. A solid material in the chiller's adsorption chamber releases refrigerant vapour when heated; subsequently, the vapour is cooled and liquefied, providing a cooling effect at the evaporator by absorbing external heat and turning back into a vapour, which is then re-adsorbed into the solid.

Auction. See Tendering.

Bagasse. The fibrous matter that remains after extraction of sugar from sugar cane.

Behind-the-meter system. Any power generation capacity, storage or demand management on the customer side of the interface with the distribution grid (i.e., the meter). (Also see Front-of-meter system.)

Biodiesel. A fuel produced from oilseed crops such as soy, rapeseed (canola) and palm oil, and from other oil sources such as waste cooking oil and animal fats. Biodiesel is used in diesel engines installed in cars, trucks, buses and other vehicles, as well as in stationary heat and power applications. Most biodiesel is made by chemically treating vegetable oils and fats (such as palm, soy and canola oils, and some animal fats) to produce fatty acid methyl esters (FAME). (Also see Hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA).)

Bioeconomy (or bio-based economy). Economic activity related to the invention, development, production and use of biomass resources for the production of food, fuel, energy, chemicals and materials.

Bioenergy. Energy derived from any form of biomass (solid, liquid or gaseous) for heat, power and transport. (Also see Biofuel.)

Biofuel. A liquid or gaseous fuel derived from biomass, primarily ethanol, biodiesel and biogas. Biofuels can be combusted in vehicle engines as transport fuels and in stationary engines for heat and electricity generation. They also can be used for domestic heating and cooking (for example, as ethanol gels). Conventional biofuels are principally ethanol produced by fermentation of sugar or starch crops (such as wheat and corn), and FAME biodiesel produced from oil crops such as palm oil and canola and from waste oils and fats. Advanced biofuels are made from feedstocks derived from the lignocellulosic fractions of biomass sources or from algae. They are made using biochemical and thermochemical conversion processes, some of which are still under development.

Biogas/Biomethane. Biogas is a gaseous mixture consisting mainly of methane and carbon dioxide produced by the anaerobic digestion of organic matter (broken down by microorganisms in the absence of oxygen). Organic material and/or waste is converted into biogas in a digester. Suitable feedstocks include agricultural residues, animal wastes, food industry wastes, sewage sludge, purpose-grown green crops and the organic components of municipal solid wastes. Raw biogas can be combusted to produce heat and/or power. It also can be refined to produce biomethane.

Biomass. Any material of biological origin, excluding fossil fuels or peat, that contains a chemical store of energy (originally received from the sun) and that is available for conversion to a wide range of convenient energy carriers.

Biomass, traditional (use of). Solid biomass (including fuel wood, charcoal, agricultural and forest residues, and animal dung), that is used in rural areas of developing countries with traditional technologies such as open fires and ovens for cooking and residential heating. Often the traditional use of biomass leads to high pollution levels, forest degradation and deforestation.

Biomass energy, modern. Energy derived from combustion of solid, liquid and gaseous biomass fuels in high-efficiency conversion systems, which range from small domestic appliances to large-scale industrial conversion plants. Modern applications include heat and electricity generation, combined heat and power (CHP) and transport.

Biomass gasification. In a biomass gasification process, biomass is heated with a constrained amount of air or oxygen, leading to the partial combustion of the fuels and production of a mix of combustion gases that, depending on the conditions, can include carbon monoxide and dioxide, methane, hydrogen and more complex materials such as tars. The resulting gas can either be used for power generation (e.g., in an engine or turbine) or else further purified and treated to form a "synthesis gas". This can then be used to produce fuels including methane, alcohols, and higher hydrocarbon fuels, including bio-gasoline or jet fuel. While gasification for power or heat production is relatively common, there are few examples of operating plants producing gas of high enough quality for subsequent synthesis to more complex fuels.

Biomass pellets. Solid biomass fuel produced by compressing pulverised dry biomass, such as waste wood and agricultural residues. Pellets typically are cylindrical in shape with a diameter of around 10 millimetres and a length of 30-50 millimetres. Pellets are easy to handle, store and transport and are used as fuel for heating and cooking applications, as well as for electricity generation and CHP. (Also see Torrefied wood.)

Biomethane. Biogas can be turned into biomethane by removing impurities including carbon dioxide, siloxanes and hydrogen sulphides, followed by compression. Biomethane can be injected directly into natural gas networks and used as a substitute for natural gas in internal combustion engines without risk of corrosion. Biomethane is often known as renewable natural gas (RNG), especially in North America.

Blockchain. A decentralised ledger in which digital transactions (such as the generation and sale of a unit of solar electricity) are anonymously recorded and verified. Each transaction is securely collected and linked, via cryptography, into a time-stamped "block". This block is then stored on distributed computers as a "chain". Blockchain may be used in energy markets, including for micro-trading among solar photovoltaic (PV) prosumers.

Building energy codes and standards. Rules specifying the minimum energy standards for buildings. These can include standards for renewable energy and energy efficiency that are applicable to new and/or renovated and refurbished buildings.

Capacity. The rated power of a heat or electricity generating plant, which refers to the potential instantaneous heat or electricity output, or the aggregate potential output of a collection of such units (such as a wind farm or set of solar panels). Installed capacity describes equipment that has been constructed, although it may or may not be operational (e.g., delivering electricity to the grid, providing useful heat or producing biofuels).

Capacity factor. The ratio of the actual output of a unit of electricity or heat generation over a period of time (typically one year) to the theoretical output that would be produced if the unit were operating without interruption at its rated capacity during the same period of time.

Capital subsidy. A subsidy that covers a share of the upfront capital cost of an asset (such as a solar water heater). These include, for example, consumer grants, rebates or one-time payments by a utility, government agency or government-owned bank.

Carbon neutrality. The achievement of a state in which every tonne of carbon dioxide emitted to the atmosphere is compensated by an equivalent tonne removed (e.g., sequestered). Emissions can be compensated for by carbon offsets.

Combined heat and power (CHP) (also called co-generation). CHP facilities produce both heat and power from the combustion of fossil and/or biomass fuels, as well as from geothermal and solar thermal resources. The term also is applied to plants that recover "waste heat" from thermal power generation processes.

Community energy. An approach to renewable energy development that involves a community initiating, developing, operating, owning, investing and/or benefiting from a project. Communities vary in size and shape (e.g., schools, neighbourhoods, partnering city governments, etc.); similarly, projects vary in technology, size, structure, governance, funding and motivation.

Competitive bidding. See Tendering.

Concentrating photovoltaics (CPV). Technology that uses mirrors or lenses to focus and concentrate sunlight onto a relatively small area of photovoltaic cells that generate electricity (see Solar photovoltaics). Low-, medium- and high-concentration CPV systems (depending on the design of reflectors or lenses used) operate most efficiently in concentrated, direct sunlight.

Concentrating solar collector technologies. Technologies that use mirrors to focus sunlight on a receiver (see Concentrating solar thermal power). These are usually smaller-sized modules that are used for the production of heat and steam below 400 °C for industrial applications, laundries and commercial cooking.

Concentrating solar thermal power (CSP) (also called solar thermal electricity, STE). Technology that uses mirrors to focus sunlight into an intense solar beam that heats a working fluid in a solar receiver, which then drives a turbine or heat engine/generator to produce electricity. The mirrors can be arranged in a variety of ways, but they all deliver the solar beam to the receiver. There are four types of commercial CSP systems: parabolic troughs, linear Fresnel, power towers and dish/engines. The first two technologies are line-focus systems, capable of concentrating the sun's energy to produce temperatures of 400 °C, while the latter two are point-focus systems that can produce temperatures of 800 °C or higher.

Conversion efficiency. The ratio between the useful energy output from an energy conversion device and the energy input into it. For example, the conversion efficiency of a PV module is the ratio between the electricity generated and the total solar energy received by the PV module. If 100 kWh of solar radiation is received and 10 kWh of electricity is generated, the conversion efficiency is 10%.

Crowdfunding. The practice of funding a project or venture by raising money – often relatively small individual amounts – from a relatively large number of people ("crowd"), generally using the Internet and social media. The money raised through crowdfunding does not necessarily buy the lender a share in the venture, and there is no guarantee that money will be repaid if the venture is successful. However, some types of crowdfunding reward backers with an equity stake, structured payments and/or other products.

Curtailment. A reduction in the output of a generator, typically on an involuntary basis, from what it could produce otherwise given the resources available. Curtailment of electricity generation has long been a normal occurrence in the electric power industry and can occur for a variety of reasons, including a lack of transmission access or transmission congestion.

Degression. A mechanism built into policy design establishing automatic rate revisions, which can occur after specific thresholds are crossed (e.g., after a certain amount of capacity is contracted, or a certain amount of time passes).

Demand-side management. The application of economic incentives and technology in the pursuit of cost-effective energy efficiency measures and load-shifting on the customer side, to achieve least-cost overall energy system optimisation.

Demand response. Use of market signals such as time-of-use pricing, incentive payments or penalties to influence end-user electricity consumption behaviours. Usually used to balance electrical supply and demand within a power system.

Digitalisation. The application of digital technologies across the economy, including energy.

Digitisation. The conversion of something (e.g., data or an image) from analogue to digital.

Distributed generation. Generation of electricity from dispersed, generally small-scale systems that are close to the point of consumption.

Distributed renewable energy. Energy systems are considered to be distributed if 1) the systems are connected to the distribution network rather than the transmission network, which implies that they are relatively small and dispersed (such as small-scale solar PV on rooftops) rather than relatively large and centralised; or 2) generation and distribution occur independently from a centralised network. Specifically for the purpose of the chapter on Distributed Renewables for Energy Access, "distributed renewable energy" meets both conditions. It includes energy services for electrification, cooking, heating and cooling that are generated and distributed independent of any centralised system, in urban and rural areas of the developing world.

Distribution grid. The portion of the electrical network that takes power off the high-voltage transmission network via sub-stations (at varying stepped-down voltages) and distributes electricity to customers.

Drop-in biofuel. A liquid biofuel that is functionally equivalent to a liquid fossil fuel and is fully compatible with existing fossil fuel infrastructure.

Electric vehicle (EV). Includes any road-, rail-, sea- and air-based transport vehicle that uses electric drive and can take an electric charge from an external source, or from hydrogen in the case of a fuel cell electric vehicle (FCEV). Electric road vehicles encompass battery electric vehicles (BEVs), plug-in hybrids (PHEVs) and FCEVs, all of which can include passenger vehicles (i.e., electric cars), commercial vehicles including buses and trucks, and two- and three-wheeled vehicles.

Energy. The ability to do work, which comes in a number of forms including thermal, radiant, kinetic, chemical, potential and electrical. Primary energy is the energy embodied in (energy potential of) natural resources, such as coal, natural gas and renewable sources. Final energy is the energy delivered for end-use (such as electricity at an electrical outlet). Conversion losses occur whenever primary energy needs to be transformed for final energy use, such as combustion of fossil fuels for electricity generation.

Energy audit. Analysis of energy flows in a building, process or system, conducted with the goal of reducing energy inputs into the system without negatively affecting outputs.

Energy conservation. Any change in behaviour of an energy-consuming entity for the specific purpose of affecting an energy demand reduction. Energy conservation is distinct from energy efficiency in that it is predicated on the assumption that an otherwise preferred behaviour of greater energy intensity is abandoned. (See Energy efficiency and Energy intensity.)

Energy efficiency. The measure that accounts for delivering more services for the same energy input, or the same amount of services for less energy input. Conceptually, this is the reduction of losses from the conversion of primary source fuels through final energy use, as well as other active or passive measures to reduce energy demand without diminishing the quality of energy services delivered. Energy efficiency is technology-specific and distinct from energy conservation, which pertains to behavioural change. Both energy efficiency and energy conservation can contribute to energy demand reduction.

Energy intensity. Primary energy consumption per unit of economic output. Energy intensity is a broader concept than energy efficiency in that it is also determined by non-efficiency variables, such as the composition of economic activity. Energy intensity typically is used as a proxy for energy efficiency in macro-level analyses due to the lack of an internationally agreed-upon high-level indicator for measuring energy efficiency.

Energy service company (ESCO). A company that provides a range of energy solutions including selling the energy services from a (renewable) energy system on a long-term basis while retaining ownership of the system, collecting regular payments from customers and providing necessary maintenance service. An ESCO can be an electric utility, co-operative, non-governmental organisation or private company, and typically installs energy systems on or near customer sites. An ESCO also can advise on improving the energy efficiency of systems (such as a building or an industry) as well as on methods for energy conservation and energy management.

Energy subsidy. A government measure that artificially reduces the price that consumers pay for energy or that reduces energy production cost.

Energy sufficiency. Entails a change or shift in actions and behaviours (at the individual and collective levels) in the way energy is used. Results in access to energy for everyone while limiting the impacts of energy use on the environment. For example, avoiding the use of cars and spending less time on electrical devices.

Ethanol (fuel). A liquid fuel made from biomass (typically corn, sugar cane or small cereals/grains) that can replace petrol in modest percentages for use in ordinary spark-ignition engines (stationary or in vehicles), or that can be used at higher blend levels (usually up to 85% ethanol, or 100% in Brazil) in slightly modified engines, such as those provided in "flex-fuel" vehicles. Ethanol also is used in the chemical and beverage industries.

Fatty acid methyl esters (FAME). See Biodiesel.

Feed-in policy (feed-in tariff or feed-in premium). A policy that typically guarantees renewable generators specified payments per unit (e.g., USD per kWh) over a fixed period. Feed-in tariff (FIT) policies also may establish regulations by which generators can interconnect and sell power to the grid. Numerous options exist for defining the level of incentive, such as whether the payment is structured as a guaranteed minimum price (e.g., a FIT), or whether the payment floats on top of the wholesale electricity price (e.g., a feed-in premium).

Final energy. The part of primary energy, after deduction of losses from conversion, transmission and distribution, that reaches the consumer and is available to provide heating, hot water, lighting and other services. Final energy forms include, among others, electricity, district heating, mechanical energy, liquid hydrocarbons such as kerosene or fuel oil, and various gaseous fuels such as natural gas, biogas and hydrogen.

(Total) Final energy consumption (TFEC). Energy that is supplied to the consumer for all final energy services such as transport, cooling and lighting, building or industrial heating or mechanical work. Differs from total final consumption (TFC), which includes all energy use in end-use sectors (TFEC) as well as for non-energy applications, mainly various industrial uses, such as feedstocks for petrochemical manufacturing.

Fiscal incentive. An incentive that provides individuals, households or companies with a reduction in their contribution to the public treasury via income or other taxes.

Flywheel energy storage. Energy storage that works by applying available energy to accelerate a high-mass rotor (flywheel) to a very high speed and thereby storing energy in the system as rotational energy.

Front-of-meter system. Any power generation or storage device on the distribution or transmission side of the network. (Also see Behind-the-meter system.)

Generation. The process of converting energy into electricity and/or useful heat from a primary energy source such as wind, solar radiation, natural gas, biomass, etc.

Geothermal energy. Heat energy emitted from within the earth's crust, usually in the form of hot water and steam. It can be used to generate electricity in a thermal power plant or to provide heat directly at various temperatures.

Green bond. A bond issued by a bank or company, the proceeds of which will go entirely into renewable energy and other environmentally friendly projects. The issuer will normally label it as a green bond. There is no internationally recognised standard for what constitutes a green bond.

Green building. A building that (in its construction or operation) reduces or eliminates negative impacts and can create positive impacts on the climate and natural environment. Countries and regions have a variety of characteristics that may change their strategies for green buildings, such as building stock, climate, cultural traditions, or wide-ranging environmental, economic and social priorities – all of which shape their approach to green building.

Green energy purchasing. Voluntary purchase of renewable energy – usually electricity, but also heat and transport fuels – by residential, commercial, government or industrial consumers, either directly from an energy trader or utility company, from a third-party renewable energy generator or indirectly via trading of renewable energy certificates (such as renewable energy credits, green tags and guarantees of origin). It can create additional demand for renewable capacity and/or generation, often going beyond that resulting from government support policies or obligations.

Heat pump. A device that transfers heat from a heat source to a heat sink using a refrigeration cycle that is driven by external electric or thermal energy. It can use the ground (geothermal/ground-source), the surrounding air (aerothermal/air-source) or a body of water (hydrothermal/water-source) as a heat source in heating mode, and as a heat sink in cooling mode. A heat pump's final energy output can be several multiples of the energy input, depending on its inherent efficiency and operating condition. The output of a heat pump is at least partially renewable on a final energy basis. However, the renewable component can be much lower on a primary energy basis, depending on the composition and derivation of the input energy; in the case of electricity, this includes the efficiency of the power generation process. The output of a heat pump can be fully renewable energy if the input energy is also fully renewable.

Hydropower. Electricity derived from the potential energy of water captured when moving from higher to lower elevations. Categories of hydropower projects include run-of-river, reservoir-based capacity and low-head in-stream technology (the least developed). Hydropower covers a continuum in project scale from large (usually defined as more than 10 MW of installed capacity, but the definition varies by country) to small, mini, micro and pico.

Hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA). Biofuels produced by using hydrogen to remove oxygen from waste cooking oils, fats and vegetable oils. The result is a hydrocarbon that can be refined to produce fuels with specifications that are closer to those of diesel and jet fuel than is biodiesel produced from triglycerides such as fatty acid methyl esters (FAME).

Inverter (and micro-inverter), solar. Inverters convert the direct current (DC) generated by solar PV modules into alternating current (AC), which can be fed into the electric grid or used by a local, off-grid network. Conventional string and central solar inverters are connected to multiple modules to create an array that effectively is a single large panel. By contrast, micro-inverters convert generation from individual solar PV modules; the output of several micro-inverters is combined and often fed into the electric grid. A primary advantage of micro-inverters is that they isolate and tune the output of individual panels, reducing the effects that shading or failure of any one (or more) module(s) has on the output of an entire array. They eliminate some design issues inherent to larger systems, and allow for new modules to be added as needed.

Investment. Purchase of an item of value with an expectation of favourable future returns. In this report, new investment in renewable energy refers to investment in: technology research and development, commercialisation, construction of manufacturing facilities and project development (including the construction of wind farms and the purchase and installation of solar PV systems). Total investment refers to new investment plus merger and acquisition (M&A) activity (the refinancing and sale of companies and projects).

Investment tax credit. A fiscal incentive that allows investments in renewable energy to be fully or partially credited against the tax obligations or income of a project developer, industry, building owner, etc.

Joule. A joule (J) is a unit of work or energy equal to the work done by a force equal to one newton acting over a distance of one metre. One joule is equal to one watt-second (the power of one watt exerted over the period of one second). The potential chemical energy stored in one barrel of oil and released when combusted is approximately 6 gigajoules (GJ); a tonne of oven-dry wood contains around 20 GJ of energy.

Levelised cost of energy/electricity (LCOE). The cost per unit of energy from an energy generating asset that is based on the present value of its total construction and lifetime operating costs, divided by total energy output expected from that asset over its lifetime.

Long-term strategic plan. A strategy to achieve energy savings over a specified period of time (i.e., several years), including specific goals and actions to improve energy efficiency, typically spanning all major sectors.

Mandate/Obligation. A measure that requires designated parties (consumers, suppliers, generators) to meet a minimum – and often gradually increasing – standard for renewable energy (or energy efficiency), such as a percentage of total supply, a stated amount of capacity, or the required use of a specified renewable technology. Costs generally are borne by consumers. Mandates can include renewable portfolio standards (RPS); building codes or obligations that require the installation of renewable heat or power technologies (often in combination with energy efficiency investments); renewable heat purchase requirements; and requirements for blending specified shares of biofuels (biodiesel or ethanol) into transport fuel.

Market concession model. A model in which a private company or non-governmental organisation is selected through a competitive process and given the exclusive obligation to provide energy services to customers in its service territory, upon customer request. The concession approach allows concessionaires to select the most appropriate and cost-effective technology for a given situation.

Merit order. A way of ranking available sources of energy (particularly electricity generation) in ascending order based on short-run marginal costs of production, such that those with the lowest marginal costs are the first ones brought online to meet demand, and those with the highest are brought on last. The merit-order effect is a shift of market prices along the merit-order or supply curve due to market entry of power stations with lower variable costs (marginal costs). This displaces power stations with the highest production costs from the market (assuming demand is unchanged) and admits lower-priced electricity into the market.

Mini-grid / Micro-grid For distributed renewable energy systems for energy access, a mini-grid/micro-grid typically refers to an independent grid network operating on a scale of less than 10 MW (with most at very small scale) that distributes electricity to a limited number of customers. Mini-/micro-grids also can refer to much larger networks (e.g., for corporate or university campuses) that can operate independently of, or in conjunction with, the main power grid. However, there is no universal definition differentiating mini- and micro-grids.

Molten salt. An energy storage medium used predominantly to retain the thermal energy collected by a solar tower or solar trough of a concentrating solar power plant, so that this energy can be used at a later time to generate electricity.

Monitoring. Energy use is monitored to establish a basis for energy management and to provide information on deviations from established patterns.

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

Net metering / Net billing. A regulated arrangement in which utility customers with on-site electricity generators can receive credits for excess generation, which can be applied to offset consumption in other billing periods. Under net metering, customers typically receive credit at the level of the retail electricity price. Under net billing, customers typically receive credit for excess power at a rate that is lower than the retail electricity price. Different jurisdictions may apply these terms in different ways, however.

Net zero carbon building / Net zero energy building / Nearly zero energy building. Various definitions have emerged of buildings that achieve high levels of energy efficiency and meet remaining energy demand with either on-site or off-site renewable energy. For example, the World Green Building Council's Net Zero Carbon Buildings Commitment considers use of renewable energy as one of five key components that characterise a net zero building. Definitions of net zero carbon, net zero energy and nearly zero energy buildings can vary in scope and geographic relevance.

Ocean power. Refers to technologies used to generate electricity by harnessing from the ocean the energy potential of ocean waves, tidal range (rise and fall), tidal streams, ocean (permanent) currents, temperature gradients (ocean thermal energy conversion) and salinity gradients. The definition of ocean power used in this report does not include offshore wind power or marine biomass energy.

Off-take agreement. An agreement between a producer of energy and a buyer of energy to purchase/sell portions of the producer's future production. An off-take agreement normally is negotiated prior to the construction of a renewable energy project or installation of renewable energy equipment in order to secure a market for the future output (e.g., electricity, heat). Examples of this type of agreement include power purchase agreements and feed-in tariffs.

Off-taker. The purchaser of the energy from a renewable energy project or installation (e.g., a utility company) following an off-take agreement. (See Off-take agreement.)

Pay-as-you-go (PAYGo). A business model that gives customers (mainly in areas without access to the electricity grid) the possibility to purchase small-scale energy-producing products, such as solar home systems, by paying in small instalments over time.

Peaker generation plant. Power plants that run predominantly during peak demand periods for electricity. Such plants exhibit the optimum balance – for peaking duty – of relatively high variable cost (fuel and maintenance cost per unit of generation) relative to fixed cost per unit of energy produced (low capital cost per unit of generating capacity).

Pico solar devices / pico solar systems. Small solar systems such as solar lanterns that are designed to provide only a limited amount of electricity service, usually lighting and in some cases mobile phone charging. Such systems are deployed mainly in areas that have no or poor access to electricity. The systems usually have a power output of 1-10 watts and a voltage of up to 12 volts.

Plug-in hybrid electric vehicle. This differs from a simple hybrid vehicle, as the latter uses electric energy produced only by braking or through the vehicle's internal combustion engine. Therefore, only a plug-in hybrid electric vehicle allows for the use of electricity from renewable sources. Although not an avenue for increased penetration of renewable electricity, hybrid vehicles contribute to reduced fuel demand and remain far more numerous than EVs.

Power. The rate at which energy is converted into work, expressed in watts (joules/second).

Power purchase agreement (PPA). A contract between two parties, one that generates electricity (the seller) and one that is looking to purchase electricity (the buyer).

Power-to-gas (P2G). The conversion of electricity, either from renewable or conventional sources, to a gaseous fuel (for example, hydrogen or methane).

Primary energy. The theoretically available energy content of a naturally occurring energy source (such as coal, oil, natural gas, uranium ore, geothermal and biomass energy, etc.) before it undergoes conversion to useful final energy delivered to the end-user. Conversion of primary energy into other forms of useful final energy (such as electricity and fuels) entails losses. Some primary energy is consumed at the end-user level as final energy without any prior conversion.

Primary energy consumption. The direct use of energy at the source, or supplying users with unprocessed fuel.

Product and sectoral standards. Rules specifying the minimum standards for certain products (e.g., appliances) or sectors (industry, transport, etc.) for increasing energy efficiency.

Production tax credit. A tax incentive that provides the investor or owner of a qualifying property or facility with a tax credit based on the amount of renewable energy (electricity, heat or biofuel) generated by that facility.

Productive use of energy. Often used in the context of distributed renewables for energy access to refer to activities that use energy to generate income, increase productivity, enhance diversity and create economic value. Productive uses of energy may include local activities such as agriculture, livestock and fishing; light mechanical works such as welding, carpentry and water pumping; small retail and commercial activities such as tailoring, printing, catering and entertainment; and small and medium-scale production such as agro-processing (grinding, milling and husking), refrigeration and cold storage, drying, preserving and smoking.

Property Assessed Clean Energy (PACE) financing. Provides access to low-interest loans for renewable energy that can be repaid through increases on property taxes.

Prosumer. An individual, household or small business that not only consumes energy but also produces it. Prosumers may play an active role in energy storage and demand-side management.

Public financing. A type of financial support mechanism whereby governments provide assistance, often in the form of grants or loans, to support the development or deployment of renewable energy technologies.

Pumped storage. Plants that pump water from a lower reservoir to a higher storage basin using surplus electricity, and that reverse the flow to generate electricity when needed. They are not energy sources but means of energy storage and can have overall system efficiencies of around 80-90%.

Regulatory policy. A rule to guide or control the conduct of those to whom it applies. In the renewable energy context, examples include mandates or quotas such as renewable portfolio standards, feed-in tariffs and technology/fuel-specific obligations.

Renewable energy certificate (REC). A certificate awarded to certify the generation of one unit of renewable energy (typically 1 MWh of electricity but also less commonly of heat). In systems based on RECs, certificates can be accumulated to meet renewable energy obligations and also provide a tool for trading among consumers and/or producers. They also are a means of enabling purchases of voluntary green energy.

Renewable hydrogen. Hydrogen produced from renewable energy, most commonly through the use of renewable electricity to split water into hydrogen and oxygen in an electrolyser. The vast majority of hydrogen is still produced from fossil fuels, and the majority of policies and programmes focused on hydrogen do not include a focus on renewables-based production.

Renewable natural gas (RNG). Gas that is produced through the anaerobic digestion of organic matter and processed to remove the carbon dioxide and other gases, leaving methane that meets a high specification and that can be interchangeable with conventional natural gas. See Biomethane.

Renewable portfolio standard (RPS). An obligation placed by a government on a utility company, group of companies or consumers to provide or use a predetermined minimum targeted renewable share of installed capacity, or of electricity or heat generated or sold. A penalty may or may not exist for non-compliance. These policies also are known as "renewable electricity standards", "renewable obligations" and "mandated market shares", depending on the jurisdiction.

Reverse auction. See Tendering.

Sector integration (also called sector coupling). The integration of energy supply and demand across electricity, thermal and transport applications, which may occur via co-production, combined use, conversion and substitution.

Smart energy system. An energy system that aims to optimise the overall efficiency and balance of a range of interconnected energy technologies and processes, both electrical and non-electrical (including heat, gas and fuels). This is achieved through dynamic demand- and supply-side management; enhanced monitoring of electrical, thermal and fuel-based system assets; control and optimisation of consumer equipment, appliances and services; better integration of distributed energy (on both the macro and micro scales); and cost minimisation for both suppliers and consumers.

Smart grid. Electrical grid that uses information and communications technology to co-ordinate the needs and capabilities of the generators, grid operators, end-users and electricity market stakeholders in a system, with the aim of operating all parts as efficiently as possible, minimising costs and environmental impacts and maximising system reliability, resilience and stability.

Smart grid technology. Advanced information and control technology that is required for improved systems integration and resource optimisation on the grid.

Smart inverter. An inverter with robust software that is capable of rapid, bidirectional communications, which utilities can control remotely to help with issues such as voltage and frequency fluctuations in order to stabilise the grid during disruptive events.

Solar collector. A device used for converting solar energy to thermal energy (heat), typically used for domestic water heating but also used for space heating, for industrial process heat or to drive thermal cooling machines. Evacuated tube and flat plate collectors that operate with water or a water/glycol mixture as the heat-transfer medium are the most common solar thermal collectors used worldwide. These are referred to as glazed water collectors because irradiation from the sun first hits a glazing (for thermal insulation) before the energy is converted to heat and transported away by the heat transfer medium. Unglazed water collectors, often referred to as swimming pool absorbers, are simple collectors made of plastics and used for lower-temperature applications. Unglazed and glazed air collectors use air rather than water as the heat-transfer medium to heat indoor spaces or to pre-heat drying air or combustion air for agriculture and industry purposes.

Solar cooker. A cooking device for household and institutional applications that converts sunlight to heat energy that is retained for cooking. There are several types of solar cookers, including box cookers, panel cookers, parabolic cookers, evacuated tube cookers and trough cookers.

Solar home system. A stand-alone system composed of a relatively low-power photovoltaic module, a battery and sometimes a charge controller that can provide modest amounts of electricity for home lighting, communications and appliances, usually in rural or remote regions that are not connected to the electricity grid. The term solar home system kit is also used to define systems that usually are branded and have components that are easy for users to install and use.

Solar photovoltaics (PV). A technology used for converting light directly into electricity. Solar PV cells are constructed from semiconducting materials that use sunlight to separate electrons from atoms to create an electric current. Modules are formed by interconnecting individual cells. Building-integrated PV (BIPV) generates electricity and replaces conventional materials in parts of a building envelope, such as the roof or facade.

Solar photovoltaic-thermal (PV-T). A solar PV-thermal hybrid system that includes solar thermal collectors mounted beneath PV modules to convert solar radiation into electrical and thermal energy. The solar thermal collector removes waste heat from the PV module, enabling it to operate more efficiently.

Solar-plus-storage. A hybrid technology of solar PV with battery storage. Other types of renewable energy-plus-storage plants also exist.

Solar water heater (SWH). An entire system consisting of a solar collector, storage tank, water pipes and other components. There are two types of solar water heaters: pumped solar water heaters use mechanical pumps to circulate a heat transfer fluid through the collector loop (active systems), whereas 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 (MW_e) is used to refer to electric power, whereas a megawatt-thermal (MW_{th}) refers to thermal/heat energy produced. Power is the rate at which energy is consumed or generated. A kilowatt-hour is the amount of energy equivalent to steady power of 1 kW operating for one hour.

LIST OF ABBREVIATIONS

AC	Alternating current
ACER	Agency for the Cooperation of Energy Regulators
AfDB	African Development Bank
AUD	Australian dollar
BEV	Battery electric vehicle
Bloomberg NEF	Bloomberg New Energy Finance
BRICS	Brazil, Russian Federation, India, China and South Africa
BRL	Brazilian real
CAD	Canadian dollar
CCA	Community choice aggregation
CHP	Combined heat and power
CNG	Compressed natural gas
CNY	Chinese yuan
CO_2	Carbon dioxide
COP	Conference of the Parties
CSP	Concentrating solar thermal power
DC	Direct current
DFI	Development finance institution
DHC	District heating and cooling
DRE	Distributed renewable energy
DREA	Distributed renewables for energy access
EC	European Commission
EGS	Enhanced (or engineered) geothermal systems
EDFI	Association of bilateral European Development Finance Institutions
EIA	Environmental impact assessment
EJ	Exajoule
EMEC	European Marine Energy Centre
EPA	Environmental Protection Agency
ESCO	Energy service company
ESIA	Environmental and social impact assessment
EU	European Union (specifically the EU-28)
EUR	Euro
EV	Electric vehicle
FAME	Fatty acid methyl esters
FCEV	Fuel cell electric vehicle
FIT	Feed-in tariff
FS	Frankfurt School
FTA	Free trade agreement
G5	Group of Five
G20	Group of Twenty
GBP	British pound
GDP	Gross domestic product
GO	Guarantee of origin
GSR	Global Status Report
GW/GWh	Gigawatt/gigawatt-hour
GW_{th}	Gigawatt-thermal
GWEC	Global Wind Energy Council
HEFA	Hydrotreated esters and fatty acids
HJT	Heterojunction cell technology
HVAC	Heating, ventilation, and air-conditioning
HVO	Hydrotreated vegetable oil
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
IDCOL	Infrastructure Development Company Limited
IEC	International Electrotechnical Commission
IEA	International Energy Agency
IEA PVPS	IEA Photovoltaic Power Systems Programme
IEA SHC	IEA Solar Heating and Cooling Programme
IFC	International Finance Corporation
IHA	International Hydropower Association
INR	Indian rupee
IPP	Independent power producer
ISCC	Integrated solar combined-cycle
IRENA	International Renewable Energy Agency
ITC	Investment Tax Credit
kgoe	Kilogram of oil equivalent
ktoe	Kilotonne of oil equivalent
kW/kWh	Kilowatt/kilowatt-hour
kW_{th}	kilowatt-thermal
LBG	Liquefied biogas
LCOE	Levelised cost of energy (or electricity)
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
M&A	Mergers and acquisitions
m^2	Square metre
m^3	Cubic metre
MAD	Moroccan dirham
MENA	Middle East and North Africa
MJ	Megajoule
MSW	Municipal solid waste
Mtoe	Megatonne of oil equivalent
MW/MWh	Megawatt/megawatt-hour
MW_{th}	Megawatt-thermal
MXN	Mexican peso
NDC	Nationally Determined Contribution
NIMBY	Not In My Back Yard
NOK	Norwegian krone
O&M	Operations and maintenance
OECD	Organisation for Economic Co-operation and Development
OTEC	Ocean thermal energy conversion
P2G	Power-to-gas
PAYGo	Pay-as-you-go
PERC	Passivated Emitter Rear Cell
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
PLN	Polish złoty
PPA	Power purchase agreement
PPP	Purchasing power parity
PTC	Production Tax Credit
PV	Photovoltaic
QAR	Qatari rial
R&D	Research and development
REC	Renewable electricity certificate
RED	EU Renewable Energy Directive
RFS	US Renewable Fuel Standard
RNG	Renewable natural gas
RPS	Renewable portfolio standard
SDG	Sustainable Development Goal
SEK	Swedish krona
SHIP	Solar heat for industrial processes
SUV	Sport utility vehicle
TES	Thermal energy storage
TFC	Total final consumption
TFEC	Total final energy consumption
THB	Thai baht
Toe	Tonne of oil equivalent
TW/TWh	Terawatt/terawatt-hour
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNHCR	United Nations High Commissioner for Refugees
USD	United States dollar
V2G	Vehicle-to-grid
VAT	Value-added tax
VC/PE	Venture capital and private equity
VNM	Virtual net metering
VRE	Variable renewable electricity
W/Wh	Watt/watt-hour
WTO	World Trade Organization
ZEV	Zero emission vehicle

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GLOBAL OVERVIEW

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POLICY LANDSCAPE

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BIOENERGY

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8 **Figure 21** estimated shares in 2018 based on historical data from IEA, *World Energy Balances*, op. cit. note 5. Figure of 2.81 EJ of renewable electricity for heat in buildings in 2018 from IEA, op. cit. note 3, and for previous years based on compound annual growth rate of 5.3%, from idem. Total heat demand in buildings includes electricity for heating and cooling, derived from estimated renewable electricity for heat and calculated share of renewable energy in electricity production for target year. See also Global Overview chapter of this report, Figures 1 and 5.

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Figures of at least 114.9 GW added in 2019 for a total of at least 627 GW are preliminary estimates from IEA PVPS, *Snapshot of Global PV Markets 2020* (Paris: April 2020), https://iea-pvps.org/snapshot-reports/snapshot-2020/, and from Becquerel Institute, Brussels, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 10 April 2020; increase over 2018 market based on idem, both sources, and on additions of 103 GW in 2018, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. this note, pp. 96-97. Additions of 113.9 GW in 2019, and cumulative shipments of cells to first buyer over the period 1975-2019 reached 591 GW in 2019, from P. 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A few countries report data officially in alternating current (AC) (e.g., Canada, Chile, India, Japan, Malaysia, Sweden and the United States); these data were converted to direct current (DC) by relevant sources provided in this section for consistency across countries. The difference between DC and AC power can range from as little as 5% (conversion losses, inverter set at DC level) to as much as 40% (due to some grid regulations limiting output or to the evolution of utility-scale solar PV plants), from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. this note, p. 9. Most utility-scale solar PV plants built in 2019 have an AC-DC ratio between 1.1 and 1.6, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 11. Conversions done by IEA PVPS and the Becquerel Institute use a multiplier of 1.3 for centralised capacity to convert capacity from AC to DC. In the United States, the median inverter loading ratio (ratio of DC nameplate rating to AC inverter nameplate rating) in 2018, for both tracked and fix-tilt utility-scale projects, was 1.33, but there is significant variation across projects, from M. Bolinger, J. Seel and D. Robson, *Utility-scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2019 Edition* (Berkeley, CA: Lawrence Berkeley National Laboratory, December 2019), p. ii, https://eta-publications.lbl.gov/sites/default/files/lbnl_utility_scale_solar_2019_edition_final.pdf. The argument is made that AC ratings are more appropriate for utility-scale capacity because other conventional and renewable utility-scale generating sources also are described in AC terms, and because the difference between a project's DC and AC capacity ratings is increasing in general (at least in the United States) due to a lower relative inverter rating, from M. Bolinger and J. Seel, *Utility-Scale Solar: Empirical Trends in Project Technology, Cost Performance, and PPA Pricing in the United States – 2018 Edition* (Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL), September 2018), p. 5, https://emp.lbl.gov/utility-scale-solar. However, most analysts, consultancies, industry groups, the IEA and many others report data in DC, from M. Schmela, SolarPower Europe, personal communication with REN21, 11 May 2019. In addition, DC capacity more accurately reflects the rating of panels, from C. Marcy, "Solar plants typically install more panel capacity relative to their inverter capacity", Today in Energy, US Energy Information Administration (EIA), 16 March 2018, https://www.eia.gov/todayinenergy/detail.php?id=35372. In order to maintain a consistent rating type across all solar PV capacity, and because the AC capacity of most countries is not available, GSR 2020 attempts to report all solar PV data in DC units; in addition, the GSR reports only capacity that has entered into operation by year's end.

2 More than making up for China from P. Mints, SPV Market Research, *The Solar Flare*, no. 6 (23 December 2019), p. 6; G. Masson, Becquerel Institute and IEA PVPS, Brussels, personal communication with REN21, 20 February 2020; IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1; decline in China from China's National Energy Administration (NEA), "PV grid-connected operation in 2019", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827923.htm (using Google Translate).

3 Based on data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 97, and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6.

4 For total at end of 2019, see endnote 1. Figure of 23 GW at end of 2009 from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 96-97. **Figure 28** based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, pp. 96, 97, and from Becquerel Institute, op. cit. note 1.

5 SolarPower Europe, op. cit. note 1, pp. 9, 13. See also, for example, International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2018* (Abu Dhabi: 2019), p. 9, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf; B. Eckhouse, "Solar and wind cheapest source of power in most of the world", *Bloomberg*, 28 April 2020, https://www.bloomberg.com/news/articles/2020-04-28/solar-and-wind-cheapest-sources-of-power-in-most-of-the-world; BloombergNEF, "Solar, wind, batteries to attract $10 trillion to 2050, but curbing emissions long-term will require other technologies too", 18 June 2019, https://about.bnef.com/blog/solar-wind-batteries-attract-10-trillion-2050-curbing-emissions-long-term-will-require-technologies; M. Brown, "Solar energy prices hit tipping point as China reaches 'grid parity'", Inverse, 14 August 2019, https://www.inverse.com/article/58495-solar-energy-prices-hit-tipping-point-as-china-reaches-grid-parity; M. Brown, "Solar vs. coal: Why the '74 percent report' signals a new era for US energy", Inverse, 28 March 2019, https://www.inverse.com/article/54399-solar-energy-cheaper-than-coal-whats-next; https://www.nature.com/articles/s41560-019-0441-z; J. Weaver, "Solar price declines slowing, energy storage in the money", pv magazine, 8 November 2019, https://pv-magazine-usa.com/2019/11/08/sola-price-declines-slowing-energy-storage-in-the-money; M. Hutchins, "Solar 'could soon be UK's cheapest source of energy'", pv magazine, 12 December 2018, https://www.pv-magazine.com/2018/12/12/solar-could-soon-be-uks-cheapest-source-of-energy; K. Samanta, "India's renewable energy cost lowest in Asia Pacific: WoodMac", *Reuters*, 29 July 2019, https://www.reuters.com/article/us-india-renewables-woodmac/indias-renewable-energy-cost-lowest-in-asia-pacific-woodmac-idUSKCN1UO0L8; 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.

6 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.

7 Estimated 18 countries (Australia, Brazil, China, Chinese Taipei, Egypt, Germany, India, Japan, the Republic of Korea, Mexico, the Netherlands, Pakistan, South Africa, Spain, Ukraine, United Arab Emirates, the United States and Vietnam) in 2019 based on preliminary estimates for IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, on data from Becquerel Institute, op. cit. note 1, and on data from country-specific sources provided throughout this section. Up from 11 countries (China, the United States, India, Japan, Australia, Germany, Mexico, the Republic of Korea, Turkey, the Netherlands and Brazil) in 2018 from SolarPower Europe, op. cit. note 1, p. 53; and up from 10 countries in 2018 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 9. There were nine countries in 2017 from IEA PVPS, *Trends in Photovoltaic Applications 2018: Survey Report of Selected IEA Countries Between 1992 and 2017* (Paris: 2018), p. 3, http://www.iea-pvps.org/fileadmin/dam/public/report/

statistics/2018_iea-pvps_report_2018.pdf, and from SolarPower Europe, *Global Market Outlook for Solar Power 2018-2022* (Brussels: 2018), p. 5, https://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf; and seven countries in 2016 from idem, p. 5.

8 Figure of 39 countries in 2019 based on data from numerous sources, including preliminary data from IEA PVPS, *Snapshot of Global PV Markets 2020,* op. cit. note 1, from A. Detollenaere, Becquerel Institute, personal communication with REN21, 10 April 2020, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 96, and from numerous sources cited throughout this section. Figure of 31 countries in 2018 from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 6.

9 IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, p. 80.

10 IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 14. Based on cumulative capacity in operation at end-2019 and assumes close to optimum siting, orientation and long-term average weather conditions, from idem.

11 **Honduras** sourced 10.7% of its gross electricity generation from solar PV, based on data from T. Vindel, Secretario de Estado en el Despacho de Energía de la República de Honduras, and provided by G. Bravo, Fundación Bariloche, personal communication with REN21, 27 April 2020; **Italy** generated 24,326 GWh of electricity with solar PV in 2019, and total net production in the system was 283,846 GWh, for a solar PV share of 8.57%, from Terna, *Rapporto mensile sul Sistema Elettrico December 2019* (Rome: 2019), p. 5, https://download.terna.it/terna/Rapporto_Mensile_Dicembre%202019_8d79d92a335c3f2.pdf; **Greece** from multiple original sources, all in Greek, and provided by I. Tsipouridis, R.E.D. Pro Consultants, Athens, personal communication with REN21, April 2020; **Germany's** solar PV generation accounted for 8.2% of Germany's gross electricity generation in 2019 (up from 7.7% in 2018), from Federal Ministry for Economic Affairs and Energy and Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Time Series for the Development of Renewable Energy Sources in Germany, Based on Statistical Data from the Working Group on Renewable Energy-Statistics (AGEE-Stat) (Status: February 2020)* (Dessau-Roßlau: February 2020), pp. 44, 45, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html; **Chile** share of generation from Asociación Chilena de Energías Renovables y Almacenamiento (ACERA), *Estadísticas Sector de Generacíon de Energía Eléctrica Renovable* (December 2019), p. 2, https://acera.cl/wp-content/uploads/2020/01/2019-12-Bolet%C3%ADn-estad%C3%ADsticas.pdf; **Australia** from Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), p. 9, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf; **Japan** from Institute for Sustainable Energy Policies (ISEP), "Share of renewable energy electricity in Japan, 2019 (preliminary report)", 10 April 2020, https://www.isep.or.jp/en/879.

12 Share of total global electricity generation based on the following: total global electricity generation in 2019 estimated at 27,011 TWh, based on 26,615 TWh in 2018 from BP, *Statistical Review of World Energy* (London: 2019), https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, and on estimated 1.49% growth in global electricity generation in 2019. Growth rate in 2019 is based on the weighted average change in actual total generation for the following countries/regions (which together accounted for more than two-thirds of global generation in 2018): United States (-1.3% net generation), EU-28 (-1.2%), Russian Federation (+1.2%), India (+0.0%), China (+4.7%), Canada (-0.2%) and Brazil (+2.0%). Generation data for 2018 and 2019 by country or region from the following: US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2019* (Washington, DC: February 2020), Table 1.1, https://www.eia.gov/electricity/monthly/archive/february2020.pdf; European Commission (EC), Eurostat database, http://ec.europa.eu/eurostat, viewed April 2020; Ministry of Energy of the Russian Federation, "Statistics", https://minenergo.gov.ru/en/activity/statistic, viewed April 2020, Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly generation report", http://www.cea.nic.in/monthlyarchive.html, viewed April 2020; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2019 national economic and social development", press release (Beijing: 28 February 2020), http://www.stats.gov.cn/english/PressRelease/202002/t20200228_1728917.html (using Google Translate); Statistics Canada, "Electric Power Generation, monthly generation by type of electricity", https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501, updated 11 May 2020; National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed April 2020. **Solar PV** worldwide production potential of 715.15 TWh, from Gaëtan Masson and Alice Detollenaere, Becquerel Institute and IEA PVPS, personal communication with REN21, 10 April 2020. Estimates for electricity generation from Masson and IEA PVPS are theoretical calculations based on average yield and installed solar PV capacity as of 31 December 2019..

13 SolarPower Europe, op. cit. note 7, p. 42; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 91; IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, pp. 4, 80.

14 Ibid.

15 Lower than a decade ago but challenges remain, fossil and nuclear, from Masson, op. cit. note 2, 20 February 2020, and 4 May 2020. Regarding utilities, in Brazil, for example, utilities are restricting approval and authorization of solar PV systems, saying that they lack the capacity to make grid connections and to integrate solar energy into the grid, among other things, from R. Baitelo, Associação Brasileira de Energia Solar Fotovoltaica (ABSOLAR), personal communication with REN21, 7 April 2020; in Australia, the energy market operator has largely prevented attempts by electricity network operators to discriminate against and financially penalise solar customers, but network operators have imposed delays and conditions on the approval of grid connections, which leads to increases in the soft costs of solar deployment, from IEA PVPS, Australian Photovoltaic Institute (APVI) and Australian Renewable Energy Agency (ARENA), *National Survey Report of PV Power Applications in Australia 2018* (Paris: 2019), prepared by R. Egan, APVI, p. 36, https://iea-pvps.org/wp-content/uploads/2020/01/NSR_Australia_2018.pdf.

16 IEA PVPS, *Trends in Photovoltaic Applications* 2019, op. cit. note 1, pp. 48-56; IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, p. 43.

17 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 48. Growth in grid-connected solar PV in particular has been due almost entirely to government support policies, mandates, and often a combination, from Mints, *Photovoltaic Manufacturer Shipments*, op. cit. note 1, p. 40.

18 Corporate purchasing from information and sources elsewhere in this section; self-consumption from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1 , p. 15.

19 IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 16; Schmela, op. cit. note 1; Masson, op. cit. note 2, 28 February 2019. See also E. Bellini, "Italy deployed 737 MW of solar in 2019", pv magazine, 21 April 2020, https://www.pv-magazine.com/2020/04/21/italy-deployed-737-mw-of-solar-in-2019; L. Stoker, "WoodMac: UK will join the subsidy-free solar club in 2019", PV-Tech, 22 January 2019, https://www.pv-tech.org/news/woodmac-uk-will-join-the-subsidy-free-solar-club-in-2019; T. Gualtieri, "Spanish developer plans 3.3 gigawatts of subsidy-free PV farms", *Bloomberg*, 28 October 2019, https://www.bloomberg.com/news/articles/2019-10-28/spanish-developer-plans-3-3-gigawatts-of-subsidy-free-pv-farms.

20 Seventh consecutive year based on data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1; declines based on idem and from data and sources provided throughout this section; Asia accounted for half based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, 20 March 2020 and 10 April 2020, and from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1.

21 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, 20 March 2020 and 10 April 2020, and from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1.

22 Market and manufacturing from SolarPower Europe, op. cit. note 1, p. 89; share of additions in 2019 based on data from IEA PVPS, *Snapshot of Global PV Markets* 2020, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; 44% in 2018 (and 52% in 2017) from SolarPower Europe, op. cit. note 1, p. 89; China's share of

total demand was 27% in 2014, 30% in 2015, 49% in 2016, 56% in 2017, 42% in 2018 and projected 29% in 2019, from P. Mints, SPV Market Research, *The Solar Flare*, no. 5 (31 October 2019), p. 5.

23 Top 10 countries and share of top 5 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; about 75% in 2018 from Becquerel Institute, op. cit. note 1, 10 May 2019, and from IEA PVPS, *2019 Snapshot of Global PV Markets* (Paris: April 2019), p. 8, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_T1_35_Snapshot2019-Report.pdf; less concentrated from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6. The share represented by the top 5 in 2017 was 84%, based on global additions of at least 98 GW_{DC}, and on additions of the top five countries (China, the United States, India, Japan and Turkey), from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018* (Paris: 2018), p. 4, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA_PVPS-A_Snapshot_of_Global_PV-1992-2017.pdf.

24 Figure for 2019 based on preliminary estimates for IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1. This was up from 1.3 GW in 2018, from Becquerel Institute, op. cit. note 1, 10 May 2019, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 23, p. 7, and from 954 MW in 2017, from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 7, p. 13. The market level to be among the top 10 for annual additions was 683 MW in 2016 and 675 MW in 2015, from IEA PVPS, idem.

25 Leading countries for total capacity based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1, 20 March 2020, and on data and sources provided throughout this section. Leaders per capita from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 7. **Figure 29** based on historical global and country-specific data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, and based on country-specific data and sources provided throughout this section for China, Germany, India, Japan and the United States. India data from the following: data for 2009 from European Photovoltaic Industry Association (EPIA), *Global Market Outlook for Photovoltaics Until 2015* (Brussels: 2011), p. 10, http://www.cogen.com.br/content/upload/1/documentos/Solar/Solar_COGEN/EPIA_Global_Market_Photovoltaics_2015.pdf; data for 2010 and 2011 from EPIA, *Global Market Outlook for Photovoltaics Until 2016* (Brussels: May 2012), p. 14, https://www.helapco.gr/pdf/Global_Market_Outlook_2015_-2019_lr_v23.pdf; data for 2012 from IEA PVPS, *PVPS Report, A Snapshot of Global PV 1992-2012* (Paris: 2013), https://iea-pvps.org/wp-content/uploads/2020/01/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2012_-_FINAL_4.pdf; data for 2013 from IEA-PVPS, *PVPS Report – Snapshot of Global PV 1992-2013: Preliminary Trends Information from the IEA PVPS Programme* (Paris: March 2014), https://iea-pvps.org/wp-content/uploads/2020/01/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2013_-_final_3.pdf; data for 2014 from Bridge to India, May 2015, provided by S. Orlandi, Becquerel Institute, Brussels, personal communication with REN21, 11 May 2015; data for 2015 from IEA PVPS, *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), https://iea-pvps.org/wp-content/uploads/2020/01/Trends_2016_-_mr.pdf; data for 2016 from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements)", data as on 31 December 2016, http://www.mnre.gov.in/mission-and-vision-2/achievements, viewed 19 January 2017; data for 2017 and 2018 from Becquerel Institute and IEA PVPS, personal communication with REN21, 3 June 2019 and 4 May 2020.

26 Year-end rally and 12.2 GW brought online from China Photovoltaic Industry Association (CPIA), cited in M. Hall, "China will add 35-38 GW of solar this year", pv magazine, 22 January 2020, https://www.pv-magazine.com/2020/01/22/china-will-add-35-38-gw-of-solar-this-year; a total of 30.11 GW was added in 2019, including 17.91 GW of utility-scale capacity and 12.2 GW of distributed, and representing a decline of 31.6% relative to 2018, from NEA, op. cit. note 2. Down more than 15% in 2018 based on 53,068 MW installed in 2017, and about 45 GW installed in 2018 (including unsubsidised capacity additions on top of official data for subsidised capacity), all from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1. An estimated 10 GW was installed in December 2019, from GlobalData Energy, "Solar PV capacity additions in China fell by 32% in 2019", Power Technology, 23 January 2020, https://www.power-technology.com/comment/solar-pv-capacity-additions-china-2019.

27 Second consecutive year based on data from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6; down in almost every region (excluding Guizhou), from F. Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 6 April 2020, and from NEA, op. cit. note 2; 12 provinces based on grid-connected capacity data from China National Renewable Energy Center, cited in China NEA, "2019 PV installations utility and distributed by province", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827923.htm (using Google Translate) (data do not include Hong Kong SAR, Macao SAR or Chinese Taipei); and more than double the size of the next largest market based on data and sources throughout this section. **Figure 30** based on IEA PVPS, op. cit. note 1, both references, and on national data and references for top 10 countries provided throughout this section (or see endnote for Reference Table R16).

28 NEA, op. cit. note 2; Guizhou considered one of the poorest provinces, from F. Haugwitz, AECEA, "China solar PV – 2019/2020 – On the ground dynamics", email newsletter, 1 April 2020.

29 Cumulative capacity was 204.66 GW (including off-grid), from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 6; cumulative capacity at end-2019 was 204.3 GW, up 17.3% over 2018, including 141.67 GW of utility-scale projects and 62.63 GW of distributed systems (all grid-connected), all from NEA, op. cit. note 2; year-end capacity was 204,680 MW, up 17.4% over 2018, from China Electricity Council (CEC), "2019 electricity & other energy statistics (preliminary)", 21 January 2020, http://www.cec.org.cn/guihuayutongji/tongjxinxi/niandushuju/2020-01-21/197077.html (using Google Translate). The national target is part of the country's 13th Five-Year Plan (2016-2020), from Haugwitz, op. cit. note 28.

30 Schmela, op. cit. note 1, 12 May 2020; F. Haugwitz, "Towards a subsidy-free era for China's solar PV market", Apricum, 19 November 2019, https://www.apricum-group.com/towards-a-subsidy-free-era-for-chinas-solar-pv-market.

31 Haugwitz, op. cit. note 30.

32 V. Shaw, "Is China's market heading toward a cliff edge?" pv magazine, 30 December 2019, https://www.pv-magazine.com/2019/12/30/is-chinas-market-heading-toward-a-cliff-edge; C. Lin, "China's new solar FIT policy", pv magazine, 5 June 2019, https://www.pv-magazine.com/2019/06/05/chinas-new-solar-fit-policy; F. Haugwitz, AECEA, "China announced 15.99 GW during Jan-Sept 2019; 45% decrease YoY – AECEA revised full-year guidance to 20-24 GW", email newsletter, 29 October 2019.

33 Shaw, op. cit. note 32; Lin, op. cit. note 32; Haugwitz, op. cit. note 32; delayed release of policies, grid connection, land availability and challenges associated with mobilising finance also from Haugwitz, cited in R. Ranjan, "AECEA: China likely to install 23-31 GW of solar in 2020 as uncertainty grips", Mercom India, 7 January 2020, https://mercomindia.com/aceca-china-likely-install-23-31-gw-solar-2020.

34 Haugwitz, op. cit. note 28. See also Wood Mackenzie, "Global solar PV installations to reach record high in 2019", press release (25 July 2019), https://www.woodmac.com/press-releases/global-solar-pv-installations-to-reach-record-high-in-2019. Another source has the total at 22.7 GW, from M. Hall, "The year in solar, part III: Battery breakthroughs, inverter trouble, sustainable role models and new tech", pv magazine, 27 December 2019, https://www.pv-magazine.com/2019/12/27/the-year-in-solar-part-iii-battery-breakthroughs-inverter-trouble-sustainable-role-models-and-new-tech. Grid parity from Haugwitz, op. cit. note 27, 21 April 2020.

35 Haugwitz, op. cit. note 28. See also Wood Mackenzie, op. cit. note 34.

36 Based on data from NEA and from China PV Industry Association (CPIA), provided by Haugwitz, op. cit. note 27, 15 May 2020 and 27 May 2020; Target of 3.5 GW based on earmarked budget of RMB 750 million, which theoretically could support 3.5 GW, from Haugwitz, op. cit. note 27, 21 April 2020. See also Shaw, op. cit. note 32.

37 Shares of capacity added are based on 30.11 GW added to the grid in 2019, including 17.91 GW of utility-scale capacity (down 22.9% relative to 2018) and 12.2 GW of distributed capacity (up 41.3% over 2018), from NEA, op. cit. note 2. Share of cumulative capacity based on 141.67 GW of utility-scale capacity and 62.63 GW of distributed capacity (all grid-connected) at

year's end, from idem, and on total grid-connected capacity of 204.3 GW. Centralised plants accounted for 53% of grid-connected installations in 2018, from NEA, "2018 added solar PV capacities," Finance World, 28 January 2019, https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&for=pc (using Google Translate).

38 NEA, op. cit. note 2.

39 In Qinghai, curtailment was up 2.5 percentage points over 2018 to 7.2%; others with significant average rates of curtailment during 2019 were Tibet, which curtailed 24.1% (down 19.5 percentage points relative to 2018), followed by Xinjiang (7.4%, down 8.2) and Gansu (4%, down 5.6), all from NEA, op. cit. note 2.

40 Figures for 2019 based on output from grid-connected systems was up 26.3% to 224.3 TWh, from NEA, op. cit. note 2, and on output up 26.5% to 223.8 TWh, from CEC, op. cit. note 29. For comparison, output was up 50%, to 177.5 TWh in 2018, from NEA, op. cit. note 37.

41 Share of generation based on 223.8 TWh of solar electricity and total generation from all sources of 7,325 TWh, from CEC, op. cit. note 29. Share of generation in 2018 (2.6%) from NEA, "Photovoltaic power generation statistics for 2018", 19 March 2019, http://www.nea.gov.cn/2019-03/19/c_137907428.htm (using Google Translate); the share was 2.5% based on 1,775 billion kWh of solar generation (note, however, that this may include a small amount of CSP) and 69,940 billion kWh of total power generation, from China Electricity Industry Development and Environmental Resources Department, cited by CEC, "2018 power statistics annual express basic data list", 19 January 2019, http://www.cec.org.cn/guihuayutongji/tongjxinxi/niandushuju/2019-01-22/188396.html. Share of generation in 2017 was 1.9%, based on data from NEA, cited in "Energy Bureau conference informed of 2017 renewable energy grid operation", 24 January 2018, http://shupeidian.bjx.com.cn/news/20180124/876448.shtml (using Google Translate).

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50 Sanjay, op. cit. note 44.

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60 ISEP, op. cit. note 11.

61 Figures of 530,000 and 2 GW, from METI, https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/008_03_00.pdf (in Japanese), p. 8, viewed 27 April 2020, provided by Matsubara, op. cit. note 57, 27 April 2020; self-consumption and net zero from idem. See also J. Movella, "End of the residential FIT in Japan. Post FIT RECs go to RE100 companies", Renewable Energy World, 19 November 2019, https://www.renewableenergyworld.com/2019/11/19/end-of-the-residential-fit-in-japan-post-fit-recs-go-to-re100-companies; Ohigashi and Kaizuka, op. cit. note 58.

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65 Figure of 4.8 GW added in 2019 for a total of 4.9 GW, based on preliminary data for IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Vietnam's additions in 2018 and 2017 from Maisch, op. cit. note 63. Vietnam ended 2018 with 106 MW and 2019 with 5,695 MW, meaning annual additions in 2019 of 5,589 MW, based on data from IRENA, op. cit. note 44.

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67 Post June from Kenning, op. cit. note 63; in December from Bellini, op. cit. note 64.

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79 Figures 26 of 28 and three-fourths from SolarPower Europe, op. cit. note 76, p. 6. Note that all EU countries added at least some capacity in 2019 – although less than 10 MW each in Latvia (1 MW), Croatia (6 MW) and the Slovak Republic (7 MW) – and additions in the top five countries accounted for 77% of the EU total, based on data from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.

80 Country rankings and data for the Netherlands (estimated 2,400 MW), France (915 MW) and Poland (estimated 800 MW) from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. **France** added 889 MW of capacity in solar parks for a year-end total of 9,435 MW, from Le réseau de transport d'électricité (RTE), *Bilan Électrique 2019* (Paris: January 2020), p. 55, https://www.rte-france.com/sites/default/files/bilan-electrique-2019_0.pdf; added 890 MW for a total of 9,436 MW, from C. Rollet, "France installed 890 MW of solar in 2019", pv magazine, 11 February 2020, https://www.pv-magazine.com/2020/02/11/france-installed-890-mw-of-solar-in-2019, and connected 965.6 MW (and decommissioned 5.1 MW) for a total of 10,575.9 MW, from EurObserv'ER, op. cit. note 1, p. 11. **The Netherlands** added 2.3 GW to 2.5 GW in 2019 and France added 1,068 MW, from SolarPower Europe, op. cit. note 76, pp. 6, 49. **Poland** added 784 MW, from SolarPower Europe, op. cit. note 77.

81 The Netherlands from SolarPower Europe, op. cit. note 76, pp. 9, 11. The Netherlands' rooftop market included residential and commercial and industrial uses; the commercial rooftop market was the largest segment, at about 40%, from idem., pp. 9, 49. Poland's market quadrupled based on 203 MW installed in 2018, from SolarPower Europe, op. cit. note 76, p. 10; rising incentives and extension of net metering in Poland from E. Bellini, "Poland tops 1.3 GW of PV capacity", pv magazine, 14 January 2020, https://www.pv-magazine.com/2020/01/14/poland-tops-1-3-gw-of-pv-capacity.

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Markets 2020, op. cit. note 1, from Becquerel Institute, op. cit. note 1, 20 March 2020, and data for 2018 from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 1, p. 96. Poland also passed 1 GW cumulative capacity in 2019, from EurObserv'ER, op. cit. note 1, p. 6.

83 SolarPower Europe, op. cit. note 76, p. 11. Italy added about 0.6 GW for a total of 20.8 GW, from IEA PVPS, *Snapshot of Global PV Markets 2020,* op. cit. note 1, pp. 8, 10, and from Becquerel Institute, op. cit. note 1; and added 737 MW, a near-69% increase over the 437 MW added in 2018, for a total of 20.9 GW at the end of 2019, from Italian renewables association Anie Rinnovabili and grid operator Terna, cited in Bellini, op. cit. note 19. For more on Italy, see E. Bellini, "Italy has 80 MW/168 MWh of storage linked to renewables", pv magazine, 2 October 2019, https://www.pv-magazine.com/2019/10/02/italy-has-80-mw-168-mwh-of-storage-linked-to-renewables.

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87 SolarPower Europe, op. cit. note 76, p. 13.

88 J. Deign, "Spain moves to prevent a second solar bubble", op. cit. note 85.

89 Based on 2,888 MW added in 2018 (year-end totals of 42,293 MW at end-2017 and 45,181 MW at end-2018), and 3,835 MW added in 2019 based on end-2019 total of 49,016 MW, from German Federal Ministry for Economic Affairs and Energy and AGEE-Stat, op. cit. note 11, p. 7. Germany added 3.94 GW for a total of 49.78 GW, from German network operator, cited in S. Enkhardt, "Germany added almost 4 GW of PV in 2019", pv magazine, 31 January 2020, https://www.pv-magazine.com/2020/01/31/germany-added-almost-4-gw-of-pv-in-2019; added 3.9 GW for a total of 49.2 GW, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 10; and added 3,856 MW (decommissioned 21 MW) for a total of 49,016 MW, from EurObserv'ER, op. cit. note 1, pp. 6, 8-9. The year 2019 was the third year running with a significant increase in new installations, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, p. 8.

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141 Record additions from Clean Energy Council, op. cit. note 11, pp. 4, 6, 18, 69, 72, 76; ranked eighth based on data from IEAP PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 1, and on data and sources throughout this section.

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installs 2.13 GW of rooftop solar in 2019", pv magazine, 15 January 2020, https://www.pv-magazine-australia.com/2020/01/15/australia-installs-2-13-gw-of-rooftop-solar-in-2019/; and household and commercial rooftop solar (up to 5 MW) installations were 2.4 GW in 2019, up 40% over the 1.7 GW installed in 2018, with 2.2 GW added being small-scale solar PV, all from Australian Government, *Clean Energy Regulator, Quarterly Carbon Market Report – December Quarter 2019* (Canberra: 2020), pp. 23, 36, http://www.cleanenergyregulator.gov.au/DocumentAssets/Documents/Quarterly%20Carbon%20Market%20Report%20-%20December%20Quarter%202019.pdf.

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WIND POWER

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6 Delayed tenders and stop-go tempo of policies from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 10, 27; notable growth includes Argentina and the Dominican Republic, which both more than doubled their installed capacities in 2019, as well as Ethiopia, Jordan, Morocco and Vietnam, which all installed more than they had in the past few years (if ever) and saw total capacity increase by at least 20% in 2019, based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.

7 At least 55 countries in 2019 based on data from GWEC, *Global Wind Statistics 2019*, op. cit. note 1, and from F. Zhao, GWEC, Copenhagen, personal communication with REN21, 13 April 2020; at least 47 countries in 2018 based on data from GWEC, *Global Wind Report 2018* (Brussels: April 2019), https://gwec.net/wp-content/uploads/2019/04/GWEC-Global-Wind-Report-2018.pdf. Senegal installed 50 MW, from Zhao, op. cit. this note, from C. Richard, "First power from first West African wind farm", Windpower Monthly, 12 December 2019, https://www.windpowermonthly.com/article/1668654/first-power-first-west-african-wind-farm, and from A. Frangoul, "West Africa's first large-scale wind farm starts generating power", *CNBC Sustainable Energy*, 13 December 2019, https://www.cnbc.com/2019/12/13/west-africas-first-large-scale-wind-farm-starts-generating-power.html. During 2019, 53 countries or territories added capacity, while 6 saw a slight decline (including Denmark, resulting from decommissioning), and Mauritania installed commercial capacity for the first time, ending the year with 34 MW, from WWEA, op. cit. note 1; 53 countries added capacity with only Denmark seeing total capacity decline during 2019, and both Senegal (plus 50 MW) and Tonga (2 MW) added capacity for the first time, from IRENA, op. cit. note 1.

8 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from Zhao, op. cit. note 7. There were 126 countries with at least 1 MW of wind power capacity and 36 with at least 1 GW of operating capacity in place at the end of 2019, from IRENA, op. cit. note 1. Figures for 2018 were at least 103 countries and 33 countries, based on data from GWEC, op. cit. note 7.

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18 Share of total in 2019 (50.5%) and in 2018 (51.9%), and total regional capacity at end-2019 (all including Turkey), based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. The share in 2017 was 48%, based on data from GWEC, *Global Wind Report – Annual Market Update 2017* (Brussels: April 2018), p. 17, https://gwec.net/publications/global-wind-report-2/.

19 Regional shares based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from WindEurope, op. cit. note 13, p. 10. Numbers here are based on regional groupings that include Turkey as part of Asia, rather than Europe, and Mexico as part of Central America or Latin America, rather than North America.

20 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 36.

21 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.

22 Based on data from Ibid. and from WindEurope, op. cit. note 13, p. 10. **Figure 38** based on country-specific data and sources provided throughout this section (see also endnote for Reference Table R19).

23 China's increase in 2019 relative to 2018 and data for 2019 based on data from H. Yu, Chinese Wind Energy Association (CWEA) and from GWEC, "Global Wind Statistics 2019", op. cit. note 1; China added 26,785 MW, including 24,292 MW onshore and 2,493 MW offshore), from Hui, op. cit. this note; and from China added 23,760 MW onshore and 2,395 MW offshore for a year-end total of 236,401.7 MW, from GWEC, "Global Wind Statistics 2019", op. cit. note 1; note that figure of 2.4 GW offshore was preliminary data provided to GWEC by the CWEA. China added 27.5 GW in 2019 for total of 237,029 MW, from WWEA, op. cit. note 1, and China added a net of 25,813 MW for a total of 210,478 MW, based on data from IRENA, op. cit. note 1. See also endnote 24.

24 Newly installed grid-connected wind power capacity was 25.74 GW, including 23.76 GW onshore and 1.98 GW offshore, for cumulative total of 210.05 GW (204 GW onshore and 5.93 GW offshore), based on 2019 data from China National Energy Administration (NEA), "Wind power grid-connected operation in 2019", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827910.htm (using Google Translate), and from China NEA and China Electricity Council (CEC), cited in China Energy Portal, op. cit. note 17, and on year-end 2018 data (184 GW cumulative), from NEA, "2018 wind power grid operation", 28 January 2019, http://www.nea.gov.cn/2019-01/28/c_137780779.htm (using Google Translate), and from China NEA and CEC, cited in China Energy Portal, op. cit. note 17. Additions of 25.74 GW were up 21% over the 21.27 GW added in 2018, and cumulative capacity increased 14%, from 184.27 GW at end-2018 to 210.05 GW at end-2019, from CEC, "Statistics of China Power Industry 2019", http://english.cec.org.cn/No.110.1941.htm, viewed 13 March 2020. The difference in statistics among Chinese organisations and agencies results from the fact that they count different things: installed capacity refers to capacity that is constructed and usually has wires carrying electricity from the turbines to a substation (i.e., CWEA annual statistics); capacity qualifies as grid-connected (i.e., included in CEC statistics) once certification is granted and

operators begin receiving the feed-in tariff (FIT) premium payment, which can take weeks or even months. Due to transmission constraints in China, there is still often a several-month lag from when turbines are wire-connected to the substation until the process of certification and payment of the FIT premium is complete. No Chinese statistics provide actual grid-connected capacity, and discrepancies among available statistics can be large. Data cited by CWEA include some capacity that is not 100% grid-connected by year's end, but they are believed to most closely reflect the status of the market in China, from L. Qiao, GWEC, personal communication with REN21, 2 May 2018 and confirmed by Yu, op. cit. note 23, 19 May 2020. For the year, investment in new wind power projects in China was up more than 81%, to RMB 117.1 billion (USD 16.5 billion), from CEC, op. cit. this note.

25 GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 8; GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 37.

26 EurObserv'ER, *Wind Energy Barometer* (Paris: March 2020), p. 3, https://www.eurobserv-er.org/wind-energy-barometer-2020.

27 Ibid., p. 3.

28 Ibid., p. 3.

29 Majority based on additions in 2019 as well as on 72% at the end of 2018, from the following: share of cumulative based on central and eastern share of 27.9% and "three north" region share of 72.1%; share of additions based on 47% of total, all from NEA, "2018 added solar PV capacities", *Finance World*, 28 January 2019, https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&for=pc (using Google Translate). Henan added 3,260 MW followed by Hebei (2,480 MW), Shanxi and Shandong (both 2,080 MW), based on cumulative capacity for end-2018 and end-2019, from China Energy Portal, op. cit. note 17; Jiangsu added 1,596 MW, from Yu, op. cit. note 24. Also, note that the top installers in 2019 were Shanxi, Inner Mongolia, Henan, Hebei and Jiangsu, from idem. Curtailment rates from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24. Curtailment rates during 2019 were 0% in Henan, 4.8% in Hebei, 1.1% in Shanxi and 0.1% in Shandong, compared with rates of 7.1% to 14% in the northern and western provinces of Inner Mongolia, Gansu and Xinjiang, from idem.

30 Curtailed generation and curtailment rates in 2019 and 2018 based on data from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24. In late 2018, China re-emphasised its aim to keep curtailment of wind generation below 10% in 2019 and 5% in 2020, from Bloomberg News Editors, "China hopes to lessen solar, wind curtailment in 2019", *Renewable Energy World*, 3 December 2018, https://www.renewableenergyworld.com/articles/2018/12/china-hopes-to-lessen-solar-wind-curtailment-in-2019.html; "China targets cut in wind-, solar-power blocked from grid access", *Bloomberg*, 1 December 2018, https://www.bloomberg.com/news/articles/2018-12-01/china-targets-cut-in-wind-solar-power-blocked-from-grid-access. National curtailment in 2017 was 12% (41.9 TWh), from China National Energy Board, cited in NEA, "Wind grid operation in 2017", 1 February 2018, http://www.nea.gov.cn/2018-02/01/c_136942234.htm (using Google Translate); national curtailment in 2016 was 17% (49.7 TWh), from NEA and CEC, provided by S. Pengfei, CWEA, personal communication with REN21, 21 March 2017, and from NEA, "Wind power grid operation in 2016", 26 January 2017, http://www.nea.gov.cn/2017-01/26/c_136014615.htm (using Google Translate).

31 In Xinjiang, the curtailment rate fell more than 9 percentage points relative to 2018, to 14%; Gansu's declined 11.4 percentage points, to 7.6%; Inner Mongolia's fell nearly 3 percentage points, to 7.1%, based on 2019 data from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24, and on 2018 data from NEA, "2018 added solar PV capacities", op. cit. note 29.

32 Generation in 2019 from NEA, "Wind power grid-connected operation in 2019", op. cit. note 24; increase in generation was about 10.9%, based on generation of 365.8 TWh in 2018, and 2019 share of total output based on wind generation relative to total generation (405.6 TWh) from CEC, op. cit. note 24. Figure of 5.2% in 2018 from China Energy Portal, "2018 wind power installations and production by province", 28 January 2019, https://chinaenergyportal.org/en/2018-wind-power-installations-and-production-by-province, and also based on data from China Electricity Council Express, cited in NEA, "National Energy Administration released statistics on national power industry in 2018", 18 January 2019, http://www.nea.gov.cn/2019-01/18/c_137754977.htm (using Google Translate). In 2017, wind energy generation was 305.7 TWh and its share of total generation was 4.8%, from China National Energy Board, cited in NEA, "Wind grid operation in 2017", 1 February 2018, http://www.nea.gov.cn/2018-02/01/c_136942234.htm (using Google Translate).

33 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.

34 Figure of 8.5% based on 2,377 MW installed in 2019 and 2,191 MW added in 2018, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44; down nearly 50% in 2018 based on 2018 additions from Idem and 4,148 MW added in 2017, from GWEC, op. cit. note 7, p. 29. In 2017, India saw a rush to capitalise on national incentives before they expired and on FIT-based power purchase agreements (PPAs) before a shift to auctions. Reverse auctions from A. Parikh, "India's wind power installations flat in 2019 with 2.4 GW", Mercom India, 20 February 2020, https://mercomindia.com/india-wind-installations-flat-2019; R. Ranjan, "India's wind sector failed to gain speed in 2019", Mercom India, 23 December 2019, https://mercomindia.com/india-wind-failed-gain-speed.

35 Year-end capacity of 37,505.18 MW, from Government of India, Ministry of New and Renewable Energy (MNRE), cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2019) (Utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2020/installed_capacity-01.pdf; net additions of 2,367.03 based on Idem, and on end-2018 capacity of 35,138.15, from Government of India, MNRE, cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2018) (Utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2018/installed_capacity-12.pdf. India added 2.4 GW in 2019 for a total of 37.5 GW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 18; added 2.4 GW for a total of 37,529 MW, from WWEA, op. cit. note 1; added 2,217 MW for a total of 37,505 MW, from IRENA, op. cit. note 1; added 2.9 GW for a total of almost 38 GW, from Campbell, op. cit. note 5; and ended 2019 with 37,733.16 MW, from J. Hossain, Renewable Energy Welfare Society, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world.

36 Figure of around 8.6 GW was the total active pipeline as of year-end 2019, from GWEC and MEC Intelligence, op. cit. note 9, p. 15. Of the 8.6 GW, nearly 3 GW was scheduled to be commissioned in 2020, 5.2 GW in 2021 and the remainder during 2022, from idem. Note that 9.355 GW of capacity was under implementation at year's end, from Government of India, MNRE, *Annual Report 2019-20* (New Delhi: 2020), p. 8, https://mnre.gov.in/img/documents/uploads/file_f-1585710569965.pdf. For delays, see sources for the following paragraph.

37 Undersubscribed from, for example, Ranjan, op. cit. note 34, and from "Undersubscription becoming a norm", Bridge to India, 3 September 2019, https://bridgetoindia.com/undersubscription-becoming-a-norm; delays and renegotiate tariffs from "Investors losing interest in troubled Indian market", Windpower Monthly, 7 October 2019, https://www.windpowermonthly.com/article/1661651/investors-losing-interest-troubled-indian-market; withdrawal from existing PPAs from A. Parikh, "Even with court's stay order in place, Andhra Pradesh to cancel 21 wind PPAs", Mercom India, 30 July 2019, https://mercomindia.com/stay-order-andhra-pradesh-cancel-wind-ppas. See also GWEC and MEC Intelligence, op. cit. note 9, p. 13, and IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), p. 14, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_RE-Auctions_Status-and-trends_2019.pdf. Over the past three years, more than 17 GW of capacity has been auctioned, but more than one-third of this has gone unsubscribed or been cancelled after being awarded; meanwhile, more than 80% of awarded projects have been delayed by 6-12 months, from MEC Intelligence, cited in GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 18. Andhra Pradesh severely curtailed wind generation, despite the national government's "must run" status for renewables, shifting from wind to coal generation, from S. Prateek, "After high court's stay, Andhra Pradesh begins curtailing wind power severely", Mercom India, 26 July 2019, https://mercomindia.com/wind-curtailment-andhra-ppa-revision; the state decided to renegotiate PPAs, from Parikh, op. cit. note 34, and it withdrew existing PPAs with 21 wind power projects, amounting to nearly 0.8 GW of capacity, from Parikh, op. cit. this note. Turbine deliveries and domestic manufacturing from S. Tenddulkar, "Indian downturn hits manufacturing production", Windpower Monthly, 26 April 2019, https://www.windpowermonthly.com/article/1583075/indian-downturn-hits-manufacturing-production.

38 Challenges from, for example, GWEC and MEC Intelligence, op. cit. note 9, p. 9; Ranjan, op. cit. note 34; Parikh, op. cit. note 34; R. K. Singh, "Developers struggle to actually build low-cost wind farms in India", Renewable Energy World, 6 December 2019, https://www.renewableenergyworld.com/2019/12/06/developers-struggle-to-actually-build-low-cost-wind-farms-in-india; Campbell, op. cit. note 5; Tenddulkar, op. cit. note 37. Projects have become financially unattractive due to low tariff caps, and most of the wind resource-rich sites are no longer available, making it difficult to acquire land; in addition, the windiest states are also those with the highest rates of curtailment, from Ranjan, op. cit. note 34. In addition, disputes between federal and state governments on the level of support needed for older wind farms have stalled India's repowering potential, from Campbell, op. cit. note 5.

39 S. Gsänger, "A dangerous trend is challenging the success of wind power around the globe: Concentration and monopolization", WindTech International, 4 February 2020, https://www.windtech-international.com/view-from-inside/a-dangerous-trend-is-challenging-the-success-of-wind-power-around-the-globe-concentration-and-monopolisation; geographically concentrated from J. Hossain, WWEA, "Experience with auctions in India", from WWEA, "Webinar: Wind power and renewable energy policies: What is best to reach 100% RE", 14 May 2020, https://wwindea.org/blog/2020/05/07/wweawebinar-wind-power-and-renewable-energy-policies-what-is-best-to-reach-100-re-14-may.

40 Turkey installed 687 MW onshore, for a total of 8,056 MW at end-2019, and added 497 MW in 2018, all from Turkish Wind Energy Association (TWEA), *Turkish Wind Energy Statistic Report* (Ankara: January 2020), p. 9, http://www.tureb.com.tr/files/bilgi_bankasi/turkiye_res_durumu/istatistik_raporu_ocak_2020.pdf. Turkey added 686 MW for a total of 8,056 MW, from WindEurope, op. cit. note 13, p. 10; added 687 MW for a total of 8,056 MW, from WWEA, op. cit. note 1; and added 586 MW for a total of 7,591 MW, from IRENA, op. cit. note 1.op. cit. note 40, p. 11.

41 Fourth and capacity based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 44, 53; drop in FIT rates and investor confidence, from GWEC, "Market to watch: Thailand", press release (Brussels: 28 February 2020), https://gwec.net/market-to-watch-thailand. Thailand added 322 MW in 2019, down from 567.5 MW in 2018, for a total of 1,532 MW, from idem, both sources; added 323 MW for a total of 1,538 MW, from WWEA, op. cit. note 1; and added 404 MW for a total of 1,507 MW, from IRENA, op. cit. note 1.

42 Based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44. Pakistan added 396.6 MW in 2019 for a total of 1,185 MW, from I. Mirza, WWEA Pakistan, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world.

43 T. Leonard, "Wind market storming ahead in Vietnam, but possible obstacles remain", DNV GL, 24 June 2019, https://blogs.dnvgl.com/energy/wind-market-storming-ahead-in-vietnam-but-possible-obstacles-remain.

44 Vietnam had a total of 228 MW at the end of 2018; the government targets 800 MW by 2020, 2 GW by 2025, and 6 GW by 2030, from idem. Vietnam added 160 MW for a total of 388 MW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 44, 51, and from WWEA, op. cit. note 1; and added 138 MW for a total of 375 MW, from IRENA, op. cit. note 1.

45 GWEC, "Industry pulse: South East Asia energy transition", press release (Brussels: 28 February 2020), https://gwec.net/industry-pulse-south-east-asia-energy-transition; GWEC, op. cit. note 42.

46 All Europe (not including Turkey) added 11,056 MW onshore and 3,627 MW offshore (14,683 MW total), for a year-end total of 196,758 MW (174,687 MW onshore and 22,071 MW offshore), based on data from WindEurope, op. cit. note 13, p. 10. Europe added 14,023 MW for a total of 195,908 MW, from IRENA, op. cit. note 1.

47 WindEurope, op. cit. note 13, pp. 8, 10. Based on additions of 9,552 MW onshore and 3,627 MW offshore (less 178 MW of decommissioned capacity), for a year-end total of 192,231 MW, of which 170,162 MW was onshore and 22,069 MW was offshore, from idem, pp. 8, 10. The EU installed 12,238.3 MW in 2019 (including 3,050 MW offshore), and decommissioned 208 MW, for a year-end total of 191,509.3 MW (including 21,803.6 MW offshore), from EurObserv'ER, op. cit. note 26, pp. 4, 10. Figure for EU-27 cumulative capacity (168,716 MW) based on data from WindEurope, op. cit. note 13, pp. 10, 14. Cumulative capacity for EU-27 was 167,578 MW, from EurObserv'ER, op. cit. note 26, p. 4.

48 Up 34% based on net additions of 13,001 MW in 2019, from WindEurope, op. cit. note 13, pp. 10, 16, and on net additions in 2018 of 9,690 MW (7,450 MW added onshore and 2,661 MW offshore, less 421 MW decommissioned), from WindEurope, *Wind Energy in Europe in 2018: Trends and Statistics* (Brussels: 2019), p. 10, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf.

49 Greece, Spain and Sweden from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 13. Greece additions of 727 MW, and Sweden additions of 1,588 MW and year-end total of 8,985 MW, from WindEurope, op. cit. note 13, pp. 10, 11, 13. Wind power installations reached a record 727.5 MW in Greece during 2019, more than double the previous annual high of 311 MW, from I. Tsipouridis, RED PRO Consultants, personal communication with REN21, April 2020. Greece added 732 MW and Sweden added 1,579 MW from WWEA, op. cit. note 1; and Greece added 670 MW and Sweden added 1,588 MW from IRENA, op. cit. note 1.

50 Figure of 19 countries in 2019 based on data (9 EU member states added no new capacity) from WindEurope, op. cit. note 13, p. 13; figure of 16 countries in 2018 based on data from WindEurope, op. cit. note 48, p. 10.

51 Top countries in 2019 from WindEurope, op. cit. note 13, p. 12, and share of installations based on data from idem., pp. 10, 16. The share was down from 80% in 2018, from WindEurope, op. cit. note 48, p. 10. France contraction from WindEurope, op. cit. note 13; for Germany, see text and sources below.

52 WindEurope, op. cit. note 13, pp. 10, 15. Also based on data from IRENA, op. cit. note 1. France added 1,336 MW for total of 16,646 MW (all but 2 MW onshore), and Italy added 456 MW for a total of 10,512 MW, from WindEurope, op. cit. note 13, p. 10. France added 1,360 MW for a total of 16,494 MW, from Réseau de transport d'électricité (RTE), *Bilan Électrique 2019* (Paris: 2020), p. 27, https://www.rte-france.com/sites/default/files/bilan-electrique-2019_1.pdf. Italy added 456 MW for a year-end total of 10,512 MW, from WindEurope, op. cit. this note, and added 450 MW for a total of 10,600 MW, from D. A. Garcia, Italian Wind Energy Association, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world.

53 The United Kingdom added 629 MW onshore and 1,764 MW offshore, and decommissioned 17 MW of capacity, for net additions of 2,376 MW and a year-end total of 23,515 MW, based on data from WindEurope, op. cit. note 13, pp. 8, 16. The UK ended 2018 with 21,771 MW (including 8,217 MW offshore) and ended 2019 with an estimated 23,975 MW (including 9,792 MW offshore), for total additions in 2019 of 2,204 MW, from UK BEIS, op. cit. note 15. The UK added 2,358 MW (1,728 MW added offshore) in 2019, for a total of 24,128 MW, from IRENA, op. cit. note 1; and added 2,772 MW for a total of 23,515 MW, from WWEA, op. cit. note 1.

54 WindEurope, op. cit. note 13, p. 12.

55 Ibid., p. 12.

56 Lows for coal and rise of wind, from A. Lee, "UK coal power hits 19th century lows as offshore wind roars on", Recharge, 26 September 2019, https://www.rechargenews.com/wind/1855732/uk-coal-power-hits-19th-century-lows-as-offshore-wind-roars-on; share of generation from wind energy was 19.8% (half of which was from onshore capacity and half from offshore wind power capacity), from UK BEIS, *Energy Trends* report, cited in D. Snieckus, "Wind delivers 'more than half' of record UK renewables power output", Recharge, 26 March 2020, https://www.rechargenews.com/transition/wind-delivers-more-than-half-of-record-uk-renewables-power-output/2-1-781960.

57 Spain added 2,319 MW for a total of 25,808 MW, from REE, cited in WindEurope, op. cit. note 13, pp. 8, 10; more than five times 2018 installations of 392 MW, from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from WindEurope, op. cit. note 48, p. 10. Spain added 2,243 MW for a total of 25.7 GW, from Spanish wind energy association, AEE, cited in D. Weston, "Spain surpasses 25GW after 'intense' 2019", Windpower Monthly, 25 February 2020, https://www.windpowermonthly.com/article/1675099/spain-surpasses-25gw-intense-2019, and added 2,148 MW based on year-end 2019 capacity of 25,742 MW and year-end 2018 capacity of 23,594 MW, from REE, "Potencia instalada nacional (MW)", as of 31 December 2019, https://www.ree.es/es/datos/publicaciones/series-estadisticas-nacionales.

58 WindEurope, op. cit. note 13, p. 8.

59 P. Dorronsoro, "Spain's new renewable energy 'reasonable return' law", Pinsent Masons, 4 December 2019,

https://www.pinsentmasons.com/out-law/analysis/spains-new-renewable-energy-reasonable-return-law.

60 WindEurope, op. cit. note 13, p. 7; Germany was the leading installer in Europe from 2011 through 2018; Spain added slightly more capacity than Germany did during 2010, based on data from past editions of the REN21 *Renewables Global Status Report*.

61 Added 2,189 MW (1,078 gross onshore and 1,111 MW offshore) and decommissioned 97 MW (onshore), for net additions of 2,092 MW (981 MW onshore and 1,111 MW offshore), for a total of 61,357 MW (53,912 MW onshore and 7,445 MW offshore) at end-2019, from WindEurope, op. cit. note 13, p. 10. Similar numbers for onshore and offshore, with the exception of a year-end total of 7,516 MW offshore, from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, https://www.windguard.com/year-2019.html, and from Deutsche Windguard, *Status of Offshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, https://www.windguard.com/year-2019.html. Also, similar numbers for onshore and offshore additions, but 7.77 GW total offshore at end-2019, from Windpower Intelligence, cited in Campbell, op. cit. note 5. Official data are net additions of 886 MW onshore and 1,111 MW offshore for net total additions of 1,997 MW, and cumulative year-end capacity of 60.8 GW (including 53.3 GW onshore and 7.5 GW offshore), based on data from BMWi and AGEE-Stat, op. cit. note 15, p. 7. Note that Germany data from WindEurope are used in text, figures and reference table for consistent methodology across all countries in Europe.

62 WindEurope, op. cit. note 13, p. 13; U. Hessler, "German wind energy stalls amid public resistance and regulatory hurdles", DW, 4 September 2019, https://www.dw.com/en/german-wind-energy-stalls-amid-public-resistance-and-regulatory-hurdles/a-50280676; D. Weston, "Why Enercon is struggling and Senvion has gone under", Windpower Monthly, 14 November 2019, https://www.windpowermonthly.com/article/1665862/why-enercon-struggling-senvion-gone; J. S. Hill, "'Collapse' of Germany onshore wind is 'jeopardizing' German & EU renewable targets", CleanTechnica, 13 May 2020, https://cleantechnica.com/2019/05/13/collapse-of-german-onshore-wind-is-jeopardizing-german-eu-renewable-targets; R. Hinrichs-Rahlwes, European Renewable Energies Federation and German Renewable Energy Federation (BEE), personal communication with REN21, 3 April 2020. Figure of 16% of the 2017 volume from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 24; auction model introduced in 2017, from WWEA and Landesverband Erneuerbare Energien Nordrhein-Westfalen (LEE NRW), *Community Wind Under the Auctions Model: A Critical Appraisal* (Bonn/Düsseldorf: September 2019), WWEA Policy Paper Series, p. 8, https://wwindea.org/download/community-power-study-september-2019. The downturn results from a number of so-called citizen-owned projects that secured contracts in 2017 without permits and with longer lead times before needing to be online, and many of these have been held up by legal proceedings, from Weston, op. cit. this note. The onshore market has been stalled by permitting, legal and administrative delays as well as NIMBY-ism and the rise of a climate-sceptic political party, from GWEC op. cit. this note, pp. 24, 25.

63 Figure of more than 10 GW stuck in the permitted process based on more than 10 GW from FA Wind, cited in GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25; an estimated 11 GW from reve, "Germany wind power industry in crisis", 17 December 2019, https://www.evwind.es/2019/12/17/germany-wind-power-industry-in-crisis/72559; increase from 10 months to more than two years from EurObserv'ER, op. cit. note 26, p. 7. The time required to get through the permitting process has nearly tripled since 2010, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25. See also WindEurope, "Collapse in wind energy growth jeopardises German and EU renewables targets", press release (Brussels: 10 May 2019), https://windeurope.org/newsroom/press-releases/collapse-in-wind-energy-growth-jeopardises-german-and-eu-renewables-targets.

64 Aviation and military from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25; public resistance and setback from idem, p. 25. Public resistance also from GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 9., and due to projects believed to be too close to residential areas or to concerns about impacts on birds and other wildlife, from Hessler, op. cit. note 62; D. Wetzel, "Collapse of wind power threatens Germany's green energy transition", *Die Welt*, 26 July 2019, https://www.thegwpf.com/collapse-of-wind-power-threatens-germanys-green-energy-transition; setback distance also from Campbell, op. cit. note 5. See also WWEA and LEE NRW, op. cit. note 62. The proposed setback was pending as of early 2020 and the legislative process had stalled, but already the proposed setback was having a significant impact on development of wind power projects in Germany, from Hinrichs-Rahlwes, op. cit. note 62. In May 2020, Germany's coalition government decided to leave the decision on turbine setbacks up to individual regions, from J. Parnell, "Onshore wind compromise averts German solar market crisis", GTM, 18 May 2020, https://www.greentechmedia.com/articles/read/onshore-wind-policy-dispute-could-decimate-germanys-distributed-solar-industry.

65 Deterrents and impacts on community wind from WWEA, "German government clearly misses all three self-imposed goals associated with auctions", press release (Bonn/Düsseldorf/Berlin: 2 September 2019), https://wwindea.org/blog/2019/09/02/german-government-clearly-misses-all-three-self-imposed-goals-associated-with-auctions, and from WWEA and LEE NRW, op. cit. note 62; deterring investors also from Wetzel, op. cit. note 64; privileges for community projects from Institute for Energy Research, "Wind power is collapsing in Germany", 20 August 2019, https://www.instituteforenergyresearch.org/international-issues/wind-power-is-collapsing-in-germany.

66 WindEurope, op. cit. note 13, pp. 13, 21; GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 25. Five of six onshore wind auctions were undersubscribed, from idem, both sources. Volume tendered was 3,675 MW and only 1,847 MW was awarded, and undersubscription was due to difficulties obtaining necessary permits, from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany, Year 2019*, op. cit. note 61, p. 8. A tender held in December was Germany's first onshore wind power tender to be oversubscribed since August 2018, from C. Richard, "Oversubscribed tender brings glimmer of hope to beleaguered German onshore sector", Windpower Monthly, 20 December 2019, https://www.windpowermonthly.com/article/1669738/oversubscribed-tender-brings-glimmer-hope-beleaguered-german-onshore-sector. For more on tenders during the year, see C. Richard, "German tender undersubscribed again", Windpower Monthly, 9 August 2019, https://www.windpowermonthly.com/article/1593487/german-tender-undersubscribed-again; reve, op. cit. note 63.

67 J. Harper, "German wind power blown off course", DW, 21 November 2019, https://www.dw.com/en/german-wind-power-blown-off-course/a-51341340; J. Harper, "Winds of change push German power grid to brink", DW, 3 November 2019, https://www.dw.com/en/winds-of-change-push-german-power-grid-to-brink/a-52701005.

68 Up almost 12% on land and 27% offshore, and total generation in 2019 was 125,975 GWh (101,270 GWh onshore and 24,705 GWh offshore), and share of total gross generation was 21.8% (17.5% onshore and 4.3% offshore), all based on data from BMWi and AGEE-Stat, op. cit. note 15, pp. 44-45. Net generation was up 13% on land (to 106 TWh), from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany*, op. cit. note 61, p. 11; up about 25% offshore (to 25.8 TWh) from Deutsche Windguard, *Status of Onshore Wind Energy Development in Germany*, op. cit. note 61, p. 11; 24.8% share of net generation, based on 127.23 TWh total net generation from wind energy and 513.76 TWh total net generation from all sources, from Fraunhofer ISE, "Annual electricity generation in Germany in 2019", https://www.energy-charts.de/energy.htm?source=all-sources&period=annual&year=2019, updated 1 February 2020.

69 J. Deign, "Germany's maxed-out grid is causing trouble across Europe", GTM, 31 March 2020, https://www.greentechmedia.com/articles/read/germanys-stressed-grid-is-causing-trouble-across-europe; Harper, "Winds of change push German power grid to brink", op. cit. note 67.

70 Curtailment decline from I. Komusanac, WindEurope, Brussels, personal communication with REN21, 29 April 2020; electricity exports declined from 48 TWh in 2018 to about 30 TWh in 2019, and were mostly to Austria and Poland, from Fraunhofer ISE, "Public net electricity generation in Germany 2019: Share from renewables exceeds fossil fuels", press release (Freiburg: 15 January 2020), p. 4, https://www.ise.fraunhofer.de/content/dam/ise/en/documents/News/0120_e_ISE_News_Electricity%20Generation_2019.pdf; transmission target and completion from Bundesnetzagentur, "Bundesnetzagentur veröffentlicht Jahresbericht 2019", press release (Bonn: 30 April 2020), https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2020/20200429_Jahresbericht.html.

71 Deign, op. cit. note 69; Komusanac, op. cit. note 70.

72 WindEurope, op. cit. note 13, pp. 18, 19. Wind energy generated an estimated 417 TWh in the EU during the year, from idem, p. 8. Wind energy generated an estimated 425.984 TWh in the EU-28 during 2019, from EurObserv'ER, op. cit. note 26, p. 6.

73 WindEurope, op. cit. note 13, p. 17.

74 Norway added 780 MW for a total of 2,444 MW, from WindEurope, op. cit. note 13, p. 10; Norway added 769 MW for a total of 2,444 MW, from WWEA, op. cit. note 1; and Norway added 734 MW for a total of 2,444 MW, from IRENA, op. cit. note 1.

75 D. Weston, "Local protests kill Norway's wind plans", Windpower Monthly, 17 October 2019, https://www.windpowermonthly.com/article/1662940/local-protests-kill-norways-wind-plans.

76 Ukraine added 637.1 MW in 2019, up from 67.8 MW in 2019, for a year-end total of 1169.9 MW (including occupied territories in the east), and policy transition all from Ukrainian Wind Energy Association (UWEA), *Wind Power Sector of Ukraine 2019* (Kyiv: 2020), pp. 8, 9, 21. Wind generation was curtailed for the first time in Ukraine in November 2019, due to imports of electricity from the Russian Federation and Belarus; also in 2019, Ukraine transitioned to a new wholesale electricity market in July, based on bilateral, day-ahead, intra-day balancing and ancillary services, compared with the previous single buyer model, all from idem, pp. 15, 29. Ukraine added 577 MW for a total of 1,170 MW, from WWEA, op. cit. note 1; and added 637 MW for a total of 1,258 MW, from IRENA, op. cit. note 1.

77 Capacity of PPAs in Europe during 2019 from Komusanac, op. cit. note 12; auctions from WindEurope, op. cit. note 13, p. 21.

78 Americas added 13,427 MW for a total exceeding 148 GW, from GWEC, "Americas wind installations rise 12% in 2019 to 13.4GW", 4 February 2020, https://gwec.net/americas-wind-installations-rise-12-in-2019-to-13-4gw; regional share of new capacity based on idem, and on data for 2018 (11,891 MW added) from GWEC, "Global Wind Statistics 2019", op. cit. note 1. The Americas (including North and South America, Central America and Caribbean) added 13,233 MW for a total of 146,187 MW, based on data from IRENA, op. cit. note 1.

79 US share based on total regional additions and US-only installations of 9,143 MW, from AWEA, op. cit. note 12, p. 3; third biggest year from idem. The top years were 2012 (13 GW added) and 2009 (10 GW), from GWEC, op. cit. note 78.

80 Additions were 9,143 MW for a year-end total of 105,583 MW, from AWEA, op. cit. note 12, p. 3; additions were 9,137 MW for a year-end total of 105,591, from AWEA, "Wind Powers America Annual Report", press release (Washington, DC: 16 April 2020), https://www.awea.org/resources/news/2020/wind-is-now-america%E2%80%99s-largest-renewable-energy-pro. Total US year-end wind power summer capacity at end-2019 was 103,584.5 MW, including 29.3 MW offshore, not including capacity from facilities with a total generator nameplate capacity of less than 1 MW, from US EIA, op. cit. note 17, Table 6.1; and annual additions totalled 7,165 MW for total available installed US generating capacity at end-2019 of 101.93 GW, from Federal Energy Regulatory Commission, Office of Energy Projects, *Energy Infrastructure Update for December 2019* (Washington, DC: 2019), https://www.ferc.gov/legal/staff-reports/2019/dec-energy-infrastructure.pdf.

81 Figure of 22,115 MW, from AWEA, op. cit. note 12, pp. 3, 4.

82 GWEC, op. cit. note 78. The USD 0.015 per kWh production tax credit (or 18% investment tax credit) is available for wind power projects that begin construction during 2020 and come into operation before the end of 2023, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 60.

83 AWEA, Washington, DC, personal communication with REN21, 8 May 2020. Corporate and utility wind PPAs reached 8,726 MW in 2019, of which 5,266 MW was with utilities, all from AWEA, op. cit. note 12, pp. 3, 4. RPS mandates and corporates also from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 37.

84 AWEA, op. cit. note 12, pp. 3, 4. Utilities signed 5,085 MW, their second highest amount, out of a record total of 8,726 MW of PPAs, from AWEA, *Wind Powers America – Annual Report 2019*, Executive Summary (Washington, DC: 2020), p. 5, https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/amr2019_executivesummary. Most of the projects under construction were expected to come online in 2020 to receive the full PTC value, from AWEA, op. cit. note 12, pp. 3, 4.

85 AWEA, op. cit. note 12, p. 7.

86 The six states were Texas with 28,843 MW, Iowa (10,190 MW), Oklahoma (8,172 MW), Kansas (6,128), California (5,973 MW) and Illinois (5,350 MW), and cumulative capacity in Texas, all from AWEA, op. cit. note 12, pp. 7, 8. Another 13 states had more than 1 GW at year's end, from idem.

87 The Southwest Power Pool, the grid throughout much of the US Midwest, saw wind's share of generation reach 66.5% in April 2019, from C. Walter, "Wind breaks a new record in Southwest Power Pool", AWEA, 26 April 2019, https://www.aweablog.org/wind-breaks-new-record-southwest-power-pool. Several other regional grids also broke wind output or penetration records in 2018 and 2019, from idem. See, for example: G. Alvarez, "2018 highlights: Six trends shaping the future of wind power", AWEA, 10 January 2019, https://www.aweablog.org/2018-highlights-six-trends-shaping-future-wind-power; E. Douglas, "Texas wind generation breaks record, ERCOT reports", *Houston Chronicle*, 20 December 2018, https://www.chron.com/business/energy/article/Texas-wind-generation-breaks-record-ERCOT-13481063.php; R. Druzin, "Texas grid operator reports record amount of wind generation", *Houston Chronicle*, 16 November 2018, https://www.chron.com/business/energy/article/Texas-grid-operator-reports-record-amount-of-wind-13398202.php; G. Alvarez, "A huge record in the Southwest Power Pool", AWEA, 22 March 2018, http://www.aweablog.org/huge-new-record-southwest-power-pool.

88 K. Balaraman, "Wind plants can provide grid services similar to gas, hydro, easing renewables integration: CAISO", Utility Dive, 13 March 2020, https://www.utilitydive.com/news/wind-plants-can-provide-grid-services-similar-to-gas-hydro-easing-renewab/574070; C. Loutan et al., *Avangrid Renewables Tule Wind Farm: Demonstration of Capability to Provide Essential Grid Services* (Folsom, CA: California ISO, Avangrid Renewables, General Electric, 11 March 2020), http://www.caiso.com/Documents/WindPowerPlantTestResults.pdf.

89 Based on data from US EIA, op. cit. note 17, Tables 1.14.B and 1.3.B

90 States include Iowa (42%), Kansas (41.4%), Oklahoma (34.6%), North Dakota (26.8%), South Dakota (23.9%), Maine (23.8%), Nebraska (19.9%), New Mexico (19.5%), Colorado (19.4%), Minnesota (19.1%), Vermont (17.6%), Texas (17.5%) and Idaho (16.2%), all based on data from US EIA, op. cit. note 17, Tables 1.14.B and 1.3.B. Figures of 7.3% in 2019 and 6.5% of US total generation in 2018 based on data for utility-scale facilities net generation during 2018 from idem, Table ES1.B.

91 US EIA, "Wind has surpassed hydro as most-used renewable electricity generation source in U.S.", 26 February 2020, https://www.eia.gov/todayinenergy/detail.php?id=42955.

92 The region added 3,686.5 MW in 2019 based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Added 3,470 MW for a total of 29,190 MW, based on data for Central America and the Caribbean, South America and Mexico, from IRENA, op. cit. note 1.

93 The decline in installations relative to 2018 was about 1.3%, based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1; due to decline in Brazil and others made up for Brazil's decline based on data from idem, and from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 39.

94 Figure of 29.2 GW based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44; number of countries based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.

95 Mexico added 1,284 MW, followed by Argentina (931 MW), Brazil (745 MW), and Chile added a record 526 MW, all from GWEC, op. cit. note 78. Data align for every country except Chile, which added only 170 MW in 2019, from Windpower Intelligence, cited in Campbell, op. cit. note 5. Argentina ended the year with a total of 1,571 MW, Chile with a total of 1,889 MW, and Uruguay added no new capacity and ended the year with a total of 1,647 MW, all from Windpower Intelligence, op. cit. this note. Mexico added 1,716 MW for a total of 6,591 MW, Argentina added 859 MW for a total of 1,609 MW, Brazil added 531 MW for a total of 15,364 MW, and Chile added 96 MW for a total of 1,620 MW, from IRENA, op. cit. note 1; and Mexico added 1,280 MW for a total of 6,215 MW, Argentina added 882 MW for a total of 1,604 MW, Brazil added 745 MW for a total of 15,452 MW, and Chile added 529 MW for a total of 2,150 MW, from WWEA, op. cit. note 1.

96 GWEC, op. cit. note 78; a total of 1,174 MW of wind power capacity, in seven projects, received 15-year PPAs, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 46. Ecuador also launched a tender for wind power, in July 2019, from G. Fenés, "Exclusivo: los pliegos de la subasta de energías renovables que lanzó el Gobierno de Ecuador", 2 August 2019, Energía Estratégica, https://www.

energiaestrategica.com/exclusivo-los-pliegos-de-la-subasta-de-energias-renovables-que-lanzo-el-gobierno-de-ecuador (using Google Translate).

97 OLADE and GWEC, cited in GWEC, "Public tenders and auctions have driven 80% of current renewable energy capacity in Latin America and the Caribbean", op. cit. note 11; OLADE, "Public tenders and auctions have boosted 80% of the current renewable energy capacity in Latin America and the Caribbean", 19 March 2020, http://www.olade.org/noticias/public-tenders-and-auctions-have-boosted-80-of-the-current-renewable-energy-capacity-in-latin-america-and-the-caribbean/?lang=en. Role of auctions also from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 48.

98 Rankings, Mexico's additions (1,281 MW) and cumulative capacity of 6,215 MW based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Mexico had a total of nearly 6 GW at year's end, from Windpower Intelligence, cited in Campbell, op. cit. note 5. Wind power grew 26%, adding a record 1,280 MW, from Mexican Association of Wind Energy, cited in "Las energías renovables baten su récord en México pese a las tensiones con el Gobierno", *El Pais*, 26 February 2020, https://elpais.com/economia/2020/02/26/actualidad/1582694040_481642.html (using Google Translate). In 2019, about 65% of production resulted from long-term power auction, especially the first and second auctions, in 2015 and 2016; the third auction was in 2017, and about half of contracted capacity was under construction as of early 2020, from idem. Note that Mexico had 6,590 MW of wind power capacity at the end of 2019, up from 4,875 MW (net additions of 1,715 MW), and wind energy accounted for 8% of Mexico's electricity generation during the year, from "Sector eólico alerta: riesgo en empleos", Heraldo de México, 12 March 2020, https://heraldodemexico.com.mx/mer-k-2/sector-eolico-alerta-riesgo-en-empleos (using Google Translate).

99 GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 4; GWEC, op. cit. note 78.

100 On-off policies and auctions, from GWEC, *Global Wind Report 2019*, op. cit. note 1, and from Zhao, op. cit. note 7, 4 May 2020. Doubling and year-end capacity based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Argentina added 931 MW in 2019 for a year-end total of nearly 1,604 MW, from idem. See also S. Marcacci, "Argentina may be the hottest renewable energy market you haven't heard of. Can it spur a global boom?" *Forbes*, 15 October 2019, https://www.forbes.com/sites/energyinnovation/2019/10/15/argentina-may-be-the-hottest-renewable-energy-market-you-havent-heard-of-can-it-spur-a-global-boom.

101 Reve, "Wind energy in Argentina: The largest wind farm begins to operate", EV Wind, 26 September 2019, https://www.evwind.es/2019/09/26/wind-energy-in-argentina-the-largest-wind-farm-begins-to-operate/71068. It has been estimated that the project will generate some 987 GWh annually, from idem.

102 Lowest since 2011 based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1, and from Windpower Intelligence, cited in Campbell, op. cit. note 5; break in auction schedule from Zhao, op. cit. note 7; Brazil added more wind (971 MW) than thermal (776 MW) power capacity in 2019, from reve, "75% of Brazil's new power comes from hydroelectric, wind energy and solar power", 19 January 2020, https://www.evwind.es/2020/01/19/75-of-brazils-new-power-comes-from-hydroelectric-wind-energy-and-solar-power/73131. Note, however, that GWEC data provide a lower number for wind power additions in 2019, of 745 MW, from GWEC, op. cit. this note.

103 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 23. About 70% has been sold for private PPAs compared with 30% for private auctions, from E. Feitosa, Eólica Tecnologia, Brazil, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world.

104 Brazil added 745 MW to end 2019 with 15,452.4 MW of wind power capacity, compared with a regional total (including Mexico) of 29,223 MW, based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1. Brazil had a total of 15,418 GW of wind power capacity in place as of mid-December 2019, up from 14,704 MW at the end of 2018, from Associação Brasileira de Energia Eólica (ABEEólica), *Infowind Brazil* (No. 14, 13 December 2019), http://abeeolica.org.br/wp-content/uploads/2020/02/Infovento-14_ENG.pdf. Brazil added a net of 855 MW in 2019, based on year-end capacity of 6,385 MW, from ONS, "Geração de energia – composição", for period 1 January 2019 to 31 December 2019, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx; and on end-2018 capacity of 5,530 MW, from ONS, "Geração de energia – composição", for period 1 January 2018 to 31 December 2018, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx. Brazil added 971 MW in 2019, from reve, "75% of Brazil's new power comes from hydroelectric, wind energy and solar power", 19 January 2020, https://www.evwind.es/2020/01/19/75-of-brazils-new-power-comes-from-hydroelectric-wind-energy-and-solar-power/73131.

105 Data for 2019 based on total annual generation of 593,591 GWh and annual wind energy generation of 55,932 GWh, and 2018 based on total annual generation of 581,923 GWh and annual wind energy generation of 48,443 GWh, all from ONS, "Geração de energia – composição", for period 1 January 2019 to 31 December 2019, op. cit. note 104.

106 Figures of 597 MW added and year-end total of 13,413 MW, from Canadian Wind Energy Association (CanWEA), "Installed capacity", December 2019", https://canwea.ca/wind-energy/installed-capacity, viewed 5 March 2020. Canada added a modest 537 MW for total of about 13.5 GW, Campbell, op. cit. note 5.

107 CanWEA, "National", https://canwea.ca/wind-energy/national, viewed 25 March 2020; drivers from P. McKay, CanWEA, cited in N. Hendley, "Windfall in wind energy?" Canadian Metal Working, 1 April 2020, https://www.canadianmetalworking.com/canadianmetalworking/article/metalworking/windfall-in-wind-energy.

108 Ontario ended the year with 5,436 MW, followed by Quebec (3,882 MW) and Alberta (1,685 MW), from CanWEA, op. cit. note 106.

109 Zhao, op. cit. note 7.

110 Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), pp. 78-82, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf.

111 Australia added 837.1 MW across eight projects for a total of 6,279.4 MW, from Ibid., pp. 9, 78, 79, 82. Australia added 837 MW for a total of 6,199 MW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44.

112 Wind power generated 19.487 TWh in 2019, accounting for 8.5% of Australia's total generation, followed (among renewables) by hydropower (14.166 TWh) and large-scale solar power (5.141 TWh), from Clean Energy Council, op. cit. note 110, pp. 6, 9, 79, 81.

113 Based on data for South Australia (29.2%), Victoria (27.8%) and New South Wales (22.9%), from Green Energy Markets, cited in Clean Energy Council, op. cit. note 110, p. 80; shares in 2018 were South Australia (35%), Victoria (28%) and New South Wales (19%), from Clean Energy Council, op. cit. note 9, pp. 72-76.

114 Clean Energy Council, op. cit. note 110, pp. 4, 7. See also Solar PV section in this chapter for more on challenges in Australia, and S. Paul, "Australia's solar, wind boom to power past grid woes in 2019", *Reuters*, 20 January 2019, https://www.reuters.com/article/us-australia-renewables-idUSKCN1PE0V8. Australia is seeing an increasing number of large-scale projects (both wind and solar) that need connection to a 5,000-kilometre transmission line that was built to carry electricity from coal plants near three large mining areas, and not designed to carry electricity from variability and remote wind and solar projects. Delays in project approvals and grid connections are causing project delays and unanticipated costs for developers who fail to account for grid-related issues (e.g., congestion, curtailment), all from Paul, op. cit. this note.

115 Clean Energy Council, op. cit. note 110, p. 78.

116 Based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1.

117 Figure of 2.6% from GWEC, "Over 60GW of wind energy capacity installed in 2019, the second-biggest year in history", 25 March 2020, https://gwec.net/gwec-over-60gw-of-wind-energy-capacity-installed-in-2019-the-second-biggest-year-in-history. An estimated 894 MW was added in 2019, from GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019, market expected to grow by over 10GW by 2024", 12 February 2020, https://gwec.net/africa-and-middle-east-add-894mw-of-wind-energy-capacity-in-2019-market-expected-to-grow-by-over-10gw-by-2024. All Africa added 300 MW and the Middle East added 109 MW, for total additions of 409 MW in 2019, bringing the year-end totals for 5,765 MW in Africa and 723 MW in the Middle East, for combined cumulative capacity of 6,488 MW at end-2019, based on data from IRENA, op. cit. note 1.

118 Numbers of countries by region from Zhao, op. cit. note 7, and

capacities based on data from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 44, and GWEC, "Global Wind Statistics 2019", op. cit. note 1. Similar year-end capacities for these countries (2,094 MW in South Africa, 1,220 MW in Morocco, and 1,375 MW in Egypt) from IRENA, op. cit. note 1. Capacity also was added during 2019 in Israel (89 MW for a total of 374 MW) and Iran (20 MW for a total of 302 MW), with a total of 19 countries in Africa and 9 in the Middle East having wind capacity in operation (although many of the additional countries have fewer than 5 MW), all from idem.

119 GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019", op. cit. note 117.

120 GWEC, "Global Wind Statistics 2019", op. cit. note 1; GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019", op. cit. note 117. All of Ethiopia's new capacity was in the Aysha II Wind Farm project. Data were supplied by Chinese Dongfang to GWEC, from Zhao, op. cit. note 7. Egypt added 363 MW for a total of 1,573 MW, from Campbell, op. cit. note 5. Note that several sources say the Lake Turkana wind project in Kenya commenced operations during 2019. See, for example, "Kenya launches largest wind power plant in Africa", CNN Marketplace Africa, 20 July 2019, https://edition.cnn.com/2019/07/20/africa/africas-largest-wind-farm-intl. However, the project was announced by Vestas (Denmark) in 2018, so was included in GWEC's data for 2018, from Zhao, op. cit. note 7, and was reported as connected to the national grid as of December 2018, from Lake Turkana Wind Power, "Lake Turkana wind power connected to the national grid", 9 December 2018, https://ltwp.co.ke/ltwp-connected-to-grid. As a result, the project was included as newly installed capacity in GSR 2019. Data also conflict for South Africa, probably due to differences in timing of reporting: the local wind energy association in South Africa reported to GWEC that no new capacity came online in 2019, from Zhao, op. cit. note 7, whereas the country added 120 MW in 2019, from Campbell, op. cit. note 5. Per IRENA, Africa added capacity during 2019 only in Egypt (250 MW) and Senegal (50 MW), from IRENA, op. cit. note 1.

121 R. Ranjan, "ENGIE Africa commissions Egypt's largest wind farm", Mercom India, 12 November 2019, https://mercomindia.com/engie-africa-commissions-egypt-largest-wind-farm.

122 Egypt's target from Campbell, op. cit. note 5; pipeline from K. Benhamou, Sahara Wind, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world.

123 C. Richard, "First power from first West African wind farm", Windpower Monthly, 12 December 2019, https://www.windpowermonthly.com/article/1668654/first-power-first-west-african-wind-farm; A. Frangoul, "West Africa's first large-scale wind farm starts generating power", CNBC Sustainable Energy, 13 December 2019, https://www.cnbc.com/2019/12/13/west-africas-first-large-scale-wind-farm-starts-generating-power.html; A. O. Diallo, "Sénégal: le plus grand parc éolien d'Afrique de l'Ouest prend forme à Taiba Ndiaye", Jeune Afrique, 27 May 2019, https://www.jeuneafrique.com/780416/economie/senegal-le-plus-grand-parc-eolien-dafrique-de-louest-prend-forme-a-taiba-ndiaye.

124 Jordan added 190 MW and Iran added 50 MW, from GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019", op. cit. note 117.

125 "Oil giant Saudi Arabia set to build first wind-power plant", Bloomberg, 26 July 2019, https://www.bloomberg.com/professional/blog/oil-giant-saudi-arabia.

126 Ibid.

127 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 13, GWEC, "Record 6.1 GW of new offshore wind capacity installed globally in 2019", 19 March 2019, https://gwec.net/record-6-1-gw-of-new-offshore-wind-capacity-installed-globally-in-2019; Europe data also from WindEurope, op. cit. note 13, p. 10. Note that 16 new offshore windfarms went into operation (meaning all turbines in the project were installed and first electricity had been generated by end-2019) in six countries (China, United Kingdom, Germany, Denmark, Belgium and Chinese Taipei) for record annual additions of 5,194 GW in 2019, bringing total capacity to 27,213 MW, from World Forum Offshore Wind, *Global Offshore Wind Report 2019* (Hamburg: February 2020), pp. 3, 4, https://x6a3i7a8.stackpathcdn.com/wp-content/uploads/2020/02/WFO_WindReport2019.pdf. This compares with 2018, when seven countries in Europe and two in Asia connected 4.5 GW (same capacity as in 2017), increasing cumulative global capacity by 24% to 23.1 GW, based on data from GWEC, op. cit. note 7. Note that offshore capacity increased by 4,679 MW in 2019, to a total of 28,308 MW, based on data from IRENA, op. cit. note 1.

128 Figure of less than 5% of capacity based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 1; figures of 10% of global installations in 2019, up from 5% in 2015, from GWEC, op. cit. note 127. Offshore accounted for 12% of commissioned wind power capacity in 2019, up from 8% in 2018, from C. Richard, "Vestas leads the pack with squeezed market share", Windpower Monthly, 18 February 2020, https://www.windpowermonthly.com/article/1674420/vestas-leads-pack-squeezed-market-share. Investment from C. Richard, "Offshore wind spending reaches record high in 2019", Windpower Monthly, 16 January 2020, https://www.windpowermonthly.com/article/1671093/offshore-wind-spending-reaches-record-high-2019; "Late surge in offshore wind financings helps 2019 renewables investment to overtake 2018", BloombergNEF, 16 January 2020, https://about.bnef.com/blog/late-surge-in-offshore-wind-financings-helps-2019-renewables-investment-to-overtake-2018.

129 GWEC, op. cit. note 127.

130 China completed 2,395 MW of capacity in 2019, from GWEC, op. cit. note 127; total of 6,838 MW, from GWEC, *Global Wind Report 2019*, op. cit. note 1, pp. 44, 61. China completed nine projects for a total of 2,450 MW, from Campbell, op. cit. note 5. National target from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 61.

131 Record installations and policy drivers from GWEC, "Webcast on wind: Market update and outlook for global offshore wind", 19 March 2020; reductions in the FIT from L. Yuanyuan, "China drops electricity subsidy price for offshore wind power", Renewable Energy World, 1 July 2019, https://www.renewableenergyworld.com/articles/2019/07/china-drops-electricity-subsidy-price-for-offshore-wind-power.html; take advantage before it expires from Richard, "Offshore wind spending reaches record high in 2019", op. cit. note 128.

132 GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 61.

133 Ibid., p. 63. More than 40 GW of projects had been approved by national or provincial governments by year's end, with half located in Guangdong, from idem, p. 62.

134 Commissioned 120 MW and 2025 target, from Campbell, op. cit. note 5; figure of 120 MW and first utility-scale offshore project from GWEC, op. cit. note 131; further 10 GW target from "Taiwan plans additional 10GW offshore", reNEWS, 12 November 2019, https://renews.biz/56366/taiwan-plans-additional-10gw-offshore, and from GWEC, "Market to watch: Taiwan offshore wind", 16 January 2020, https://gwec.net/market-to-watch-taiwan-offshore-wind.

135 Japan's 3 MW of floating capacity from GWEC, op. cit. note 127; Japan had 65.6 MW of offshore capacity including 19 MW of floating capacity in five turbines, from B. Backwell, GWEC, "Take offshore wind global", presentation for Renewable Energy Institute, REvision – Webinar, 4 March 2020, Slide 16, https://www.renewable-ei.org/pdfdownload/activities/11_BenBackwell.pdf; capacity in the pipeline (14 GW) from Japan Wind Power Association, "Total capacity of wind in Japan by end of 2019" (Japanese only), provided by H. Matsubara, Institute for Sustainable Energy Policies, personal communication with REN21, April 2020. Capacity in pipeline was 13 GW, from Japan's Ministry of Economy, Trade and Industry, cited in O. Tsukimori, "With coal under fire, 2020 could be a big year for wind power in Japan", *Japan Times*, 2 January 2020, https://www.japantimes.co.jp/news/2020/01/02/business/wind-power-2020-japan. Getting through Japan's environmental assessment process takes 4-5 years; as of January 2020, there was 14.8 GW of offshore wind capacity in the pipeline, from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 64. Vietnam from GWEC, op. cit. note 131, and from GWEC, *Global Wind Report 2019*, op. cit. note 1, p. 50; India from GWEC, *Global Offshore Wind Report 2019* (Brussels: 2019), p. 9.

136 Europe added 3,627 MW for total of 22,069 MW, and national data all from WindEurope, op. cit. note 13, pp. 8, 10. Up 36% based on 2,661 MW added in 2018, from Komusanac, op. cit. note 12, and increase of 36.5% over 2018, from Zhao, op. cit. note 7. Europe added a gross capacity of 3,627 MW (3,623 MW net), and two turbines of 2 MW each were decommissioned in the United Kingdom, for a cumulative total of 22,072 MW offshore, from WindEurope, *Offshore Wind in Europe: Key Trends and Statistics 2019* (Brussels: February 2020), pp. 7, 8, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2019.pdf.

137 WindEurope, op. cit. note 13, pp. 8, 10. Denmark's 407 MW Horns Rev 3, completed in 2019, is reportedly the country's largest wind

farm and was expected to increase wind generation in Denmark by 12%, from "Denmark opens country's largest wind farm with royal inauguration", Smart Energy International, 23 August 2019, https://www.smart-energy.com/renewable-energy/denmark-opens-countrys-largest-wind-farm-with-royal-inauguration, and from A. Frangoul, "Scandinavia's biggest offshore wind farm is officially open", CNBC, 23 August 2019, https://www.cnbc.com/2019/08/23/scandinavias-biggest-offshore-wind-farm-is-officially-open.html.

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BACK

ENERGY EFFICIENCY AND RENEWABLES

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28 Based on IEA, op. cit. note 17.

29 Based on Ibid. and on Enerdata, op. cit. note 17.

30 Based on IEA, op. cit. note 17, World Bank, op. cit. note 26 and Enerdata, op. cit. note 17. Without these improvements in final energy intensity, the estimated share of modern renewables in TFEC in 2017 could have been 9.2%, as opposed to the actual share of 10.2%. These calculations are an imperfect approximation and assume that the remaining demand in a case of stagnant energy intensity would be supplied by non-renewable resources.

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41 IEA, op. cit. note 16; energy demand of buildings based on IEA, op. cit. note 17.

42 Based on IEA, op. cit. note 17.

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FEATURE: PUBLIC SUPPORT FOR RENEWABLES

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14 **Table R14** from sources in endnote 1 of this section.

15 **Table R15** from sources in endnote 1 of this section.

16 **Table R16** from the following sources: Unless noted otherwise, data for end-2018 from the following: IEA Photovoltaic Power Systems Programme (PVPS), *Trends 2019 in Photovoltaic Applications: Survey Report of Selected IEA Countries Between 1992 and 2018* (Paris: 2019), pp. 96, 97, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/5319_iea-pvps_report_2019_08_lr.pdf; Becquerel Institute, Brussels, personal communication with REN21, February-May 2020; SolarPower Europe, *EU Market Outlook for Solar Power, 2019-2023* (Brussels: December 2019), https://www.solarpowereurope.org/wp-content/uploads/2019/12/SolarPower-Europe_EU-Market-Outlook-for-Solar-Power-2019-2023_.pdf; SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023* (Brussels: 2019), p. 22, https://www.solarpowereurope.org/global-market-outlook-2019-2023. Data for 2019 from the following: IEA PVPS, *Snapshot of Global PV Markets 2020* (Paris: April 2020), https://iea-pvps.org/wp-content/uploads/2020/04/IEA_PVPS_Snapshot_2020.pdf; Becquerel Institute, op. cit. this note; SolarPower Europe, *EU Market Outlook for Solar Power, 2019-2023*, op. cit. this note; and sources provided below. This report aims to provide all solar PV data in direct current (DC) units. Note that some countries (for example, Canada, Chile, India, Japan, Malaysia, Sweden and the United States) report data officially in alternating current (AC); for consistency across countries, AC data were converted to DC by the relevant sources listed. Additional country sources are as follows: **China:** Total end-2018 from the following: Becquerel Institute, op. cit. this note; China's National Energy Administration (NEA), "2018 added solar PV capacities," Finance World, 28 January 2019, https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&for=pc (using Google Translate); NEA, "Photovoltaic power generation statistics for 2018," 19 March 2019, http://www.nea.gov.cn/2019-03/19/c_137907428.htm (using Google Translate); China Electricity Council (CEC), cited in China Energy Portal, "2018 electricity & other energy statistics," 25 January 2019, https://chinaenergyportal.org/en/2018-electricity-other-energy-statistics. Additions and total in 2018 from NEA, "PV grid-connected operation in 2019", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827923.htm (using Google Translate), and from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 10. **United States:** Solar Energy Industries Association and Wood Mackenzie, *U.S. Solar Market Insight, 2019 Year in Review – Executive Summary* (Washington, DC: March 2020), p. 5, https://www.woodmac.com/research/products/power-and-renewables/us-solar-market-insight; US EIA, *Electric Power Monthly with Data for December 2019* (Washington, DC: February 2020), Table 6.1, https://www.eia.gov/electricity/monthly/archive/february2020.pdf. **India:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 10; Government of India, MNRE, "Physical progress (achievements)", http://mnre.gov.in/mission-and-vision-2/achievements, viewed 30 January 2019; MNRE, "Physical progress (achievements)", https://mnre.gov.in/the-ministry/physical-progress, viewed 9 January 2020. **Japan:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; RTS Corp, cited in T. Ohigashi and I. Kaizuka, "The beginnings of a post FIT-market", pv magazine, 25 February 2020, https://www.pv-magazine.com/2020/02/25/the-beginnings-of-a-post-fit-market; data in AC, based on grid-connected capacity of utilities, provided by H. Matsubara, Institute for Sustainable Energy Policies, Tokyo, personal communication with REN21, 14 April 2020. **Vietnam:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; Becquerel Institute, provided by A. Detollenaere, Becquerel Institute, personal communication with REN21, 10 April 2020. **Spain:** Carlos De Sande, Unión Española Fotovoltaica (UNEF), Madrid, personal communication with REN21, 28 May 2020. UNEF numbers are based on data from the Spanish system operator RED Eléctrica de España, which are in DC and for utility-scale plants only, plus UNEF's estimates of solar PV capacity for self-consumption. See also RED Eléctrica de España, "Potencia instalada nacional (MW) – nacional", data as of April 2020, https://www.ree.es/es/datos/publicaciones/series-estadisticas-nacionales. **Germany:** German Federal Ministry for Economic Affairs and Energy and Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Time Series for the Development of Renewable Energy Sources in Germany, Based on Statistical Data from the Working Group on Renewable Energy Statistics* (AGEE-Stat)(Status: February 2020) (Dessau-Roßlau: February 2020), p. 7, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html.

Australia: IEA PVPS, *Trends 2019 in Photovoltaic Applications*, op. cit. this note, p. 25; Australian Photovoltaic Institute, personal communication with REN21, 12 May 2020; IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), pp. 4, 6, 18, 69, 72, 76, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf. **Ukraine:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, pp. 6, 12, Becquerel Institute, provided by Detollenaere, op. cit. this note; Ukrainian Wind Energy Association, *Wind Power Sector of Ukraine 2019* (Kyiv: February 2020), p. 18. **Republic of Korea:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note; Becquerel Institute, provided by Detollenaere, op. cit. this note. **Italy:** IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, pp. 8, 10; Becquerel Institute, provided by Detollenaere, op. cit. this note; Italian renewables association Anie Rinnovabili and grid operator Terna, cited in E. Bellini, "Italy deployed 737 MW of solar in 2019", pv magazine, 21 April 2020, https://www.pv-magazine.com/2020/04/21/italy-deployed-737-mw-of-solar-in-2019. **United Kingdom:** UK BEIS, "Solar photovoltaics deployment in the UK", https://www.gov.uk/government/statistics/solar-photovoltaics-deployment, updated 27 February 2020. See Solar PV section in Market and Industry chapter and related endnotes for additional statistics and details.

17 **Table R17** from the following sources: New Energy Update, "CSP Today global tracker", http://tracker.newenergyupdate.com/tracker/projects, viewed on numerous dates leading up to 27 April 2020; US National Renewable Energy Laboratory, "Concentrating solar power projects", https://solarpaces.nrel.gov, with the page and its subpages viewed on numerous dates leading up to 27 April 2020 (some subpages are referenced individually throughout the CSP section) and references cited in the CSP section of Renewable Energy Policy Network for the 21st Century (REN21), *Renewables 2019 Global Status Report* (Paris: 2019), pp. 107-09, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf. In some cases, information from the above sources was verified against additional country specific sources, as cited in the endnotes for the CSP section. Global CSP data are based on commercial facilities only; demonstration and pilot facilities are excluded, with the exception of certain plants in China that are described as "demonstration" plants by the government but are nonetheless large- (utility-) scale, grid-connected plants that are operating or will operate commercially. Data discrepancies between REN21 and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals.

18 **Table R18** from the following sources: cumulative solar thermal capacity in operation nationally and globally at end-2018 from M. Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communications with REN21, March-May 2020; W. Weiss and M. Spörk-Dür, *Solar Heat Worldwide. Global Market Development and Trends in 2019, Detailed Market Figures 2018* (Gleisdorf, Austria: IEA Solar Heating and Cooling Programme, 2020), https://www.iea-shc.org/solar-heat-worldwide. Gross additions on a national level from the following associations and experts: David Ferrari, Sustainability Victoria, Melbourne, Australia; Werner Weiss, AEE INTEC, Vienna, Austria; Danielle Johann, Brazilian Solar Thermal Energy Association (ABRASOL), São Paulo, Brazil; Hongzhi Cheng, Shandong SunVision Management Consulting, Dezhou, China; Panayiotis Kastanias, Cyprus Union of Solar Thermal Industrialists (EBHEK), Nicosia, Cyprus; Daniel Trier and Jan Erik Nielson, PlanEnergi, Skørping, Denmark; Andrea Liesen, BSW Solar, Berlin, Germany; Costas Travasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; Jaideep Malaviya, Solar Thermal Federation of India (STFI), Pune, India; Eli Shilton, Elsol, Kohar-yair, Israel; Federico Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milan, Italy; Daniel Garcia, Solar Thermal Manufacturers Organisation (FAMERAC), Mexico City, Mexico; Janusz Staroscik, Association of Manufacturers and Importers of Heating Appliances (SPIUG), Warsaw, Poland; Karin Kritzinger, Centre for Renewable and Sustainable Energy Studies, University of Stellenbosch, Stellenbosch, South Africa; Pascual Polo, Spanish Solar Thermal Association (ASIT), Madrid, Spain; Abdullah Azzam, Palestinian Central Bureau of Statistics, Ramallah, State of Palestine; David Stickelberger, Swissolar, Zurich, Switzerland; Abdelkader Baccouche, ANME, Tunis, Tunisia; Kutay Ülke, Bural Heating, Kayseri, Turkey; Les Nelson, Solar Heating & Cooling Programs at the International Association of Plumbing and Mechanical Officials (IAPMO), Ontario, California, United States, all personal communications with REN21, February-April 2020. Data for China and World Total assume that systems in China have a 10-year operational lifetime; national data for all other countries reflect a 25-year lifetime, with the exceptions of Turkey (14 years prior to 2018, and 15 years starting with 2018) and Germany (20 years). Total gross additions worldwide for 2018 are based on estimates from Spörk-Dür, op. cit. this note.

19 **Table R19** from the following sources: Unless noted otherwise, data are from the following: Global Wind Energy Council (GWEC), *Global Wind Report 2019* (Brussels: March 2020), pp. 13, 42, 43, https://gwec.net/global-wind-report-2019; GWEC, "Global Wind Statistics 2019: Status as End of 2019" (Brussels: March 2020); WindEurope, *Wind Energy in Europe in 2019: Trends and Statistics* (Brussels: 2020), pp. 8, 10, 13, 15, 16, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf; World Wind Energy Association (WWEA), "Global wind installations", https://library.wwindea.org/global-statistics, viewed 16 April 2020. **China:** Official total for end-2018 from NEA, "2018 wind power grid operation", 28 January 2019, http://www.nea.gov.cn/2019-01/28/c_137780779.htm (using Google Translate), and from NEA and CEC, cited in China Energy Portal, "2018 wind power installations and production by province", 28 January 2019, https://chinaenergyportal.org/en/2018-wind-power-installations-and-production-by-province, viewed 30 April 2020; official data for 2019 additions and total from NEA, cited in National Energy Board, "2019 wind power grid operation", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827910.htm (using Google Translate), and from NEA and CEC, cited in China Energy Portal, "2019 wind power installations and production by province", 28 February 2020, https://chinaenergyportal.org/en/2019-wind-power-installations-and-production-by-province. Unofficial data from H. Yu, Chinese Wind Energy Association, personal communication with REN21, 18 May 2020, and from GWEC, "Global Wind Statistics 2019", op. cit. this note; unofficial data for 2019 additions and total from GWEC, idem. **United States:** American Wind Energy Association (AWEA), *U.S. Wind Industry Quarterly Market Report, Fourth Quarter 2019* (Washington, DC: January 2020), p. 3, https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/4q2019_marketreport; AWEA, "Wind Powers America Annual Report", press release (Washington, DC: 16 April 2020), https://www.awea.org/resources/news/2020/wind-is-now-america%E2%80%99s-largest-renewable-energy-pro. **United Kingdom:** WindEurope, op. cit. this note, pp. 8, 16. Also based on data from UK BEIS, op. cit. note 1, viewed 29 April 2020. **India:** Government of India, MNRE, cited in Ministry of Power, Central Electricity Authority (CEA), "All India installed capacity (in MW) of power stations (as on 31.01.2019) (utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2020/installed_capacity-01.pdf; Government of India, MNRE, cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2018) (utilities)", p. 1, http://www.cea.nic.in/reports/monthly/installedcapacity/2018/installed_capacity-12.pdf; GWEC, *Global Wind Report 2019*, op. cit. this note. **Spain:** WindEurope, op. cit. this note, pp. 8, 10; Red Eléctrica de España, "Potencia instalada nacional (MW)", as of 31 December 2019, https://www.ree.es/es/datos/publicaciones/series-estadisticas-nacionales. **Germany:** WindEurope, op. cit. this note, pp. 10, 16; Federal Ministry for Economic Affairs and AGEE-Stat, op. cit. note 16, p. 7; Deutsche Windguard, *Status of Offshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, https://www.windguard.com/year-2019.html; Deutsche Windguard, *Status of Offshore Wind Energy Development in Germany, Year 2019* (Varel, Germany: 2020), p. 3, https://www.windguard.com/year-2019.html. **Sweden:** WindEurope, op. cit. this note, pp. 10, 11, 13. **France:** WindEurope, idem, p. 10. Also based on data from Réseau de transport d'électricité (RTE), *Bilan Électrique 2019* (Paris: 2020), p. 27, https://www.rte-france.com/sites/default/files/bilan-electrique-2019_1.pdf. **Mexico:** GWEC, "Global Wind Statistics 2019", op. cit. this note; Mexican Association of Wind Energy, cited in "Las energías renovables baten su récord en México pese a las tensiones con el Gobierno", *El Pais*, 26 February 2020, https://elpais.com/economia/2020/02/26/actualidad/1582694040_481642.html (using Google Translate). **Argentina:** GWEC, "Global Wind Statistics 2019", op. cit. this note. **Brazil:** GWEC, idem. Also based on data from Associação Brasileira de Energia Eólica (ABEEólica), *Infowind Brazil*, no. 14

(13 December 2019), http://abeeolica.org.br/wp-content/uploads/2020/02/Infovento-14_ENG.pdf; Operador Nacional do Sistema Eléctrico (ONS), "Geração de energia – composição", for period 1 January 2019 to 31 December 2019, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx; ONS, "Geração de energia – composição", for period 1 January 2018 to 31 December 2018, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx. **Canada:** End-2018 from CanWEA, "Installed capacity", December 2018, https://canwea.ca/wind-energy/installed-capacity, viewed 11 March 2019; additions and total in 2019 from CanWEA, "Installed capacity", December 2019, https://canwea.ca/wind-energy/installed-capacity, viewed 5 March 2020. **Italy:** WindEurope, op. cit. this note, p. 10. Also based on data from D. A. Garcia, Italian Wind Energy Association, presentation for WWEA, "Webinar: Wind power markets around the world", 8 April 2020, https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world. See Wind Power section in Market and Industry chapter and related endnotes for additional statistics and details.

20 **Table R20** from the following sources: share of population with access derived from IEA, *World Energy Outlook 2019 Access to Electricity Database*, https://iea.blob.core.windows.net/assets/ecaa2844-dce8-4710-80fb-4085a58f292f/WEO2019-Electricity-database.xlsx, viewed 25 April 2020; population without access derived from idem and from A. Contejean, IEA, Paris, personal communication with REN21, 20 May 2020; targets derived from World Bank, Access to Electricity Database, https://data.worldbank.org/indicator/eg.elc.accs.zs, viewed 25 April 2020, and from J. Rafalowicz, "Power for All Fact Sheet: Energy Access Target Tracker" (Power for All, 4 April 2017), https://www.powerforall.org/application/files/4715/2385/7938/Energy_Access_Target_Tracker_Fact_Sheet_April_2017.pdf.

21 **Table R21** from the following sources: IEA, World Energy Outlook 2019 Access to Clean Cooking Database, https://iea.blob.core.windows.net/assets/b6baec29-6a12-40d6-8333-b89519660299/WEO2019-Clean-Cooking-database.xlsx, viewed 25 April 2020; Rafalowicz, op. cit. note 20.

22 **Table R22** from Frankfurt School–United Nations Environment Programme Centre for Climate & Sustainable Energy Finance and BloombergNEF, *Global Trends in Renewable Energy Investment 2020* (Frankfurt: May 2020).

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