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RENEWABLES 2019
GLOBAL STATUS REPORT

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REN21 COMMUNITY

REN21 is an international policy network of experts from governments, inter-governmental organisations, industry associations, NGOs, and science and academia. It grows from year to year and represents an increasing diversity of sectors. REN21 provides a platform for this wide-ranging community to exchange information and ideas, to learn from each other and to collectively build the renewable energy future.

This network enables the REN21 Secretariat to, among other activities, produce its annual flagship publication, the *Renewables Global Status Report* (GSR), making the report process a truly collaborative effort.

REN21 COMMUNITY INVOLVEMENT IN THE GSR:

Over **1,500** experts have contributed to the GSR since its start in 2005.

70% of these experts have participated in more than one GSR.

On average, nearly **60%** of the community consists of new experts each year.

INPUT FOR GSR 2019:

Over **350** experts contributed to GSR 2019, working alongside an international authoring team and the REN21 Secretariat.

45% of these were new experts.

REN21

RENEWABLE ENERGY POLICY NETWORK **FOR THE 21st CENTURY**

BUILDING THE SUSTAINABLE ENERGY FUTURE

REN21 is an international policy network of passionate players dedicated to building a sustainable renewable energy future. This means…

… having a clear vision: REN21 stands for a renewables-based energy system that includes all renewable energy technologies and serves all energy end-use sectors.

… making the right decisions: REN21 provides high-quality, up-to-date information to shape the energy debate.

… telling a compelling story: REN21 consolidates information about what is happening across the energy landscape to show that the global transition to renewables can happen.

… inspiring and mobilising people: REN21 builds on a worldwide community of players from governments, inter-governmental and non-governmental organisations, industry, science and academia.

… moving beyond the familiar: REN21 makes renewable energy relevant to decision makers outside the energy world, by developing an understanding of relevant concerns in these sectors.

Making the invisible visible.

REN21 changes the way we think about renewable energy.

SHAPE THE FUTURE

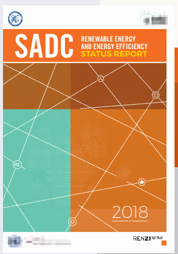
KNOWLEDGE

RENEWABLES GLOBAL STATUS REPORT (GSR)

First released in 2005, this report is the industry standard for the status of renewables for a given year. The GSR's robust process for collecting data and information makes it the most frequently referenced report on renewable energy market, industry and policy trends.

RENEWABLE IN CITIES – GLOBAL STATUS REPORT (REC-GSR)

The cities report is the first comprehensive resource to map out the current trends and renewable energy developments in cities. It uses the same rigorous standards found in the *Renewables Global Status Report* series.



REGIONAL REPORTS

These reports detail renewable energy developments in a region, improving data and knowledge and, in turn, informing decision making and changing perceptions.

DEBATES

REN21 RENEWABLES ACADEMY

A biennial event developed by, and for, the REN21 community, where members meet and discuss how to spur the renewable energy transition. The REN21 Academy's structure reflects REN21's collaborative and transparent culture.

REN21
RENEWABLES NOW

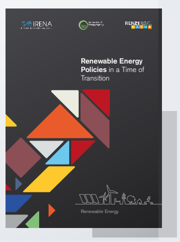
NETWORK AND COMMUNITY

INTERNATIONAL RENEWABLE ENERGY CONFERENCE (IREC)

A high-level political event where government, private sector and civil society meet to build collective know-how to advance renewables at the international, national and sub-national levels. The IREC is hosted by a national government and is held biennially.

GLOBAL FUTURES REPORT (GFR)

This series captures the current thinking about a sustainable energy future. Each report presents the collective and contemporary thinking of many experts.



THEMATIC REPORTS

Each report covers, in detail, a specific topic where a knowledge gap exists.

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REPORT CITATION

REN21. 2019.
Renewables 2019 Global Status Report
(Paris: REN21 Secretariat).

ISBN 978-3-9818911-7-1

DISCLAIMER:

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ACKNOWLEDGEMENTS

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

The ***Global Trends in Renewable Energy Investment*** report (GTR) is jointly prepared by the Frankfurt School UNEP Collaborating Centre for Climate & Sustainable Energy Finance, BloombergNEF and UN Environment. The GTR, formerly *Global Trends in Sustainable Energy Investment*, was produced for the first time in 2007 under UN Environment's Sustainable Energy Finance Initiative (SEFI). It grew out of efforts to track and publish comprehensive information about international investments in renewable energy. The latest edition of this authoritative annual report tells the story of the most recent developments, signs and signals in the financing of renewable power and fuels. It explores the issues affecting each type of investment, technology and type of economy.

The GTR is the sister publication to the ***REN21 Renewables Global Status Report***. The latest edition of the GTR, supported by the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety, will be published later in 2019 and available at www.fs-unep-centre.org.

UN environment

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Federal Ministry for Economic Cooperation and Development

aufgrund eines Beschlusses des Deutschen Bundestages

This report was commissioned by REN21 and produced in collaboration with a global network of research partners. Financing was provided by the German Federal Ministry for Economic Cooperation and Development (BMZ), the German Federal Ministry for Economic Affairs and Energy (BMWi) and UN Environment. A large share of the research for this report was conducted on a voluntary basis.

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ACKNOWLEDGEMENTS (continued)

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FOREWORD

The *Renewables 2019 Global Status Report* (GSR 2019) marks 15 years since Bonn2004, the landmark international conference that gave rise to REN21. Then, a "coalition of the willing" came together with one objective in mind: to support and accelerate the development of renewable energy. From the outset, REN21's mandate has been to collect, consolidate and synthesise a vast body of renewable energy data to provide clear and reliable information on what is happening in real time. This mandate still holds today.

The evidence from 2018 clearly indicates that renewable power is here to stay. Solar photovoltaics (PV) and wind are now mainstream options in the power sector, with an increasing number of countries generating more than 20% of their electricity with solar PV and wind. This is good news. But current trends show that bolder policy decisions are needed across all sectors of energy end-use to make our energy systems sustainable.

The lack of ambitious and sustained policies to drive decarbonisation in the heating, cooling and transport sectors means that countries are not maximising the benefits of the transition – including cleaner air and energy security – for their populations. On a global level, these sectors remain heavily reliant on fossil fuels, which are highly subsidised in many countries. In addition, the policy effort focused on these sectors has been insufficient compared to the power sector. Data in this year's report clearly illustrate that ambitious policy and regulatory frameworks are needed to create favourable and competitive conditions, allowing renewable energy to grow and displace more expensive and carbon-emitting fuels.

Cities increasingly are strong drivers in renewable energy deployment, adopting some of the most ambitious targets for renewables globally. This year's Feature chapter outlines commitments and actions at the city level that are, in numerous cases, exceeding national and state/provincial initiatives. Given the role of cities in the energy transition, REN21 has initiated the *Renewables in Cities Global Status Report*, using the same process and rigorous standards of the GSR but looking at the city level.

The underlying data and information in GSR 2019 show that an array of opportunities exist to extend the benefits of the energy transition throughout the economy. These opportunities, overarching trends and developments are detailed in the complementary *Perspectives on the Global Renewable Energy Transition*, which has been written to help readers more easily grasp the significance of the latest renewable energy developments. Together, these two publications make a powerful statement about the central role of renewables in establishing a sustainable energy future.

These publications are the product of the collective work of a robust and dynamic international community of renewable energy contributors, researchers and authors, making the GSR a truly collaborative effort. On behalf of the REN21 Secretariat, I would like to thank all those who have contributed to the successful production of GSR 2019. Particular thanks go to the REN21 Research Direction Team of Hannah E. Murdock, Duncan Gibb and Thomas André; Special Advisors Janet L. Sawin, Adam Brown and Hugo Lucas; Data Advisor Freyr Sverrisson; REN21 editor Lisa Mastny; the chapter authors; and the entire team at the REN21 Secretariat, under the leadership of REN21's Executive Secretary Rana Adib.

Achieving 2030 development objectives means moblising people to think critically about the energy sector, starting with making renewable energy relevant to decision makers both inside and outside of the energy world. I believe that this year's report and the accompanying *Perspectives* contribute to that process.

Arthouros Zervos

Chair, REN21

ES

Project and City:
Tokyu Setagaya rail line, Tokyo, Japan

Technologies:
Geothermal power and hydropower

Tokyo, Japan

In March 2019, the five-kilometre Tokyu Setagaya rail line, connecting Tokyo's Sangenjaya and Shimotakaido stations, became the first urban rail service in Japan to be powered entirely by renewable energy. The light rail line, which transports 57,000 passengers each day, is owned and operated by Tokyu Corporation and is powered by geothermal power and hydropower supplied by Tohoku Electric Power Co. The rail service used 2,200 megawatt-hours of electricity in 2018, and the switch to renewable power is projected to reduce carbon dioxide emissions by an estimated 1,263 metric tonnes per year.

EXECUTIVE SUMMARY

01 GLOBAL OVERVIEW

Progress in renewables remains concentrated in the power sector, while far less growth has occurred in heating, cooling and transport.

The year 2018 saw a relatively stable market for renewable energy technologies. A total of 181 gigawatts (GW) of renewable power was added, a consistent pace compared to 2017, and the number of countries integrating high shares of variable renewable energy (VRE) keeps rising.

Progress once again was concentrated in the power sector, as renewable energy became increasingly cost-competitive compared to conventional thermal generation. Renewables provided an estimated more than 26% of global electricity generation by year's end. Uptake has been driven by targets and stable policies. As in previous years, renewables saw far less growth in the heating, cooling and transport sectors, with progress constrained by a lack of strong policy support and by slow developments in new technologies.

Decarbonisation pathways and frameworks were developed further during 2018. At the sub-national level, a growing number of governments in many regions became leaders, setting more ambitious targets than their national counterparts. Developing and emerging economies continued to increase their deployment of renewables, and distributed renewable energy systems further helped to spread energy access to households in remote areas.

The private sector is playing a key role in driving renewable energy deployment through its procurement and investment decisions. Corporate sourcing of renewables more than doubled during 2018, and renewable energy has spread in significant amounts around the world. While global investment in renewables decreased from the previous year, developing and emerging economies again provided over half of all investment in 2018. The renewable energy sector overall employed (directly and indirectly) around 11 million people worldwide in 2018.

As of 2017, renewable energy accounted for an estimated 18.1% of total final energy consumption (TFEC). Modern renewables supplied 10.6% of TFEC, with an estimated 4.4% growth in demand compared to 2016. Opportunities continue to grow for increased use of renewable electricity in end-use sectors. Sector integration attracted the attention of policy makers, and the markets for enabling technologies (such as battery storage, heat pumps and electric vehicles) grew. However, meaningful action to directly support the interconnection of power, heating and cooling, and transport is still lacking.

Despite progress in renewables uptake, energy efficiency and energy access, the world is not on track to meet the targets of the Paris Agreement or of Sustainable Development Goal 7. Global energy-related carbon dioxide (CO_2) emissions grew an estimated 1.7% in 2018 due to increased fossil fuel consumption. Global subsidies for fossil fuel use increased 11% from 2017, and fossil fuel companies continued to spend hundreds of millions of dollars on lobbying to delay, control or block climate change policies and on advertisements to influence public opinion.

HEATING AND COOLING

Uptake of renewables in heating and cooling remains slow due to a lack of policy support.

Modern renewable energy met around 10% of worldwide heating and cooling demand in 2016, but its growth in the sector continues to be minor. Even though heating and cooling accounted for around half of total final energy demand, policy attention in this area is still lacking. In 2018, only 47 countries had targets for renewable heating and cooling, while the number of countries with regulatory policies in the sector fell from 21 to 20.

Effective policies for the heating and cooling sector (such as building energy codes) exist mainly at a local level, and sub-national governments are beginning to acknowledge the urgency of increasing renewable energy shares in the sector. Sector integration is a key opportunity to boost renewables in buildings and industry. Policy approaches that integrate renewable energy and energy efficiency are needed both to curtail the growth in heat demand and to increase the uptake of modern renewable technologies.

TRANSPORT

Renewable energy penetration in the transport sector remains low. Although biofuels dominate the renewables contribution, the market for EVs is growing significantly.

The renewable energy share of transport increased slightly from the previous year to reach 3.3%. The majority of this is provided by liquid biofuels; however, the sector is increasingly open to electrification, presenting opportunities to further integrate renewable energy. Despite increases in ethanol and biodiesel production in 2018, growth in the use of biofuels for transport remains constrained by policy uncertainties and by the slow progress in developing renewable fuels for markets such as aviation. There were some positive signs during the year from rail, aviation and maritime transport, with new targets, partnerships and initiatives to support renewables and decarbonisation.

The deployment of electric vehicles (EVs) on the world's roads increased in 2018, driven largely by efforts to reduce air pollution. The global number of electric passenger cars increased 63% compared with 2017, and more cities are moving to electric bus fleets.

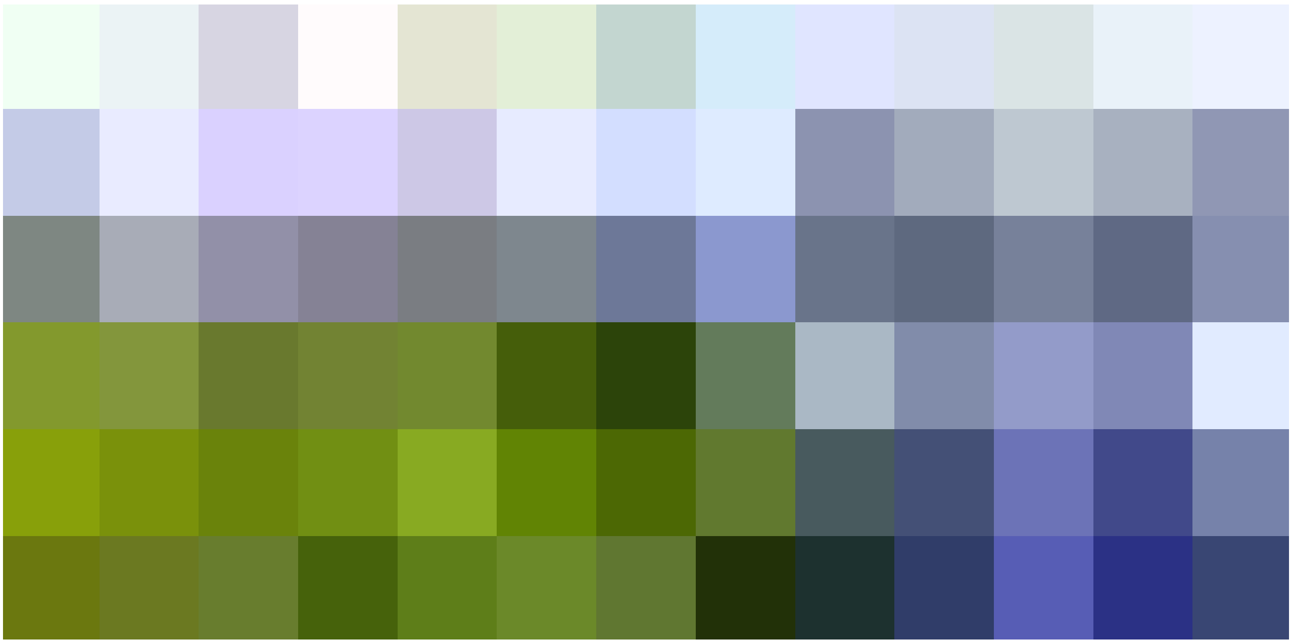
POWER

Renewable energy is expanding in the power sector, with 181 GW newly installed in 2018. However, the rate of new capacity additions levelled off, following years of growth.

Global renewable power capacity grew to around 2,378 GW in 2018. For the fourth year in a row, additions of renewable power generation capacity outpaced net installations of fossil fuel and nuclear power combined. Around 100 GW of solar photovoltaics (PV) was installed – accounting for 55% of renewable capacity additions – followed by wind power (28%) and hydropower (11%). Overall, renewable energy has grown to account for more than 33% of the world's total installed power generating capacity.

Renewable energy has established itself on a global scale. In 2018, more than 90 countries had installed at least 1 GW of generating capacity, while at least 30 countries exceeded 10 GW of capacity. Wind power and solar PV further increased their shares in some locations, and a growing number of countries now have more than 20% variable renewables in their electricity mixes.

Global renewable power capacity totalled **2,378 GW** in 2018.



RENEWABLE ENERGY INDICATORS 2018

		2017	2018
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	326	**289**
POWER			
Renewable power capacity (including hydropower)	GW	2,197	**2,378**
Renewable power capacity (not including hydropower)	GW	1,081	**1,246**
Hydropower capacity[2]	GW	1,112	**1,132**
Wind power capacity	GW	540	**591**
Solar PV capacity[3]	GW	405	**505**
Bio-power capacity	GW	121	**130**
Geothermal power capacity	GW	12.8	**13.3**
Concentrating solar thermal power (CSP) capacity	GW	4.9	**5.5**
Ocean power capacity	GW	0.5	**0.5**
Bioelectricity generation (annual)	TWh	532	**581**
HEAT			
Solar hot water capacity[4]	GW_{th}	472	**480**
TRANSPORT			
Ethanol production (annual)	billion litres	104	**112**
FAME biodiesel production (annual)	billion litres	33	**34**
HVO biodiesel production (annual)	billion litres	6.2	**7.0**
POLICIES[5]			
Countries with national/state/provincial renewable energy targets[6]	#	179	**169**
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	**65**
States/provinces/countries with heat obligations/mandates	#	19	**18**
States/provinces/countries with biofuel mandates[7]	#	70	**70**
States/provinces/countries with feed-in policies	#	112	**111**
States/provinces/countries with RPS/quota policies	#	33	**33**
Countries with tendering (held in 2018)	#	29	**48**
Countries with tendering (cumulative)[8]	#	84	**98**

1 Investment data are from BloombergNEF and include 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.

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 Solar hot water capacity data include water collectors only. The number for 2018 is a preliminary estimate.

5 A country is counted a single time if it has at least one national or state/provincial target or policy.

6 The decline in the number of jurisdictions with targets is due primarily to several targets having expired and not having been replaced.

7 Biofuel policies include policies listed both under the biofuel obligation/mandate column in Table 2 (Renewable Energy Targets and Policies, 2018) and in Reference Table R10 (Renewable Transport Mandates at the National/State/Provincial Levels, 2018).

8 Data for tendering reflect all countries where tenders have been held at any time up through the year of focus at the national or state/provincial level.

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

02 POLICY LANDSCAPE

Policy frameworks are still far from the ambition level required to reach international goals. Targets are increasingly ambitious for power, but those for heating, cooling and transport lag behind.

Renewable energy support policies and targets were present in nearly all countries worldwide by the end of 2018 and are found at all levels of government. Policy makers have the opportunity to design an effective mix of support policies tailored to their respective jurisdictions. As the costs for renewable technologies fall, these measures continue to evolve and adapt. The diverse benefits of renewable energy – such as improved public health through reduced pollution, increased reliability and resilience, and job creation – are driving policy action around the world. However, renewable energy policy frameworks vary greatly in scope and comprehensiveness, and most remain far from the ambition level required to reach international climate goals.

By 2018, renewable energy targets had been adopted in 169 countries at the national or state/provincial level. New and revised targets have become increasingly ambitious, particularly in the power sector, but far fewer countries had renewable energy targets specifically for the heating, cooling and transport sectors, and targets for economy-wide energy transformation remain rare. Sub-national governments are often the first movers in establishing innovative and ambitious mechanisms, including 100% renewable energy or power targets.

HEATING AND COOLING

Policy coverage for renewables and energy efficiency in buildings and industry is far from global. The number of countries with heating and cooling mandates fell in 2018.

Policies supporting renewable energy uptake for heating and cooling in buildings and industry have advanced slowly, and the number of countries, states and provinces with renewable heating and cooling regulatory policies fell to just 20 in 2018. Building energy codes are a primary mechanism for promoting renewable energy generation and energy efficiency. However, less than a third of all countries worldwide had mandatory building energy codes in place for all or part of the sector, while 60% of the total energy used in buildings in 2018 occurred in jurisdictions that lacked energy efficiency policies.

Europe has been one of the most fervent supporters of renewable heat technologies. In 2018, the European Union (EU) established its first binding renewable heating and cooling target to be implemented at the national level, while simultaneously working towards the region-wide goal of a decarbonised buildings sector by 2050. Cities and local governments are at the forefront of policy trends for energy use in buildings, and many of the world's largest municipalities pledged in 2018 to reach net-zero carbon operating emissions in their buildings sector by 2050.

In contrast, renewable energy support policies focused on the industrial sector are more limited, and new or revised policies for the promotion of renewable energy in industry were scarce in 2018. Standards and targets for energy efficiency of industrial processes covered only 25% of total industrial energy use in 2016.

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169 countries

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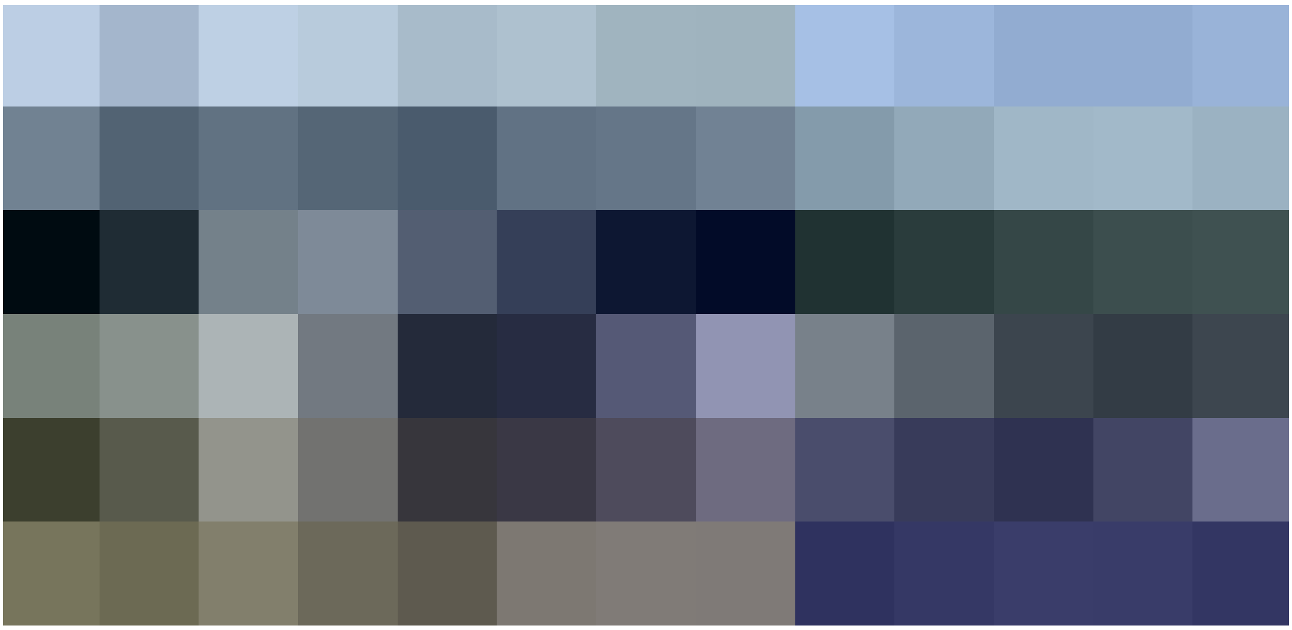


TRANSPORT

Biofuels are a central component of policy frameworks, although no new countries added mandates in 2018. Direct policy support linking EVs to renewables remains limited.

Policies for renewable energy in the transport sector still focus largely on road transport; however, the growing use of electricity and advanced biofuels in road transport, along with increasing efforts for decarbonisation, have encouraged support for renewables in rail, shipping and aviation as well. Biofuels have been a central component of national renewable transport policy frameworks, with blending mandates existing in 70 countries at the national or state/provincial level by the end of 2018. No new countries introduced blending mandates during the year, but some countries that had mandates in place added new ones, and several existing mandates were strengthened.

Conversely, fuel economy policies for light-duty vehicles existed in only 40 countries by year's end and have been largely offset by trends towards larger vehicles. EVs are becoming an important component of the road transport mix, but direct policy support linking their promotion to renewable energy deployment is limited.

POWER

The use of auctions is spreading to an increasing number of countries, but FIT policies and other incentives are still important for advancing renewable power.

The power sector again received most of the renewable energy-focused policy attention in 2018. Policy makers continued to turn to competitive auctions in lieu of traditional fixed-price policies, and auctions were held in at least 48 countries (up from 29 the year before), including many in Africa. At least one of the auctions in 2018 was technology-neutral (in Brazil), while at least six were neutral for renewable technologies. China halted financial support for solar projects in favour of auctions, and a transition to auctions for wind energy projects in the country is to follow in the coming years.

Despite the shift to auctions in many countries, feed-in tariff (FIT) policies, in place in 111 jurisdictions at the national, state or provincial levels by the end of 2018, continue to play an important role. Many FITs have been revised in recent years to keep pace with changing market conditions, particularly for large-scale installations, which have seen rate reductions or the elimination of FIT support in favour of auctions. Other policies, including renewable portfolio standards, net metering and fiscal incentives, also remain key for promoting renewable energy development and deployment.

POLICIES TO INTEGRATE VARIABLE RENEWABLE ENERGY

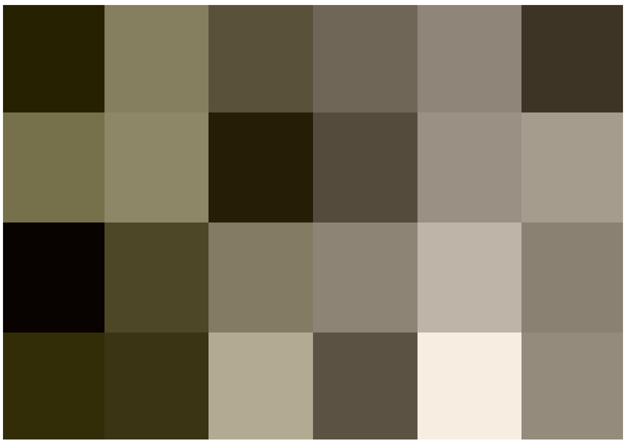
Policy makers are expanding support to further integrate VRE, while encouraging sector integration and deployment of enabling technologies.

Policy makers also have focused on the development and deployment of enabling technologies to facilitate the integration of variable renewable energy. Policies to integrate VRE can address both supply and demand to increase the flexibility of the overall system. This can focus on sector integration, the deployment of technologies offering ancillary grid services, or new and emerging technologies such as battery storage. An emerging trend is policies encouraging the joint installation of renewables and energy storage systems.

CLIMATE POLICY AND RENEWABLES

Carbon pricing policies can stimulate interest in renewables to meet climate goals. Although such policies are expanding, they currently cover just 13% of global emissions.

Renewable energy technologies have received both direct and indirect support through policies targeting climate change mitigation and adaptation. Carbon taxes and emissions trading systems are among the policy mechanisms that can stimulate interest in renewables to meet climate goals. At least 54 carbon pricing initiatives had been implemented by the end of 2018 (up from 46 in 2017), including 27 emissions trading systems and 27 carbon taxes.



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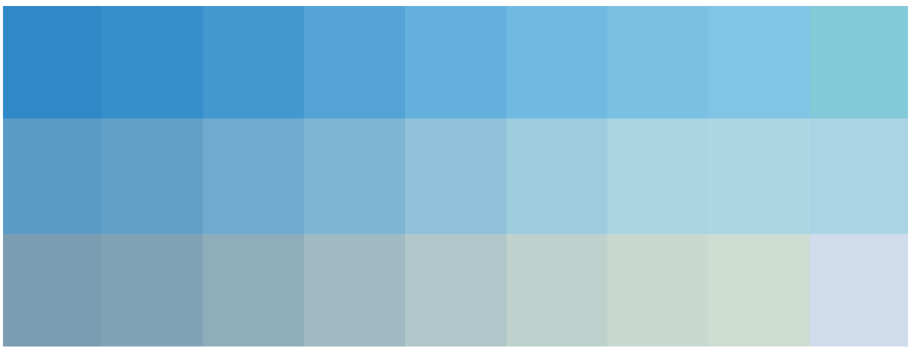


03 MARKET AND INDUSTRY TRENDS

BIOENERGY

Modern bioenergy is the largest contributor to the global renewable energy supply.

In 2017, modern bioenergy provided an estimated 5% of global final energy consumption, nearly half of the entire contribution of renewable energy. Bioenergy made its largest contribution to the heating and cooling sector (5%), followed by the transport sector (3%) and the electricity supply (2.1%). Bioenergy use is growing most quickly in the electricity and transport sectors, while it lags in the heating sector.

In 2018, the EU maintained its lead for the use of modern bioenergy for heating, with progress driven mainly by the EU Renewable Energy Directive. China is the world leader in bioelectricity generation, followed by the United States, Brazil, India and Germany. Biofuels production is dominated by the United States and Brazil, which together produced 69% of all biofuels in 2018.

Bioenergy markets and industrial activity were driven strongly by policy, but trade patterns, especially for transport biofuels, were influenced greatly by changing import tariffs and other similar measures.

Industrial development continued to focus on the development of advanced biofuels that can offer improved sustainability performance and also be used in new applications such as aviation. Progress is being made in developing and deploying these new fuels, but so far they account for only a small share of biofuels production.

GEOTHERMAL POWER AND HEAT

Geothermal energy is growing only gradually, and most power capacity is being added in only two countries.

Geothermal energy output in 2018 was estimated at 630 petajoules, with around half of this in the form of electricity (89.3 terawatt-hours (TWh)) and half as heat.

An estimated 0.5 GW of new geothermal power generating capacity came online in 2018, bringing the global total to around 13.3 GW. Turkey and Indonesia accounted for about two-thirds of the new capacity installed. Other additions included Croatia's first geothermal power plant as well as projects in Iceland, Kenya, New Zealand, the Philippines and the United States. Direct extraction of geothermal energy for thermal applications grew in 2018, especially for space heating, with most apparent market activity in Europe and China.

In 2018, the global geothermal industry continued to express measured optimism for geothermal development, tempered by ongoing concerns about various industry-specific challenges as well as by the perception of insufficient or wavering government support. International agencies and development banks explored opportunities to overcome some of these challenges and to fund new development.

HYDROPOWER

Hydropower is characterised by market stability, rising industry competition and a growing demand for energy storage.

The global hydropower market in 2018 looked very similar to the preceding year in terms of capacity growth and concentration of activity. An estimated 20 GW was added to reach a total installed capacity of around 1,132 GW. Worldwide generation from hydropower, which varies each year with shifts in weather patterns and other local conditions, was an estimated 4,210 TWh. As in many preceding years, China led in commissioning new hydropower capacity, representing more than 35% of new installations in 2018. Brazil came second (as in 2017), followed by Pakistan and Turkey, all adding more than 1 GW of capacity.

Pumped storage capacity increased 1.9 GW in 2018, for a year-end total of 160 GW, representing the vast majority of global energy storage capacity. New capacity was installed in China, Austria and the United States. Some new pumped storage projects are being optimised for fast response to changing grid conditions, in part to better accommodate the growing use of variable renewable power technologies.

A notable feature of the hydropower industry in 2018 was the swelling ranks of ageing facilities that require repairs and upgrades. More than half of all hydropower facilities worldwide have either already undergone, or will soon require, upgrades and modernisation. Another trend was growing recognition of the value that hydropower facilities can offer for the effective integration of variable sources of renewable energy, such as solar PV and wind power, and of the potential synergies between hydropower and other renewable energy technologies, depending on local conditions.

OCEAN POWER

Certain technologies appear close to commercialisation, but consistent support policies and revenue guarantees remain critical.

Ocean power represents the smallest portion of the renewable energy market, with most projects focused on relatively small-scale demonstration and pilot projects of less than 1 megawatt (MW). Net additions in 2018 were approximately 2 MW, with an estimated 532 MW of operating capacity at year's end.

Development activity is found around the world but is concentrated primarily in Europe, and particularly off the shores of Scotland, where several arrays of tidal turbines were being deployed in 2018. The resource potential of ocean energy is enormous, but it remains largely untapped despite decades of development efforts.

The year 2018 was one of stark contrasts for the ocean power industry. On the one hand, manufacturers of tidal turbine arrays, in particular, indicated technological success and progression towards commercialisation. On the other hand, a negative outlook prompted one prominent tidal technology developer to abandon all plans for further manufacturing and deployment. Financial and other support from governments, particularly in Europe and North America, continued to reinforce private investments in ocean power technologies, especially tidal stream and wave power devices.

SOLAR PHOTOVOLTAICS (PV)

Solar PV had another strong year for new additions, boosted by growth in emerging markets.

The annual global market for solar PV was up slightly to exceed 100 GW (direct current) for the first time, with a year-end total of 505.5 GW. Higher demand in emerging markets and in Europe compensated for a substantial decline in China that resulted from policy changes mid-year, although Asia still eclipsed other regions for new installations.

While support schemes of some kind are still needed for solar PV in most countries, interest in purely competitive systems is growing quickly. Self-consumption remained an important driver of the market for new distributed systems in some regions, and corporate purchasing of solar PV expanded considerably, particularly in the United States and Europe. Around the world, mining, manufacturing and other industries were erecting solar PV (and other renewable) plants to power their operations.

The solar PV industry experienced significant growing pains in 2018. China's decision to constrain domestic demand led to global turmoil as Chinese modules flooded the world market, and trade disputes affected the industry in some countries. Record-low auction prices, driven by intense competition and lower panel prices, brought further consolidation. Nonetheless, the year also saw investment in new, more-efficient production capacity and additional advances in solar PV technology.

By year's end, at least 32 countries, representing every region, had a cumulative capacity of 1 GW or more. Solar PV played a significant and growing role in electricity generation in several countries, including Honduras (12.1%), Italy and Greece (both about 8.2%), and by late 2018 one in five Australian households generated at least some of their electricity with solar energy.

CONCENTRATING SOLAR THERMAL POWER

New CSP additions are being installed exclusively in emerging markets, while significant new capacity is in the pipeline.

Global concentrating solar thermal power (CSP) capacity increased 11% to just under 5.5 GW in 2018. An estimated 550 MW came online, representing the largest gain since 2014. At year's end, around 2 GW of new plants was under construction in 10 countries, with most of this capacity being built in the United Arab Emirates (0.7 GW) and China (just over 0.5 GW). All but 3 of the 23 plants under construction plan to include thermal energy storage (TES). Operational TES reached almost 17 gigawatt-hours by the end of 2018.

For the third consecutive year, new capacity came online only in emerging markets. China and Morocco led in new additions at 200 MW each, followed by South Africa and Saudi Arabia. Costs continue to decline due to wider project deployment, technological innovation and competition. On a national level, the future of CSP in South Africa is uncertain, with no new plants being allocated under the government's latest resource plan. In China, projects under construction were estimated to be 40% cheaper than facilities elsewhere due to rapid industry growth.

SOLAR THERMAL HEATING AND COOLING

Despite a decline in global installations, key markets are growing again, and additions of large-scale systems more than doubled during the year.

Approximately 33.3 gigawatts-thermal (GW_{th}) of new solar thermal capacity was commissioned in 2018, increasing total global capacity 2% to around 480 GW_{th}. China accounted for about 74% of global additions, followed by Turkey, Brazil and the United States. While China's gross additions declined for the fifth consecutive year, most of the largest solar heating and cooling markets outside of China saw demand increase for the first time since 2015. This was due to several factors, including clean air policies and the improving cost-competitiveness of solar thermal systems. Furthermore, rising demand in the Middle East and in East and Central Africa allowed several southern European solar collector manufacturers to enlarge their production volumes.

Market growth also was driven by rising interest among commercial and industrial clients. At least 37 new large-scale systems were commissioned globally to provide heat for district networks or large buildings, up from 17 systems a year earlier.

The number of new solar heat for industrial processes (SHIP) installations in 2018 matched the level of 2017, with Mexico and China being the global leaders.

The year 2018 also marked a milestone for new deals for solar heat projects that use concentrating technologies. A memorandum of understanding for a world-record size 2 GW_{th} solar steam producing plant was signed in Oman, and construction started on the first large SHIP (and large concentrating solar) plant in Brazil.

WIND POWER

Wind power is characterised by stable installations, falling prices in a competitive industry and growing interest in offshore wind power, following successes in Europe.

The global wind market was fairly stable, with about 51 GW added in 2018, boosting cumulative capacity 9% to 591 GW. Following a record year for wind power in Europe and India in 2017, both markets contracted in 2018, but notable growth occurred in several other regions and countries. Asia was the largest regional market, representing nearly 52% of added capacity.

In the offshore segment, seven countries in Europe and two in Asia connected 4.5 GW, increasing cumulative global capacity 24% to 23.1 GW. The success of offshore wind power in Europe has sparked interest in almost every other region.

While falling prices are helping to move wind power into new markets and driving up sales, the global transition from FITs to more-competitive mechanisms, such as auctions and tenders, has resulted in intense price competition that is squeezing the entire value chain and challenging wind turbine manufacturers and developers alike. Further, wind power's success is coming with new challenges resulting from poorly designed and executed tenders, as well as limitations of power systems and markets that were designed for centralised, large-scale fossil power.

The industry is meeting these challenges with ongoing technology advances (including larger turbines) that are increasing energy production per turbine, improving plant efficiency and output, and reducing the levelised cost of electricity (LCOE) from wind energy. At least 12 countries around the world met 10% or more of their annual electricity consumption with wind energy in 2018.

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

DREA systems continue to play an important role in providing access to modern energy services to households in remote areas of developing and emerging economies.

In 2017, the global population without access to electricity fell below the 1 billion mark, with 61% of those still lacking access living in sub-Saharan Africa and around 35% in developing Asia. With regard to energy for clean cooking, 2.7 billion people still did not have access in 2017, 33% of them living in sub-Saharan Africa and 64% of them in developing Asia.

Building on the momentum of the past five years, distributed renewables for energy access (DREA) systems are increasingly being used to provide access to electricity. In 2017, more than 122 million people obtained access mainly through off-grid solar systems. While pico-solar systems dominate the off-grid solar market, the sales volume of affiliated larger solar home systems increased 77% in 2018, highlighting an increasing demand for more power.

The off-grid electricity access sector attracted a record USD 512 million of corporate-level investment in 2018, up 22% from the previous year. Start-ups involved in the off-grid solar PV sector raised USD 339 million in 2019, up 6% compared to 2017. The mini-grid sector expanded in 2018, with some 2,000 solar mini-grids in operation in Asia and about 800 in Africa. Mini-grid start-ups attracted around USD 51 million in investment, down 18% from 2017.

The market for clean[i] cooking solutions also grew. The clean cooking sector attracted USD 40 million of investment in 2017, up 36% from the previous year. Although the sector is yet to be scaled to the level of off-grid solar PV, various delivery models are being tested that focus on an integrated approach: sales of both the stove and the associated fuels. Companies using this integrated approach attracted around 70% of all investment in the sector in 2017.

Development finance institutions increased their support to DREA in 2018, directing some 7% of their total investment in energy projects to off-grid systems. However, finance for energy access decreased in 2018 for the second year running and remains far behind the estimated amounts needed to reach universal access to electricity and clean cooking.

In 2017, the global population without access to electricity **fell below 1 billion.**

05 INVESTMENT FLOWS

Global investment fell, driven by a sharp decline in China. For the fourth year running, investment in developing and emerging countries exceeded that of developed countries.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) was USD 288.9 billion in 2018[ii]. This represents a decrease of 11% compared to the previous year. Investment in renewable power and fuels has exceeded USD 280 billion per year for the past five years. Including investments in hydropower projects larger than 50 MW, total new investment in renewable power and fuels was at least USD 304.9 billion in 2018.

Dollar investment in new renewable power capacity (including all hydropower) once again far exceeded that invested in fossil and nuclear power capacity in 2018. Investment in renewable energy continued to focus on solar power, particularly solar PV, which secured USD 139.7 billion during the year. Asset finance of utility-scale[iii] projects, such as wind farms and solar parks, dominated investment at USD 236.5 billion. Small-scale solar PV installations (less than 1 MW) accounted for USD 36.3 billion worldwide, a decrease of 15%.

Developing and emerging economies overtook developed countries in renewable energy investment for the first time in 2015. After extending their lead in 2017, they retained it in 2018, albeit by a smaller amount. Investment in developing and emerging countries decreased 25% to USD 152.8 billion (due largely to decreases in China), while that in developed countries increased 11% to USD 136.1 billion.

Developments in renewable energy investment varied by region, rising in Europe, in Africa and the Middle East, in Asia (except China and India) and in the United States, and falling in the Americas (excluding the United States but including Brazil), China and India. Considering all financing of renewable energy (but excluding hydropower larger than 50 MW), China accounted for 32% of the global total, down from 45% in 2017. China was followed by Europe (21%), the United States (17%) and Asia-Oceania (excluding China and India; 15%). Smaller shares were seen in India (5%), Africa and the Middle East (5%), the Americas (excluding Brazil and the United States, 3%) and Brazil (1%).

i "Clean" in this section refers to clean and/or efficient cook stoves as per the methodology of the Clean Cooking Alliance. This definition of clean encompasses only the health and environment impacts of cooking as indicators, regardless of the type of stoves/fuels being used (for example, liquefied petroleum gas (LPG) is counted alongside modern renewable fuels, and LPG cook stoves continue to make up the majority of clean cook stoves on the market)

ii Investment-related data do not include hydropower projects larger than 50 MW, except where specified.

iii "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.

TOP FIVE COUNTRIES

Annual Investment / Net Capacity Additions / Production in 2018

	1	2	3	4	5
Investment in renewable power and fuels (not including hydropower over 50 MW)	**China**	United States	Japan	India	Australia
Investment in renewable power and fuels per unit GDP[1]	**Palau**	Djibouti	Morocco	Iceland/Serbia	
Geothermal power capacity	**Turkey**	Indonesia	United States	Iceland	New Zealand
Hydropower capacity	**China**	Brazil	Pakistan	Turkey	Angola
Solar PV capacity	**China**	India[2]/United States		Japan	Australia
Concentrating solar thermal power (CSP) capacity	**China/Morocco**		South Africa	Saudi Arabia	–
Wind power capacity	**China**	United States	Germany	India	Brazil
Solar water heating capacity	**China**	Turkey	India	Brazil	United States
Biodiesel production	**United States**	Brazil	Indonesia	Germany	Argentina
Ethanol production	**United States**	Brazil	China	Canada	Thailand

Total Capacity or Generation as of End-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)[3]	**Iceland**	Denmark	Germany/Sweden		Finland
Bio-power generation	**China**	United States	Brazil	Germany	India
Bio-power capacity	**China**	United States	Brazil	India	Germany
Geothermal power capacity	**United States**	Indonesia	Philippines	Turkey	New Zealand
Hydropower capacity[4]	**China**	Brazil	Canada	United States	Russian Federation
Hydropower generation[4]	**China**	Canada	Brazil	United States	Russian Federation
Solar PV capacity	**China**	United States	Japan	Germany	India
Solar PV capacity *per capita*	**Germany**	Australia	Japan	Belgium	Italy
Concentrating solar thermal power (CSP) capacity	**Spain**	United States	South Africa	Morocco	India
Wind power capacity	**China**	United States	Germany	India	Spain
Wind power capacity *per capita*	**Denmark**	Ireland	Germany	Sweden	Portugal
HEAT					
Solar water heating collector capacity[5]	**China**	United States	Turkey	Germany	Brazil
Solar water heating collector capacity *per capita*	**Barbados**	Austria	Cyprus	Israel	Greece
Geothermal heat output[6]	**China**	Turkey	Iceland	Japan	Hungary

1 Countries considered include only those covered by BloombergNEF; GDP (at purchasing power parity) data for 2017 from World Bank. BloombergNEF data include the following: 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 those less than 1 MW (small-scale capacity) estimated separately; all ocean power projects; all biofuel projects with an annual production capacity of 1 million litres or more. Small-scale capacity data used to help calculate investment per unit of GDP cover only those countries investing USD 200 million or more.

2 Solar PV data for India are highly uncertain. See Solar PV section in Market and Industry chapter for details.

3 Per capita renewable power capacity (not including hydropower) ranking based on data gathered from various sources for more than 70 countries and on 2017 population data from the World Bank.

4 Country rankings for hydropower capacity and generation 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.

5 Solar water heating collector rankings for total capacity and per capita are for year-end 2017 and are based on capacity of water (glazed and unglazed) collectors only. Data from International Energy Agency Solar Heating and Cooling Programme. Total capacity rankings are estimated to remain unchanged for year-end 2018.

6 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, solar PV, wind power and solar water heating collector capacity).

06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

Strong growth in VRE is being managed in power systems around the world, while markets for energy storage, heat pumps and EVs expanded further.

Rising shares of renewable energy continue to transform energy systems around the world. In recent years, many countries have seen significant growth in installed capacity and generation from sources of variable renewable energy. In 2018, at least nine countries supplied more than 20% of their electricity generation from VRE, while some countries have seen rapid annual growth of VRE penetration.

Power systems are adapting to rising shares of VRE through a range of measures. Countries and sub-national entities are linking electricity systems across large regions in part to address the issues of curtailment and localised variability. Other strategies include system-level design of operations, regulations and markets; grid enhancements; and boosting flexibility in energy demand and supply.

Certain technologies – such as energy storage, heat pumps and EVs – can help integrate higher shares of VRE in the power sector by unlocking new sources of flexibility. In addition, these technologies can provide new sources of demand in heating and transport, allowing for further increases in the supply of renewables to these sectors. Some of these technologies are already widely deployed, while others are still emerging but experienced rapid growth in 2018.

Energy storage can enable higher penetration of VRE by improving system flexibility, reducing curtailment and minimising costs. Pumped hydropower storage, the largest contributor to the global energy storage stock, added 1.9 GW in 2018 to reach 160 GW. Global battery storage capacity totalled just over 3 GW in early 2019, with nearly 80% of new additions concentrated in five countries. Behind-the-meter battery storage also grew, and direct coupling of batteries with VRE generation continued to increase, especially with solar PV.

Heat pump markets expanded during the year. China maintained its lead in the global market for heat pumps, while the European market increased 12% in 2018, marking several years of strong growth. Large heat pumps are being deployed in district heating and cooling applications where the technologies can offer a significant flexibility resource to power systems. In the industry, several mergers took place as manufacturers looked to expand product lines and move into new markets.

EVs support the integration of VRE by presenting an opportunity for demand-side management. The global stock of electric cars reached more than 5.1 million units in 2018, a 63% increase over 2017. However, EV markets remain highly concentrated, with China making up nearly 50% of the global EV stock. The first specific use of VRE to charge EVs was piloted in California in 2018. Globally, more than 100,000 public EV charging points were installed in 2018. Manufacturers invested in bi-directional charging, continuing to advance the linkages between EVs and VRE.

Countries are managing growing shares of **variable renewables** through a range of measures.

07 ENERGY EFFICIENCY

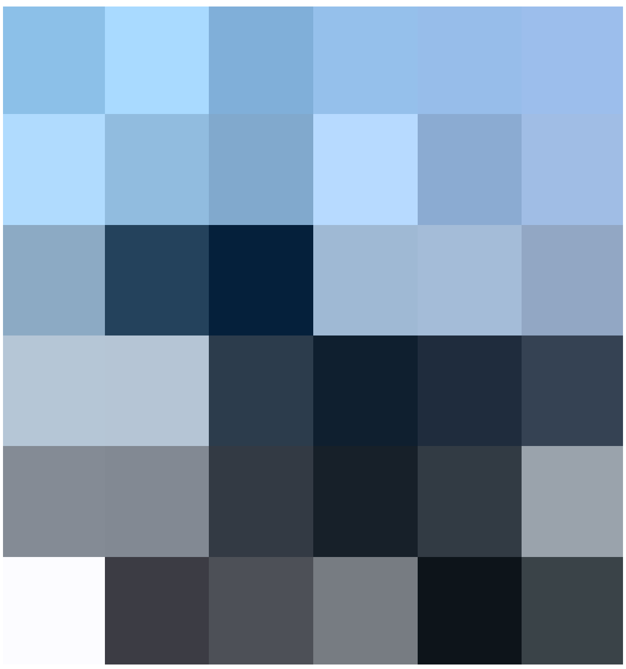
Global energy intensity continues to fall, and an integrated approach for renewables and energy efficiency remains crucial.

International efforts to map trajectories towards the achievement of sustainable development goals generally acknowledge the complementarity of renewable energy deployment and energy efficiency measures. Government policy support – which is instrumental in improving energy efficiency in buildings, industry and transport – has become stronger in recent years, albeit with more focus on action plans and targets than specific national mandates. Cities play an increasingly prominent role in designing and implementing policies for energy efficiency.

All regions of the world have shown some improvement in the energy intensity of their economic activity in recent years, with a global average rate of decline at around 2.2% between 2012 and 2017. During this period, the global economy grew almost three times faster than primary energy demand.

In some mature economies, growth in total energy demand has long since levelled off and even begun to retract. However, despite the ongoing advances in energy efficiency in many countries and across various end-use sectors, total energy demand is still rising in regions with rapid economic growth and improved access to energy.

In buildings, total energy demand has increased despite energy efficiency improvements, due primarily to increasing population and incomes. Global energy demand for cooling has grown more rapidly than any other end-use in buildings. Energy demand for transport also rose significantly during 2012-2017 and has far exceeded the effect of greater vehicle efficiency. Energy demand of industry has grown only half as fast as industrial activity in recent years, mitigated by structural changes as well as greater energy efficiency.



08 FEATURE: RENEWABLES IN CITIES

Cities are taking a leading role in advancing renewable energy through their efforts to achieve a wide range of interlinked environmental, economic and social goals.

Cities are at the forefront of the energy transition, accounting for around 65% of global energy demand and home to more than half the world's people. Some cities are able to accomplish more ambitious renewables goals than national and state/provincial bodies, as they can tap into their direct responsibility for providing services for residents and ensuring day-to-day quality of life, their contractual relationships with energy providers and large-scale users, and their authority to create incentives that drive lifestyle and development choices at the local level.

Cities are taking a leading role in advancing renewable energy through their efforts to achieve a wide range of interlinked environmental, economic and social goals, including reducing air pollution, creating local jobs, improving energy access, and enhancing energy security and governance. Renewables have the potential to achieve all of these objectives, and most cities pursue renewable energy for more than one of these reasons.

Building on these multiple drivers, cities are advancing renewable energy as a means to provide urban services such as electricity, heating and cooling, and transport. They also are developing cross-sectoral approaches, for example using urban waste and wastewater streams to produce biogas, biomethane and other renewable energy sources.

Cities are adopting some of the world's most ambitious targets for renewables. By the end of 2018, more than 230 cities worldwide had adopted targets for 100% renewable energy in at least one sector, and more than 50 cities had set comprehensive renewables targets covering the power, heating and cooling, and transport sectors. Climate action at the city level has contributed to national-level commitments to climate mitigation and adaption, as well as to reduce greenhouse gas emissions.

Despite the importance of cities in the energy transition, data on local- and city-level renewable energy policies and achievements are decentralised; consolidated data are limited; and the data that are available often are outdated.

To fill in some of the data gaps and to showcase the many trends and developments related to renewables at the local level, REN21 is producing a new report series, the *Renewables in Cities Global Status Report* (REC-GSR).

More than
230 cities worldwide
had adopted targets for
100% renewables
in at least one sector by the end of 2018.

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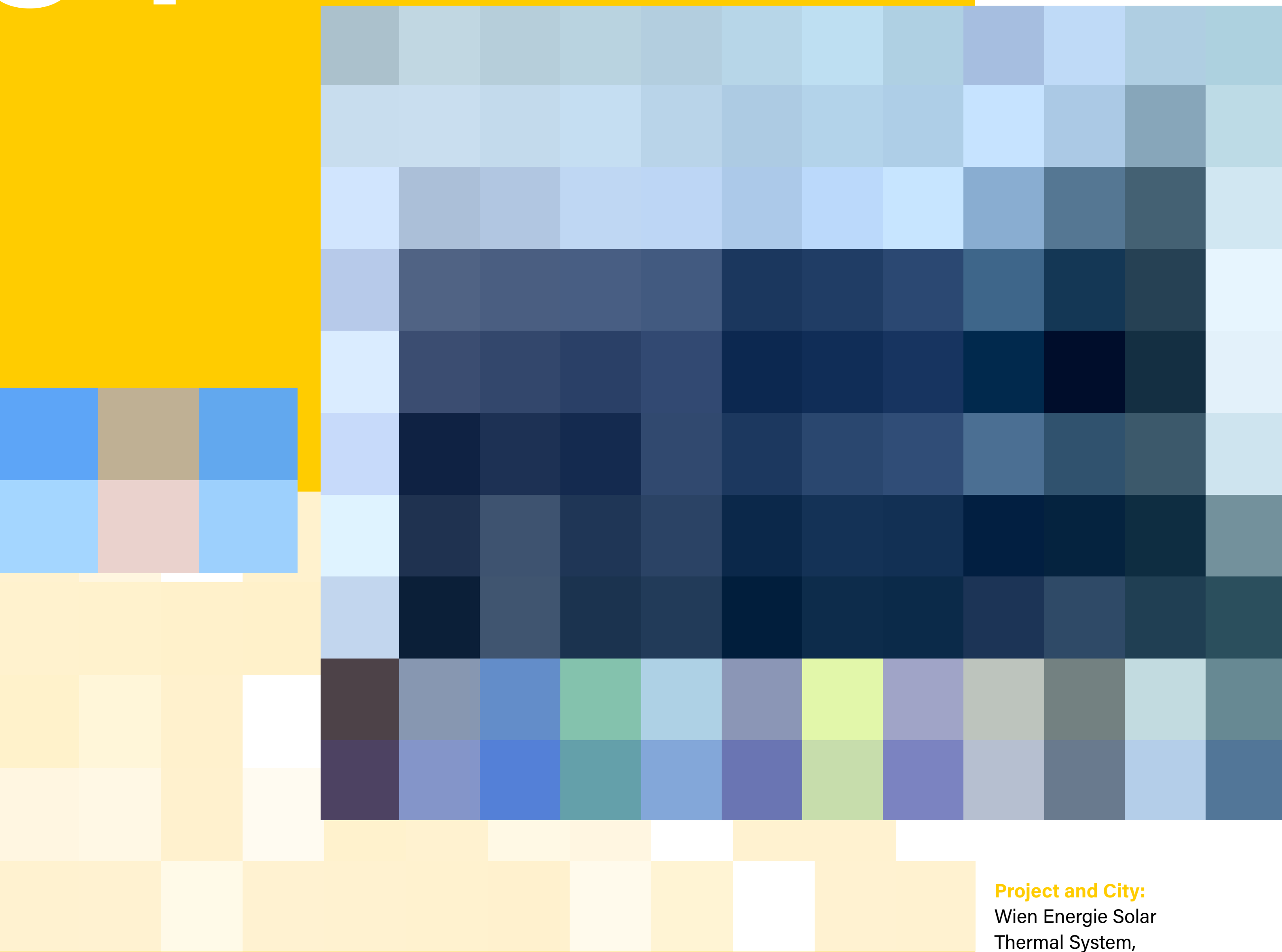


Project and City:
Wien Energie Solar Thermal System, Vienna, Austria

Technology:
Solar district heating

Vienna, Austria

As part of the Vienna Public Utility, Wien Energie GmbH uses a 656 square metre solar thermal plant to supply heat to the Vienna district heating network. With a solar yield of 510 megawatt-hours thermal per year, the plant offers savings of an estimated 2,132 tonnes of carbon dioxide over 25 years. The Vienna district heating network is nearly 1,200 kilometres in length and provides energy to around 350,000 households.

GLOBAL OVERVIEW

INTRODUCTION

The year 2018 saw a relatively stable market for renewable energy technologies. Total renewable power capacity grew at a consistent pace compared to 2017, and the number of countries integrating high shares of variable renewable energy (VRE) continued to rise. Corporate sourcing of renewables more than doubled compared to 2017, and renewables have spread in significant amounts all around the world.[1]

Renewable energy has been established globally as a **mainstream source of electricity** generation for several years.[2] The estimated share of renewables in global electricity generation was more than 26% by the end of 2018.[3] Net capacity additions for renewable power were higher than for fossil fuels and nuclear combined for a fourth consecutive year, and renewables now make up more than one-third of global installed power capacity.[4] This is due in part to stable policy initiatives and targets that send positive signals to the industry, along with decreasing costs and technological advancements.

Renewable power is **increasingly cost-competitive** compared to conventional fossil fuel-fired power plants. By the end of 2018, electricity generated from new wind and solar photovoltaics (PV) plants had become more economical than power from fossil fuel-fired plants in many places. (→ *See Sidebar 4.*) In addition, in some locations it was more cost-effective to build new wind and solar PV power plants than to continue to run existing fossil fuel power plants.[5] Record-low bids in tenders for renewable power were held in many countries around the world, especially for solar PV and wind power, although this development was not necessarily positive for the industry. (→ *See Market and Industry chapter.*)

As in previous years, renewables saw far less growth in the heating, cooling and transport sectors than in the power sector. The uptake of modern[i] renewable energy for heating and cooling in buildings and industrial applications progressed at a slow pace, while the use of biofuels for transport grew moderately during the year. Progress in these sectors remains constrained by a lack of strong policy support and slow developments in new technologies (such as advanced biofuels).

Renewable energy targets are in place in nearly all countries, and several jurisdictions made their existing targets more ambitious in 2018. The number of renewable energy **support policies** increased again during the year, mostly for renewable electricity. In the power sector, a general shift to auctions from feed-in policies and other support mechanisms continued, but feed-in policies remained widely used. The number of countries with mandates for renewable heat in buildings fell by one in 2018, while 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 enacted a policy directly linking renewables and electric vehicles (EVs) by year's end.[6] (→ *See Policy Landscape chapter.*)

i Modern renewable energy for heating and cooling includes bioenergy (excluding the traditional use of biomass), geothermal and solar thermal heat, as well as electricity generated from renewable sources when used in thermal applications.

In developing and emerging economies, distributed renewable energy systems continued to play an important role in connecting households in remote areas to electricity services. An estimated 5% of the population in Africa and 2% of the population in Asia has access to electricity through off-grid solar PV systems.[7] In 2017, the global population lacking access to electricity fell below 1 billion, with around 122 million people worldwide gaining access since the previous year.[8] During the same period, around 100 million people gained access to clean cooking facilities.[9] However, finance for energy access decreased in 2018 for the second year running and remains far behind the estimated amounts needed to reach universal access to electricity and clean cooking.[10] (→ *See Distributed Renewables chapter.*)

At the sub-national level, community renewable energy projects have spread, mostly in the power sector.[11] The 2018 European Union (EU) Renewable Energy Directive included a definition of "renewable energy communities" and the basis for developing national rules to support community initiatives.[12] In addition, the prevalence of prosumers[i] is growing, while attention to their legal and regulatory options for participating in local energy markets and networks grew during the year.[13] Sub-national governments continued to sign on to renewable energy and energy efficiency initiatives in 2018, often setting more ambitious targets than their national counterparts.[14] Additional communities, cities and regions introduced 100% renewable energy targets in 2018, and by year's end at least 100 cities were sourcing 70% or more of their electricity from renewables.[15] (→ *See Feature chapter.*)

The **private sector** is playing a key role in driving renewable energy deployment through its procurement and investment decisions. By early 2019, 175 companies had joined RE100 – committing to 100% renewable electricity targets – up from 130 companies the year before.[16] These and other private sector targets have supported the expansion of corporate power purchase agreements (PPAs), which are spreading to new countries and regions but remain concentrated in the United States and Europe.[17] (→ *See Power section in this chapter, and Feature chapter in GSR 2018.*)

Shareholder pressure and the rising competitiveness of the renewables sector have resulted in increased investment by the fossil fuel industry – including some large oil corporations – in both renewable energy projects and companies.[18] An increasing number of companies that own, develop or operate fossil fuel power plants shifted away from the coal business during 2018.[19] Some firms are investing more in renewable energy – although still in relatively small amounts – in order to economically and reliably meet their own energy needs, to spread their risk or to become players in the rapidly growing renewables sector.[20]

Global investment in renewable power and fuels in 2018 totalled USD 288.9 billion (USD 304.9 billion including hydropower plants larger than 50 megawatts, MW); this was an 11% decrease from the previous year (largely as a result of a significant fall in China) but the fifth year in a row that investment exceeded the USD 230 billion mark.[21] With more or less stable growth in renewable power capacity, the decline in investment reflects to some extent the falling costs of renewables – essentially, more capacity can be installed for less money.[22]

Nearly all of the investment was in solar PV and wind power.[23] Developing and emerging economies accounted for 53% of total renewable energy investment, with China alone accounting for 32% of the total.[24] (→ *See Investment chapter.*) Several developing countries are investing equivalent or higher amounts in renewable power and fuels than developed countries on a per gross domestic product (GDP) basis, particularly as energy demand continues to increase at a faster rate in developing markets, such as in Djibouti, Morocco and Palau.[25] (→ *See Top 5 Countries table.*)

The world is **not on track** to meet international climate and sustainable development goals.

Developments not directly linked to renewables are continuing to open opportunities for increased use of renewable electricity in the end-use sectors, such as heating and transport. These include a significant increase in incentives and targets for electrification of transport and bans on fossil fuel-powered vehicles in a few jurisdictions. The cost-competitiveness of renewable electricity for heating depends strongly on local fuel and electricity prices; however, the use of heat pumps continues to grow in major markets around the world, such as in Europe.[26] In addition, digitalisation and smart metering are offering more options for supply-side and demand-side management.[27] (→ *See Systems Integration chapter.*)

Decarbonisation pathways and frameworks continued to be developed during 2018.[28] For example, the EU presented its long-term climate strategy to be carbon-neutral by 2050.[29] An increasing number of countries also have adopted (or are considering) plans to phase out the use of coal for power generation, or the economy-wide consumption of fossil fuels.[30] Additional national and sub-national governments adopted carbon pricing policies in 2018, lending support to renewables indirectly across all sectors.[31] (→ *See Policy Landscape chapter.*) By the end of 2018, carbon pricing initiatives covered about 13% of global greenhouse gas emissions.[32]

Several high-profile developments in 2018 had an impact on the renewable energy sector. These include:

- The 24th Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change, held in Poland, ended with an agreement on implementation of the Paris Agreement, although many details were left unresolved.[33] Calls stressed the need for a rapid and just transition to renewable energy, and the timeline for the next Nationally Determined Contributions (NDCs) was confirmed.[34]
- In August 2018, a school strike for the climate was held outside the Swedish parliament building in Stockholm – an event that rapidly expanded from one person in a single country to millions of students in at least 125 countries around the world.[35] Termed "Fridays for Future", the movement has spurred a growing number of students to demonstrate and call for urgent action on the climate crisis from their political leaders.

i A prosumer is an individual, household or small business that not only consumes energy but also produces it.

- By the end of 2018, more than 1,000 institutions (ranging from cities and banks to insurance companies, pension funds and faith groups) with professionally managed investment funds amounting to nearly USD 8 trillion had committed to divesting from fossil fuels.[36]
- The Global Climate Action Summit in the United States convened 4,000 non-state[i] actors – including policy makers at the sub-national level, businesses, investors and civil society – and resulted in a surge of new climate commitments.[37]
- The International Solar Alliance (ISA) was strengthened through the opening of membership to all UN member countries, in addition to increased assistance, including a commitment by France of EUR 700 million (USD 800 million) towards the ISA objective of mobilising investment of USD 1 trillion by 2030 for the deployment of solar energy.[38] As part of the ISA's Affordable Finance at Scale programme, six African countries launched the Lomé Initiative, a platform to aggregate demand for financing for large-scale solar PV projects.[39]
- The World Bank Group announced a target of investing USD 200 billion over five years starting in 2021 to support 35 gigawatts (GW) of renewable energy and enabling infrastructure.[40] However, the Bank has continued to finance fossil fuels in developing countries in the meantime, amounting to nearly USD 6 billion since 2016.[41]

While there has been much progress on renewables, energy efficiency, and access to electricity and clean cooking facilities over the past decade, **the world is not on track** to meet international goals, most notably limiting the average rise in global temperatures to 1.5 degrees Celsius (°C) as stipulated under the Paris Agreement.[42] Released during 2018, the Intergovernmental Panel on Climate Change (IPCC) Special Report on the impacts of global warming of 1.5°C above pre-industrial levels found that just over a decade remained to keep global warming below this threshold.[43] Any increase beyond that point would greatly intensify the risk of extreme climate events, such as drought, floods and very high temperatures for much of the world's population.[44]

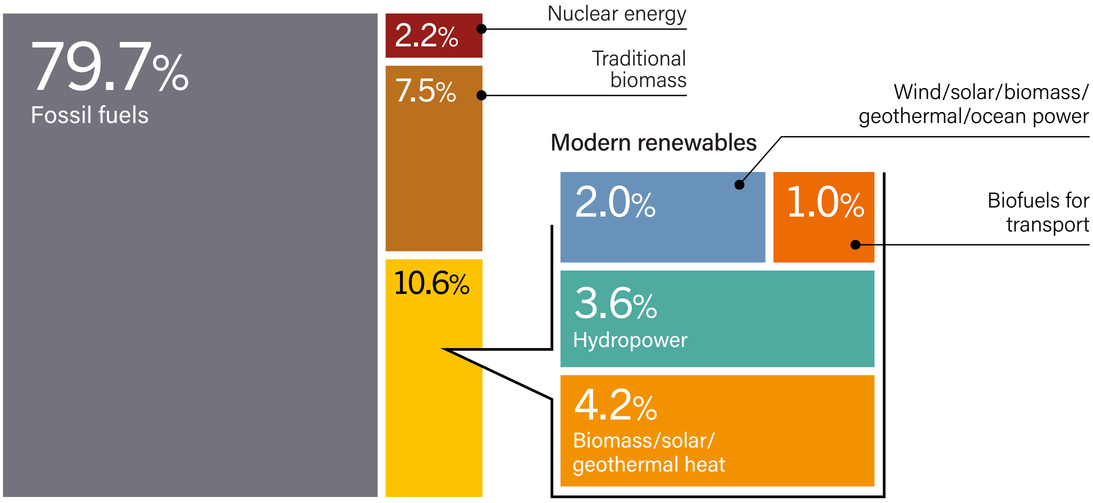
In addition, the annual review of UN Sustainable Development Goal 7 (SDG7) found that the objectives for renewables, energy efficiency and energy access set out for 2030 under SDG7 will not be achieved unless efforts are significantly scaled up.[45] The High-Level Political Forum on Sustainable Development held in 2018 emphasised this point as well and underscored that greater ambition was necessary.[46]

In 2018, **global energy demand** increased an estimated 2.3%, the greatest rise in a decade.[47] This was due to strong global economic growth (3.7%) and to higher heating and cooling demand in some regions.[48] China, the United States and India together accounted for almost 70% of the total increase in demand.[49] Due to a rise in fossil fuel consumption, global energy-related carbon dioxide (CO_2) emissions grew an estimated 1.7% during the year.[50]

As of 2017, renewable energy accounted for an estimated 18.1% of total final energy consumption (TFEC).[51] Modern renewables supplied 10.6% of TFEC, with an estimated 4.4% growth in demand compared to 2016.[52] Traditional use of biomass for cooking and heating in developing countries accounted for the remaining share.[53] The greatest portion of the modern renewable share was renewable thermal energy (an estimated 4.2% of TFEC), followed by hydropower (3.6%), other renewable power sources including wind power and solar PV (2%), and transport biofuels (about 1%).[54] (→ *See Figure 1.*)

i Non-state actors are not affiliated with any particular national government.

FIGURE 1. Estimated Renewable Share of Total Final Energy Consumption, 2017



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 OECD/IEA and IEA SHC. See endnote 54 for this chapter.

The overall share of renewable energy (both modern renewables and traditional biomass) in TFEC has increased only gradually, averaging 0.8% annually between 2006 and 2016.[55] This modest rise is due to a negligible change in the traditional use of biomass coupled with overall growth in global energy demand since 2006 (annual average increase of 1.5%).[56] Despite strong demand growth in modern renewables, especially renewable electricity, these two factors have slowed gains in the combined share of renewable energy in TFEC.[57] (→ *See Figure 2.*)

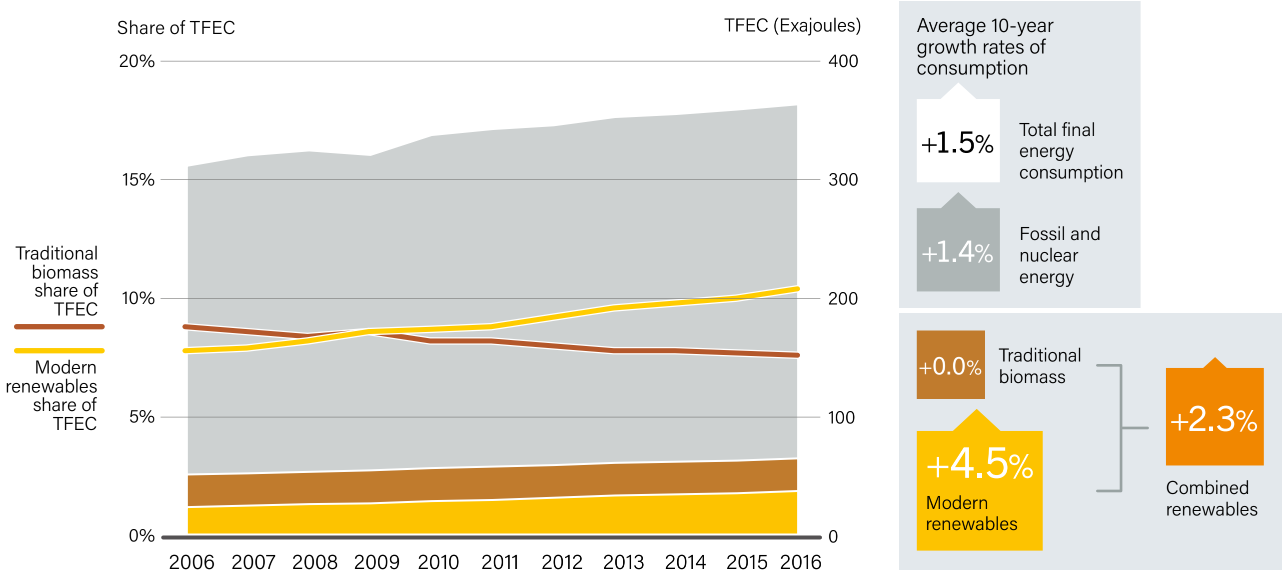
In the power sector, renewables are increasingly preferred for new electricity generation. Around 181 GW of renewable power capacity was added in 2018 – setting a new record just above that of the previous year.[58] Overall, renewable energy now accounts for around one-third of total installed power generation capacity worldwide.[59] Nearly two-thirds (64%) of net installations in 2018 were from renewable sources of energy, marking the fourth consecutive year that net additions of renewable power were above 50%.[60] (→ *See Figure 3.*)

As of the end of 2016, heating and cooling[i] accounted for around 51% of final energy use, transport for 32%, and final electricity demand (excluding the purposes of heating, cooling or transport) for around 17%.[61] (→ *See Figure 4.*) Modern renewable heat supplied around 10% of heating and cooling demand and has not grown significantly. While renewable electricity demand increased 25% between 2013 and 2017, modern renewable heat demand grew just under 5% during this period (around the same rate as global energy demand).[62] In transport, consumption of biofuels (principally ethanol and biodiesel) increased around 18% between 2013 and 2017, although starting from a small base.[63]

Given the growing share of renewables in power generation, the electrification of heating and transport can provide an opportunity to further expand the use of renewable energy in these sectors, as well as to facilitate the integration of growing shares of VRE.[64] Sector integration – the linking of the power, heating and cooling, and transport sectors – continued to gain policy maker attention during the year, although initiatives to directly support it remain limited.[65] (→ *See Systems Integration chapter.*)

i Heating and cooling in the *Renewables 2019 Global Status Report* (GSR 2019) 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.

FIGURE 2. Growth in Global Renewable Energy Compared to Total Final Energy Consumption, 2006-2016



Source: Based on OECD/IEA. See endnote 57 for this chapter.

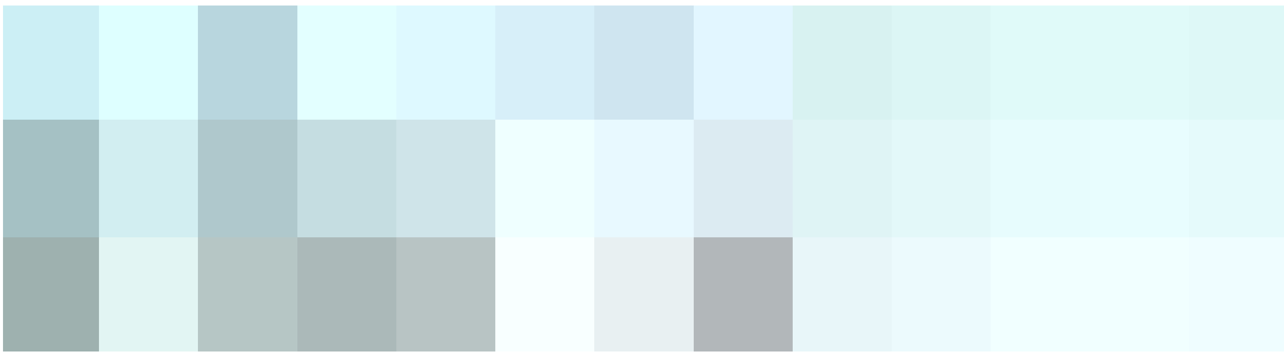
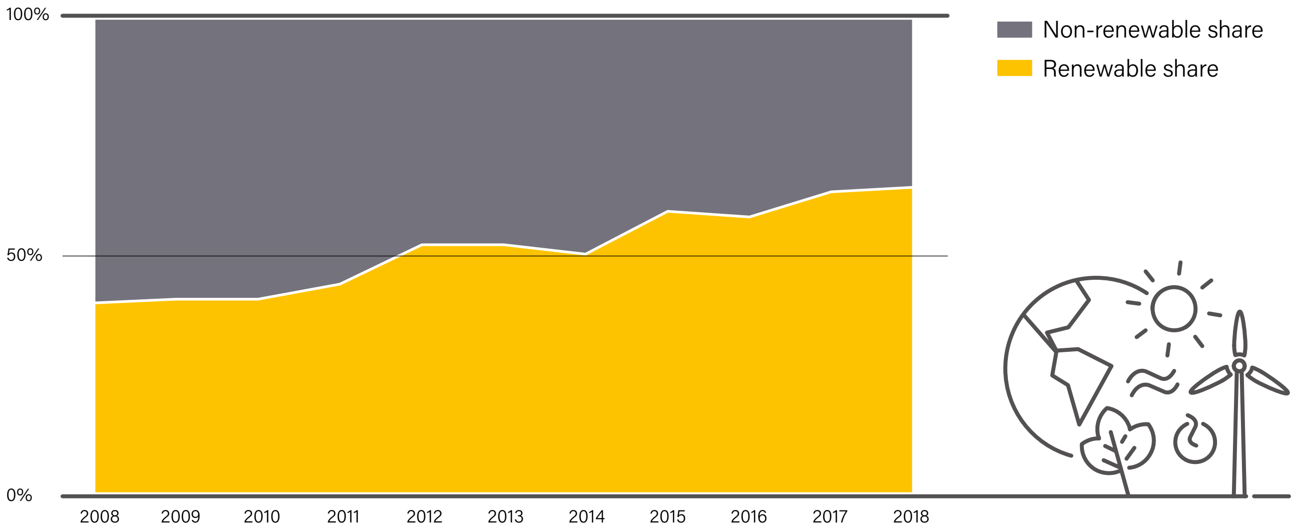
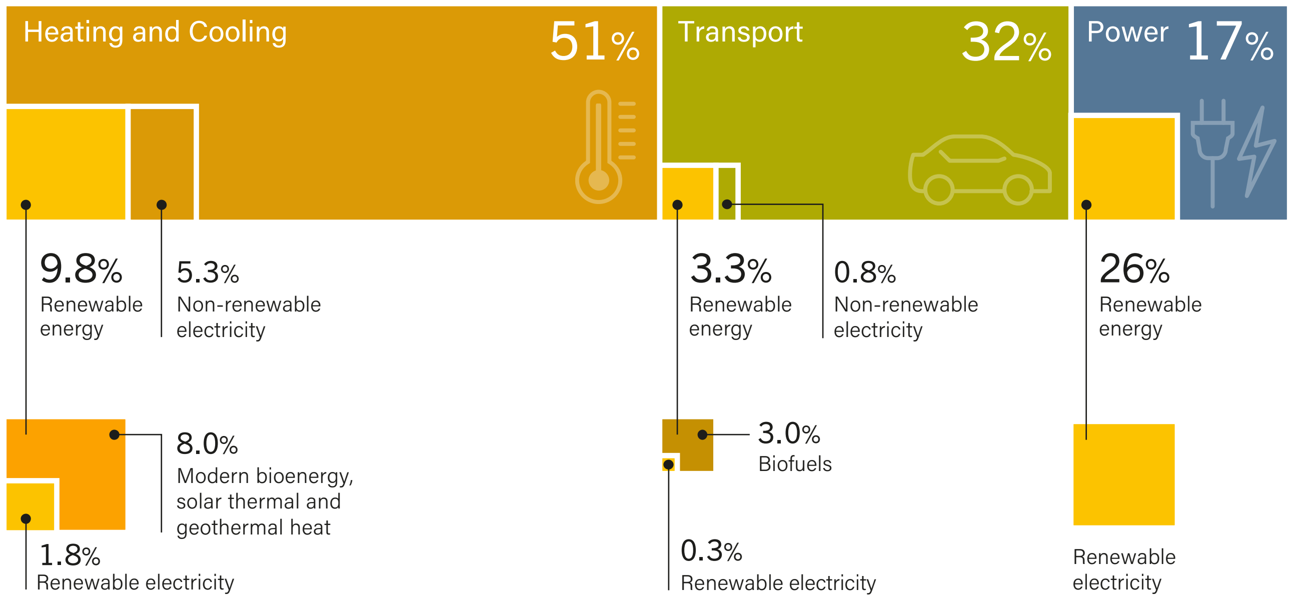


FIGURE 3. Share of Renewables in Net Annual Additions of Power Generating Capacity, 2008-2018



Source: See endnote 60 for this chapter.

FIGURE 4. Renewable Energy in Total Final Energy Consumption, by Sector, 2016



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

Source: Based on OECD/IEA. See endnote 61 for this chapter.

Many countries continued to invest in and develop new coal-fired power plants in 2018, despite the cost-competitiveness of renewable energy in many cases and other multiple benefits, such as improved public health through reduced pollution, increased reliability and resilience, and job creation.[66] (→ *See Sidebar 1 in this chapter.*) The majority of coal-fired generation capacity – whether existing, new, under construction or planned – is located in Asia.[67] Building new coal-fired power plants, with average lifetimes of approximately 40-50 years, can both lock in carbon-intensive generation and lock out renewable power.[68] Asia also has seen the majority of new nuclear power plants in recent years. The number of new grid-connected nuclear plants tripled in 2018, with 80% of these located in China, and construction starts for new nuclear plants increased 50% during the year.[69]

Global consumption of oil and natural gas rose in 2018, with natural gas growing at its fastest rate since 2010 (4.6%) due to increased demand and coal substitution.[70] The United States was the main driver of higher global natural gas demand, which

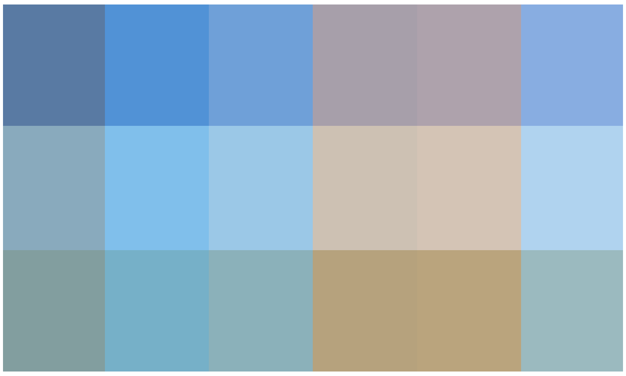
Fossil fuel subsidies are **double** the support for renewable energy.

was used primarily in power generation and in buildings, due largely to more extreme temperatures during the year.[71] Meanwhile, global oil demand rose 1.3% despite higher prices than in 2017, with the United States responsible for the largest growth because of expanding petrochemical demand as well as a rise in industrial production and demand for trucking.[72] China was in second place, but the country's growth in oil demand slowed as China transitions to less oil-intensive development and to reduced vehicle use to improve urban air quality.[73]

Between the adoption of the Paris Agreement in 2016 and the end of 2018, cumulative bank finance for fossil fuels amounted to USD 1.9 trillion.[74] Global **subsidies for fossil fuel consumption**[i] reached an estimated USD 300 billion in 2017, an 11% increase from the USD 270 billion the year before, and about double the estimated support for renewable power generation.[75] In addition, one estimate places the true cost[ii] of fossil fuels at upwards of USD 5.2 *trillion*.[76] While at least 40 countries have undertaken some level of fossil fuel subsidy reform since 2015, fossil fuel subsidies remained in place in at least 115 countries in 2017, with at least 73 countries providing subsidies of more than USD 100 million each.[77] (→ *See Figure 5.*)

Whether supported by subsidies or not, low fossil fuel prices encourage further demand for fossil fuels and challenge renewable energy markets, especially in the heating and transport sectors.[78] Additionally, the coal industry and major oil and gas companies spend upwards of USD 200 million each year lobbying to delay, control or block policies aimed at addressing climate change and on advertisements to influence public opinion.[79]

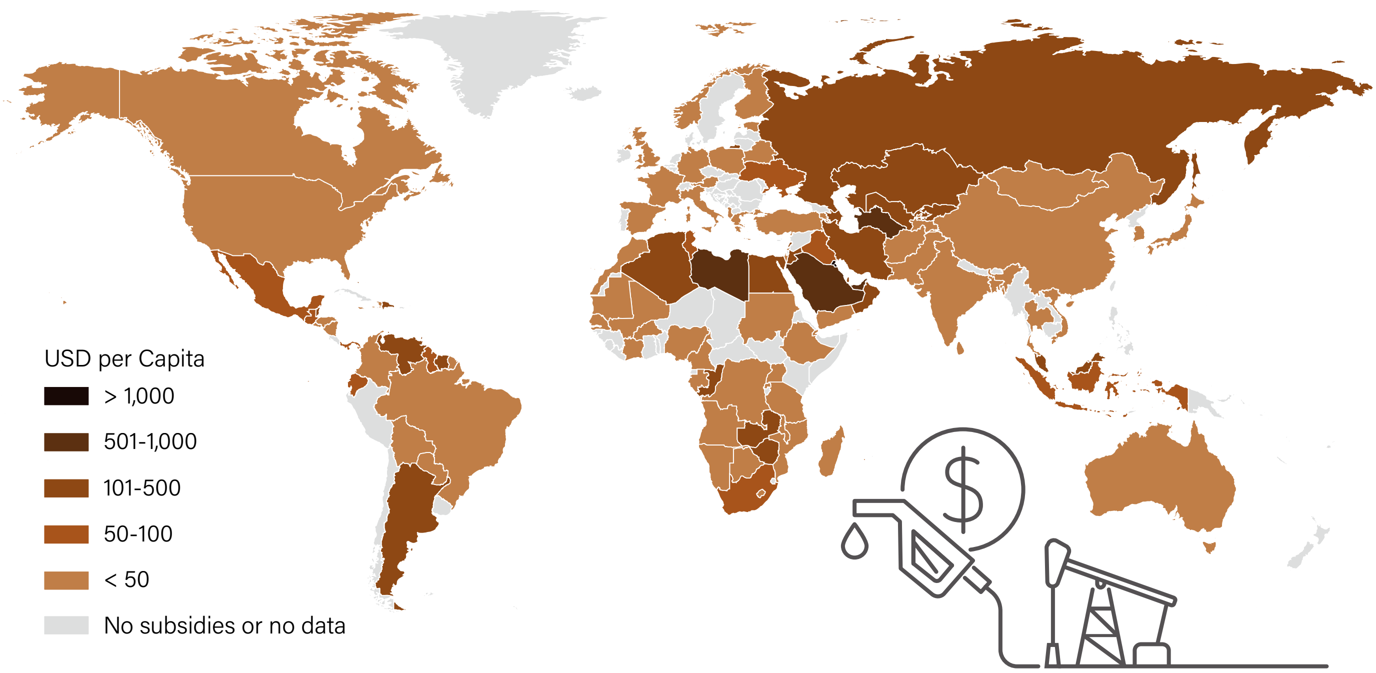
The following sections discuss key developments and trends in renewable energy in 2018 by sector in order of contribution to TFEC.



i The values reported here are estimates of consumption subsidies only. See endnote 75 for this chapter..

ii So-called post-tax consumption subsidies reflect the difference between end-use prices and what consumers would pay if the price reflected the estimated costs of negative externalities, such as local air pollution, effects of climate change, traffic congestion, etc. See endnote 76 for this chapter.

FIGURE 5. Fossil Fuel Subsidies, per Person, by Country, 2017



Note: Shading depicts pre-tax consumption subsidies only.

Source: Based on IMF. See endnote 77 for this chapter.

HEATING AND COOLING

Global demand for thermal energy, including the end-uses of heating and cooling, accounts for around half of final energy consumption.[80] Heat demand makes up the vast majority, although energy demand for cooling is growing rapidly.[81] Consumption of energy for heating and cooling remains heavily based on fossil fuels and contributes nearly 40% of global energy-related CO_2 emissions.[82]

Renewable energy supplies about a quarter of global heating and cooling demand; however, only around 40% of this is attributed to modern renewables, while the rest is supplied by traditional biomass.[83] Modern sources of renewable energy include direct renewables such as modern bioenergy, geothermal and solar thermal heat, as well as renewable electricity that is used for heating and cooling (for example, via air-source heat pumps). In contrast, the traditional use of biomass – predominantly in open fires or very inefficient indoor stoves – leads to significant health problems and is often linked to unsustainable levels of fuelwood collection. (→ *See Distributed Renewables chapter.*)

In 2016, modern renewables contributed only 9.8% of final heat consumption.[84] Direct renewables supplied some 8% of global heat demand, while renewable electricity accounted for the remaining share in total final consumption.[85] (→ *See Figure 4.*) Global consumption of modern renewable heat continues to increase only slowly, with demand growth averaging 1.8% annually in recent years.[86] Due to the continued rise in both populations and incomes in developing and emerging economies, energy demand for cooling has seen consistent annual growth (averaging around 4%) and accounted for an estimated 6% of energy consumption in buildings in 2016.[87] While direct renewables for cooling exist (for example, solar adsorption chilling), cooling demand continues to be met primarily through electric air conditioners or fans.[88]

The **buildings and industry sectors** consume roughly equivalent amounts of final thermal energy, but differ in their shares of renewable heat. Modern renewables contribute just below 9% of final heat consumption in the buildings sector, with bioenergy supplying most of this share.[89] Heating demands in buildings are at lower temperatures, typically in the range of 40°C to 70°C, and include end-uses such as space and water heating. In residential and commercial buildings, these demands can be met by direct renewables such as solar thermal and geothermal heat, either on-site or as a heat input to a district network. Renewable electricity also can be used for space heating, cooling and refrigeration, among other applications.

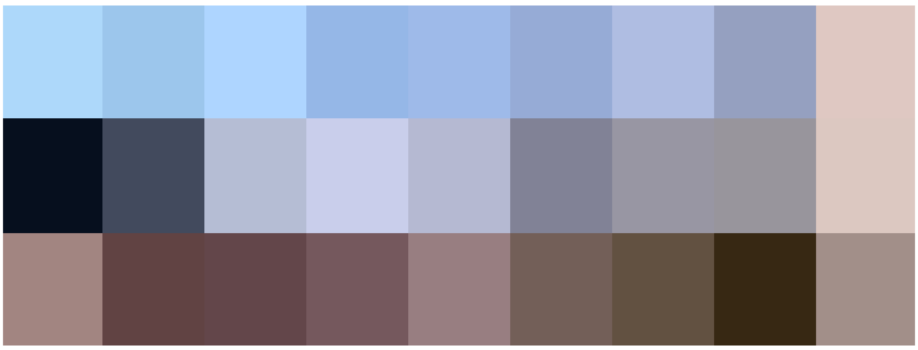
In the industry sector, renewable energy supplies around 11% of heat demand, the majority of which is low-temperature heat (below 100°C).[90] While renewables face technical challenges supplying heat at very high temperatures, nearly half of industrial heat demand falls below 200°C, opening avenues for further integration of renewable energy into the sector as technologies advance and business cases develop.[91] As in buildings, bioenergy provides the largest share of renewable heat to industry: in 2017, bioenergy, met an estimated 7% of total industrial heat demand.[92] Bioenergy technologies for heat have been successfully deployed in industries such as agriculture and pulp and paper; in the latter, they supplied 30% of heat demand in 2017.[93] Solar thermal technologies 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.[94]

Policy attention for increasing the uptake of renewables in heating and cooling continues to be lacking, despite the large share of total final energy consumed in the sector. Only around 20% of countries had national targets for heating and cooling as of 2018, and the number of countries with regulatory policies to support renewable heating and cooling fell from 21 to 20, as Kenya suspended its renewable heat mandate.[95] In some cases, sub-national governments have effectively set targets and implemented policies that spur renewable heat uptake. Especially considering the local nature of the sector, these governments play an important role for integration of renewable energy. (→ *See Feature chapter, and Box 1 in this chapter.*)

Energy efficiency also plays a key role for growing total shares of renewable energy in heating and cooling. Global thermal energy demand continues to rise, slowing the overall progress of renewables in the sector.[96] To address this, some policy makers are promoting both the deployment of modern renewable energy and energy efficiency measures in integrated policy approaches to help reduce thermal demand or mitigate its growth.[97] (→ *See Heating and Cooling section in Policy Landscape chapter.*)

In buildings, final energy demand has grown as global increases in both population and the building floor area have overcome any reductions in demand resulting from energy efficiency measures.[98] In 2018, building energy codes, municipal commitments on net-zero energy buildings, and incentive schemes for renewable heating and cooling technologies were all important strategies for growing shares of renewables in the sector.[99] By year's end,

Policy attention is **still lacking** in the heating and cooling sector.



69 countries had implemented building energy codes (up from 60 in 2017) that have been used to mandate the deployment of renewable energy technologies and to implement energy efficiency measures.[100] Nevertheless, less than one-third of all countries worldwide had mandatory building energy codes in place for all or part of the sector, and only around 40% of building energy use in 2016 fell under the reach of energy efficiency standards and targets.[101] (→ *See Figure 14 in Policy Landscape chapter.*)

Final energy use in the industry sector has risen (by 2% in 2017), even though energy efficiency measures helped reduce global growth in industrial energy demand by an estimated 20% between 2000 and 2017.[102] New or revised policies covering industrial energy use were scarce in 2018, and overall only one-quarter of energy use in the industry sector was under the reach of energy efficiency policies.[103]

In general, the uptake of modern renewables for heat proceeded at a slow pace in 2018, and the sector faced challenges similar to previous years.[104] (→ *See Box 1.*) Despite consuming the largest share of renewable heat, global bioenergy demand for heating has grown slowly, averaging around 1.8% annually.[105] In Europe, which accounts for nearly half of global bio-heat demand in buildings, overall use of bio-heat is growing slightly faster, by 2.2% annually on average.[106] The global bioenergy industry also is expanding: in 2018, facilities to upgrade biogas to biomethane (thus enabling its transmission in natural gas networks) were opened in China as well as in Europe, where three new countries (Belgium, Estonia and Ireland) connected biomethane facilities to national gas grids for the first time.[107]

The global market for solar thermal heat contracted slightly in 2018, with capacity additions falling 4% compared to 2017.[108] Nevertheless, certain key markets grew, including in many countries in Europe as well as in India and Mexico. Industrial solar heat projects were installed on many continents, and Mexico led 2018 additions, commissioning more than 50 systems.[109] Projects in a diversity of industries (pulp and paper, food processing, etc.) were announced or completed in Asia (China, India), Europe (France, Germany), the Middle East (Israel, Jordan) and South America (Argentina, Brazil, Chile), among many other places.[110] The global geothermal heat market was relatively stable compared to 2017, with projects commissioned in applications such as co-generation and district heating. (→ *See Market and Industry chapter.*)

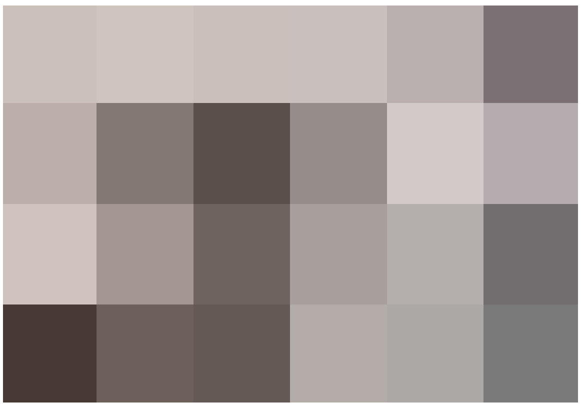
BOX 1. Challenges for Renewable Energy in the Heating and Cooling Sector

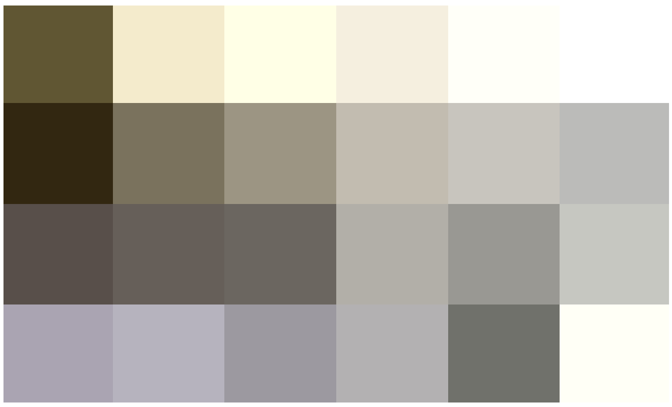
Renewable energy faces certain challenges to growing its share in the heating and cooling sector. Heat supply is highly localised and often is produced directly at the point of demand, such as steam generation in industrial processes or hot water boilers in residential and commercial buildings. As such, firms in the sector operate mainly in local, diverse markets, meaning that a global industry does not exist and that reliable, consolidated data on the heating and cooling sector are largely unavailable.

In addition, there are technical challenges to growing shares of renewables in the sector. Thermal energy can occupy a wide range of temperatures and pressures that complicate the pairing of a thermal demand with a (renewable) heating or cooling supply. Heat demand also is dispersed over many individual sites, and infrastructure to transport thermal energy is often lacking or uneconomical to construct, especially covering large distances. If modern direct renewables (for example, bio-heat, solar thermal and geothermal heat) are intended to be used, the choice often is a mix of technologies that are specific to local resource potential, unique heat demand/supply and available infrastructure, such as district heating and cooling networks.

Despite these challenges, national and sub-national governments around the world are increasingly acknowledging the urgency of growing the shares of renewables in heating and cooling, although few have taken ambitious steps.

Source: See endnote 104 for this chapter.





As shares of renewables rise in power systems around the world, **sector integration** (for example, electrification of heating end-uses) has continued to emerge as a route to increase energy efficiency, reduce system costs and ultimately grow renewable shares in the heating supply for buildings and industry.[111] Policies supporting this transition gained attention in 2018: the European Commission identified, as one of seven main strategic building blocks, the decarbonisation of end-use sectors through renewable electricity in heating and through the production of renewable fuels (including biogas and hydrogen).[112] Policies for electrification also are attracting interest in the United States, where they are considered increasingly as a key strategy to facilitate the uptake of renewables in heating and cooling end-uses.[113]

Heat pumps are an entry point for renewable electricity to meet these growing demands. The global market for heat pumps in building applications continues to grow and is led by China, followed by Europe, Japan and the United States.[114] In Europe, more than 1.2 million units were sold in 2018, a 12% increase from the previous year.[115] The use of renewable electricity in industrial applications is similarly rising, as technologies advance and are able to move into new applications, including higher-temperature processes.[116] In 2018, heat pumps were brought online in district heating networks or received financial support in countries including Denmark and Finland.[117] (→ *See Systems Integration chapter.*)

District heating and cooling networks draw on a varied combination of heat sources including co-generation plants, waste heat and renewable energy.[118] Although district energy supplies a minor share of global heat demand in buildings (an estimated 6-7% in 2016), opportunities exist to integrate renewables into these networks, boosting the overall share of renewable energy in the heat supply.[119] Often deployed at a lower cost and higher overall efficiency than in individual applications, renewable energy provides less than 10% of global district heat supply, the vast majority of which is bioenergy.[120]

Some European countries have achieved very high shares of renewables in their district heat supply (more than 40%, in at least eight countries[i]), helping to boost overall renewable energy penetration in the region's heat demand.[121] While district heating capacity in Europe has not risen substantially in recent years, shares of renewables in existing networks have been growing, most significantly in Lithuania but also in Finland, France and Switzerland, among others.[122]

Solar district heating continued to attract interest and financial support in 2018, with projects installed in Austria, China, Denmark, France, Germany, Turkey and elsewhere.[123] For the first time, there were more annual additions of large-scale solar heating systems (including solar district heating) outside of Europe than on the continent. (→ *See Solar Thermal section in Market and Industry chapter.*)

TRANSPORT

The main entry points for renewable energy 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 converted to run on upgraded biomethane; and the electrification of transport modes, including through the use of battery-electric and plug-in hybrid[ii] vehicles or of hydrogen, synthetic fuels and electro-fuels[iii], provided that the electricity is itself renewable.[124] Some renewable energy carriers can be used in the internal combustion engines of conventional vehicles, whereas others require the application of alternative drivetrains, such as in battery-electric or fuel cell vehicles.

Energy for the transport sector accounts for around one-third of TFEC globally.[125] In 2016, the vast majority (95.9%) of global transport energy needs were met by oil and petroleum products (and 0.8% non-renewable electricity), with small proportions met by biofuels (3.0%) and renewable electricity (0.3%).[126] (→ *See Figure 4.*)

Global ethanol production increased nearly 7% in 2018 compared to 2017, and biodiesel production rose about 5%.[127] (→ *See Bioenergy section in Market and Industry chapter.*) Growth in the use of biofuels for transport remains constrained by policy uncertainties related to feedstock and other sustainability issues, and by slow progress in bringing forward new technologies that can produce fuels for markets such as aviation. There is growing interest in the use of sustainable biofuels for aviation, although the current proportion of energy provided by such fuels is low.[128]

Until recent years, the use of electricity in transport was limited mainly to trains, urban rail and some buses; however, by the end of 2018 the sector had opened entirely to electrification, as plug-in hybrid and fully electric passenger cars, electric scooters and electric bicycles became more commonplace in many locations, and as more demonstration and prototype models were released for electric heavy-duty trucks and ships.[129] In aviation, some prototype electric drones and small planes have been developed.[130]

Despite gains in energy efficiency, particularly in road transport, global energy demand in the transport sector increased 45% between 2000 and 2017, a rise attributed to the growing number and size of light-duty vehicles (and corresponding increases in tonne-kilometres and passenger-kilometres travelled) as well as to rising demand for air travel and freight transport.[131] The result has been a global increase in CO_2 emissions from the transport sector, even as transport emissions in some regions (such as the EU and the United States) have fallen.[132] The sector as a whole accounted for an estimated 23% of global energy-related CO_2 emissions in 2016.[133]

i The eight countries are, in descending order, Norway, Sweden, Lithuania, France, Denmark, Switzerland, Austria and Finland.

ii Plug-in hybrids differ from simple hybrid vehicles, as the latter use electric energy produced only by braking or through the vehicle's internal combustion engine. Therefore, only plug-in hybrid electric vehicles allow for the use of electricity from renewable sources. Although not an avenue for increased penetration of renewable electricity, hybrid vehicles contribute to reduced fuel demand and remain far more numerous than EVs.

iii Also known as e-fuels, these are synthetic fuels that do not technically differ from conventional fuels such as diesel or petrol, generated in procedures known as Power-to-Liquids (PtL) and Power-to-Gas (PtG). Renewable electro-fuels are generated exclusively from electricity from renewable sources.

Increased electrification of transport can help to dramatically reduce sector-related CO_2 emissions, particularly in countries that are reaching high shares of renewables in their electricity mix.[134] In addition, some countries have seen gradual increases in the use of hydrogen and synthetic fuels for transport, although the vast majority of hydrogen is still produced from fossil fuels.[135] (→ *See Systems Integration chapter.*)

Around 80% of countries worldwide have acknowledged the transport sector's role in mitigating CO_2 emissions by including transport in their NDCs under the Paris Agreement.[136] The 2018 IPCC Special Report also included transport in its call for urgent action to increase mitigation of climate change.[137] Still, many jurisdictions lack a holistic strategy for decarbonising transport. Such strategies include greater incorporation of renewable energy (through both renewable fuels and renewable electricity) along with reducing the overall need for transport; transitioning to more-efficient transport modes, such as public transport, cycling or rail; and improving vehicle technology, such as through higher fuel efficiencies and emission standards[i].[138]

Road transport accounted for around 75% of global transport energy use in 2016, with passenger vehicles representing more than two-thirds of this.[139] In 2016, biofuels comprised nearly all (91%) of the renewable energy share in road transport energy use.[140]

One of the largest developments during the year for road transport was the increased deployment of electric vehicles[ii]. The number of electric passenger cars on the road reached more than 5.1 million in 2018 (almost half of them in China), up 63% from the previous year.[141] However, only limited examples are available of direct policy linkages between EVs and renewable electricity.[142] Nevertheless, an increasing number of countries have independent targets both for EVs and for renewable power generation, which could result in greater use of renewables for transport. (→ *See Policy Landscape chapter.*) While many challenges remain for scaling up EVs, further electrification of road transport has the potential to ease the integration of VRE by providing balancing services to the grid[iii], although this is still in its infancy.[143] (→ *See Systems Integration chapter.*)

Heightened global awareness about the higher pollution levels of diesel vehicles is one of the factors pressuring auto manufacturers to develop low-carbon and low-emission solutions (such as renewable fuels and electric mobility) and contributing to support for bans on fossil fuel-powered vehicles.[144] By the end of 2018, at least 19 countries and several sub-national governments had announced their intention to ban sales of new fossil fuel vehicles in favour of lower-emission alternatives (sometimes explicitly EVs).[145] (→ *See Sidebar 2 in Policy Landscape chapter.*) In addition to incentivising increased EV uptake, these targets can stimulate interest in biogas and biomethane vehicles that result in fewer emissions, as well as interest in increased biofuel use in hybrid vehicles, as a major part of a transition towards complete electrification where bans on internal combustion engine (ICE) vehicles are envisioned.[146]

A modal shift to public transport can greatly decrease energy use in the sector and allow for the renewable share to increase.

Another significant development during the year was the EU decision to phase out the use of palm oil in transport fuels from 2030, as well as to freeze limits on the shares of conventional biofuels used at the EU member country level by 2020 (so as not to surpass 7%).[147] The decision was a significant step for advanced biofuels and sent a signal to the global market.[148] To date, very few countries have introduced mandates for advanced biofuels, whereas at least 70 countries have blending mandates for conventional biofuels. (→ *See Policy Landscape chapter* and ***Reference Table R10.***)

A modal shift to **public transport** can greatly decrease energy use in the sector and allow for the renewable share in transport to increase, particularly as more local governments decarbonise their fleets.[149] (→ *See Feature chapter.*) More cities are moving to electric bus fleets as prices have fallen, although the use of these vehicles is not yet always linked to renewable energy.[150] Stockholm phased out its last fossil fuel-powered public bus in early 2019, with the result being a diverse mix of different kinds of buses on its streets, from liquid biofuel to biogas and biomethane to electric.[151] (→ *See Box 1 in Policy Landscape chapter.*) Many more examples exist of public urban rail running on electricity, sometimes directly linked to renewables, and in other cases running on biofuels. For example, in 2018 the Delhi Metro Rail Corporation began purchasing power from the 750 MW Rewa solar PV project for its public rail operations.[152]

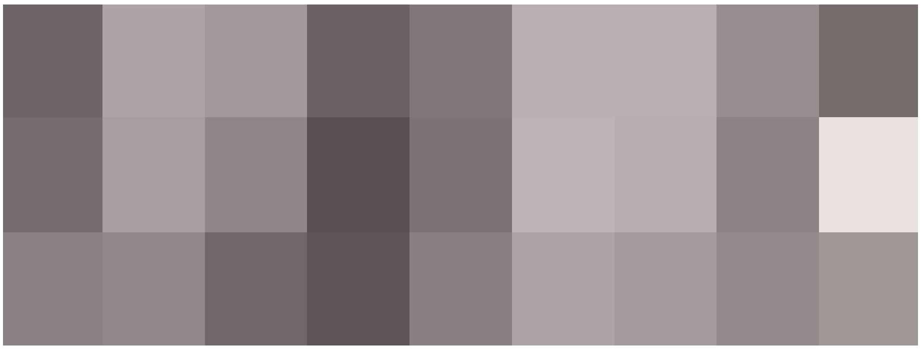
Rail transport accounts for around 1.8% of the total energy used in transport and is the most highly electrified transport sector.[153] Around three-quarters of passenger rail transport, and nearly half of freight rail transport, is electric.[154] An estimated 9% of the electricity used for rail transport was renewable in 2015, while another estimated 0.4% of renewable energy use in the sector came from biofuels.[155] Some jurisdictions are opting to increase the share of renewables in rail transport to well above the share in their power sectors.[156]

Hybrid trains have traditionally been diesel-electric, but advances in lithium-ion batteries have enabled some companies to develop battery-electric hybrid trains – such as Bombardier with its recently released "Talent 3" train.[157] Hydrogen fuel cells also open rail to further renewable energy penetration if the hydrogen is produced using renewable electricity. (→ *See Box 1 in Systems Integration chapter.*) Alstom's Coradia iLint became the world's first hydrogen fuel cell passenger train when it was approved for service in Germany in July 2018.[158]

i These actions together are commonly referred to as Avoid-Shift-Improve.

ii EVs include any road-, rail-, sea- and air-based 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 (FCEVs). 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.

iii EVs could ease the integration of 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. Vehicle-to-grid, or 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.



As of early 2019, more than
150,000
commercial flights had flown on blends of alternative fuels.

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.[159] 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, the vehicles account for three-quarters of the energy demand and CO_2 emissions from freight.[160] Fuel economy standards apply to 80% of light-duty vehicles globally, but 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.[161]

The larger the vehicles and the longer the range, the more challenging it is to find cost-effective alternatives to diesel.[162] However, many alternative fuels[i] are already commercially viable, although not all of them come from renewable sources. While hybridisation of trucks and buses is already economical and quickly pays for itself with fuel savings, fully electric heavy-duty vehicles are still more expensive; however, manufacturers are having to adapt when operating in cities that have banned ICE vehicles, such as Madrid.[163]

The internationally co-ordinated maritime and aviation sectors rely almost exclusively on the use of fossil fuels, thereby contributing greatly to global greenhouse gas emissions. Planning was initiated in 2017 for emissions reduction in both sectors, which culminated in international bodies for each sector implementing new standards and targets in 2018.

Maritime transport consumes around 10% of the global energy used in transport and is responsible for approximately 2% of total CO_2 emissions.[164] Maritime cargo shipping is the sixth-largest source of human-caused greenhouse gas emissions worldwide, responsible for approximately 800 million tonnes each year.[165] In 2018, the International Maritime Organization (IMO) adopted energy efficiency standards for international shipping, targeting a 40% reduction in total carbon intensity by 2030 and a 50% reduction in overall greenhouse gas emissions for the sector by 2050, relative to 2008 levels.[166]

In addition to the previously mentioned entry points for renewable energy, 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.[167] In 2018, the Norwegian cruise operator Hurtigruten announced plans to fuel its ships using liquefied biogas.[168] Elsewhere, such as in Finland, Greece, and Singapore, companies are developing demonstration ships using wind power or hybrid systems.[169]

Ports increasingly took the stage during the year with new initiatives to reduce emissions in the sector. The Port of Rotterdam Authority in the Netherlands announced an incentive to support vessel owners that use low-carbon or zero-carbon fuels, in addition to a commitment to reduce emissions from the port itself (Europe's largest) starting in 2030.[170] Also in 2018, the Port of Rotterdam along with six other ports – Antwerp (Belgium), Barcelona (Spain), Hamburg (Germany), Long Beach and Los Angeles (United States) and Vancouver (Canada) – established the World Ports Climate Action Program to advance reductions in maritime transport emissions in support of the Paris Agreement.[171]

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, with biofuels making up just 0.1% of all airline fuel in 2018.[172] In 2018, the International Civil Aviation Organisation (ICAO) made headway on a new agreement for its members to operationalise emissions mitigation actions in the aviation sector by specific deadlines. This followed the ICAO's landmark Carbon Offsetting and Reduction Scheme for International Aviation of two years prior, which aims for carbon-neutral growth from 2020 using average emissions from 2019 as the baseline.[173]

By early 2019, 111 ICAO member states (representing 92.3% of global air traffic) had submitted State Action Plans, up from 107 a year before.[174] Action Plans support the production and use of sustainable aviation fuels, specifically drop-in fuels[ii] produced from biomass and from different types of organic waste.[175] As of early 2019, more than 150,000 commercial flights had flown on blends of alternative fuels.[176] In 2018, the International

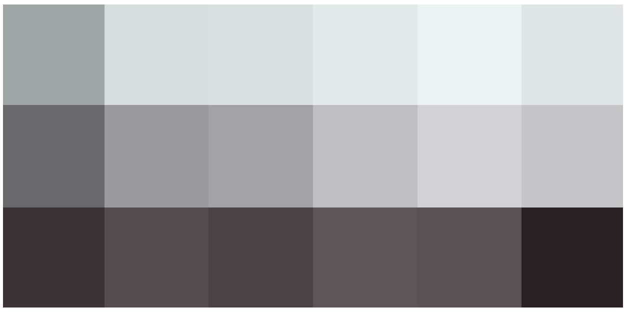
i Alternative fuels refer to alternative propulsion systems to the traditional diesel (or petrol) internal combustion engine and are not always exclusively from renewable sources. See endnote 163 for this chapter.

ii 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.

Air Transport Association, a trade association representing 290 airlines, set a goal of having 1 billion passengers fly on flights fuelled by sustainable aviation fuel by 2025.[177]

Some companies have announced targets for their own aircraft and are developing planes made specifically to run on biofuels. For example, in 2018 US-based FedEx Corporation unveiled a biofuel-powered plane and set a target for 30% of its fleet to use biofuels by 2030.[178] However, some technological limitations persist for biofuels in aviation. (→ *See Bioenergy section in Market and Industry chapter.*) Furthermore, only five airports had regular biofuel distribution as of early 2019: Brisbane (Australia), Bergen and Oslo (Norway), Stockholm (Sweden) and Los Angeles (United States).[179]

Although interest in the electrification of aviation is rising, so far only drone or small planes for 1 to 12 passengers have been developed (or are under development).[180] In 2018, Norway became the first country to announce a target for electric air travel, with its goal of having all short-haul domestic flights run on electricity by 2040.[181] In addition, some companies are already envisioning fully electric airliners to carry more than 120 passengers.[182]



POWER

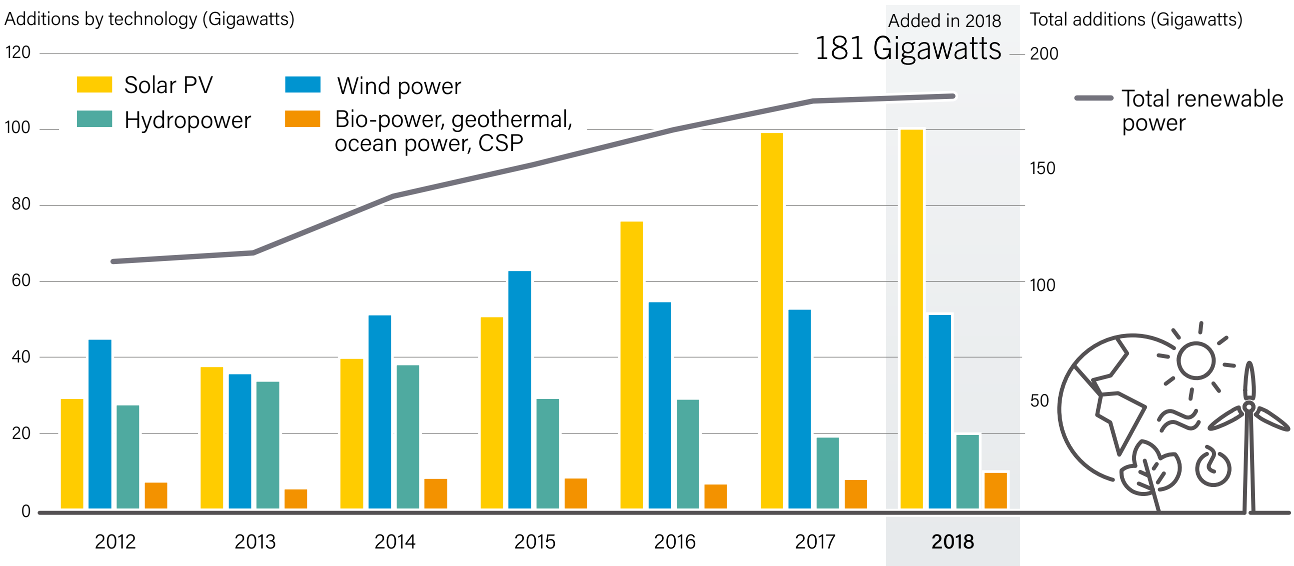
Renewable energy in power generation continued its strong pace in 2018. An estimated 181 GW was installed worldwide, slightly above 2017 additions, and total installed capacity grew more than 8%.[183] (→ *See Figure 6.*) After years of steady growth, the rate of new capacity additions levelled off during the year, and the overall global renewable power capacity totalled some 2,378 GW by the end of 2018.[184]

With around 100 GW added, solar PV[i] was once again the frontrunner for **installed renewable power capacity**.[185] Additions from solar PV accounted for 55% of new renewable capacity, followed by wind power (28%) and hydropower (11%).[186] For the fourth year in a row, additions of renewable power generation capacity outpaced net installations of fossil fuel and nuclear power capacity combined.[187] (→ *See Figure 3* and ***Reference Table R1.***)

The global composition of installed renewable power capacity continued to shift during 2018. Hydropower no longer accounted for half of the cumulative renewable power capacity in operation, falling below 48% by year's end.[188] Meanwhile, wind power rose to comprise roughly 25% of the installed renewable power generation capacity, while solar PV exceeded 20% for the first time.[189] Overall, renewable energy has grown to account for more than 33% of the world's total installed power generating capacity.[190] (→ *See Figure 7.*)

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

FIGURE 6. Annual Additions of Renewable Power Capacity, by Technology and Total, 2012-2018



Note: Solar PV capacity data are provided in direct current (DC).

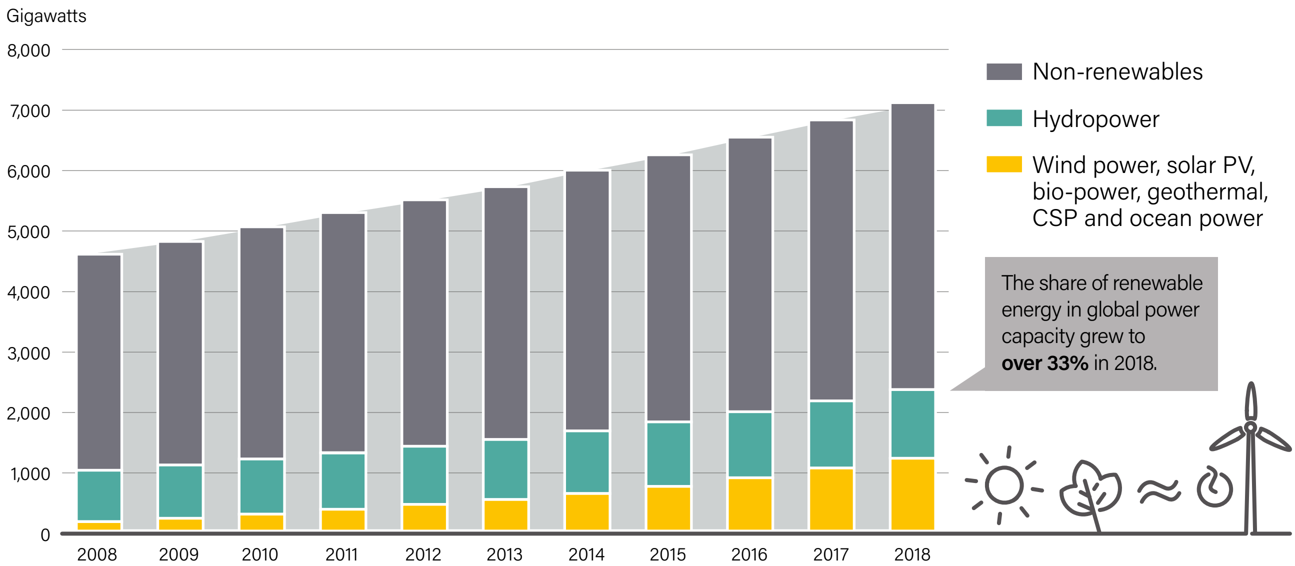
Source: See endnote 183 for this chapter.

Each year, more electricity is generated from renewable energy than in the previous year. Hydropower still accounted for some 60% of **renewable electricity production** in 2018, followed by wind power (21%), solar PV (9%) and bio-power (8%).[191] Overall, the installed renewable power capacity at year's end was enough to supply around 26.2% of global electricity production[i,192] (→ *See Figure 8.*)

Although renewable electricity is gaining ground quickly in many individual countries and regions, it faces challenges in achieving a larger share of the global total. This is due mainly to continued strong growth in total electricity production (up 4.0% in 2018) as well as to persistent investment in fossil fuel (and nuclear) power capacity and subsidies. (→ *See Figure 5.*)

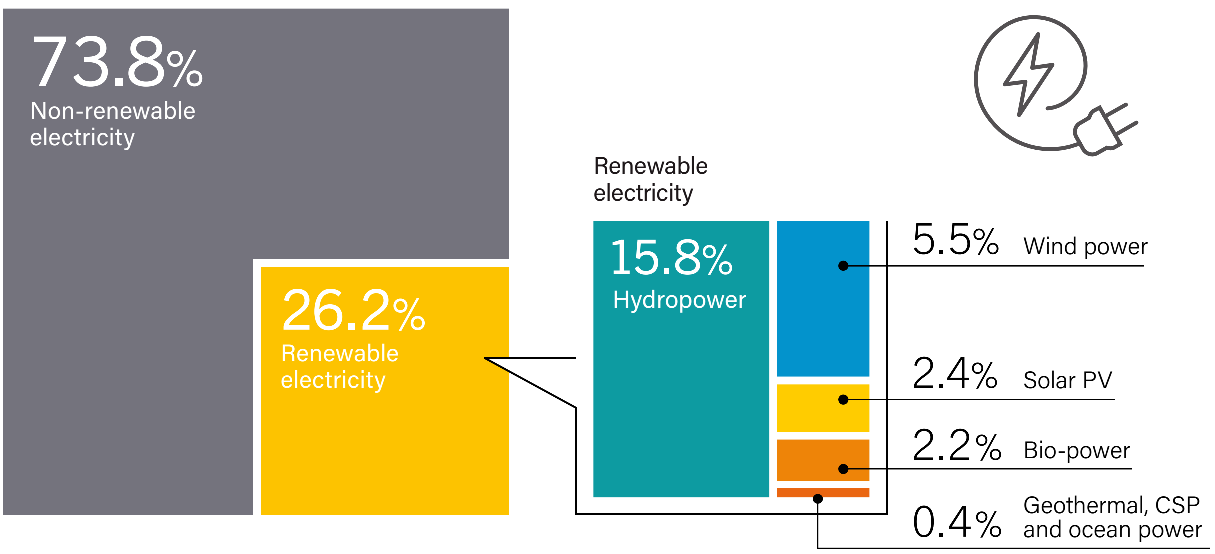
i Methodological adjustments and data revisions contribute in part to the variation in the share of renewable energy in global electricity production between GSR years. Data should not be compared with previous years, and this value is not intended to suggest any trends.

FIGURE 7. Global Power Generating Capacity, by Source, 2008-2018



Source: See endnote 190 for this chapter.

FIGURE 8. Estimated Renewable Energy Share of Global Electricity Production, End-2018



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

Source: See endnote 192 for this chapter.

Renewable energy has established itself on a global scale: by the end of 2018, more than 90 countries had installed at least 1 GW of generating capacity (including hydropower), while at least 30 countries exceeded 10 GW of capacity.[193] As in previous years, the top country for installed renewable power generating capacity was China, followed distantly by the United States, Brazil, India[i] and Germany.[194]

Considering only non-hydropower[ii] capacity, at least 45 countries have topped the 1 GW mark, while 17 countries have more than 10 GW combined of wind power, solar PV, bio-power and geothermal power[iii]. In 2018, the top countries for non-hydro capacity were China, the United States and Germany (all over 100 GW), followed by India and Japan, then the United Kingdom, Italy and Brazil/Spain[iv]. The top countries for non-hydro renewable power capacity per inhabitant were Iceland, Denmark, Germany, Sweden and Finland.[195] (→ *See Figure 9* and ***Reference Table R2***.)

Despite a second consecutive year of rising global energy-related CO_2 emissions, some regions have achieved significant reductions in electricity generation emissions due in part to deployment of renewable power capacity.[196] European emissions related to electricity production reportedly fell 5% in 2018 as a result of renewables, and emissions in the Australian power sector continued a three-year decline during a record year for renewable power generation.[197] US CO_2 emissions from power generation fell nearly 30% between 2005 and 2018, due in part to slower demand growth (improvements in energy efficiency) and growing renewable electricity production, especially from wind energy.[198]

Many milestones in renewable electricity generation were reached in various locations around the world in 2018. Australia surpassed 20% of total electricity production from renewables for the first time, while Costa Rica powered itself for 300 days on 100% renewable energy.[199] By early 2019, renewable electricity generation in the United States was edging towards levels of coal-fired power production, with renewable generation nearly doubling between 2008 and 2018.[200] In Europe, Portugal derived more than half of its electricity consumption for 2018 from renewable sources, and the United Kingdom hit annual records in shares of generation for both onshore (9.1%) and offshore (8%) wind power.[201] For the first time, the EU generated more than 15% of its annual electricity from wind power and solar PV.[202]

Electricity from **variable wind energy and solar PV** achieved high penetration levels in several countries in 2018. Variable renewables met high shares of generation in Denmark (51%), Uruguay (36%), Ireland (29%), Germany (26%) and Portugal (24%), and overall at least nine countries produced more than 20% of their electricity from VRE in 2018.[203] (→ *See Figure 10*.)

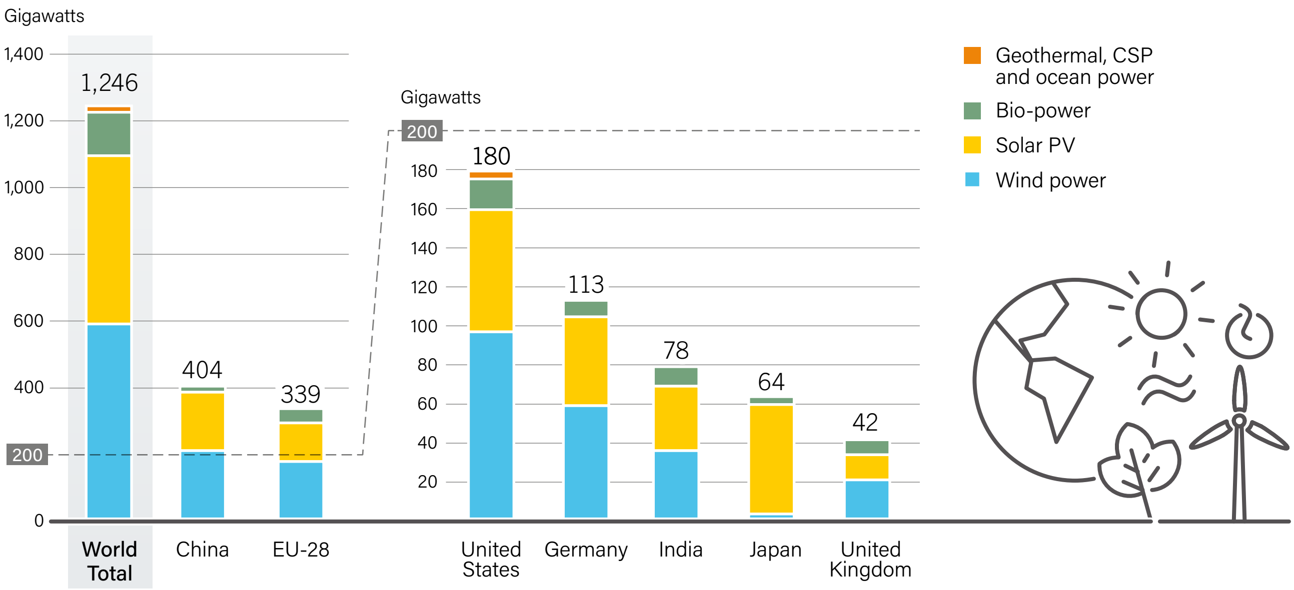
i Solar PV data for India are highly uncertain. See Solar PV section in Market and Industry chapter for details.

ii The distinction of non-hydropower capacity is made because hydropower remains the largest single component of renewable power capacity and output, and thus can mask trends in other renewable energy technologies if always presented together.

iii Neither CSP nor ocean power were decisive in whether any of these 17 countries reached 10 GW of non-hydro capacity.

iv Both Brazil and Spain had installed around 32 GW of capacity (excluding hydropower) by the end of 2018.

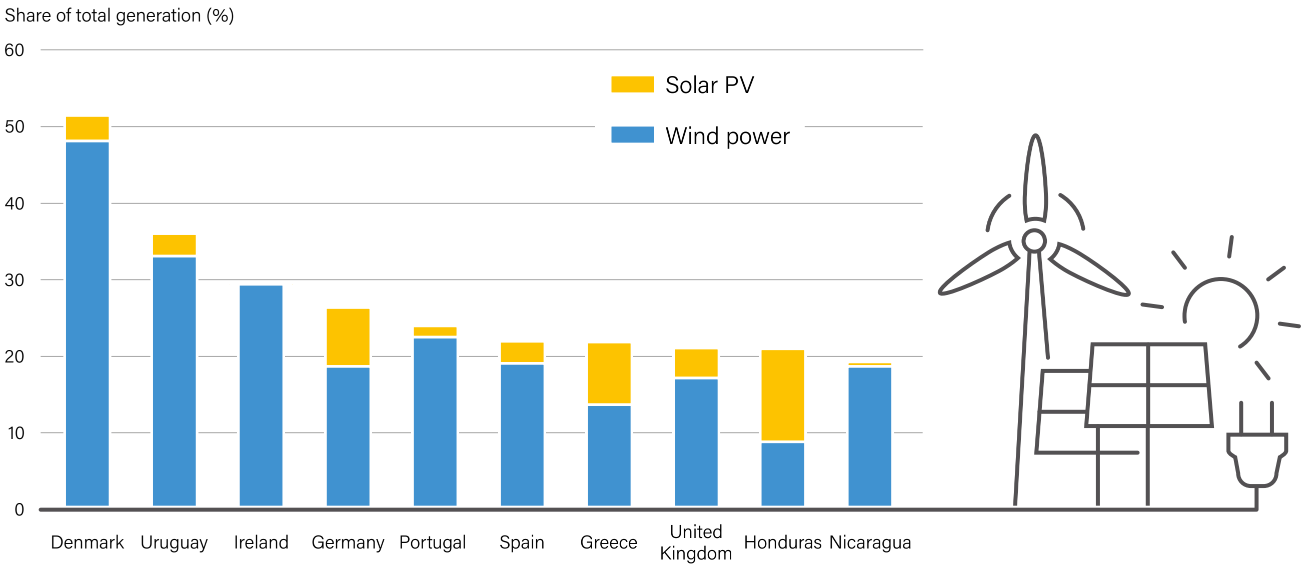
FIGURE 9. Renewable Power Capacities in World, EU-28 and Top 6 Countries, 2018



Note: Not including hydropower.

Source: See endnote 195 for this chapter.

FIGURE 10. Share of Electricity Generation from Variable Renewable Energy, Top 10 Countries, 2018



Note: This figure includes the top 10 countries according to the best available data known to REN21 at the time of publication.

Source: See endnote 203 for this chapter.

Rising shares of variable renewable electricity are prompting efforts in many countries to integrate this generation into national and regional power grids through a range of measures. Some countries (including Argentina, Australia, Chile, China, Colombia, Germany and South Africa) are building or investing in new transmission infrastructure in part to deal with rising shares of variable renewables in their power systems.[204] In China, nine transmission projects were announced in 2018 to transmit electricity from the wind-rich northwest to eastern areas with rising electricity demand.[205] (→ *See Systems Integration chapter.*)

Several new or revised targets were set in 2018, and action at a sub-national level kept growing. Many communities, cities and regions have set more ambitious goals than their national governments, with more than 200 cities committing by year's end to 100% renewable power.[206] (→ *See Feature chapter.*)

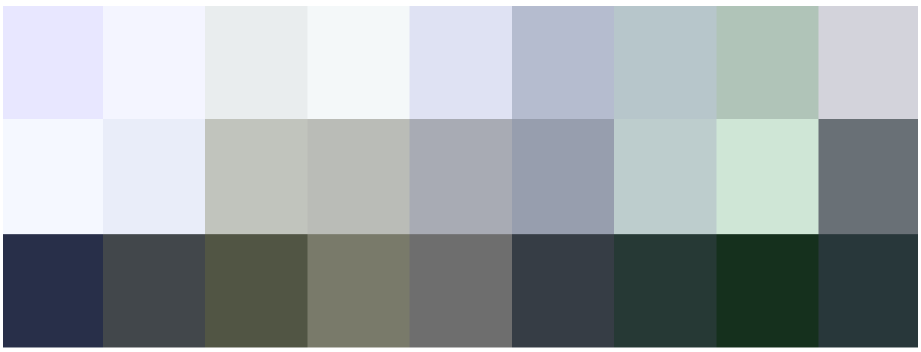
In 2018, **government policy and regulatory frameworks** continued to shape the development of the renewable power sector. An unexpected policy shift had major consequences for the solar PV industry, as China's decision to constrain its domestic market had global implications for the price and manufacturing of solar PV modules, as well as for project development in some locations.[207] Overall, the year saw the continuation of a global shift from tariff-based instruments to competitive auctions. Renewable power auctions were held in at least 48 countries in 2018, up from 29 in 2017.[208] However, feed-in policies still play a role in national and sub-national policy frameworks and were in place in at least 111 countries by year's end. (→ *See Policy Landscape chapter.*)

In many countries, the resulting competition through auctions caused bid levels for new solar PV and wind power to reach record lows[i], including in Brazil, China, Germany, Greece, India, Poland,

At least nine countries produced more than

20%

of their electricity from wind energy and solar PV in 2018.



Saudi Arabia, the United Arab Emirates and the United States.[209] In some cases, solar PV bids and announcements reached prices below USD 20 per megawatt-hour.[210] Technology-neutral or mixed auctions also were held in some countries in 2018, often with solar PV or wind energy as the technology choice of the winning bid.[211] Auctioning processes struggled in some instances, however, with auctions postponed or cancelled in a handful of countries around the world.[212] (→ *See Market and Industry chapter.*)

Auctions in 2018 also led to the emergence of winning bids that did not rely on direct financial support. Although the resulting price may not be backed by a long-term guarantee from, for example, a feed-in tariff, the offer is highly dependent on the local market conditions, the prevailing policy framework and indirect financial support.[213] This indirect support could take the form of a guaranteed grid connection, assumption of project risk, certain exemptions (for example, from an environmental assessment or planning study) or indirect pledges that reinforce the future economic prospects of renewable energy projects (such as carbon pricing or guaranteed technology capacity volumes).[214] In Europe, auctions in both Germany and the Netherlands resulted in bids for wind energy projects without direct financial support.[215] Solar PV and wind energy projects with no additional financial support also were announced or approved in Italy, Finland, Portugal, Spain and the United Kingdom (with energy storage).[216]

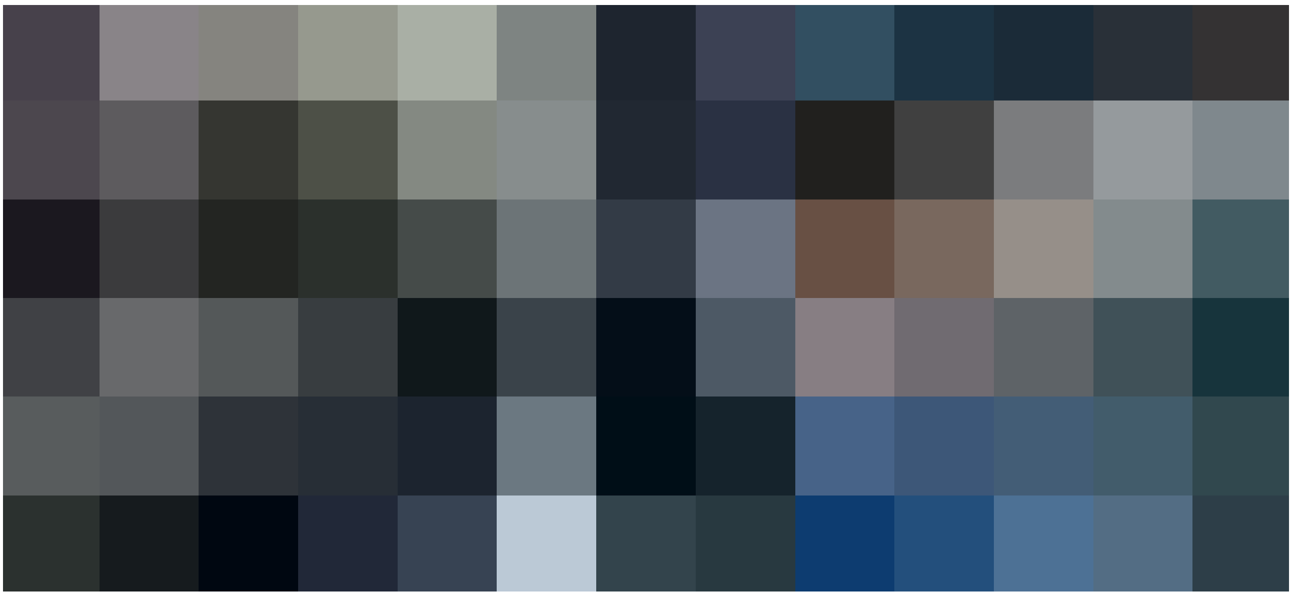
Across the largest **industries in the renewable energy sector**, mounting competition and price pressure, due partly to the rise of competitive auction processes, has slimmed margins along supply chains.[217] Even some of the biggest wind turbine manufacturers, for example, have seen profits fall despite increasing unit sales.[218] In some cases, price pressures as well as unfavourable policy changes and shifting or shrinking markets in some countries have resulted in mergers, acquisitions or even bankruptcies of manufacturers and suppliers.[219]

To meet such challenges, firms are working to drive down costs in operations, manufacturing and project construction, sometimes resulting in quality-related issues, most notably in the solar PV industry.[220] Manufacturers also are working to further improve their technologies: in 2018, solar PV researchers were developing new, more efficient cell and module technologies, while wind turbine manufacturers were developing larger turbines and advancing tower and blade materials.[221] Both industries are taking advantage of digitalisation and other new technologies to improve plant monitoring processes and help manage grid integration. The hydropower industry has similarly reported a growing intensity of project competition during the year, which firms have cited as a key driver for improving the efficiency and flexibility of their turbines.[222]

As another way to find a competitive edge, some companies are developing new revenue streams, expanding into new services (such as operations and maintenance) or even moving beyond their core business – for example, solar PV companies moving into storage, and wind turbine manufacturers expanding into EV charging. (→ *See Market and Industry chapter.*)

Ongoing, widespread deployment of solar PV and wind power capacity in 2018 can be attributed in part to years of **steady declines in the levelised cost of electricity**, making these technologies ever more competitive for meeting new power generation needs. Solar PV and onshore wind power generation costs fell rapidly between 2010 and 2018, while hydropower generation costs rose slightly over the same period but still lie in the range of fossil fuel generation.[223] Hydropower is an attractive, cost-effective option for grid balancing and services, adding further value to its generation assets.[224] (→ *See Sidebar 4* and *Table 3.*)

Corporations are turning towards renewable energy in growing numbers, and a record number of corporate **power purchase agreements** (PPAs) were signed in 2018. Around 13 GW of renewable power was sourced through corporate PPAs during the year, more than doubling the previous record of 6 GW set in 2017.[225] The United States accounted for nearly 9 GW of this capacity, and



i For many reasons, tender prices may be lower than the actual cost of installed technologies. For example, bids may include annual increments, and tender conditions might include the provision of grid connection to developers. In addition, bids reflect expected future costs, rather than current costs.

Annual corporate sourcing of renewable power

doubled

compared to 2017.

in Europe corporations sourced more than 2 GW of renewable electricity (primarily wind power) through PPAs.[226] The increasing cost-competitiveness of wind power and solar PV has been cited as a major driver for the surge in corporate PPAs.[227]

Major energy-intensive industries around the world are installing and procuring renewable electricity to power their activities.[228] Among them, the mining industry had commissioned more than 1.7 GW of solar PV and wind power capacity at over 52 mining sites by the end of 2018.[229] In Chile, 200 MW of solar PV and wind power capacity was installed at a copper mine during the year, and the country is planning further deployment of large-scale solar PV and concentrating solar thermal power (CSP) to support mining operations.[230] Australia and Zimbabwe also saw the commissioning of solar PV projects in the mining industry during the year.[231] Solar PV and wind power capacity was procured through PPAs in various other sectors in 2018, including aluminium, cement, oil and steel.[232]

Rising levels of distributed renewable generation, such as rooftop solar PV, and increased competitive pressure have had major implications for **electric utilities** as they struggle to remain profitable using traditional business models.[233] In Europe, two of the largest energy utilities chose to exchange and restructure their fossil fuel, renewable energy and infrastructure assets in an effort to adapt to the transforming power sector.[234] Some electricity providers are dealing with the rise in residential and commercial self-consumption of renewable power by expanding their consumer offers, rolling out new leasing models or engaging with time-of-use pricing and net billing, among other strategies.[235] Others have met the ongoing transition with resistance, filing legal challenges and issuing proposals for revised regulations that attempt to hinder the profitability and development of renewable energy markets and industries.[236]

Utilities also are adjusting to the energy transition by directly procuring or generating renewable power. Some firms in Chile, France, Japan, the United Kingdom, the United States and elsewhere have begun to shift their electricity production to renewables, or have made large investments in renewables and energy storage.[237] Worldwide, utilities are upgrading transmission infrastructure as well as joining common electricity markets and procuring demand response capacity to better integrate renewable energy.[238] Commitments and pledges towards integration of renewables are increasingly common, as utilities in Africa, Australia, China, Europe, India and the United States signal their intentions to move out of fossil fuel generation and into large-scale renewables.[239] In 2018, two US utilities announced plans to transition to 100% carbon-free energy by 2030.[240]

Energy storage continues to be an effective tool for integrating variable renewable electricity into power systems. Pumped storage remains the largest source of energy storage, with 160 GW installed worldwide, and some plant operators have indicated rising shares of variable renewables as a growing opportunity to maximise the value of their storage assets.[241] Also increasing is the use of utility-scale batteries for grid services and participation in day-ahead markets to regulate power networks and cut peak pricing or to provide ancillary grid services, such as reserve power.[242] In some countries, solar PV-plus-storage for residential and commercial rooftop systems is growing quickly.[243]

Hybrid renewable energy systems (for example, solar PV with wind power, solar PV with CSP, or renewables with energy storage) use the complementarity of generation patterns of different renewable energy technologies in certain locations to reduce variability in renewable power generation and bring about more efficient use of transmission infrastructure and land[i].[244] Several countries announced or commissioned solar PV-wind power hybrid projects in 2018, including Australia, Chile, Gabon, India, Spain and the United States. Tendering and construction on solar PV-CSP hybrid plants (with thermal energy storage) were announced in Morocco and Spain.[245]

In **developing and emerging economies**, as well as in isolated locations such as islands and rural areas, communities and companies are turning to renewable power (primarily solar PV and often connected with micro-grids) to meet their energy needs.[246] On the side of individual electricity access, rising power demand in 2018 translated into a strong increase (77%) in larger solar home system sales, which are mostly pay-as-you-go and progressively including more energy-efficient appliances.[247] On the side of collective electrification, mini-grids powered by renewable energy expanded at a faster pace across Asia and Africa.[248] The growing volume of mini-grid projects with transparent track records has reassured development finance institutions as well as commercial financiers and led to the emergence of new investment vehicles that specifically target mini-grids as well as their productive use.[249] (→ *See Distributed Renewables chapter.*)

i In general, a smaller land area is required for the same generation capacity from a hybrid renewable energy system than for a single solar PV or wind power installation.

SIDEBAR 1. Jobs in Renewable Energy, 2018

The renewable energy sector employed (directly and indirectly) around 11 million people worldwide in 2018[i]. This figure includes 2.1 million direct jobs in hydropower.

A number of factors shape how and where employment is generated. As costs continue to decline, enabling policies remain critical to the continued expansion of renewables, along with industrial policies to enhance domestic value creation, as well as educational, training and labour market policies. Corporate strategies strongly influence the geographical distribution of jobs. Industry consolidation means that fewer actors drive the diversification of supply chains and the resulting trade flows and occasional frictions. As renewable energy industries scale up and mature, labour productivity rises.

Women represent 32% of the total renewable energy workforce, whereas they account for only 22% of the oil and gas workforce. A number of barriers to hiring and retaining women remain, the most important of which are social and cultural norms and related perceptions of gender roles.

Solar photovoltaics (PV) was again the largest employer of all renewable energy industries in 2018, followed by biofuels, hydropower, wind power, and solar heating and cooling. (→ *See Table 1.*)

Global employment in solar PV is estimated at 3.6 million jobs; this figure incorporates a larger share of the world's off-grid solar employment than available information allowed in previous years. China retained the lead in solar PV manufacturing, as well as in exports and domestic deployment, but a sudden change in subsidy policies during the year led to a slower pace of new installations and caused a small drop in national employment, to 2.19 million jobs. India's employment in grid-connected solar PV is estimated at 115,000 jobs. A variety of economic and policy factors led solar PV employment to drop in the United States, Japan and the European Union (EU).

Biofuels employment totalled an estimated 2 million jobs, a small increase over 2017. Most of these jobs are in the agricultural supply chain in developing countries, and many are informal. This is the case in Southeast Asia, for example, where there were an estimated 413,000 jobs, an increase of 8.5% over 2017. In Brazil, which accounts for the largest biofuels workforce, employment expanded from 795,000 to 832,000 jobs. Biofuels employment in the United States and in Europe also grew, but operations are more mechanised and therefore require less labour input.

Some 1.16 million people were employed in the wind power industry in 2018, up relative to 2017 and just slightly higher than the previous peak in 2016. This reflects diverging developments in various countries. Although the pace of new installations in China picked up, policy changes concerning subsidies and competitive bidding made companies reluctant to undertake additional hiring. Employment thus remained unchanged at 510,000 jobs in 2018. In the United States, employment in the wind power sector increased 8% relative to 2017 to 114,000 jobs. By contrast, the European wind power workforce declined 9% to 314,200 jobs in 2017 (the most recent year for which data are available).

Global employment in solar thermal heating and cooling was estimated at 801,400 jobs, a decrease of about 1% from 2017. Employment in some major markets including China, Brazil and the European Union declined or stagnated, while others such as India showed increased activity.

Knowledge about job creation in the context of energy access remains limited. Off-grid solar in South Asia and parts of sub-Saharan Africa is estimated to support 372,000 full-time equivalent jobs, at many different skill levels. Women hold about a quarter of these jobs.

By country or region, the largest employers across all renewable energy technologies were China, the EU, Brazil, the United States and India. China retained its lead in 2018, although its jobs total declined somewhat to around 4.1 million. Solar PV remained the largest source of jobs in the country's renewable energy sector.

The number of jobs in the EU was estimated at 1.2 million in 2017, down slightly from 2016. The region's solid biomass, wind power and biofuels sectors were the largest employers. Employment in solar PV dropped again in 2017 to 96,000 jobs. Germany remained the leader in Europe.

Employment in Brazil's renewable energy sector rose 4.5% in 2018. Biofuels are the country's mainstay due to high employment in the agricultural supply chain. Although mechanisation continues to shrink the ethanol workforce, that decline was more than offset by the expansion of biodiesel operations. Hydropower is Brazil's second-largest employer in the renewable energy sector, followed at a distance by wind power and solar water heating, two sectors where employment remained similar to 2017.

In the United States, total jobs in renewable energy increased 5% relative to 2017 to 855,000. Including jobs in the agricultural supply chain, biofuels are the country's leading employer among all renewables. The US solar workforce contracted for a second year due to uncertainties about the impacts of import tariffs. Wind power employment is at the country's highest level to date with 114,000 jobs, benefiting from steady policies in the last few years.

In India, the total number of renewable energy jobs remained virtually unchanged. Most of these jobs are in hydropower, followed by solar PV.

Employment in the renewable energy sector – particularly solar PV – is spreading to ever more countries (including Egypt, Malaysia and Morocco), although the numbers of jobs in these countries have remained comparatively small. Macro-economic trends, regulatory changes and other challenges such as land scarcity have caused employment to decline in other countries (for example, Japan, the Philippines and Turkey).

i This sidebar is primarily drawn from International Renewable Energy Agency (IRENA), *Renewable Energy and Jobs – Annual Review 2019* (Abu Dhabi: 2019). Data are principally for 2017 and 2018, although actual dates vary by country and technology. Where possible, employment numbers include direct and indirect employment. All jobs figures should be regarded as indicative, as estimates draw on a large number of studies with different underlying methodologies and uneven data quality.

Source: IRENA. See endnote 250 for this chapter.

TABLE 1. Estimated Direct and Indirect Jobs in Renewable Energy, by Country/Region and Technology, 2017-2018

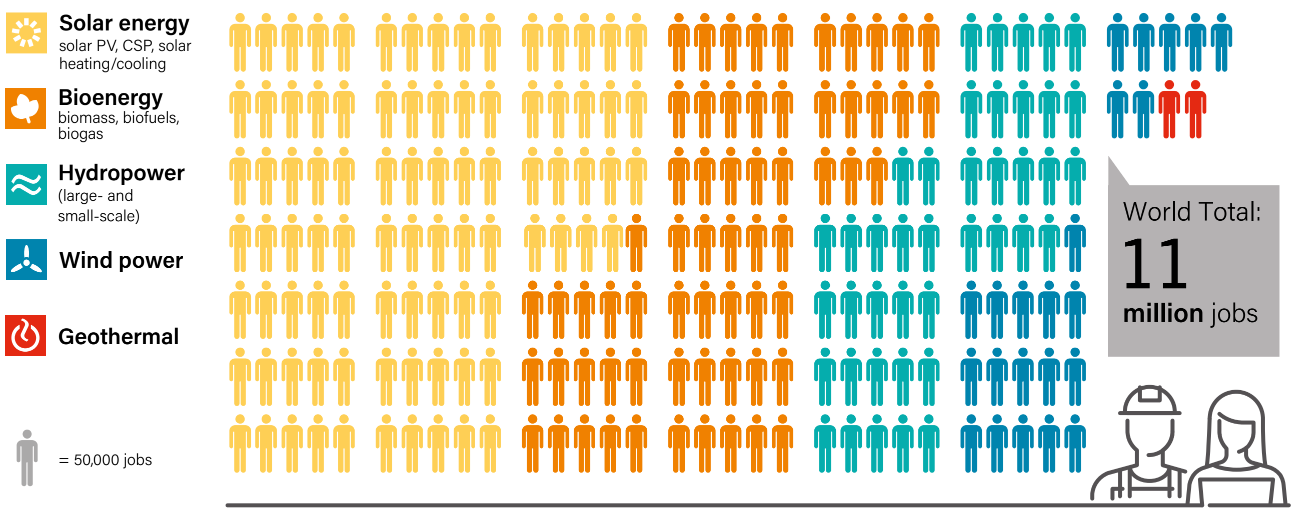
	World	China	Brazil	United States	India	European Union[l]
	Thousand jobs					
Solar PV	**3,605[e]**	2,194	15.6	225	115[k]	96
Liquid biofuels	**2,063**	51	832[g]	311[h]	35	208
Hydropower[a]	**2,054**	308	203	66.5	347	74
Wind power	**1,160**	510	34	114	58	314
Solar thermal heating/cooling	**801**	670	41	12	20.7	24[m]
Solid biomass[b, c]	**787**	186		79[i]	58	387
Biogas	**334**	145		7	85	67
Geothermal energy[b,d]	**94**	2.5		35[j]		23
Concentrating solar thermal power (CSP)	**34**	11		5		5
Total	**10,983[f]**	**4,078**	**1,125**	**855**	**719**	**1,235[n]**

Note: Jobs estimates generally derive from 2017 or 2018 data, although some data are from earlier years. Estimates result from a review of primary sources such as national ministries and statistical agencies, as well as secondary sources such as regional and global studies. Totals for individual countries/regions may not add up due to rounding.

[a] The estimates provided here are for direct jobs only. Note that past editions of the GSR provided employment estimates for small- and large-scale hydropower separately. [b] Power and heat applications. [c] Traditional biomass is not included. [d] Includes ground-source heat pumps for EU countries. [e] Includes an estimate by GOGLA of 372,000 jobs in off-grid solar PV in South Asia and in East, West and Central Africa. South Asia accounts for 262,000 of these jobs. IRENA estimates Bangladesh's solar PV employment at 135,000 jobs; most of the remainder of the South Asian regional total is in India. [f] Total includes waste-to-energy (41,100 jobs) and ocean power (1,100 jobs), principally reflecting available employment estimates in the EU, as well as non-technology-specific jobs (7,600) jobs. [g] About 217,000 jobs in sugarcane cultivation and 158,000 in ethanol processing in 2017, the most recent year for which data are available. Figure also includes a rough estimate of 200,000 indirect jobs in equipment manufacturing, and 256,900 jobs in biodiesel in 2018. [h] Includes 238,500 jobs in ethanol and 72,300 jobs in biodiesel in 2018. [i] Based on employment factor calculations for bioelectricity. [j] Based on an IRENA employment-factor estimate. [k] Grid-connected solar PV only; see also note e. [l] All EU data are from 2017. [m] May include CSP for some countries. [n] Total includes waste-to-energy (35,600 jobs) and ocean power (1,050 jobs).

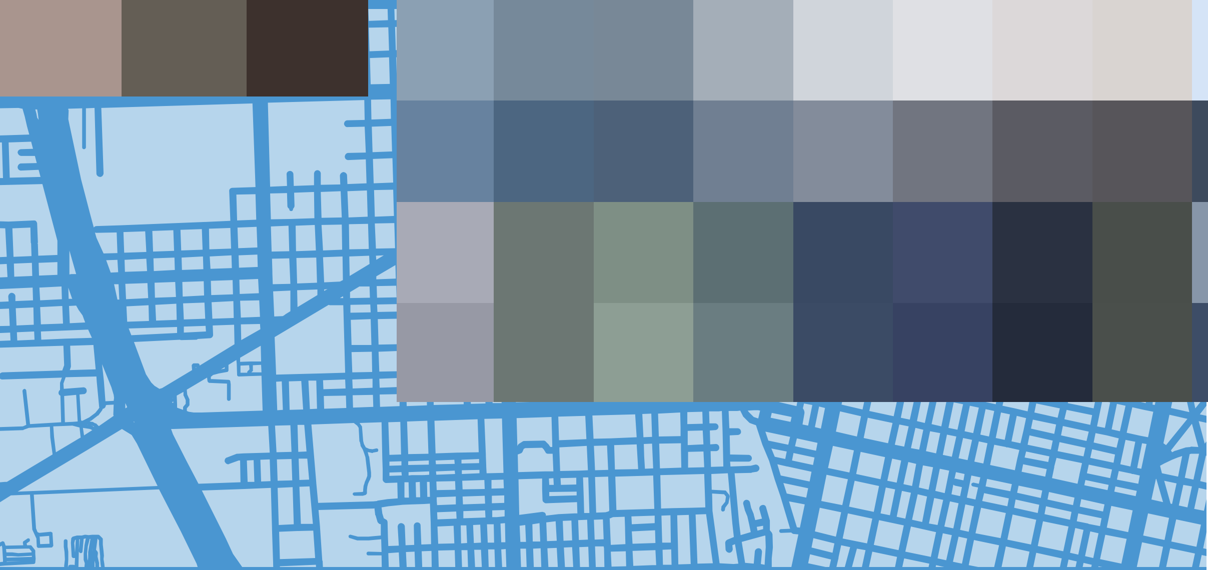
Source: IRENA.

FIGURE 11. Jobs in Renewable Energy, 2018



Source: IRENA.

02



Project and City:
Solar water heaters, Cozumel, Quintana Roo, Mexico

Technology:
Solar water heaters

Cozumel, Quintana Roo, Mexico

Mexico's MiSol project is a result of a financing scheme of Conuee (the National Commission for the Efficient Use of Energy) in collaboration with UNDP and Bancomext. It aims to ensure market certainty to accelerate the growth of solar water heating and has begun with a focus on hotels in the Yucatan Peninsula. The first two installations in the cities of Cancún and Cozumel have energy outputs of 93 megawatt-hours and 61 megawatt-hours per year, respectively. Some local and state governments in the region play a role in promoting the project.

POLICY LANDSCAPE

Renewable energy support policies and targets are now present in nearly all countries worldwide.[1] As the costs for renewable technologies fall, these measures continue to evolve and adapt, and in some places they are expanding to ease the integration of higher shares of variable renewable energy (VRE)[i] into electric grids. The power sector again received most of the renewable energy-focused policy attention in 2018. Similarly, targets for renewable energy continued to be more ambitious in the power sector than in the heating, cooling and transport sectors, with some countries – and many more sub-national governments – aiming for 100% renewable electricity.

Outside the power sector, policies for renewables have advanced at a slower pace, and targets for renewable heating, cooling and transport are not only far less numerous, but also often far less ambitious. This trend has continued despite the much greater contribution of the heating, cooling and transport sectors to total final energy consumption (TFEC). (→ *See Global Overview chapter.*)

> Renewable energy policies and targets **remain far from the ambition level** required to reach international climate goals.

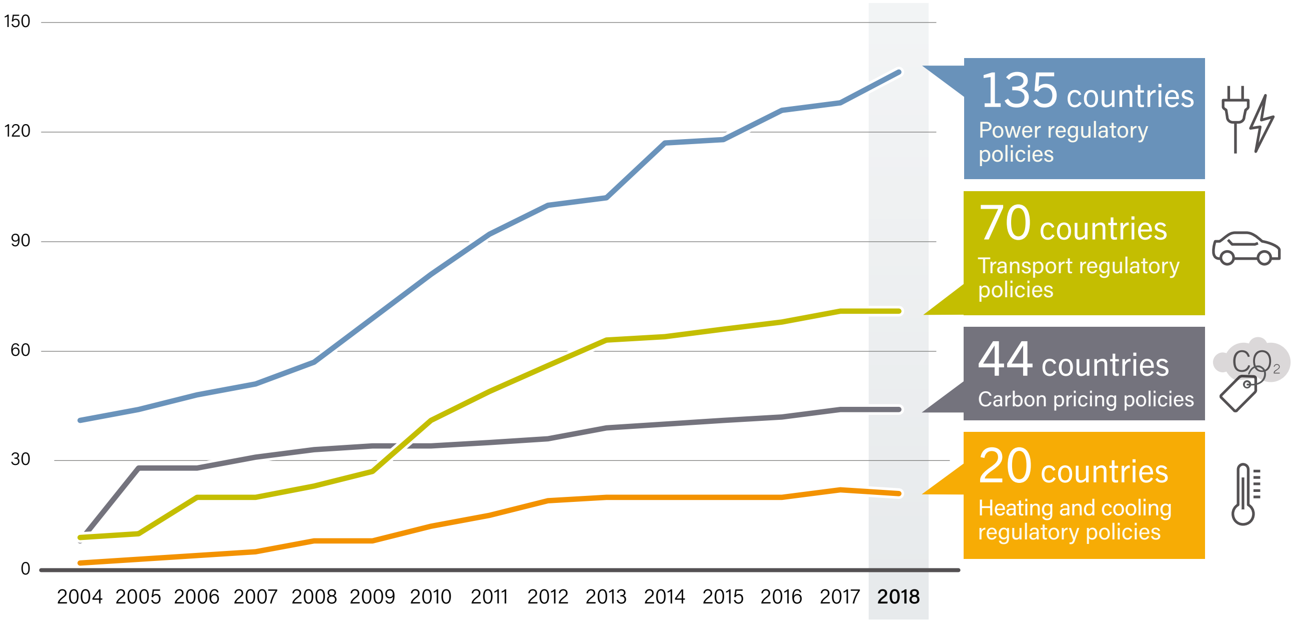
Overall, renewable energy policy frameworks continue to vary greatly in scope and comprehensiveness, and most remain far from the ambition level required to reach international climate goals.[2] (→ *See Figure 12* and ***Reference Tables R3-R13***.)

Still, the diverse benefits of renewable energy are driving policy action in countries around the world[ii,3] Policies have played a significant role in the growth of renewable energy and have helped advance technologies and reduce costs. Well-designed support mechanisms can spur deployment in nascent renewable energy markets; promote renewable energy in sectors with limited deployment, such as heating, cooling and transport; and guide the integration of technologies across different sectors of the economy. Policies also play an important role in supporting technology development that can lead to new advances, thereby

i Defined more broadly, VRE also can include some forms of ocean power and hydropower. This chapter focuses primarily on solar PV and wind power, as these represent the fastest-growing VRE markets that are having the greatest impacts on energy systems. See Glossary for an extended definition of VRE.

ii Multiple benefits of renewables include improved public health through reduced pollution, increased reliability and resilience, and job creation and other economic benefits.

FIGURE 12. Number of Countries with Renewable Energy Regulatory Policies and Carbon Pricing Policies, 2004-2018



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. Carbon pricing policies include carbon taxes and emissions trading systems (ETS) and are not renewable energy policies per se. The EU ETS covers EU countries and Iceland, Liechtenstein and Norway, so the total number of EU countries covered are counted from 2005, when it was implemented. For more information, see Table 2 in this chapter and Reference Tables R9-R12.

Source: See endnote 2 for this chapter.

increasing efficiency, driving down system costs and transitioning new technologies or applications to market.

Targets, regulations, public financing and fiscal incentives supporting renewable energy development and deployment are found at the international, regional, national and sub-national levels. At each level, policy makers have the opportunity to design an effective mix of support policies tailored to their respective jurisdictions.

Although regional or national policies regularly receive the most widespread attention, provinces, states and cities are often the first movers in establishing innovative and ambitious mechanisms for renewable energy deployment. Many cities have direct control of public transport networks, building codes and, in some cases, electric utilities, allowing them to use their regulatory and purchasing authority – as well as their position as large energy users – to procure and deploy renewable technologies.[4] (→ *See Feature chapter.*) In many developing countries, the renewable energy push comes from international agreements, which can have an impact on policy implementation at all levels of government.

Evolving energy markets and geopolitical uncertainty have moved energy security and energy infrastructure resilience to the forefront of many national energy strategies. Security of supply is a significant concern in energy markets worldwide, from the European Union (EU) and the United States to Egypt and India.[5] Debates in this realm are often complex and can be contentious, as they may involve the introduction of new energy production sources, the emergence of decentralised renewable technologies and a departure from traditional producer-consumer dynamics.

As countries develop national energy strategies to transform their energy sectors, they continue to focus on renewable power technologies. System integration is important to ensure the long-term viability of power systems that comprise a growing range of technologies and higher shares of VRE. Policy makers increasingly are exploring opportunities to ensure that power systems have the flexibility to manage disruptions as well as fluctuations in supply. Promoting integration has included dynamic policy and market measures that provide varying levels of support based on factors such as the time or place of generation.[6] (→ *See Integration section in this chapter, and Systems Integration chapter.*)

The following sections provide an overview of trends in renewable energy policy development worldwide in 2018[i].

i The chapter highlights key trends and developments in 2018 and is not intended to be a comprehensive list of all policies enacted to date. In addition, the chapter does not assess or analyse the effectiveness of specific policy mechanisms. Further details on newly adopted policies and policy revisions are included in the Reference Tables and endnotes associated with this chapter. Policies for energy access are covered in the Distributed Renewables chapter.

TARGETS

Policy makers at all levels of governance continued to revise or adopt renewable energy targets in 2018. The spectrum of ambition ranges from vision statements to legally binding requirements.[7] For the purposes of this chapter, only official targets are discussed.

By 2018, nearly all countries and many sub-national jurisdictions had adopted some form of renewable energy target. New and revised targets have become increasingly ambitious in scope; however, targets for economy-wide energy transformation remain rare: by year's end, fewer than 10 countries, states and provinces had economy-wide targets for at least 50% renewable energy.[8] In contrast, at least 92 countries, states and provinces had targets specifically for the use of renewables in the power sector, a slight increase from 2017.[9] (→ *See Figure 13 and* ***Reference Tables R3-R8***.) Although few countries had renewable energy targets specifically for the heating, cooling and transport sectors, Estonia, Finland, Latvia and Sweden all achieved shares of renewable heating and cooling greater than 50%.[10]

Several new or revised renewable energy targets were established in 2018, including the EU's goal of meeting at least 32% (revised upwards from 27%) of its final energy consumption from renewable sources by 2030.[11] The EU agreement also establishes a 14% minimum share of renewable fuels for transport energy, a 1.3% annual increase in renewable heating and cooling installations, and a process for individual EU member countries to develop National Energy and Climate Plans by the end of 2019 that would outline their individual commitments towards the collective goals between 2021 and 2030.[12]

The 100% renewable energy movement continued to gain traction worldwide in 2018. However, the majority of commitments apply only to the power sector.[13] While the 100% renewables movement has taken place largely at the local and sub-national levels, a handful of countries have adopted national targets as well. ***(→ See Reference Table R6.)*** For example, in 2018 Lithuania approved a revised national energy strategy that commits the country to meet 80% of total energy demand with renewables by 2050.[14] Denmark remains the only country globally with a target for 100% renewables in total final energy.[15]

At the sub-national level, US cities were particularly active in setting new 100% renewable electricity goals in 2018. By year's end, at least 100 US cities and towns had made the commitment to 100% renewables, with new goals set in Cincinnati and Cleveland (Ohio), Denver (Colorado), Minneapolis (Minnesota) and Washington, D.C.[16] Targets for 100% renewable power typically are set for years ranging from 2020 to 2050, although some cities already had achieved 100% renewables by the end of 2018.[17] (→ *See* ***Reference Table R13*** *and Feature chapter.*)

Many other targets focus on scaling up renewable energy in the power sector to shares below 100% – including China's new goal of achieving 35% renewable electricity consumption by 2030.[18] Bahrain and France set capacity-specific targets for solar photovoltaics (PV), while several countries established targets for offshore wind power capacity.[19] (→ *See* ***Reference Table R7*** *and Market and Industry chapter.*)

Denmark remains the only country with

a target for 100% renewables

in total final energy.

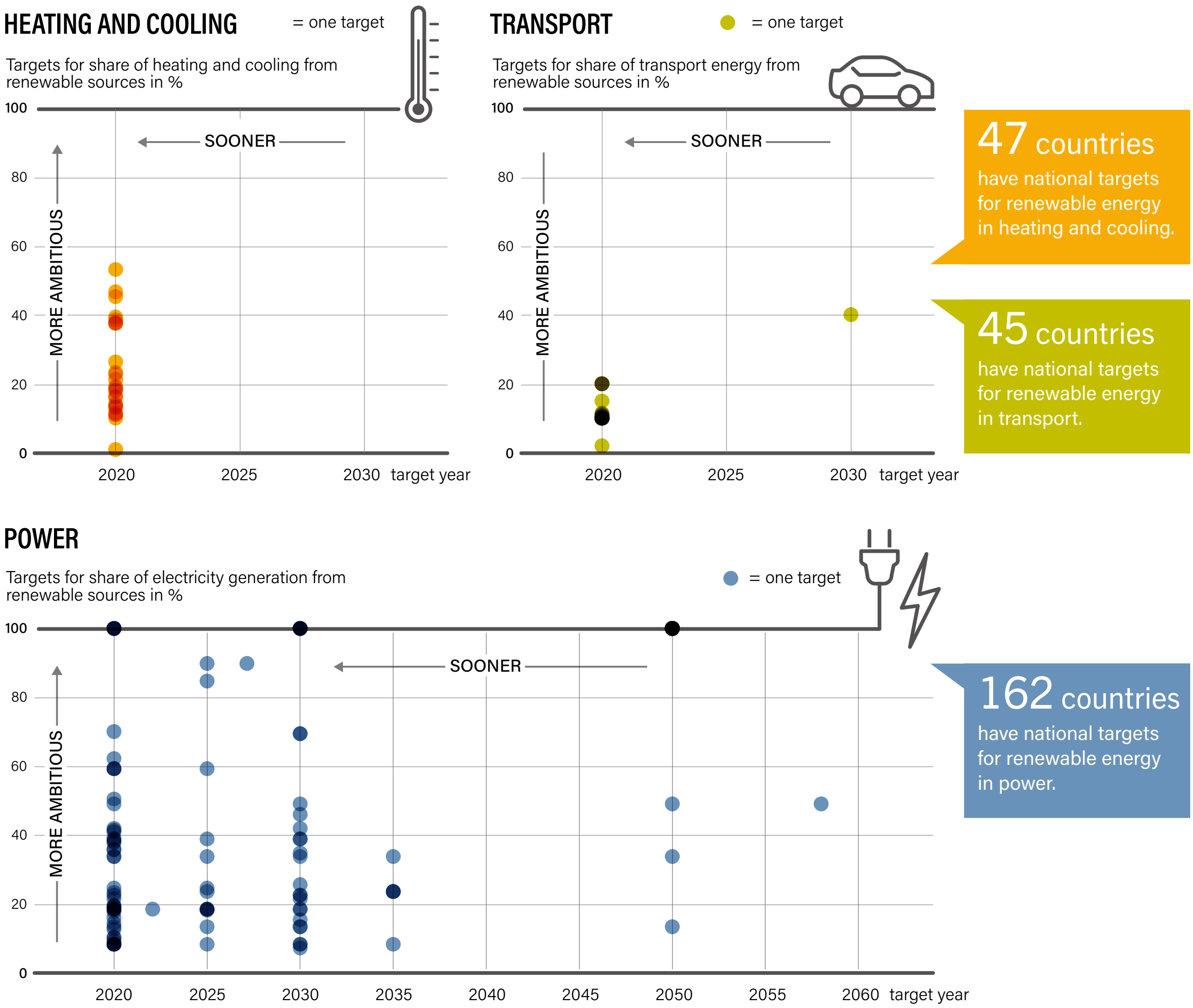
HEATING AND COOLING

Policy support for renewable energy uptake for heating and cooling in the buildings and industry sectors has been relatively flat in recent years. No new countries added regulatory incentives or mandates for renewable heating and cooling in 2018, and Kenya suspended its solar water heating regulation in August 2018.[20] ***(→ See Reference Table R9.)***

Where they exist, policies to increase the use of renewables in buildings and industry often are implemented alongside energy efficiency policies. They include policies to promote the use of renewable heat technologies, to reduce energy consumption, to mandate the use of efficient lighting or appliances, and to require the integration of renewable energy technologies (primarily solar PV and solar thermal) in buildings. Renewable heat sources – geothermal, biomass and solar thermal energy – can help to decarbonise both the buildings and industrial sectors.

Expanding renewable energy in heating and cooling – an important energy end-use within buildings and industry – presents an opportunity for policy makers seeking to decarbonise or transform their energy sectors. In 2016, the heating and cooling sector accounted for about half of TFEC, underscoring the importance of decarbonisation of this sector.[21] (→ *See Global Overview chapter.*)

FIGURE 13. National Sector-Specific Targets for Share of Renewable Energy by a Specific Year, by Sector, 2018



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. Darker shades indicate multiple countries having the same share and target year. 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 47 in heating and cooling, 45 in transport and 162 in power.

Source: REN21 Policy Database.

RENEWABLE ENERGY AND ENERGY EFFICIENCY IN BUILDINGS

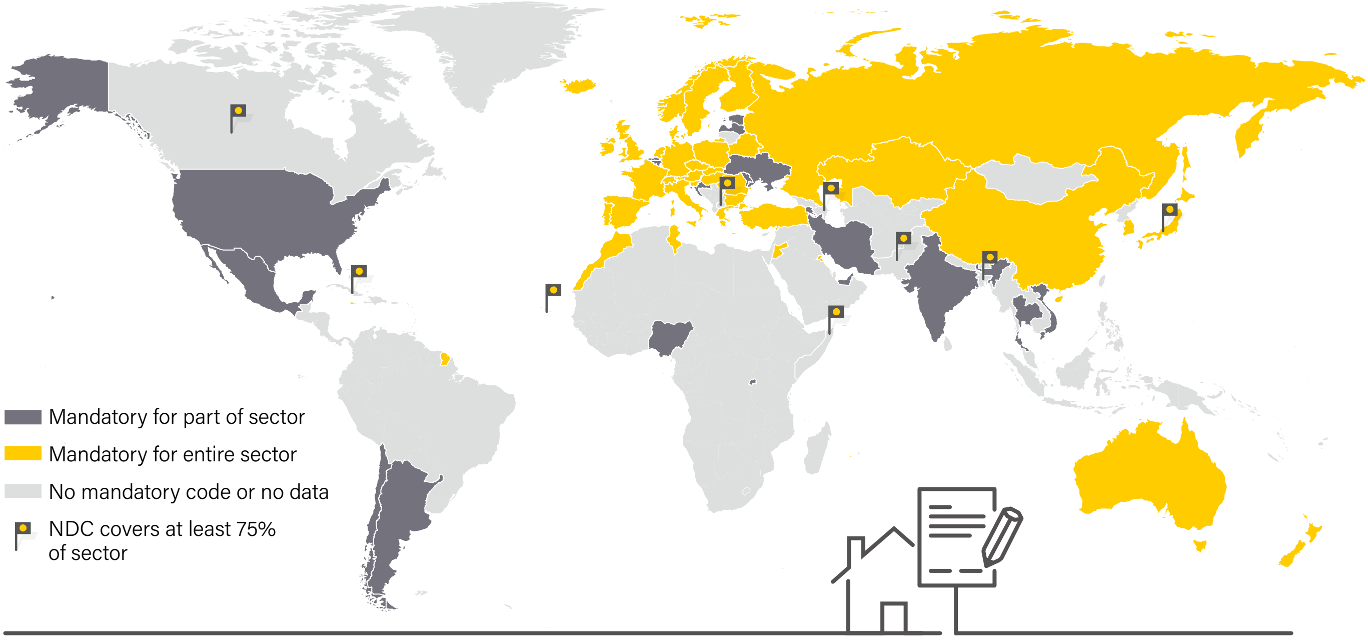
As of the end of 2018, 135 countries had mentioned buildings in their Nationally Determined Contributions (NDCs) submitted to the United Nations under the Paris Agreement; however, only 51 countries specifically cited the use of renewable energy in buildings as a means to reduce emissions.[22] Overall, as much as 60% of the total energy use in buildings that occurred in 2018 was in jurisdictions that lacked energy efficiency policies.[23]

Voluntary or mandatory building energy codes are one of the primary mechanisms used to promote the deployment of both renewables and energy efficiency technologies. Building energy codes were in place in 69 countries as of the end of 2018, up from some 60 countries in 2017; however, only around 29% of all countries worldwide had mandatory building energy codes in place for all or part of the sector.[24] (→ *See Figure 14.*) Building energy codes have been used to mandate the deployment of renewable generation sources and to promote standards for the efficiency of energy use. These codes usually target new construction or retrofits, although some jurisdictions also target existing buildings for renewable energy adoption.[25]

60% of the total energy used in buildings in 2018 occurred in jurisdictions that **lacked** energy efficiency policies.

The EU's revised Energy Performance of Buildings

FIGURE 14. Countries with Mandatory Building Energy Codes, 2018



Note: Energy codes or standards for buildings focus on decreasing energy use for specific end-uses or building components and can apply to new and/or existing buildings. Nationally Determined Contributions for the sector have focused on strengthening energy codes and standards, energy conservation and phasing out inefficient products and equipment. Coverage in Belgium, India and the United States varies by sub-national region or state. All Belgian regions have mandatory energy codes for buildings addressing part of the sector. More than half of India's states have mandatory building energy codes for part of the sector. At least 82% of US states and territories have mandatory building energy codes for the entire sector.

Source: OECD/IEA. See endnote 24 for this chapter.

Directive came into force in 2018, establishing a framework for working towards the goal of decarbonising the region's buildings sector by 2050.[26] The strategy also establishes standards for integrating new technologies, such as electric vehicles (EVs), into building infrastructure.[27] At the country level in Europe, Denmark adopted new energy regulations for buildings, enacting efficiency standards as well as requirements for solar heating systems.[28] Malta issued its own Energy Performance of Buildings Regulations to put the EU standards into practice nationally.[29]

In the United States, California released revised energy standards for residential and non-residential buildings in 2018, introducing requirements for both energy efficiency and renewable energy use. The measures include the first state-wide mandate for solar PV in new homes and the promotion of enabling technologies such as battery storage and heat pumps.[30] The state of New York also set a target of 185 trillion British thermal units (Btu) of energy reduction in residential and commercial buildings and industrial facilities by 2025.[31]

Cities and local governments are at the forefront of policy trends for energy use in buildings. (→ *See Feature chapter.*) In 2018, many of the world's largest municipalities, including London, New York and Tokyo, joined the Net Zero Carbon Buildings Commitment, pledging to reach net-zero carbon[i] operating emissions in their buildings sector by 2050.[32] By the end of 2018, 22 cities and 5 states and regions had joined the commitment.[33] In a separate initiative, 19 city mayors from around the world, representing 130 million people, committed to ensuring that all new buildings will meet net-zero carbon standards by 2030 and that both new and old buildings will operate as zero-carbon by 2050.[34] In Bogotá (Colombia), a new energy-efficient construction policy aims to reduce energy use in the buildings sector by 20%.[35]

Incentives also have been developed to simultaneously promote both renewable electricity generation and energy efficiency improvements in the residential sector, although this remains less common than promoting each individually. For example, in 2018 Canada began implementing a support scheme designed to help residents retrofit their homes in order to improve efficiency and ultimately produce as much energy (using on-site renewables) as they consume.[36]

Although the use of renewable heat in the buildings sector has grown in recent years, the adoption of new direct policy support mechanisms for these technologies slowed in 2018.[37] Renewable heat technologies often benefit from indirect support, however, through policies aimed at addressing climate change or promoting energy efficiency.[38] (→ *See Climate Policy section in this chapter.*)

In Europe, Ireland announced a long-awaited support scheme to help commercial heat users replace fossil fuel heating systems with renewable energy systems.[39] The United Kingdom launched a scheme providing grants and loans for renewable

i A net-zero carbon building is a building that is highly energy efficient and fully powered from on-site and/or off-site renewable energy sources, from World Green Building Council, "What is Net Zero?", https://www.worldgbc.org/advancing-netzero/what-net-zero, viewed 10 May 2019.

heat networks that serve two or more buildings in the public or private sectors, including residences, hospitals, schools and council buildings.[40] In addition, changes to the UK Renewable Heat Incentive included higher tariffs for biogas and biomethane to benefit those industries, as well as proposed restrictions on new biomass heating installations in urban areas to reduce air quality impacts.[41] In France, the budget for the Fonds Chaleur renewable heat incentive programme was increased 14% to EUR 245 million (USD 273 million), and in Germany biomass and deep geothermal installations became eligible for funding under the country's Market Incentive Programme for renewable heat.[42]

RENEWABLE ENERGY AND ENERGY EFFICIENCY IN INDUSTRY

Renewable energy can be used to meet thermal energy (heat) demands of industrial processes, which are supplied by direct renewables (bioenergy, solar thermal and geothermal heat) and electricity.[43] (→ *See Box 1 in Global Overview chapter.*) However, renewable energy support policies focusing on the industrial sector are limited, and new or revised policies in the sector were scarce in 2018.[44] Meanwhile, as of 2016, standards and targets for energy efficiency for industrial processes covered only around 25% of total industrial energy use worldwide.[45] Monitoring and enforcement of such standards is far less common than their overall adoption.[46]

Standards and targets for energy efficiency of industrial processes covered only
25%
of total industrial energy use in 2016.

Existing policy mechanisms in the industry sector include Vietnam's feed-in tariff for co-generation projects, and targets in Lao People's Democratic Republic for biomass, biogas and solar energy (although not exclusively for industry).[47] In 2018, Germany continued to offer low-interest loans for solar thermal, heat pump and biomass systems, with the stipulation that applicants use at least half of the generated heat for industrial processes such as production, processing or refining.[48]

TRANSPORT

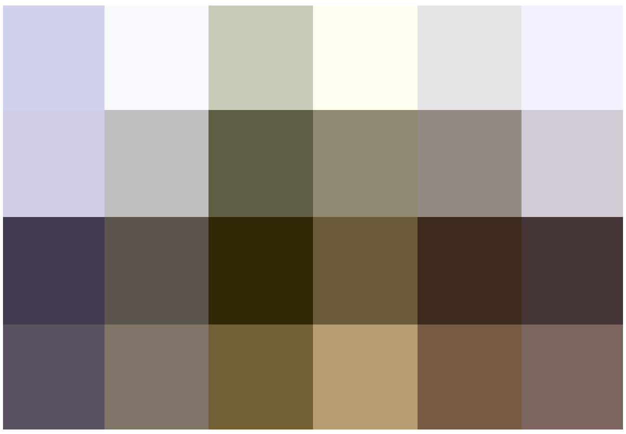
The transport sector accounts for about one-third of TFEC, and reducing fossil fuel use in the sector is critical for improving fuel security, reducing air pollution and reaching international emissions reduction goals.[49] However, policy support for increasing the share of renewables in transport remains relatively static. Policy makers in some countries have enacted measures to increase the use of renewable energy sources and to improve fuel efficiency in specific sectors, including road, rail, aviation and maritime transport. Existing policies support technologies ranging from first-generation biofuels to EVs and more advanced fuels, as well as strategies to reduce transport demand or encourage a shift to less energy-intensive transport modes.[50]

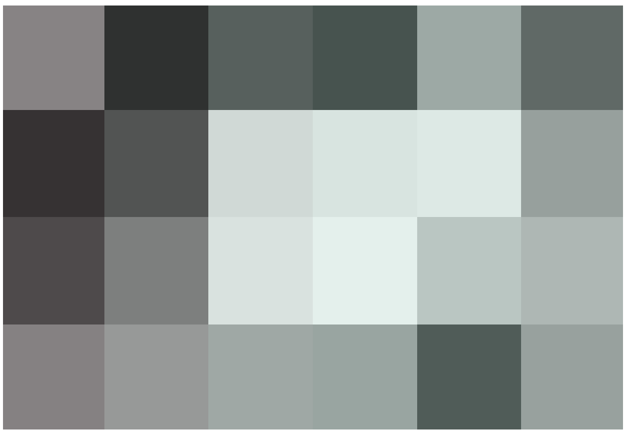
Policy developments in the transport sector are focused largely on road transport. However, the growing use of electricity and advanced biofuels in road transport has, to a limited degree, encouraged policy makers to support renewable energy use in rail, aviation and shipping as well. Although some policies are aimed at fuel use across the transport sector, most focus on specific modes of transport.[51] ***(→ See Reference Table R10.)***

ROAD TRANSPORT

In the road transport sector, the use of fuel-efficient vehicles as well as vehicles powered by alternative fuels[i] or electricity continues to grow. Policies supporting these technologies and fuels include consumer-focused grants and rebates; tax incentives, deployment quotas and mandates; and research and development (R&D) support. Policy makers also have used their purchasing and regulatory oversight to ensure that public transport networks and public fleets use alternative or fuel-efficient vehicles.

Only
36%
of countries have biofuel blend mandates globally.





i Alternative fuels refer to alternative propulsion systems to the traditional diesel (or petrol) internal combustion engine, including biofuels, synfuels or low-carbon liquid fuels produced from agriculture crops or waste, liquified 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).

Some regions, such as Scandinavia, have been particularly active in adopting measures to spur transformation of their road transport sectors.[52] (→ *See Box 1.*) Globally, however, fuel economy policies for light-duty vehicles existed in only 40 countries as of the end of 2018 and have been largely offset by trends towards larger vehicles.[53] Meanwhile, only five countries – Canada, China, India, Japan and the United States – had fuel economy standards for trucks.[54]

Biofuels remain a central component of national renewable transport policy frameworks. By the end of 2018, biofuel blend mandates existed at the national and/or sub-national level in at least 70 countries, or 36% of countries globally.[55] (→ *See Figure 15.*) No additional countries adopted biofuel mandates in 2018, but some countries that had mandates in place added new ones, and several existing mandates were strengthened.

BOX 1. Policy Spotlight: Transformation of Road Transport in Scandinavia

Scandinavia has taken a central role in the burgeoning transition to renewable or alternative fuel vehicles. Both Sweden (in 2011) and Finland (in 2013) have already met the EU-wide target for a 10% renewable energy share in transport final energy by 2020, well ahead of schedule, and as of 2016 Norway was slightly below the 10% benchmark.

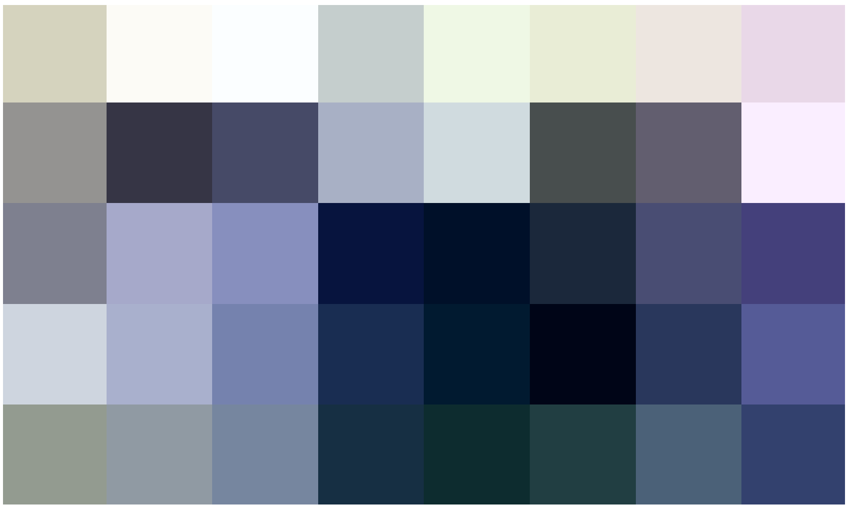
Scandinavia has a long history of promoting the deployment of alternative transport fuels (including advanced biofuels) – and the vehicles that use them – through policy mandates and incentives at both the national and sub-national levels. Denmark is still the only country in the world with a target for 100% renewables in total final energy, with a strategy to dramatically increase electricity and biomass use in the transport sector.

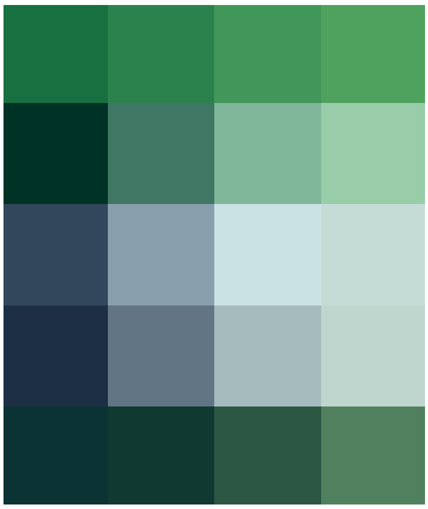
Sweden's capital, Stockholm, has set a goal to phase out fossil fuel use by 2040. Mechanisms to reduce emissions in the city's transport sector include the promotion of renewable fuels, the use of digital monitoring to increase the efficiency of bus lanes, and reserved parking for "green" vehicles. The city has taken a novel approach to public procurement of transport services, progressively strengthening environmental standards – first set in the 1990s – to help achieve its goals. The requirements vary by contract area and are flexible in design: companies may adopt the technologies they prefer, stimulating competition while meeting environmental goals in multiple ways. This has resulted in a diverse mix of vehicles in the city's fleet, with about 96% qualifying as "clean" under the city's definition. Following Stockholm's success, many other Scandinavian cities have adopted similar policies.

At the national level, both Norway and Sweden have demonstrated strong growth both in the overall share of EVs in their vehicle fleets (39%) and in the share of new cars that are EVs (6%), ranking first and third in the world, respectively, in 2017. Both countries have ambitious renewable energy targets and support policies, meaning that the EVs effectively are being powered by growing shares of renewable power, although not linked directly.

Financial incentives for EV purchases have been a central component of national efforts to increase adoption of the vehicles, along with the development of public charging infrastructure and deterrents for purchasing higher-carbon emitting cars. EV adopters receive additional benefits including the ability to use high-occupancy vehicle or bus lanes, toll-free roads and ferries, free charging or free parking in some public spaces.

Source: see endnote 52 for this chapter.





Ethanol received expanded support in at least three countries: Colombia increased its blend mandate from E8 to E10, Zimbabwe increased its mandate from E15 to E20, and China expanded its ethanol promotion from 11 regions to 15 regions.[56] For biodiesel, new policy support included Ireland's announcement of a 10% biodiesel blending mandate to take effect in 2019, and Brazil's increase in the voluntary mixture of biodiesel allowed in fuel blending.[57] At the sub-national level, the US state of Minnesota implemented a B20 mandate originally passed in 2008, and Vancouver (Canada) announced plans to transition its city-owned diesel vehicle fleet to 100% renewable diesel[i] by the end of 2019.[58]

Few new measures promoting advanced biofuels or other fuel sources were adopted in 2018. However, the EU provisionally agreed on an advanced biofuels and biogas mandate of 1% by 2025 and 3.5% by 2030, as part of its goal to have at least 14% of transport fuels come from renewable sources by 2030.[59] The EU also placed a 7% cap on the share of first-generation biofuels in final transport energy consumption.[60] At the national level, Croatia enacted a 0.1% second-generation biofuel mandate, Denmark adopted a 0.9% advanced biofuel blend mandate effective by 2020, and Italy introduced a support scheme for the production and distribution of advanced biofuels and biomethane for use in the transport sector.[61] The United States announced an increase in its advanced biofuels mandate starting in 2019.[62]

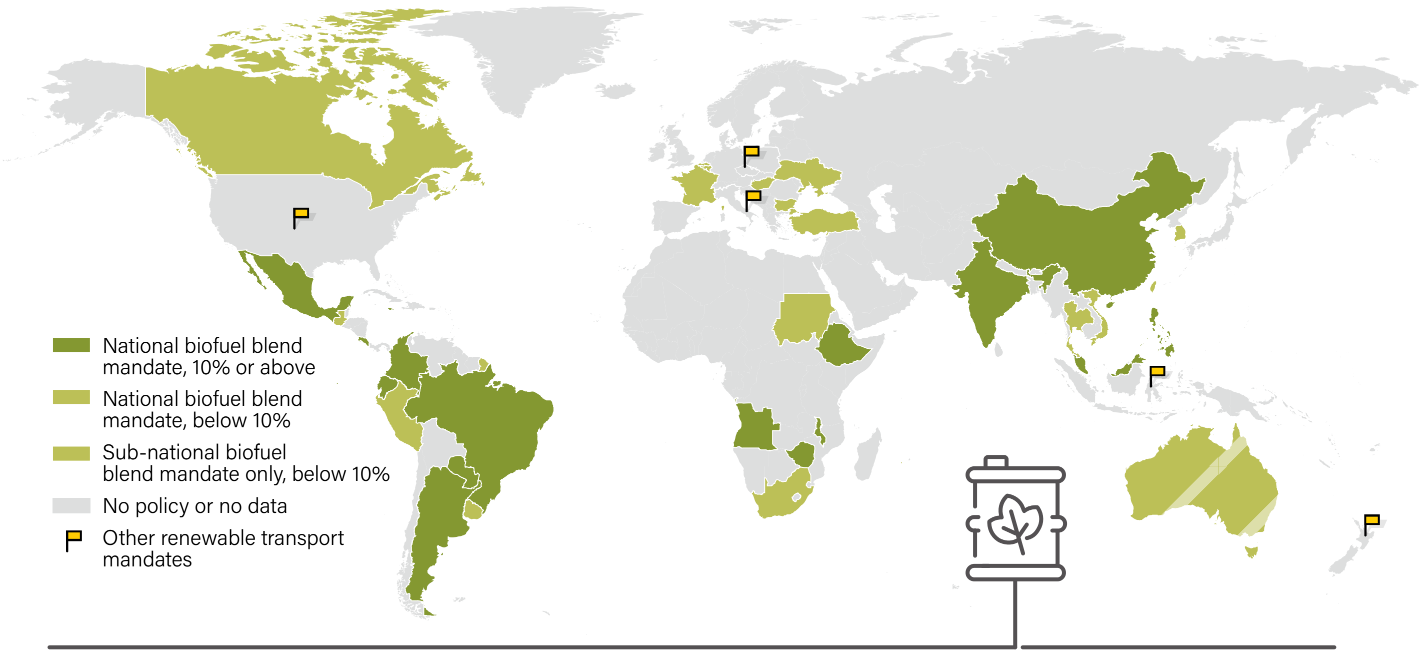
Only Austria has a national policy directly linking renewable electricity with EVs.

Electric vehicles can play an important role in increasing the use of renewables in the transport sector and in reducing global carbon emissions, particularly when powered with rising shares of renewable electricity. Although numerous measures have been adopted in recent years to scale up EV use, few efforts have been made to link renewable electricity production directly with this use, or to ensure that EVs support the integration of renewable energy into energy supplies.[63] At the national level, only Austria had a policy directly linking renewables with EVs as of the end of 2018.[64]

Nevertheless, EVs are becoming an important component of national energy development strategies in the transport sector.[65] (→ *See Figure 16 and Sidebar 2 in this chapter.*) Similarly, some initiatives are emerging for hydrogen fuel cell vehicles, but the vast majority of hydrogen continues to be produced using non-renewable sources. (→ *See Systems Integration chapter.*)

i Both renewable diesel and biodiesel are made from organic biomass, but differences can be seen, for example, in their production process, cleanliness and quality. (→ *See Bioenergy section in Market and Industry chapter.*)

FIGURE 15. National and Sub-National Renewable Transport Mandates, 2018

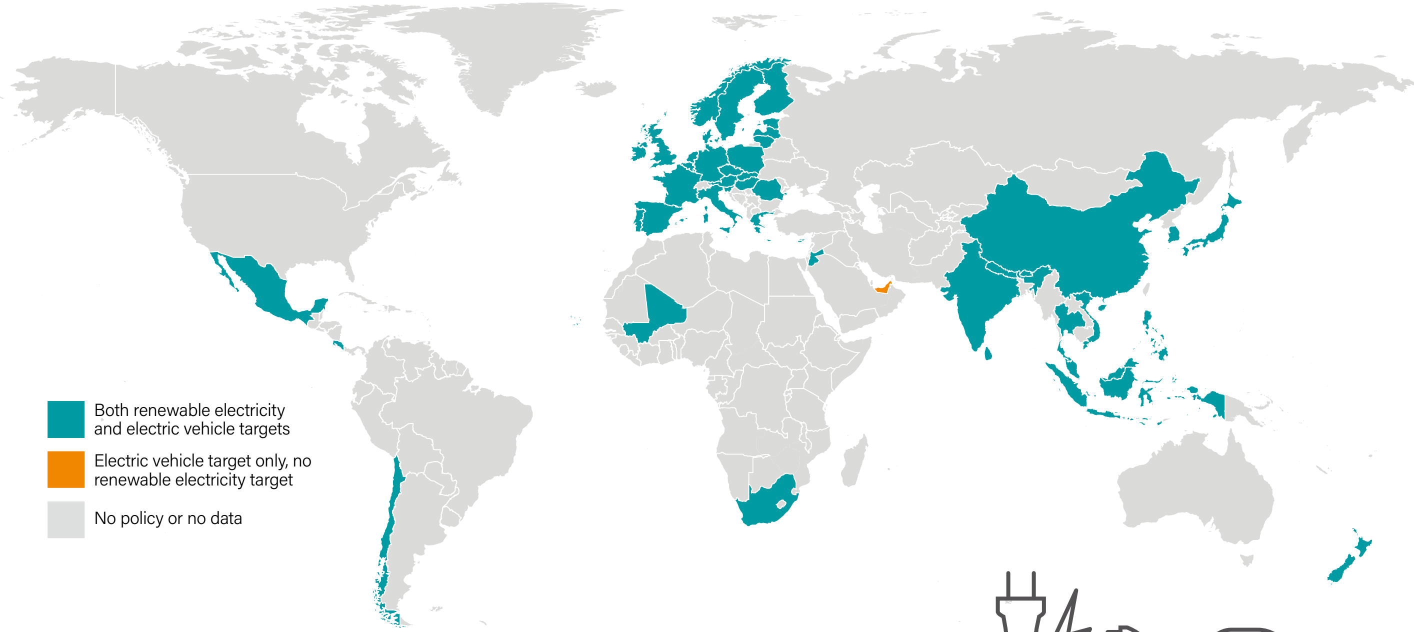


Note: Shading shows countries and states/provinces with mandates for either biodiesel, ethanol or both. Other renewable transport mandates include mandates for advanced biofuels and for sectors other than road transport, among others. See Reference Table R10.

Source: REN21 Policy Database.

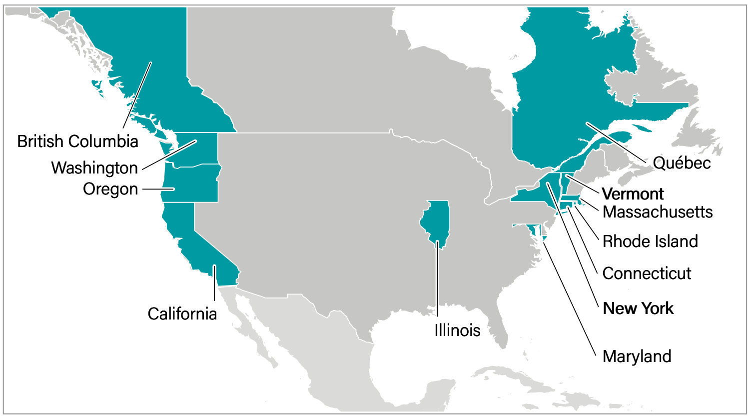
FIGURE 16. Targets for Renewable Power and/or Electric Vehicles, 2018

NATIONAL TARGETS



STATE/PROVINCIAL TARGETS

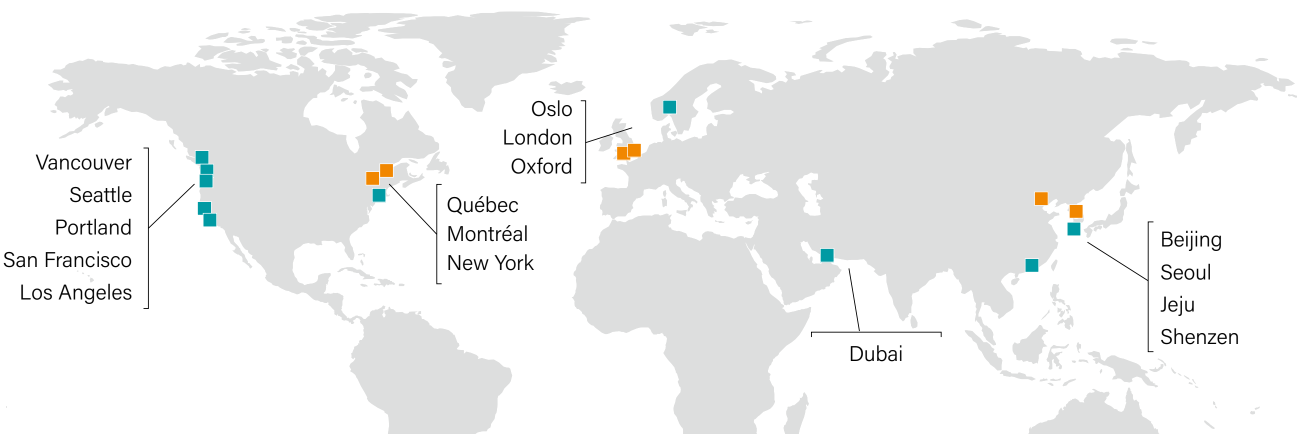
United States and Canada



United Kingdom

India

SELECTED CITY TARGETS



Note: The figure provides a sample of local renewable energy commitments worldwide. It does not aim to present a comprehensive picture of all municipal electric vehicle or renewable electricity goals.

Source: See endnote 65 for this chapter.

SIDEBAR 2. Policies Potentially Enabling Renewable Energy Penetration in Transport

Policies and targets for electric and hydrogen fuel cell vehicles are not renewable energy policies and targets by themselves. Similarly, "zero-emission vehicles" typically refer to vehicles that produce no atmospheric pollutants during operation but are not necessarily fuelled by renewable sources. In most cases, the term refers to EVs, albeit without reference to the source of the electricity. However, while EVs and hydrogen fuel cell vehicles do not necessarily increase the renewable energy share in transport, they do offer the potential for greater penetration of renewables and lower emissions.

Many governments are providing financial incentives for EVs. In 2018, Costa Rica, Germany, the Kyrgyz Republic and Ukraine all reduced various taxes for EVs. India allocated INR 87.3 billion (USD 1.3 billion) to incentives for EVs, electric buses and other electrified vehicles such as scooters, and Scotland instituted GBP 1.3 million (USD 1.7 million) in grants and loans to encourage electric bike purchases. In Sweden, the government introduced a new tax system, increasing taxes on light-duty petrol and diesel vehicles and providing a tax incentive for EVs. Beyond EVs, the Republic of Korea eased regulations on the production and transport of hydrogen fuel cell buses as part of an effort to reach 1,000 such buses on the road by 2022.

At least 19 countries aim to replace or phase out internal combustion engine (ICE) vehicles and "non zero-emission vehicles" to stimulate EV uptake. In 2018, Cabo Verde announced a plan to gradually replace ICE vehicles with EVs by 2050. Nepal announced plans to replace all ICE vehicles with EVs by 2030, while Israel pledged to sell only electric passenger cars by the same year. Also in 2018, China set a target of 2 million EV sales annually by 2020, and India launched a national E-Mobility Programme with a goal of having more than 30% of new car sales come from EVs by 2030. By the end of 2018, China was considering a ban on inefficient ICE vehicles and, in the meantime, was implementing production quotas for "new energy vehicles"[i].

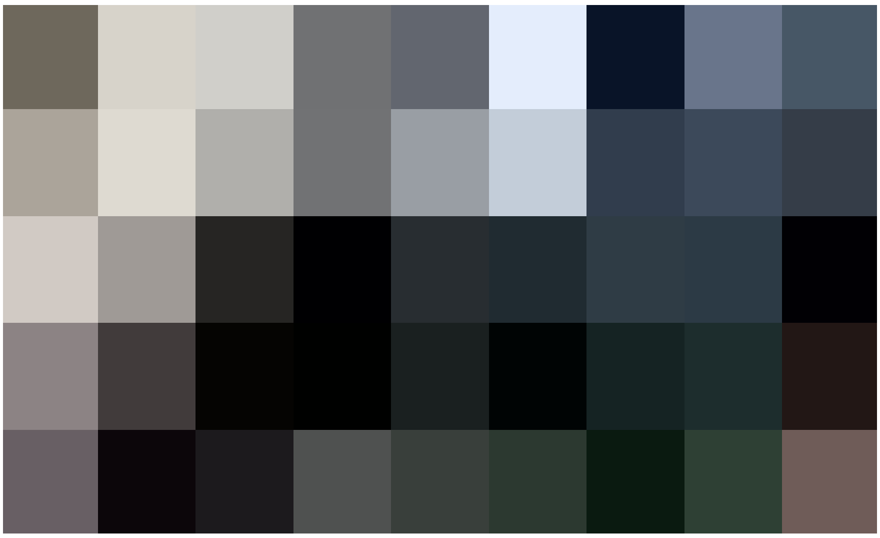
In Europe, Denmark pledged to sell only electric passenger cars by 2030. Ireland and Portugal pledged that by 2030 and 2040, respectively, no new "non zero-emission vehicles" will be sold within their jurisdictions. Ireland's National Development Plan for 2018-2027 also targets the sale of 500,000 EVs. The United Kingdom released its Road to Zero strategy in 2018, which sets targets for 50% to 70% of new car sales and 40% of van sales to be ultra-low emission by 2030, 100% of cars to be zero-emission by 2040 and 25% of the government fleet to be ultra-low emission by 2022.

At the sub-national level, Brussels (Belgium) agreed to ban diesel cars from the city starting in 2030, and British Columbia (Canada) and California (United States) adopted 2040 phase-out targets for ICE vehicles. California also called for 5 million zero-emission vehicles on the road by 2030. Madrid (Spain) banned the majority of non-zero-emissions vehicles from its city centre, and Rome (Italy) announced its intention to ban all diesel cars from its roads by 2024.

Countries also are pledging to develop supporting infrastructure to encourage EV adoption. For example, in 2018 Germany established a target of 100,000 public EV charging stations installed by 2020, which it supported with a EUR 70 million (USD 78 million) scheme for charging stations and electric buses. California set a target to commission 250,000 vehicle charging stations by 2025 and a goal to have 200 hydrogen refuelling stations in place state-wide by 2025.

i In China, "new energy vehicles" include plug-in hybrid electric vehicles, battery electric vehicles and hydrogen fuel cell vehicles.

Source: see endnote 65 for this chapter.



RAIL, AVIATION AND MARITIME TRANSPORT

> Renewables in aviation, rail and maritime transport continue to receive **less policy attention** than those in road transport.

The use of renewable fuels and electricity to power rail, aviation and maritime transport has developed more slowly than it has for road transport. Several barriers to commercialisation and deployment – such as the cost of advanced biofuels as well as challenges related to battery weight and range – have limited the applicability of many of the technologies used in road transport to other transport sectors.[66] Aviation and maritime transport also face jurisdictional challenges associated with regulating cross-border industries. Policy support has been limited in these sectors, despite their large overall contribution to global fuel use. (→ *See Transport section in Global Overview chapter.*)

In recent years, some jurisdictions and companies have attempted to link renewable power generation with rail transport.[67] In 2018, Toronto (Canada) began to develop a new light rail line using solar PV-plus-storage systems to reduce peak energy demand and to add backup capacity as part of a CAD 190 billion (USD 150 billion) public infrastructure plan.[68] Indonesia expanded the country's B20 biofuel blending mandate from the road transport sector to cover fuel used by railroads and power plants.[69]

National governments, as well as the aviation industry[i], have taken initial steps towards increasing the use of alternative fuels in aviation – including issuing either mandates for use of these fuels or incentives for their development. In 2018, Norway established a quota for 0.5% advanced biofuel use in aviation starting in 2020, and the Indian Air Force announced plans to begin using ethanol-blended fuel in its aircraft.[70] Canada established the Sky's the Limit Challenge with the goal of supporting R&D in the renewable aviation fuel supply chain.[71] The programme offers a prize of CAD 1 million (USD 740,000) for the first cross-Canada commercial flight fuelled by a minimum 10% blend of Canadian-made biojet fuel.[72]

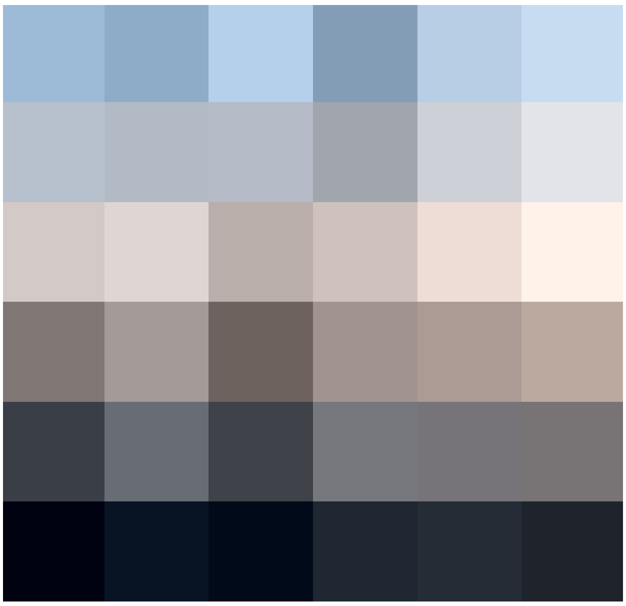
For the maritime shipping sector, few policies were directly promoting the use of renewable energy sources as of the end of 2018, although some indirect policy support existed[ii]. The Port of Rotterdam Authority in the Netherlands announced an incentive to support vessel owners that use low-carbon or zero-carbon fuels, as well as a commitment to reduce emissions from the port (Europe's largest) starting in 2030.[73] Alternative measures – such as funding for shore-side renewable electricity for ports – also can help reduce fossil fuel use in the sector.

POWER

Worldwide, governments have focused their renewable energy policy attention primarily on promoting the development and deployment of renewable power generation technologies. Countries at all levels of economic development have turned to renewable power sources to meet goals ranging from decarbonising electricity generation to expanding energy access. (→ *See Distributed Renewables chapter.*) These policies have evolved in response to technology advances and cost reductions, rapidly increasing shares of renewables in the power mix in some countries, and advances in the development and use of energy storage and other enabling technologies. (→ *See Systems Integration chapter.*)

The increasing electrification of end-use sectors – such as heating, cooling and transport – combined with decarbonisation of the electricity supply has begun to play an important role in the global energy transformation. When paired with renewable power development, the electrification of these sectors means that the impact of renewable power policies can be felt across a larger segment of the economy.[74]

Regulatory policies – including feed-in policies and renewable portfolio standards – have been instrumental in guaranteeing market access for renewable power suppliers, in setting power prices for grid-connected renewable systems and in establishing mechanisms for achieving new lower prices for technology delivery. Although different policies have been adopted to support large- and small-scale, as well as centralised and distributed, projects, many of the same price-reduction or technology maturation trends are prevalent in each of these market segments.



i The International Air Transport Association (IATA), a trade association representing 290 airlines, set a goal of having 1 billion passengers fly on flights fuelled by sustainable aviation fuel by 2025. IATA, "Aim for 1 billion passengers to fly on sustainable fuel flights by 2025", 26 February 2018, https://www.iata.org/pressroom/pr/Pages/2018-02-26-01.aspx.

ii In 2018, the International Maritime Organization adopted energy efficiency standards targeting a 40% reduction in total carbon intensity from shipping by 2030 and a 50% reduction in greenhouse gas emissions by 2050. Dale Hall, Nikita Pavlenko and Nic Lutsey, *Beyond Road Vehicles: Survey of Zero-emission Technology Options Across the Transport Sector* (International Council on Clean Transport, 18 July 2018), https://www.theicct.org/sites/default/files/publications/Beyond_Road_ZEV_Working_Paper_20180718.pdf.

Renewable power auctions were held in at least

48 countries

worldwide in 2018, up from 29 the year before.

Accurately accounting for system costs and benefits in renewable power support mechanisms remains an important challenge for policy makers looking to promote the deployment of renewable power projects. Adjustments – such as updating long-standing fixed-price policies by introducing pricing measures such as automatic rate reductions tied to specific deployment levels – have been implemented to keep up with declining technology costs. To better match declining costs, manage capacity levels and steer deployment to specific areas or technologies, policy makers have continued to turn to competitive auctions in lieu of traditional fixed-price policies.[75] These objectives also can be achieved through feed-in tariffs and other policies, depending on policy design.

Renewable power auctions were held in at least 48 countries worldwide[i] in 2018, up from 29 countries in 2017.[76] At least one of the auctions in 2018 was technology-neutral (in Brazil), while six were neutral for renewable technologies[ii].[77] (→ ***See Reference Table R12.***) Both Ireland and Kenya announced that they would employ auctions to support renewable energy project development in future years.[78] Auctions were delayed in several countries, and some contracts were annulled (especially in India), resulting in significant impacts on industry.[79]

Policy makers have used the flexibility of auction mechanisms to design tenders to meet various national goals beyond awarding contracts at minimum prices.[80] This includes the use of domestic content requirements to promote domestic manufacturing – such as in India, which mandated that all future solar power bids include at least 50% locally manufactured components.[81] Auctions also can be designed to overcome unintended consequences that have been overlooked previously in power sector development, such as the exclusion of local communities and small actors, or the concentration of projects in specific areas.[82]

Likely the biggest auction-related policy development in 2018, and perhaps in all recent years, occurred in China. As part of broad changes to its national solar power policy, Chinese officials halted all financial support for utility-scale and distributed solar projects in favour of project support through auctions.[83] Wind energy projects in China also will be supported through auctions in the coming years.[84]

Other notable developments worldwide included the first renewable energy auction ever held in Benin, for a 25 megawatt (MW) solar PV project; a contract awarded in the Netherlands for up to 750 MW of grid-connected offshore capacity; and a series of power purchase agreements signed in South Africa for 2.3 gigawatts (GW) of long-delayed renewable power capacity, awarded under its national auction scheme.[85]

Policy makers in some countries used auctions for more specialised renewable energy projects. Bahrain announced plans to develop 150 MW of solar PV through tenders on a landfill site, and Jordan auctioned 30 MW of solar PV capacity to support water pumping stations throughout the country.[86] At the sub-national level, the Indian states of Maharashtra and Uttar Pradesh auctioned projects for floating solar PV to generate electricity on dam reservoirs.[87] (→ *See Sidebar 3 in Market and Industry chapter.*)

Several offshore wind power auctions were held in Europe in 2018, and in the United States both Rhode Island and Massachusetts used competitive bidding through auctions to select offshore wind projects for development.[88] The US Bureau of Ocean Energy Management continued to hold auctions to allocate leases for offshore wind power projects, bringing the total number of active leases nationwide to 15 by the end of 2018.[89]

111 countries, states or provinces

had feed-in tariff policies in place by the end of 2018.

Despite the shift to auctions in many countries, feed-in tariff (FIT) policies continue to play a role in national and sub-national policy schemes and were in place in 111 countries by year's end.[90] FIT support for utility-scale renewable projects is often now limited to countries with nascent renewable energy markets. FITs also are used to support less-established technologies, or technologies with relatively high project development costs that often are not included in auctions. ***(→ See Reference Table R11.)***

In 2018, Zambia's FIT-based renewable energy support scheme – modelled on an existing programme in Uganda – entered its first round after officially launching in 2017.[91] Japan postponed to September 2019 its deadline for planned cuts to FIT solar projects larger than 2 MW, and Serbia extended its existing FIT scheme – which was set to expire at the end of 2018 – for an additional year.[92] Serbia ultimately plans to replace the scheme with new mechanisms including feed-in premiums and tenders.[93] Also in 2018, Switzerland increased its geothermal power FIT, and Vietnam raised its FIT for onshore and offshore wind power.[94]

Some countries reduced their FIT rates in 2018. Although the roll-back of feed-in policies has tended to focus primarily on large-scale installations, even smaller-scale systems have seen reductions in rates. For example, in 2018 the United Kingdom

i African nations were particularly active in 2018, with auctions held in Algeria, Benin, Egypt, Eswatini, Ethiopia, Madagascar, Malawi, Niger, Senegal, Seychelles, South Africa, Tanzania, Tunisia and Zambia. Auctions were also held in Asia and Oceania (Australia, Bangladesh, China, India at both the national and sub-national level, Japan, Kazakhstan, Singapore, Sri Lanka and Tonga); in Europe (Albania, Armenia, Denmark, Finland, France, Germany, Greece, Malta, Montenegro, the Netherlands, Poland, the Russian Federation); in the Middle East (Afghanistan, Bahrain, Jordan, Kuwait, Lebanon, Oman, State of Palestine, Qatar, Saudi Arabia and Turkey); and in North America, Latin America and the Caribbean (Argentina, Brazil, Canada and the United States).

ii The specific design of individual auction mechanisms – including rules governing critical features such as permitting, grid connection or local content requirements – can impact the ability of auctions to attract developer interest or result in successful project development. Auction design varies widely: while some are technology-specific calls for individual projects, others are technology-neutral tenders where renewable, nuclear and fossil fuel generation options all compete to provide new power capacity, or are neutral for renewable technologies only.

confirmed its plans to eliminate the FIT for new household solar PV systems, starting in 2019.[95] In Japan, 2018 marked the final full year of the 10-year FIT contracts for household solar PV systems under the FIT implemented in 2009.[96] At the sub-national level, New South Wales (Australia) approved a 44% reduction in its FIT rate for solar PV.[97]

Renewable obligations, often in the form of renewable portfolio standards (RPSs), remained in place in many jurisdictions, typically at the sub-national level. In the United States, five states and the District of Columbia increased RPS levels in 2018, and the District of Columbia also passed a new mandate for 100% renewable power by 2032.[98] California, the world's fifth largest economy, committed to 100% clean power[i] by 2045 as part of its RPS.[99] New Jersey established an RPS for 50% renewable electricity by 2030, and Connecticut set a new requirement of 40% by the same year.[100] Massachusetts increased its RPS, while voters in Nevada passed a ballot measure supporting a 50% RPS by 2030.[101]

In China, quotas were established for grid utilities and power purchasers, setting rules for the use of renewable power.[102] The move was driven by growing curtailment rates for wind and solar power, which were in turn the result of China's rapid expansion of new variable renewable power generation capacity. Under the new regulations, curtailment of wind power is capped at 10% in 2019 and 5% by 2020, and solar power is capped at 5% from 2018 to 2020.[103]

Smaller-scale renewable energy projects often find support through policies that provide access to grid networks as well as remuneration for surplus electricity that is fed into the grid. Net metering or net billing[ii] is a primary mechanism used at the residential and commercial levels. These policies often are adopted to spur the development of small-scale rooftop solar PV systems or, less commonly, small-scale wind turbines. By the end of 2018, net metering policies existed in at least 66 countries at the national or sub-national level; in the United States alone, they had been adopted in 45 states and territories.[104]

By the end of 2018, net metering policies existed in at least

66 countries

at the national or sub-national level.

In 2018, Indonesia adopted a new metering policy opening grid access for the first time to residential, commercial and industrial rooftop solar PV systems.[105] Romania approved new rules for net metering of renewable installations up to 100 kilowatts (kW) and will also support these installations via a new rebate scheme.[106] Malaysia revised its existing net metering policy to strengthen incentives for energy producers, increasing payments for surplus electricity fed into the grid.[107] Spain revised its net metering policy for solar PV to simplify registration procedures and to remove the charge on self-consumption adopted in 2015.[108]

The increased deployment of grid-connected systems under net metering policies has led to political and legal challenges, and policy makers often have had to revise policies in response. In some cases, rate adjustments have been enacted to keep pace with falling technology costs, and revisions have resulted in the adoption or elimination of fees that utilities charge to connect to the grid. The EU reached an agreement in 2018 to ensure that all prosumers[iii] with systems of 25 kW or smaller be allowed to connect to grid networks without being subject to connection fees.[109] Meanwhile, the US state of Michigan rolled back net metering incentives, reducing payments for surplus generation fed to the grid.[110]

Community power projects also increase local renewable energy generation. In 2018, the European Commission guaranteed energy communities the right to operate within the EU by ensuring that they can own, rent or purchase their own electricity distribution networks.[111] In the United States, the newly approved Massachusetts SMART programme promotes solar development (including community solar) across the state.[112]

Fiscal incentives – grants, rebates, tax credits, etc. – also play an important role in overcoming fiscal and financial barriers to renewable energy development and deployment.[113] Non-regulatory policies can be used to promote technologies ranging from large-scale commercial installations to small-scale residential renewable energy systems. For example, in 2018 the United States reinstated the Residential Renewable Energy Tax Credit, which provides homeowners with a 30% credit for the cost of installing a small-scale wind turbine at their residence; the federal government also launched a USD 133.5 million initiative for energy-resilient infrastructure upgrades at military bases, including solar PV and energy storage (as well as natural gas).[114]

i California's policy calls for all retail electricity sales by 2045 to come from renewable energy resources and zero-carbon resources.

ii See Glossary for definition.

iii See Glossary for definition.

POLICIES TO INTEGRATE VARIABLE RENEWABLE ENERGY

As the transformation of energy systems continues in many countries, policy makers have focused on the development and deployment of enabling technologies to facilitate the integration of renewable energy technologies. (→ *See Systems Integration chapter.*) Policies to integrate VRE can address both supply and demand to increase the flexibility of the overall energy system. Traditional fiscal and regulatory mechanisms have been used to advance the deployment of enabling technologies, and new mechanisms also have emerged.

Sector integration[i] offers the potential to overcome challenges associated with higher shares of VRE or to maximise the value of renewable energy investments. Policy makers can directly link sectors, as in the case where renewable electricity is used for charging EVs. This leads to numerous benefits: for example, renewable electricity can help to decarbonise transport or other sectors, while the batteries found in EVs offer electricity storage capacity, which can help integrate VRE into the wider energy system. To date, however, few countries have implemented policies to advance sector integration specifically with renewables.

Increasingly, policy makers are promoting the ancillary grid services[ii] offered by enabling technologies and, to a lesser extent, by renewable energy. The design of appropriate power market rules is an important lever for increased participation of VRE and other enabling technologies in electricity markets and trade. In China, the 13th Five-Year Plan (2016-2020) and related initiatives aim in part to create new wholesale electricity markets that work for renewables.[115] In the EU, the Clean Energy for Europeans Package, finalised in late 2018, further opens markets to renewable electricity, energy storage and demand response; it will allow energy consumers to be exposed to wholesale electricity pricing, increasing opportunities for arbitrage and for higher levels of distributed renewables.[116]

In 2018, Australia's Renewable Energy Agency and the government of the state of Victoria jointly funded battery storage at a transmission terminal to help stabilise the grid by drawing power at peak times.[117] At the transmission level, in a major development in the United States, the Federal Energy Regulatory Commission issued orders to grid operators to develop rules for energy storage to participate in wholesale, capacity and ancillary services markets.[118]

The ongoing maturation of battery storage technologies – driven largely by the rapidly expanding EV sector – has created opportunities for the deployment of battery and other storage solutions alongside more traditional technologies such as pumped (hydropower) storage. This has led to a push for mandates and incentives promoting the deployment of energy storage capacity both in front of the meter (for example, utility-scale, centralised) and behind the meter (for example, residential and commercial). These storage mandates have focused increasingly on battery storage technologies, and some, such as California's, explicitly exempt pumped storage.[119]

> To date, **few countries** have implemented policies to advance **sector integration** specifically with renewables.

Among new policies in 2018, Jordan issued a tender for a new energy storage project that aims to put 30 MW of storage capacity online by early 2019.[120] Ireland established new rules that accelerate the process for approving connections for more than 370 MW of energy storage projects.[121] For household systems, the state of South Australia launched an AUD 100 million (USD 70.5 million) subsidy scheme for the installation of home battery systems, particularly to facilitate rooftop solar PV, and the Australian Capital Territory began a household energy storage rebate programme.[122]

Another emerging trend is policies that encourage the joint installation of renewables (primarily solar PV) and energy storage systems. Both Lebanon and Madagascar held solar PV-plus-storage auctions in 2018, and India solicited bids for a 160 MW solar PV-wind-storage hybrid project.[123] Multiple jurisdictions also offered incentives for the development or deployment of solar PV-plus-storage, including Ireland, which began providing household grants in 2018, and Thailand.[124] At the sub-national level, the US states of California, Massachusetts and New York introduced new incentives for solar PV-plus-storage projects.[125]

Governments continued to invest in R&D to further advances in battery storage technology. In 2018, the UK government invested GBP 246 million (USD 312 million) in battery R&D; the US Department of Energy provided USD 27.7 million for long-duration energy storage; and the US state of Iowa began supporting battery technology research.[126]

Targets focused on enabling and integrating technologies – such as energy storage and EVs – also have gained prominence in recent years. For example, in 2018 the US state of New York established an initial target of 1.5 GW of energy storage by 2025 and later doubled this target to 3 GW by 2030.[127] In addition, many countries have set targets for specific shares or volumes of EVs, which can enable increasing shares of renewable electricity in the transport sector. (→ *See Sidebar 2 in this chapter, and Systems Integration chapter.*)

i Sector integration refers to the interconnection of the power, heating and cooling, and transport sectors to facilitate the integration of higher shares of renewable energy.

ii Ancillary grid services support the transmission and distribution of electric power so that supply will continually meet demand.

CLIMATE POLICY AND RENEWABLES

Energy production and consumption remains a key focal point in global efforts to address climate change. Renewable energy technologies have received both direct and indirect support through policies targeting mitigation as well as adaptation. Direct mechanisms include renewable-specific targets set through national emissions reduction strategies, such as the NDCs submitted by 181 countries under the United Nations Framework Convention on Climate Change.[128] (→ See *Policy Landscape chapter in GSR 2018*.) Approximately three-quarters of NDCs specifically reference renewables as tools for mitigating climate change, and more than half establish renewable energy targets.[129]

Climate strategies that set targets for partial or complete decarbonisation can establish indirect mechanisms for scaling growth in the renewable energy sector. These goals often necessitate a shift away from fossil fuels in many sectors of the economy. For example, in 2018 the European Commission outlined its strategy for reaching a zero-carbon economy across the region by 2050, and individual EU member countries were required to establish national energy and climate plans to meet EU-wide 2030 targets.[130]

In 2018, Costa Rica announced its plan to ban fossil fuels and become the first decarbonised country in the world.[131] Israel pledged to eliminate the use of coal, gasoline and diesel for energy production and transport by 2030, in favour of natural gas and renewable fuels.[132] At the sub-national level, California established a state-wide goal to achieve carbon neutrality no later than 2045, and London outlined its strategy for zero carbon by 2050.[133] Municipal initiatives continued to be advanced through partnerships such as the Global Covenant of Mayors for Climate & Energy, which by the end of 2018 included over 9,200 cities committed to combatting climate change.[134]

The ongoing transformation of power systems – spurred by factors such as the closure of coal and nuclear power plants – has led to an increased focus on ensuring the reliability of electricity supply using new generation mixes. This has resulted in opportunities for renewable energy and enabling technologies that offer ancillary grid services.[135] (→ *See Integration section in this chapter, and Systems Integration chapter.*) New developments in 2018 included a commitment to phase out coal power in Hungary by 2030.[136]

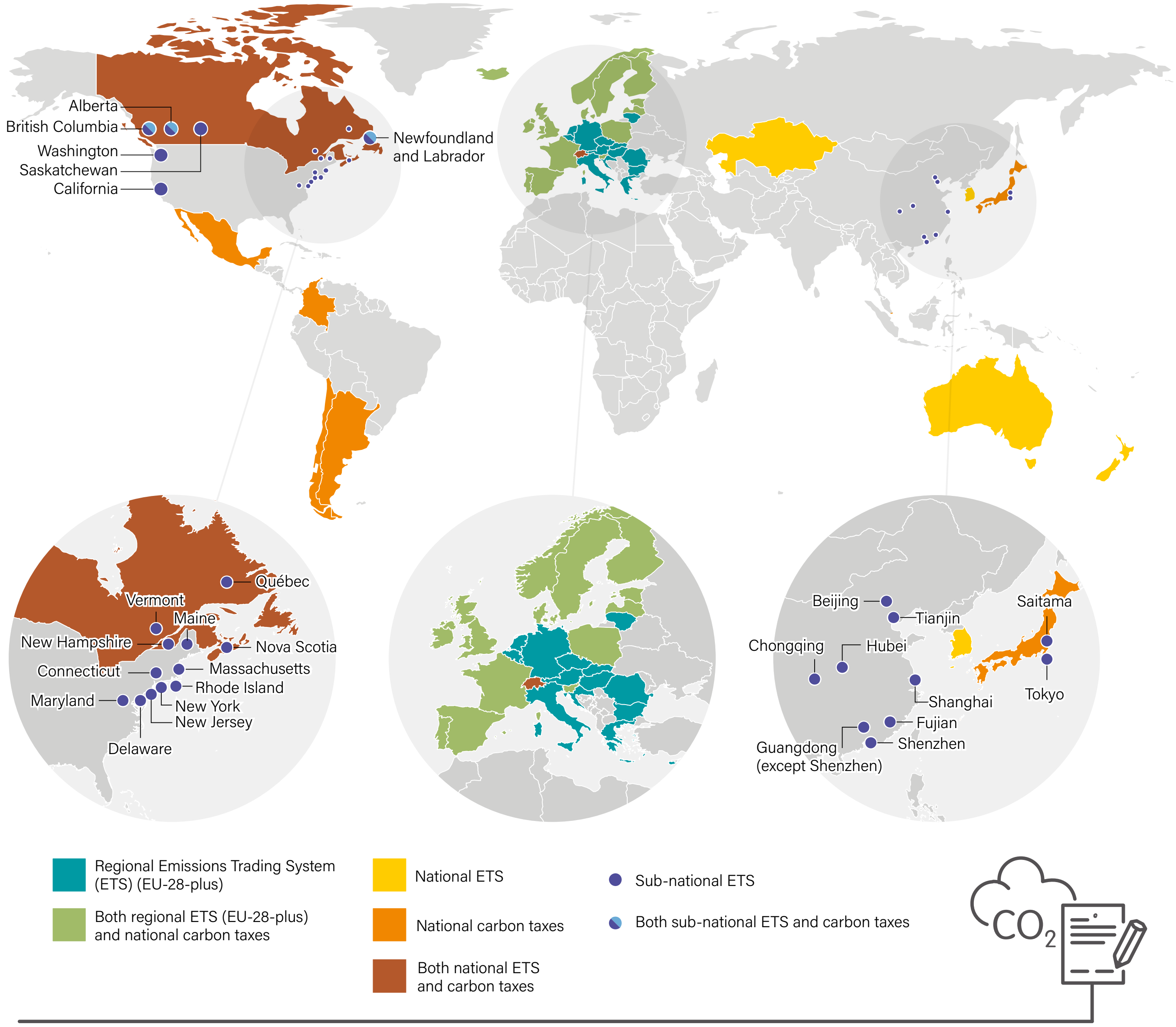
Carbon taxes and emissions trading systems are among the policy mechanisms that can stimulate interest in low-carbon, renewable energy technologies to meet climate mitigation goals. At least 54 carbon pricing initiatives had been implemented by the end of 2018 (up from 46 in 2017), including 27 emissions trading systems and 27 carbon taxes.[137] (→ *See Figure 17.*) Carbon pricing initiatives that were being implemented by the end of 2018 covered around 13% of global greenhouse gas emissions, while those that were scheduled for implementation would cover an additional 7%.[138]

At least

54

carbon pricing initiatives had been implemented by the end of 2018.

FIGURE 17. Carbon Pricing Policies, 2018



Note: The Regional Greenhouse Gas Initative (RGGI) includes the US states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont.

Source: World Bank. See endnote 137 for this chapter.

If well-designed, carbon pricing policies can incentivise the deployment of renewable energy technologies by internalising at least some externalities of fossil fuels, thereby increasing the relative cost of these fuels. However, some uncertainty exists as to whether these mechanisms are sufficient to drive deployment of renewable energy, particularly in the power sector, as many other factors are at play, including the structure of power markets and regulations governing market access.

The impacts of carbon pricing policies on renewable energy vary by technology and sector, and according to factors such as market prices within trading systems. Revenue accrued through these systems can be used to fund new renewable energy projects – as demonstrated in the European Commission's New Entrants' Reserve mechanisms – or can be returned to residents through carbon dividends (→ *see Box 2 in this chapter*).[139]

In 2018, the European Commission established new rules for phase IV (2021-2030) of the EU Emissions Trading System, with adjustments designed to accelerate the deployment of low-carbon technologies.[140] At the national level, Canada established a revenue-neutral carbon tax that was scheduled to be implemented in 2019.[141] Finland increased its carbon tax rate for coal and for heavy and light fuel oil, and Kazakhstan restarted its emissions trading system following a two-year hiatus.[142]

BOX 2. Policy Spotlight: Carbon Dividends

Carbon dividends – also known as a carbon fee-and-dividend policy or a revenue-neutral carbon tax – place a gradually increasing fee or tax on fossil fuel use, with the resulting revenue redistributed to taxpayers via "dividends": through rebates, reductions on other taxes or fixed payments. The dividend is key to ensuring that the policy is consistent with the notion of a "just transition" away from fossil fuels because it counterbalances the financial impact that a fee on fossil fuel consumption might have on households and businesses.

Such a policy can encourage changes in consumption habits – for both individuals and large consumers – either through more-efficient energy use or through the replacement of fossil fuels with lower-emission alternatives such as renewable energy sources. In turn, as consumption decreases, the predictably increasing fee is intended to send a strong price signal to fossil fuel producers, spurring them to shift investment to innovative and renewables-based solutions. This type of policy tends to be popular with voters and often receives support across political divides.

In early 2019, the Canadian government applied a carbon fee-and-dividend policy in provinces that did not already have a carbon pricing plan – whether a carbon dividend or otherwise – that met federal thresholds. For 70% of affected Canadian households, the annual dividends are expected to exceed any increase in energy costs that might result from the carbon fee, with lower-income households benefiting most. The federal policy builds on a similar policy that has been in place since 2008 in the Canadian province of British Columbia.

More than 10 years on, British Columbia's policy has maintained support of more than half of the province's population. It has reduced per capita fossil fuel consumption – even as British Columbia has maintained the strongest economic growth of any Canadian province – and has seen positive effects on the overall labour market.

Between 2007 and 2016, British Columbia's per capita fossil fuel consumption decreased by at least 10%, while annual emissions declined an estimated 2.2%. However, the policy coverage has narrowed over time, and the possibility of "leakage" remains, with emissions reductions in the province potentially associated with increases elsewhere.

Source: see endnote 139 for this chapter.

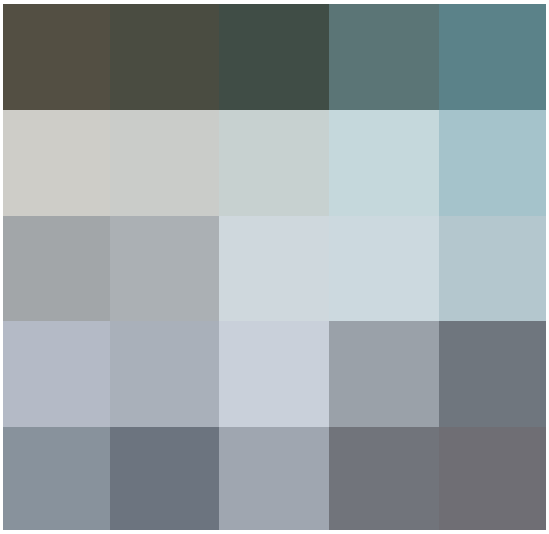


Table 2. Renewable Energy Targets and Policies, 2018

Country	Renewable energy targets[7]	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/ billing	Biofuel blend obligation/mandate	Renewable heat obligation/mandate	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Tax incentives	Investment or production tax credits	Reductions in sales, energy, CO_2, VAT or other taxes	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
High Income Countries														
Andorra			●										●	
Antigua and Barbuda	P													
Argentina	P	●	●		●	●			○		●	●	●	●
Australia	P	●	◖☆	●	◖	◖	●	●	◑					●
Austria	E, P, HC, T		●			●		●		●	●			●[6], ★*
Bahamas, The	P													
Bahrain	**P(R)**	●			●				○					●
Barbados[1]	P	●			●					●		●		●
Belgium	E, P, HC, T			◖	◖	●		●	●	●	●	●		◖
Brunei Darussalam	E, P													
Canada	P*	●	◖	◖	◖	●			◑	●	●	●		●, ★[7]
Chile	P	●		●	●			●	●	●	●[6]	●		●
Croatia	E, P, HC, T		●			☆								●[6]
Cyprus	E, P, HC, T		●		●	●			●					●
Czech Republic	E, P, HC, T		●			●		●		●	●	●		●[6]
Denmark	E, P, HC, T		●		●	☆		●	○	●	●	●		●[6]
Estonia	E, P, HC, T		●			●							●	●
Finland	E, P, HC, T		●			●		●	○	●		●	●	●
France	E, **P(R)**, HC, T		●			●	●	●	○	●[6]	●[6]	●		☆[6]
Germany	E, P, HC, T		●			●	●	●	○	●	●	●		●[6]
Greece	E, P, HC, T		●	●	●	●	●	●	○	●	●	●		●
Hungary	E, P, HC, T		●			●			●[6]	●		●		
Iceland	E, T					●								
Ireland	E, P, HC, T	●	●			●	●	●	●					★[6]
Israel	E, P, **T**	●	●	●	●		●		●	●		●		●
Italy	E, P, HC, T		●		●	●			●	●	●	●		☆, ●[6]
Japan	E, P	●	☆					●	○	●		●		●
Korea, Republic of	E, R(P)			●	●	●	●	●		●	●	●	●	●[6]
Kuwait	P	●							○					
Latvia	E, P, HC, T		●		●	●			●	●		●		
Liechtenstein			●											
Lithuania	E, **P(R)**, **HC(R)**, T		●	●	●	●				●		●		●
Luxembourg	E, P, HC, T		●			●								●
Malta	E, P, HC, T		●		●	●			○	●		●		●[6]
Monaco														
Netherlands	E, P, HC, T		●[6]		●	●		●	○	●[6]	●[6]		●	●[6]
New Zealand	P	●			◖	●								●
Norway	E, T, P	●		●		●, ★[7]	●	●	●	●		●		●[6]
Oman									○					
Palau	E, P	●		●										
Panama	E	●	●		●	●			●	●	●	●	●	
Poland	E, P, HC, T		●	●		●		●	○	●		●		●[6]
Portugal[2]	E, P, HC, T		●	●		●	●	●		●		●		●
Qatar	P, T	●							○					
San Marino		●	●											
Saudi Arabia	P	●			●				○					
Seychelles	P	●			●				○	●	●	●		●
Singapore	P	●			●				○					●
Slovak Republic	E, P, HC, T		●			●		●		●		●		●[6]
Slovenia	E, P, HC, T		●		●	●		●	●	●	●	●		●[6]
Spain[3]	E, **P(R)**, HC, T				☆	●	●		●	●	●		●	●[6]
St. Kitts and Nevis														
Sweden	E, P, HC, T		●	●		●		●		●	●	●		●
Switzerland	E, P		☆					●		●		●		●[6]
Trinidad and Tobago	P	●								●	●	●		
United Arab Emirates	E, P	●		◖	◖		●		◖				◖	◖
United Kingdom	E, P, T, HC		☆[6]	●		●		●	●	●		●	●	☆[6]
United States[4]	**P*(R)**		◖	◖☆	◖☆	●, ◖☆	●, ★*	◖	◑	☆	☆	●		☆[6]
Uruguay		●			●	●	●		●			●	●	●[6]

Note: Please see key on last page of table.

Table 2. Renewable Energy Targets and Policies, 2018 (continued)

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

Note: Please see key on last page of table.

■ **Table 2.** Renewable Energy Targets and Policies, 2018 (continued)

Country	Renewable energy targets[7]	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/ billing	Biofuel blend obligation/mandate	Renewable heat obligation/mandate	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Tax incentives	Investment or production tax credits	Reductions in sales, energy, CO_2, VAT or other taxes	Energy production payment	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, P													
Egypt	E, P	●	●		●				○	●		●		●
El Salvador		●							●	●	●	●	●	●
Eswatini									○					
Georgia														●[6]
Ghana	E, P	●	●	●	●	●		●		●		●		●
Honduras	P	●	●		●				●	●	●	●		
India	P, HC, **T**	●	◖	●	◖	●		●	○	●	●	●	●	●[6]
Indonesia	E, P	●	●	●	★	☆[7]			●	●	●	●		●
Kenya	P, HC	●	●		●		● (grey)		●	●		●	●	●
Kiribati	P													
Kosovo	E, P, HC		●											
Kyrgyz Republic				●						●		●		●
Lao PDR	E													
Lesotho	P	●			●				●	●	●		●	●
Mauritania	E													
Micronesia, Federated States of	P	●			◖									
Moldova	E, P, HC, T		●		●	●			●					●
Mongolia	E, P	●	●						●	●		●		
Morocco	P, HC	●			●				●					●
Myanmar	P	●								●		●		
Nicaragua	P		●							●	●	●		●
Nigeria	P	●	●	●					●	●		●		●
Pakistan			●		●			●		●		●		●
Palestine, State of	E, P		●		●				○	●		●		
Papua New Guinea	P													
Philippines	P	●	●	●	●	●			●	●	●	●	●	●
São Tomé and Príncipe	P													
Solomon Islands	P													
Sri Lanka	P, T	●	●	●	●	●			○	●		●	●	●
Sudan	E, P	●				●								
Timor-Leste	P													
Tunisia	P	●			●				○	●		●		●[6]
Ukraine	E, P, HC, T	●	●		●	●				●		●		●[6]
Uzbekistan	P								●					
Vanuatu	E, P	●	●							●		●		
Vietnam	E, P, T	●	☆[6]	●	●	●		●		●	●	●		●
Zambia		●	★						○	●		●		●

Note: Please see key on last page of table.

Table 2. Renewable Energy Targets and Policies, 2018 (continued)

Country	Renewable energy targets[7]	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/ billing	Biofuel blend obligation/mandate	Renewable heat obligation/mandate	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Tax incentives	Investment or production tax credits	Reductions in sales, energy, CO_2, VAT or other taxes	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	P	●												●
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, P		●		●				●	●	●			
Tajikistan	E, P	●	●							●		●		●
Tanzania	E, P	●	●		●				○	●		●	●	●
Togo	E, P	●								●		●		
Uganda		●	●						●	●		●		●
Yemen	P	●												
Zimbabwe		●				☆				●		●		●

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

- ★ New
- ☆ Revised
- (grey circle) Removed

Policies
- ● Existing national policy or tender framework (could include sub-national)
- ◖ Existing sub-national policy or tender framework (but no national)
- ○ National tender held in 2018
- ◖ Sub-national tender held in 2018

[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 for projects is based on the "reasonable return" concept meant to ensure a fixed return on investment over the lifetime of a plant. Incentives for projects that previously had qualified for FIT support continue to be revised.
[4] State-level targets in the United States include RPS policies.
[5] The area of the State of Palestine is included in the World Bank country classification as "West Bank and Gaza".
[6] Includes renewable heating and/or cooling technologies.
[7] Aviation, maritime, or rail transport.

Note: Countries are organised according to annual gross national income (GNI) per capita levels as follows: "high" is USD 12,056 or more, "upper-middle" is USD 3,896 to USD 12,055, "lower-middle" is USD 996 to USD 3,895, and "low" is USD 955 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 2019. 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 1 for this chapter.

03

Project and City:
McNeil Generating Station, Burlington, Vermont, US

Technology:
Biomass power plant

Burlington, Vermont, US

In 2018, renewable energy supplied 100% of Burlington's electricity. More than a third of the renewable power comes from bioenergy produced at the McNeil Generating Station. Operational since 1984, the 50 megawatt biomass power plant is fuelled by wood, most of which arrives via rail from sustainably managed forests in Vermont and New York, within a 100-kilometre radius of Burlington. The plant is owned and operated by Burlington Electric Department, the sole electricity provider to the city of 42,000 inhabitants. The remainder of Burlington's electricity is provided by wind power, solar PV and hydropower.

MARKET AND INDUSTRY TRENDS

BIOENERGY

A wide range of biological feedstocks can be converted via a number of different processes into thermal energy, electricity and fuels for transport (biofuels). Many bioenergy conversion pathways are well established and fully commercial, while others are still at the early stages of development, demonstration and commercialisation.[1]

BIOENERGY MARKETS

Bioenergy makes the largest renewable contribution to global energy supply. Including the traditional use of biomass[i], bioenergy contributed an estimated 12.4% – or 46.0 exajoules (EJ) – to final energy consumption as of the end of 2017.[2] Modern sustainable bioenergy[ii] (excluding the traditional use of biomass) provides around half of all renewable energy in final energy consumption.[3]

In 2017, modern bioenergy contributed an estimated 5.0% to total final energy consumption (TFEC).[4] (→ *See Figure 18.*) It contributed an estimated 13.3 EJ to the global supply of heat (5.0% of the heat total), 3.5 EJ in transport (3.0% of the transport total) and 1.6 EJ to global electricity supply (2.1% of the electricity total).[5] Modern bioenergy use is growing most quickly in the electricity sector (at around 9% per year), compared to around 7% in the transport sector; its use for heating is growing more slowly, at around 1.8%.[6]

Bio-heat Markets

Bioenergy – in the form of solid fuel (biomass), liquids (biofuels) or gases (biogas or biomethane) – can be used to produce heat for cooking and for heating residential spaces and water, either in traditional stoves or in modern appliances such as pellet-fed central heating boilers. At a larger scale, bioenergy can provide heat for public and commercial buildings as well as for industry. Bioenergy also can be used to co-generate electricity and heat via combined heat and power (CHP) systems to serve residential, commercial and industrial buildings – either on-site or distributed from larger production facilities via district heating and cooling systems.

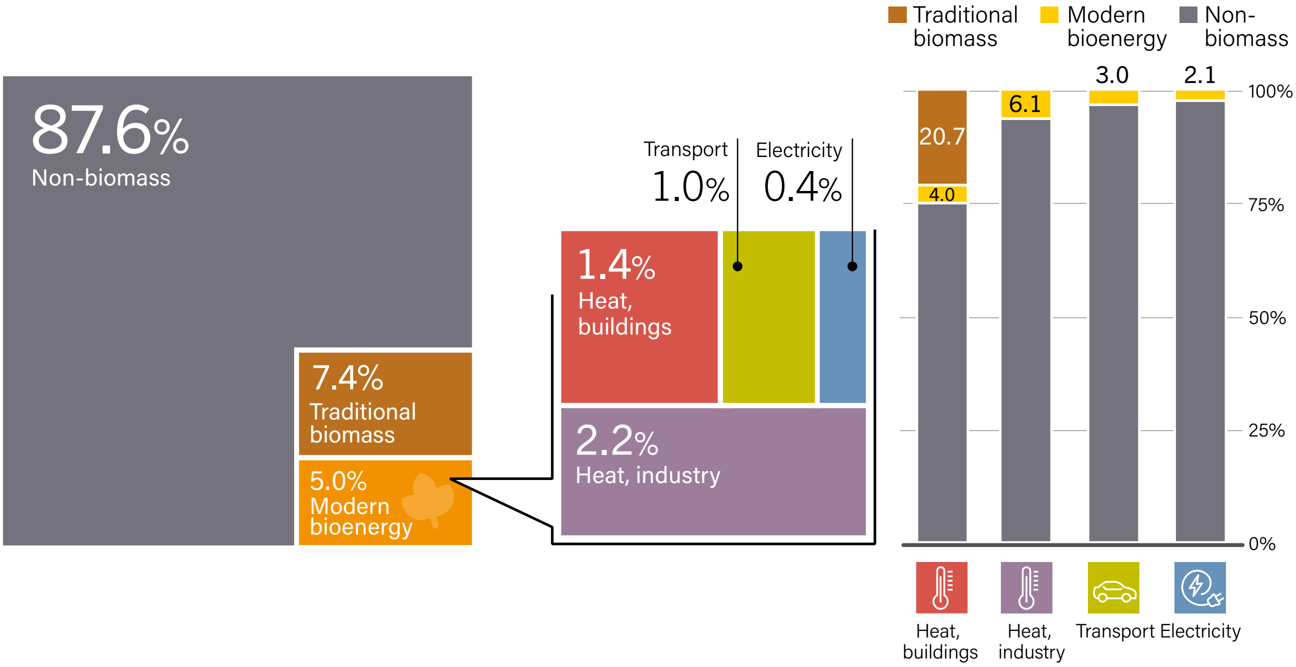
The traditional use of biomass to supply energy for cooking and heating in simple and usually inefficient devices, mostly in developing and emerging economies, is still the largest use of bioenergy.[7] (→ *See Figure 18.*) Given the serious negative health impacts of traditional biomass use, the effects on local air quality and the unsustainable nature of much of the supply of this biomass, efforts are being made to reduce the use of traditional biomass in the push to improve access to clean fuels. (→ *See Distributed Renewables chapter.*)

Because the supply of biomass for traditional use is informal, obtaining accurate data on this usage is difficult.[8] The amount of

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 Bioenergy is considered to be sustainable when its use reduces greenhouse gas emissions compared to the use of fossil fuels in the applications where it is used, and where its use avoids significant negative environmental, social or economic impacts and plays a positive role in the achievement of sustainable development objectives. See endnote 3 for this section.

FIGURE 18. Estimated Shares of Bioenergy in Total Final Energy Consumption, Overall and by End-Use Sector, 2017



Source: Based on OECD/IEA. See endnote 4 for this section.

biomass used in traditional applications has been largely stable in recent years, totalling an estimated 27.5 EJ in 2017.[9] However, the share of traditional biomass in TFEC has been declining gradually for several years, from 8.8% of global consumption in 2006 to 7.6% in 2017.[10] (→ *See Figure 2 in Global Overview chapter.*)

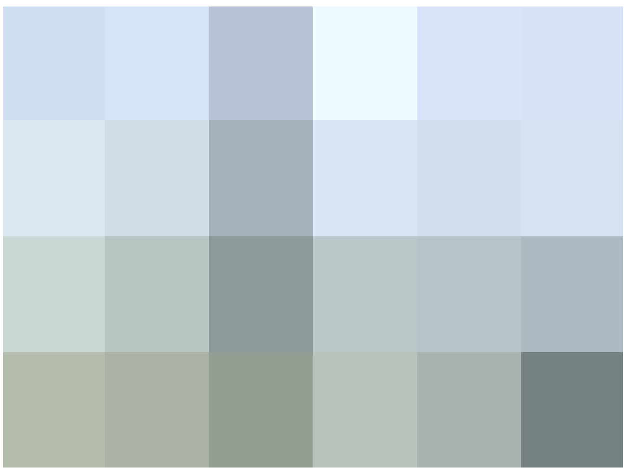
The use of modern bioenergy for direct heat production has grown only around 1.8% annually on average since 2006, mainly because of a lack of policy interest.[11] Use of modern bioenergy in district heating – where bioenergy provides 95% of the renewable energy used – grew more rapidly, at more than 5% annually during the period 2006-2017.[12] In 2017, modern bioenergy applications provided an estimated 13.3 EJ of heat, including 0.9 EJ provided by district heating; of this total, 8.0 EJ is consumed in industry and the rest in buildings.[13]

Europe is the largest consumer of modern bio-heat by region. European Union (EU) member states have promoted the use of renewable heat in both buildings and industry in order to meet mandatory national targets under the EU Renewable Energy Directive.[14] Bioenergy use for heat production in the region rose at an average rate of around 2.2% annually between 2012 and 2017, and totalled an estimated 4.0 EJ in 2018.[15] Other major users of bioenergy for heat include the United States (1.8 EJ), Brazil (1.6 EJ) and India (1.6 EJ).[16] China also is expanding its use of biomass for heating in both the industry and buildings sectors.[17]

Globally, modern bioenergy provided around 4.0% of the energy used for heating buildings in 2017.[18] Modern use of bioenergy for heating in the buildings sector is concentrated in the EU.[19] In 2016, the region accounted for some 46% of all bioenergy used for heat in individual buildings, and for an even higher share of global bioenergy use in the residential sector (54%); together, Italy, France and Germany accounted for 44% of the global total.[20]

The market for pellets for heating residential and commercial buildings is based mainly in Italy, Germany and Sweden. The use of wood pellets in stoves for residential heating (rather than for boiler systems) has grown rapidly in France and Italy in recent years.[21] Sweden and Finland lead globally in the use of bioenergy in district heating schemes, but this practice also is widespread in other countries, including Denmark and Lithuania.[22]

North America followed the EU for bioenergy consumption in buildings. In 2017, more than 2 million US households (2% of the total) used wood or wood pellets as their primary heating fuel, and a further 8% of households used wood as a secondary heat source.[23] In the industry sector, heat supplied from bioenergy accounted for some 6.1% of all heat consumption.[24] Generally, the use of bioenergy has been concentrated in industries where biomass residues are created as part of the production process – such as



pulp and paper (where bioenergy provides 30% of energy needs), food, tobacco, and wood and wood products.[25]

Bioenergy can deliver low-temperature heat for heating and drying applications, as well as high-temperature process heat – either through direct use of the fuel or by gasifying the biomass and using the resulting fuel gas. However, very little bioenergy is used in the more energy-intensive industrial sectors where very high-temperature heat is required, such as iron and steel and chemicals; in these sectors, lower-cost, higher energy density fossil fuels usually are preferred.[26]

One exception is the cement industry, where wastes and biomass can substitute for the coal that typically is used in cement production. The extent of this substitution varies by region: for example, the EU's cement industry is the largest user of wastes and biomass, especially in Germany and the United Kingdom. As coal replacement in the EU has grown, the level of substitution in the region's cement sector reached 25% in 2018, compared to only 15% in Brazil.[27] In India and China, the two largest global cement manufacturers, only low levels of substitution have been achieved, although in 2018 the use of wastes and biomass in clinker production was being considered as part of the evolving waste management strategy in both countries.[28]

Bio-power Markets

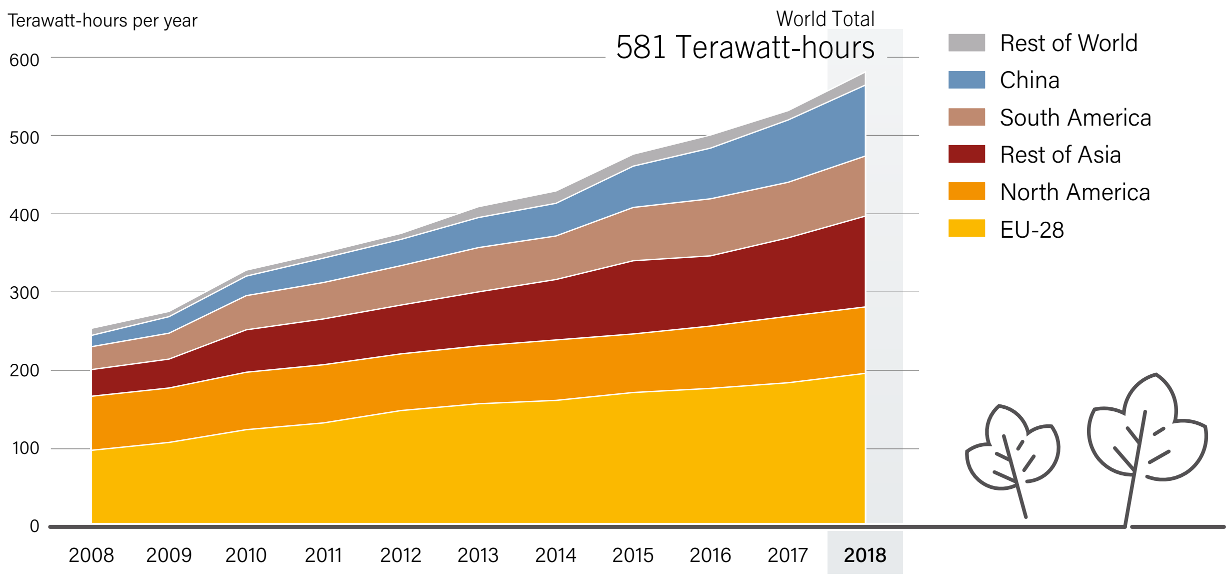
Global bio-power capacity increased an estimated 6.5% in 2018 to 130 gigawatts (GW), up from 121 GW in 2017.[29] Total bioelectricity generation rose 9%, from 532 terawatt-hours (TWh) in 2017 to 581 TWh in 2018.[30] The EU remained the largest generator by region, with generation growing 6% in 2018, stimulated by the Renewable Energy Directive.[31] Other trends of previous years continued: generation grew most rapidly in China – up 14% in 2018 – and in the rest of Asia (16%), while generation in North America remained essentially stable.[32] (→ *See Figure 19.*)

China maintained its position as the largest country producer of bioelectricity, followed by the United States.[33] The other major producers in 2018 were Brazil, Germany, India, the United Kingdom and Japan.[34]

Europe continued to lead regionally in bioelectricity production, with capacity rising from 39 GW to 42 GW during 2018 and generation increasing 6% to 196 TWh.[35] However, in Germany, Europe's largest bioelectricity producer (primarily from biogas), generation rose less than 1%, to 51 TWh.[36] This continued Germany's slow growth trend that began in 2014, when feed-in tariff (FIT) rates for bioelectricity generation became less favourable.[37] In the United Kingdom, bio-power capacity increased 30% to 7.7 GW, due primarily to the conversion of coal capacity to use imported biomass fuels, and generation rose 11% in 2018, to 35.6 TWh.[38] Generation also increased strongly in the Netherlands (8%) and France (5%).[39]

In China, bio-power capacity increased 21% to 17.8 GW in 2018, growing in line with the provisions of the country's 13th Five-Year Plan (2016-2020).[40] Generation continued to grow strongly as well, increasing 14% to 91 TWh.[41] Elsewhere in Asia, India's bio-power capacity increased 16% to 10.2 GW and generation rose 4% to 50 TWh.[42] Capacity and generation growth also remained strong in Japan, where the capacity of dedicated biomass plants increased 11% to reach 4 GW and generation totalled some 29 TWh in 2018 (a 25% increase from 2017), stimulated by a generous FIT.[43] Biomass generation increased 50% in the Republic of Korea (to 11.2 TWh) and 39% in Thailand (to 14 TWh), and it doubled in Vietnam (to 0.5 TWh).[44]

FIGURE 19. Global Bioelectricity Generation, by Region, 2008-2018



Source: See endnote 32 for this section.

The United States had the second-highest national levels of bio-power capacity (16 GW) and generation (69 TWh) in 2018.[45] However, generation did not increase during the year and has not grown significantly over the last decade, due to a lack of strong policy drivers and to increasing competition from other renewable generation sources.[46] In some cases, biomass generation plants were closed down when supply contracts were not renewed.[47]

Brazil is the third-largest producer of bioelectricity globally and the largest producer in South America. In 2018, the country's capacity reached 14.7 GW and generation rose 9% to 54 TWh.[48] Most of the bioelectricity generation is from sugarcane bagasse (fibrous sugarcane waste).

Transport Biofuel Markets

In 2018, global production of all biofuels increased nearly 7% compared to 2017, reaching 153 billion litres (equivalent to 3.8 EJ).[49] The United States and Brazil dominated production – together producing 69% of all biofuels in 2018 – followed by China (3.4%), Germany (2.9%) and Indonesia (2.7%).[50] ***(→ See Reference Table R14.)***

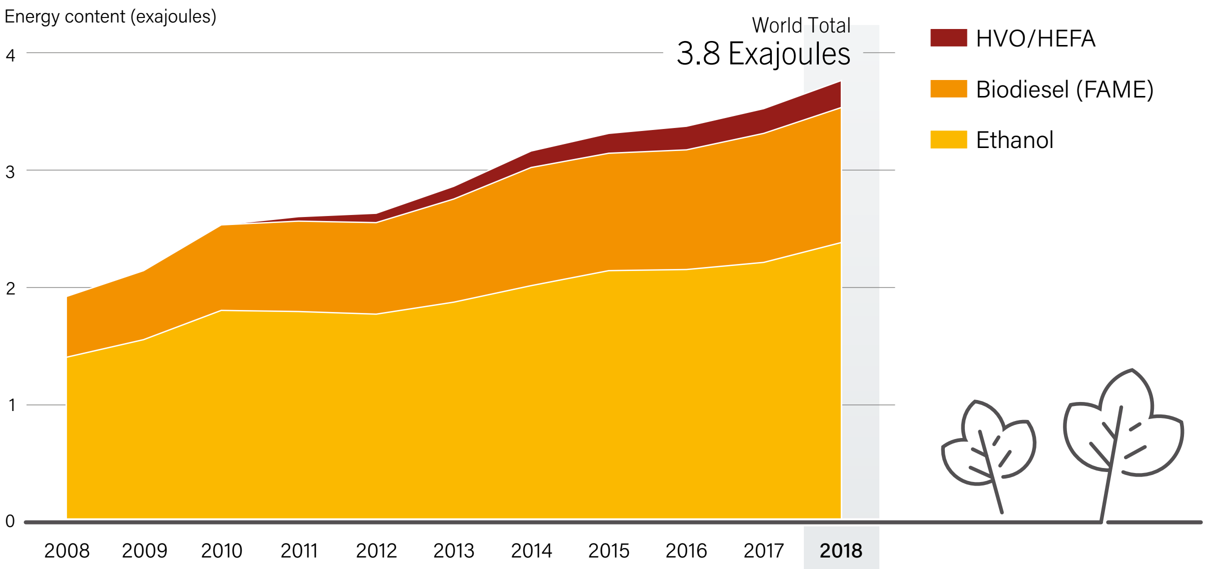
The main biofuels produced are ethanol (produced mostly from corn[i], sugar cane and other crops) and biodiesel (fatty acid methyl ester, or FAME, fuels produced from vegetable oils and fats, including wastes such as used cooking oil).[51] In addition, the production and use of diesel substitute fuels – made by treating animal and vegetable oils and fats with hydrogen (hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA)) – is growing. In 2018, ethanol accounted for an estimated 63% of biofuel production (in energy terms), FAME biodiesel for 31% and HVO/HEFA for 6%.[52] (→ *See Figure 20.*)

The contribution from biomethane is also increasing rapidly in some countries. Nevertheless, it represented less than 1% of the biofuel total in 2018, and other advanced biofuels had shares below 0.5%.[53]

Production, consumption and trade in biofuels are affected by numerous factors, including biomass growing conditions (such as the weather), the demand for biofuels in the producing countries, and import markets, which are influenced by policy developments. Changing import tariffs and other measures also affect international trade in biofuels.[54]

i The word "corn" has various meanings depending upon different geographical regions. 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 51 for this section.

FIGURE 20. Global Ethanol, Biodiesel and HVO/HEFA Fuel Production by Energy Content, 2008-2018



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

Source: See endnote 52 for this section.

Ethanol production in the United States and Brazil accounted for

83%

of the global total.

The biofuel market is driven strongly by the policy and regulatory regimes within regions and countries. In the United States, for example, the Renewable Fuel Standard (RFS) has driven the market by setting an overall obligation at the federal level to use low-carbon fuels.[55] Synergies exist with state-level initiatives such as California's Low Carbon Fuel Standard, which incentivises the development and use of fuels that can provide lower levels of greenhouse gas emissions.[56] In Brazil, the RenovaBio initiative has played a strong role in increasing the domestic use of biofuels.[57]

In Europe, the revised EU Renewable Energy Directive for 2020-2030, approved in December 2018, sets a target for a 14% share of renewable energy in the transport sector by 2030, with a sub-target of at least 3.5% use of advanced biofuels and biomethane.[58] The Directive also places a 7% cap on the share of the overall target that can be met by conventional biofuels based on feedstocks that also could be used as food, reflecting EU concerns about competition between food and fuel and about potential indirect land-use change impacts.[59]

In India, biofuels are being given greater priority, with a medium-term emphasis on advanced biofuels that can use as feedstock the country's widespread agricultural residues.[60] In China, the use of ethanol in petrol is being expanded by initiating blending mandates in every province by 2020, and advanced biofuel technologies and the large-scale production of cellulosic ethanol are expected to play an important role by 2025.[61]

Global annual ethanol production increased more than 7% during 2018, from 104 billion litres to 112 billion litres.[62] Ethanol production remains concentrated in the United States and Brazil, which together accounted for 83% of the global total that year (a similar share as in 2017).[63] The next-largest producers were China, Canada, Thailand and India.[64]

US ethanol production rose 1.7% to a record 61 billion litres during 2018, following a good corn harvest.[65] While demand for ethanol in the United States plateaued as blending limits were approached, a record volume of the fuel (10.6% of total production) was exported.[66] The top five importers of US ethanol were Brazil, Canada, India, the Republic of Korea and the Netherlands, followed by a further 75 importing countries.[67] Ethanol production in Canada, which ranked fourth globally in 2018, increased 7% to 1.9 billion litres.[68]

In Brazil, ethanol production increased 15% to a record 33 billion litres.[69] Not only did low global sugar prices favour production of the fuel, but ethanol also benefited from lower federal taxes and rising global oil prices, which gave it a price advantage and contributed to an increase in domestic demand.[70]

Although most of the ethanol produced in Brazil was used domestically, some was exported. Ethanol production grew 25% in China during 2018, to an estimated 4.1 billion litres.[71] To reduce oil imports and make use of excess grain stocks, a 10% ethanol blend was introduced in additional provinces, helping to increase demand.[72] China's ethanol production was based largely on the use of corn in the country's north-east, although the fuel also was produced from cassava in the south.[73]

In Thailand, the fifth-largest producer, production increased 23% to 1.5 billion litres.[74] Ethanol production also grew sharply in India (70%), the sixth-largest producer, reaching 1.4 billion litres in 2018.[75] The growth was stimulated by changes in regulations surrounding the feedstocks that can be used for ethanol production in India – particularly by allowing greater use of molasses – as part of a national effort to boost biofuel production as a means to reduce oil imports.[76]

Global production of biodiesel also increased in 2018, up around 5% to 41.3 billion litres.[77] Biodiesel production is more geographically diverse than ethanol production (due to policy priorities) and is spread among many countries. The top five countries in 2018 accounted for 53% of global production.[78] Europe was the largest biodiesel producer by region, and the leading country producers were the United States (17%), Brazil (13%), Indonesia (10%), Germany (8%) and Argentina (5%).[79]

Europe produced some 15 billion litres of biodiesel in 2018. Although the market did not contract, production was down 6% relative to 2017 as producers faced increased competition from less-expensive biodiesel imported from Argentina and Indonesia.[80] Germany was again the largest producer in Europe, but the country's production fell 3% to 3.5 billion litres.[81] Production also declined in other major European producers: France (which produced a total of 2.2 billion litres), and the Netherlands (1.9 billion litres).[82]

The global increase in biodiesel production was due mainly to growth in the United States, where production rose 14% to a record 6.9 billion litres.[83] Factors behind this growth included a good soya crop, increased opportunities for biodiesel in the RFS, and the impact of US anti-dumping duties, which constrained imports from Argentina and Indonesia.[84]

Biodiesel production in Brazil increased 13% in 2018 – a similar growth rate as in 2017 – to a record 5.3 billion litres.[85] Contributing factors included a good soya harvest and an increase in the biodiesel blending level in diesel from 8% to 10% in March 2018.[86] In Argentina, biodiesel production fell 15% to 2.8 billion litres, due in part to the US anti-dumping duties on biodiesel imports (Argentina's largest market) and to uncertainties about whether the EU would re-apply similar duties to its imports of the fuel.[87]

In Indonesia, production rose 30% to 4.1 billion litres in 2018.[88] The rise was due to higher domestic use following an increase in the blending levels in order to utilise surplus palm oil production. The mandate for blending biodiesel with fossil diesel was increased to 20% for both the transport and power sectors.[89] In addition, new mandates were introduced requiring 5% blending in fossil diesel used in the rail sector and 10% in the mining sector.[90]

After ethanol and biodiesel, HVO/HEFA accounts for most of the remaining biofuels consumed in the transport sector. The use of HVO/HEFA is concentrated in Finland, the Netherlands, Singapore and the United States.[91] Global HVO production grew an estimated 12% during 2018, from 6.2 billion litres to 7.0 billion litres.[92]

Biomethane is used for transport mainly in the United States and Europe. The United States is the largest producer and user of biomethane for transport, and domestic production of the fuel has increased since 2015, when biomethane was first included in the advanced cellulosic biofuels category of the RFS, thereby qualifying for a premium.[93] US biomethane consumption grew more than seven-fold between 2014 and 2017 and then increased another 13% in 2018 to some 22 petajoules (PJ).[94]

In Europe, the other globally significant market for biomethane for transport, consumption increased 13% in 2017, to 7.8 PJ (latest data available).[95] Production and use were concentrated in Sweden (5.2 PJ), where methane production from food wastes is encouraged as part of a sustainable waste reduction policy and where the use of biomethane in transport fuel is prioritised over its use for electricity production or for injection into gas grids.[96] The next-largest European users of transport biomethane in 2017 were Germany (1.6 PJ), Norway (0.42 PJ) and the Netherlands (0.23 PJ).[97]

Biofuels of all types have been used principally for road transport. The total quantity of biofuels used in aviation and shipping has been very small (only 0.1% of all airline fuel in 2018), although these applications are seen as a long-term priority by both policy makers and the airline industry.[98]

The United States produced **7.3 million tonnes** of wood pellets in 2018.

BIOENERGY INDUSTRY

Bioenergy requires a more complex supply chain than other renewable technologies, given the many potential feedstocks and conversion processes for bioenergy and the need to collect, process and convert biomass raw materials to fuels. With support from academia, research institutions and governments, the industry is developing and commercialising new technologies and fuels, especially advanced biofuels for use in transport.[99]

Solid Biomass Industry

Many entities are involved in growing, harvesting, delivering, processing and using solid biomass to produce heat and electricity. These range from locally based companies that manufacture and supply smaller-scale heating appliances, to regional and global players involved in the supply and operations of large-scale district heating and power generation technology.

Bioenergy projects that produce electricity and/or heat often rely on solid fuels that are sourced locally – such as municipal solid waste[i], residues from agricultural and forestry processes, and purpose-grown energy crops. The fuels also can be processed and transported for use where markets are most profitable. For example, the international trade in biomass pellets is growing to meet requirements for fuels for large-scale heat and power generation and to provide residential heating in markets where the use of pellets is supported, notably in Europe but also increasingly in Japan and the Republic of Korea.[100]

Global production and trade in wood pellets continued to expand in 2018, with production reaching an estimated 35 million metric tonnes.[101] Wood pellets are used in industry (mostly in power stations) and for heating residential and commercial buildings. The United States was the largest producer and exporter of wood pellets in 2018 and had the capacity to produce 10.6 million tonnes (11.9 million short tons) annually in 83 operating plants by year's end.[102] Actual US production in 2018 was 7.3 million tonnes (8.2 million short tons).[103]

US exports of wood pellets increased 16% in 2018 to 5.4 million tonnes (6.1 million short tons).[104] Most of the exports went to Europe – primarily to the United Kingdom, although exports increased significantly to Denmark, Italy and the Netherlands.[105] Canada exported some 2.7 million tonnes of pellets – a 60% increase from 2015 – primarily to the United Kingdom (1.6 million tonnes, representing 60% of Canadian exports) but also to Japan (0.6 million tonnes, or 24% of exports).[106] The Russian Federation was a major producer and exporter of wood pellets as well: annual production capacity reached 3.6 million tonnes in 2018, although Russian plants were operating at only a 50% load factor.[107] Russian exports rose 30% for the second year running and totalled 1.5 million tonnes.[108]

In Europe, a number of biomass-fired CHP plants were commissioned or under construction during 2018, stimulated by measures designed to help achieve the EU's Renewable Energy Directive targets for 2020 and 2030. For example,

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".

Ethanol production capacity is expanding rapidly in
China
to meet growing demand.

in the United Kingdom, a 27 megawatt (MW) capacity CHP plant, fuelled with locally sourced wood, was commissioned in Sandwich and began delivering renewable heat and power to a nearby business and science park and some 50,000 homes.[109] In the Netherlands, a 15 MW biomass CHP plant was under construction in Duiven; when completed, it will run on the city's wood waste and provide heat, electricity and steam to an animal feed mill in addition to supplying surplus electricity to the grid.[110]

Bagasse and other agricultural residues, commonly used to produce heat and power in Brazil, are attracting increasing attention elsewhere. For example, a new biomass plant in Mexico owned by Grupo Piasa was commissioned in 2018 and is fuelled by sugarcane wastes, supplying 50 MW of electricity and steam to a sugar mill and to nearby bottling plants, with the surplus power delivered to the grid.[111] In Argentina, as part of the country's RenovAr Program to support the use of renewable electricity, the major peanut producer Prodeman began commercial operation of its 10 MW bioenergy facility, which is expected to use 50,000 tonnes of peanut shell waste annually to generate energy.[112]

Forest products are being used increasingly as an energy source as well. In 2018, plans were announced for a new 50 MW biomass power plant in La Coruña, Spain, fuelled by locally sourced forest waste.[113] In South Africa, the Ngodwana Energy Biomass Project – the first such project supported under the country's Renewable Energy Independent Power Producer Procurement Programme and one of four expected biomass projects in the country – reached financial close.[114]

In India, the country's largest power producer, NTPC, announced its intention to start biomass co-firing at all of its coal-based thermal power stations, using biomass pellets as well as briquettes made from scrap lumber, crop residues, forest debris, manure and some types of waste residues.[115] One of NTPC's objectives is to reduce the air pollution caused by the burning of surplus agricultural residue in fields.[116]

In Japan, where support from a generous FIT has stimulated rising interest in bioelectricity, a large pipeline of projects is being established, using as fuel both indigenous resources and imported pellets.[117] Among the developments in 2018, Nippon Paper Industries started operating a bio-power plant at its paper mill in Ishinomaki, which will use wood residues from local forests as well as wood pellets from Asia and North America.[118] Toshiba announced an agreement to collaborate with Omuta City of Fukuoka Prefecture to construct a new 44 MW bio-power plant that was expected to start operation in 2019; in addition, Toshiba converted the Mikawa coal-fired power to operate as a biomass power plant.[119] Meanwhile, Sumitomo Heavy Industries was building a 75 MW bio-power plant based on circulating fluidised bed boiler technology in Kanda City, Fukuoka Prefecture.[120]

Liquid Biofuels Industry

The United States is home to the world's two largest ethanol producers, POET and Archer Daniels Midland (ADM). POET is increasing its capacity by making upgrades at several of its 27 ethanol plants, and in 2018 the company began expanding a facility in Marion, Ohio and also building a new plant in Indiana.[121] ADM, meanwhile, reduced its ethanol capacity slightly, shifting production to other high-value chemicals.[122]

In Brazil, ethanol production is based principally on fermentation from sugar cane, the country's traditional ethanol feedstock. Production capacity is not fully utilised, however, and in 2018 some eight sugar mills were operating below capacity, leaving room for ramp-ups in production in response to increases in demand and when sugar prices are low.[123] The trend to produce ethanol from corn also continued in 2018. Brazil's FS Bioenergia announced plans to double the capacity of its 265 million litre Lucas do Rio Verde plant, and also broke ground on a second, BRL 1 billion (USD 267 million) corn ethanol plant in Sorisso that is expected to produce 530 million litres of ethanol annually starting in 2020.[124]

In Europe, by contrast, changes to the EU's Renewable Energy Directive limiting the role of "food-based biofuels" have led to uncertainties about future markets for the region's ethanol industry.[125] This has led to some plants being shut down either temporarily or permanently: for example, the two largest ethanol production plants in the United Kingdom, owned by Vivergo and Crop Energies, were closed in 2018.[126]

Ethanol production capacity is expanding rapidly in China to meet growing demand, including from a nationwide E10 mandate that is expected to be in place by 2020.[127] China's ethanol production capacity totalled some 3.5 million litres at the end of 2017, and new plants capable of producing 8.4 million litres were either under construction or going through the approval process in 2018.[128] For example, China Beidahuang Industry Group Holdings Ltd announced plans to build a CNY 960 million (USD 152 million) plant in Inner Mongolia with the capacity to produce 443,000 litres of ethanol per year, consuming 924,000 tonnes of corn and some 350,000 tonnes of straw and sweet sorghum.[129]

Chinese-based companies also are developing biofuel production facilities elsewhere in the world. For example, the Nigerian National Petroleum Corporation announced plans in 2018 to realise several biofuel projects in Nigeria with the help of Chinese companies.[130] The company signed memoranda of understanding with China that include a plan to develop Nigeria's first biofuel production facility as well as at least three other projects to help the African country meet its 10% blending mandates for ethanol and biodiesel.[131]

Global biodiesel production capacity has been expanding to meet increasingly ambitious blending mandates worldwide, especially in North America.[132] In response to rising demand in the United States, US-based Renewable Energy Group Inc. expanded and upgraded its Ralston, Iowa biodiesel plant in 2018 through a USD 32 million project that more than doubled the plant's production capacity from 45 million litres to 114 million litres per year.[133] To the north, Canada-based Benefuel Inc. announced plans to build a new 76 million litre per year biodiesel plant in Sarnia, Ontario.[134]

Efforts to demonstrate the production and use of advanced biofuels continued in 2018, with the aim of producing fuels that

By year's end, just **five airports** worldwide had biofuel distribution systems in place.

show improved sustainability performance.[135] Some advanced biofuels can replace fossil fuels directly in transport systems ("drop-in biofuels"), including in aviation and for blending in high proportions with conventional fuels in road transport (such as HVO in diesel-fuelled vehicles).[136] A number of different pathways to produce advanced biofuels are under development and include bio-based fuels (from an array of feedstocks) in the form of ethanol, butanol, diesel jet fuel, gasoline, biomethanol and mixed higher alcohols.[137]

HVO/HEFA led the development of these new biofuels in 2018, followed by ethanol from cellulosic materials such as crop residues and by fuels from thermochemical processes, including gasification and pyrolysis[i],[138] Production of HVO/HEFA fuels (based on feedstocks such as used cooking oil, tall oil[ii] and others) continued to increase to meet rising demand for both road transport (especially for heavy-good vehicles) and aviation. For example, "renewable diesel" based on HVO/HEFA[iii] supplied 10% of all diesel used for transport in the US state of California in 2018, and HVO-derived fuels provided most of the biofuel used worldwide in aviation.[139]

In 2018, Neste (Finland), the world's largest HVO producer, announced an investment of EUR 1.4 billion (USD 1.6 billion) to more than double its renewable diesel production capacity in Singapore by adding a further 1.3 million tonnes (1.7 billion litres) of annual capacity.[140] In the United States, where most of the remaining HVO expansion occurred, Renewable Energy Group increased the combined capacity at its 13 biomass-based diesel refineries to more than 2 billion litres per year, and began working with Phillips 66 to build another large-scale renewable diesel plant on the west coast.[141]

Also in 2018, US-based World Energy acquired a biorefinery facility in California from Paramount (formerly owned by Altair) that can produce 151 million litres per year of biojet fuel and renewable diesel; in addition, the company announced a USD 350 million investment over two years to increase total production capacity to 1.15 billion litres per year.[142] In Norco, Louisiana, the annual capacity of the Diamond Green Diesel plant was expanded in 2018 from 0.6 billion litres to more than 1 billion litres, and the company had plans for a further increase of 1.5 billion litres per year by late 2021.[143]

In Europe, Eni (Italy) ramped up HVO production at its Venice refinery to 250,000 tonnes (320 million litres) in 2018 and aims to expand the facility's capacity to 600,000 tonnes (770 million litres); the company also expected its Sicily plant to come online in 2019.[144] Total S.A. (France) received an operating licence for its La Mède biorefinery in the south of France, a conversion project that cost an estimated EUR 275 million (USD 315 million) and that was scheduled to begin producing renewable diesel in 2019.[145]

There is increased emphasis on using non-food feedstocks to produce HVO fuels.[146] For example, Neste now produces its HVO from 80% waste vegetable oils and residual materials rather than from virgin feedstock.[147] In 2018, UPM (Finland) undertook an environmental impact assessment for a proposed second biorefinery, Kotka Biorefinery, that would produce some 500,000 tonnes (640 million litres) of advanced biofuels for transport using a different raw material base and technology than the tall oil used in the company's Lappeenranta Biorefinery.[148] The renewable and sustainable feedstocks being considered include oil from *Brassica carinata*, a crop that UPM has been evaluating in large-scale trials in Uruguay and that can be grown between harvests, thus complementing rather than competing with food production.[149]

The emerging cellulosic ethanol industry also saw progress in 2018, with some of the technical and commercial difficulties of recent years being overcome and large-scale production increasing. However, only a small number of facilities was operating successfully worldwide. In the United States, POET and DSM's Liberty plant in Emmetsburg, Iowa, which produces ethanol from corn residues, was reported to be operating reliably after the key issue of feedstock pre-treatment was resolved.[150]

DuPont's commercial-scale plant in Iowa, which was shut down temporarily in 2017 after the company's merger with Dow, was bought by Verbio (Germany), and production was expected to restart in 2020.[151]

Elsewhere, the Chemtex cellulosic ethanol plant in Crescentino, Italy, which was closed following the failure of the parent company Gruppo Mossi Ghisolfi (Italy) in 2017, was purchased at auction by Versalis (part of Italy's Eni).[152] In Brazil, production was due to resume in early 2019 at GranBio's 82 million litre per year Bioflex 1 cellulosic ethanol plant.[153] And in India, construction

i Biomass pyrolysis involves the thermal decomposition of materials at elevated temperatures in an inert atmosphere, producing a mixture of gases, liquids (pyrolysis oil) and solid biochar.

ii Tall oil is a mixture of compounds found in pine trees and is obtained as a by-product of the pulp and paper industry.

iii In some markets HVO/HEFA fuels used as fossil diesel replacements are called renewable diesel.

started in 2018 on the first of 12 scheduled cellulosic ethanol plants: Bharat Petroleum Corporation Ltd's USD 135 million facility is expected to produce 30 million litres of ethanol annually using 200,000 tonnes of rice straw as feedstock.[154]

The production of cellulosic ethanol from corn residues, such as kernel fibre, at corn-based ethanol facilities expanded in 2018. The sharing of the plants and facilities can allow for lower-cost production. D3MAX LLC and Ace Bioethanol LLC (both United States) announced the construction of a dual cellulosic and corn-based ethanol plant at their facility in Stanley, Wisconsin in 2018.[155]

Commercialisation of thermal advanced biofuel processes such as pyrolysis and gasification also developed further during the year. Enerkem (Canada) continued work on a number of potential projects based on its waste gasification technology, including projects in China, in the US state of Minnesota and in the Dutch city of Amsterdam (along with Air Liquide of France, AkzoNobel of the Netherlands and the Port Authority).[156] IR1 Group (United States) began construction on the Red Rock Biofuels LLC biorefinery in Lakeview, Oregon, which plans to convert some 136,000 dry tons (123,000 metric tonnes) of wood waste biomass into more than 15 million gallons (57 million litres) of renewable jet diesel and gasoline blend-stock fuels using Fischer-Tropsch[i] technology.[157]

Developments continued in the use of biofuels in aviation, although these fuels replaced only a small fraction of aviation fuel in 2018.[158] By year's end, more than 150,000 flights had used biofuels, five airports had biofuel distribution systems in place, and airlines worldwide had committed to purchasing a total of 6 billion litres[ii] of biofuel in the future through long-term offtake agreements.[159]

Among the milestones in 2018, United Airlines operated the longest non-stop transatlantic biofuel journey to date when a biojet blend of 30% carinata oilseed and 70% conventional jet fuel powered a Boeing 787 flight from San Francisco to Zurich.[160] Gulfstream Aerospace announced that its G280 jet flew a record distance of more than 4,000 kilometres on biofuels, travelling from Savannah, Georgia, to Van Nuys, California.[161] And the Indian Air Force (IAF) flew a military aircraft with blended biofuel for the first time when an AN-32 transport plane was flight-tested with a 10% biojet fuel using jatropha oil; if additional flight trials succeed, the IAF expects to begin using the biofuel in its fighter jets.[162]

In partnership with the Japanese airline ANA, the company Euglena (Japan) started mass production of biojet and biodiesel from algae and waste cooking oil at its Yokohama plant, based on an investment of JPY 6 billion (USD 54 million); this is the first such production in Japan, with the capacity to produce 0.13 million litres per year of the fuels.[163] The Swedish airline SAS aims to replace all of its jet fuel used on domestic flights with biofuel by 2030, and in 2018 it signed an agreement with Sweden's largest oil company, Preem, to supply the airline with renewable aviation fuels from forestry residues and other waste materials.[164] In the United States, the Port of Seattle announced that 13 airlines – including Alaska Airlines, Delta Air Lines, Horizon Airlines and Spirit Airlines – will collaborate on a plan to provide all airlines operating at Seattle-Tacoma International Airport with access to biojet fuel.[165]

Gaseous Biomass Industry

Until recently, the focus in the gaseous biomass sector was on producing biogas for use in electricity generation, often in CHP plants. Industry growth was supported by favourable FITs and other support mechanisms. Such technologies are now well developed and widely deployed, and policy makers are focusing on the production and refining of biogas to produce biomethane fuel, which can be injected into gas pipelines and used as a heating or transport fuel.

The use of biogas to generate electricity and heat is an increasingly common practice, and in 2018 more than 10,000 digesters in Europe and 2,200 sites in all 50 US states were producing biogas.[166]

Although the technology has been deployed mainly in Europe and North America, it is now expanding to more countries. In 2018, the wastewater treatment company Fluence (United States) was awarded a EUR 1.7 million (USD 1.9 million) contract to develop a waste-to-energy digestion project for Arrebeef Energia, a prominent beef producer in Argentina.[167] The system will produce biogas for conversion to electricity and heat, which ArreBeef will use in its own operations to help lower costs, and surplus electricity also will be fed into the electricity grid in Buenos Aires.[168]

In Asia, construction was under way on a new waste-to-biogas production facility in Yabu City, Japan that was expected to start operation in 2019 and will convert farm and food waste into renewable energy; the biogas is to be converted into some 1.4 megawatt-hours (MWh) of electricity per year, and the waste heat will be used by a nearby greenhouse.[169] In the Philippines, Metro Pacific Investments has pledged PHP 1 billion (USD 19 million) to work with Surallah Biogas Ventures to design, build and operate a facility for Dole Philippines in Mindanao that will produce the energy equivalent of some 50,000 MWh annually of biogas.[170] In the Middle East, four biogas plants to be built in Oman at a cost of OMR 50 million (USD 130 million) are expected to produce electricity from more than 500,000 tonnes of food waste annually, helping to reduce the country's estimated OMR 56 million (USD 146 million) in waste disposal costs.[171]

Biogas can be upgraded to biomethane by removing the carbon dioxide and impurities, facilitating its injection into natural gas pipelines. Policy makers increasingly view this as an important route to decarbonising the heat and transport sectors.[172] Systems for producing and converting biogas to biomethane are now being widely deployed, with the refined biomethane either being injected into natural gas pipelines for use for heating or being used directly for transport.

In Europe, more than 500 biomethane installations were in operation by the end of 2018.[173] Ørsted and Bigadan (both Denmark) completed construction of a biogas plant in the city of Kalundborg that will use 300,000 tonnes of waste annually from the nearby pharmaceutical companies to produce 8 million cubic metres of biogas that will be upgraded to biomethane.[174] In the Belgian municipality of Beerse, a gas upgrading system was being added to an existing digester facility that uses garden

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

ii Equivalent to about 1.8% of annual aviation fuel use.

In Europe, more than **500 biomethane installations** were in operation by the end of 2018.

and vegetable waste from local households as feedstock; the aim is to upgrade 25% of the gas that is produced and to use the rest in a CHP plant.[175]

The United States was home to numerous biomethane facilities in 2018, and deployment has been stimulated by the inclusion of biomethane in the RFS. Anaergia (Canada) was building an organic waste-to-energy facility in the city of Rialto, California that aims to process 700 tonnes of food and 300 tonnes of biosolids daily to produce biomethane (renewable natural gas[i], or RNG) and electricity.[176] In Hawaii, the state's gas utility commenced operations at a biomethane facility at the Honouliuli Wastewater Treatment Plant in Honolulu that converts biogas derived from sewage waste into pipeline-quality RNG.[177]

In China, where biomethane plants have been developed rapidly in recent years, some 140 plants were in operation countrywide by the end of 2018.[178] The German company EnviTec began work on its fifth biogas project in China, a facility in Shanxi where the biogas will be converted to biomethane, compressed and sold locally from the plant premises.[179] Elsewhere in Asia, 200 buses in Karachi, Pakistan, will be powered by biomethane produced from 3,200 tonnes of cow manure.[180] And India's Sustainable Alternative Towards Affordable Transport initiative is expected to support the opening of 5,000 biomethane plants by 2023, which would use agricultural waste, municipal solid waste and cattle manure as feedstock to produce 15 million tonnes of biomethane annually, helping to displace half of India's imports of natural gas.[181]

Biomethane also is being used as a fuel for marine transport. Skangas (Norway) has supplied biomethane from its biogas facility in Lidköping for use in a tanker ship.[182] During 2018, the shipping company was building five more vessels that can be fuelled by biomethane (when the fuel is available) as well as by liquefied natural gas.[183] Norway-based cruise operator Hurtigruten announced in 2018 that it plans to invest EUR 742 million (USD 849 million) to power its ships with biomethane starting in 2021.[184]

GEOTHERMAL POWER AND HEAT

GEOTHERMAL MARKETS

Geothermal energy is harnessed for the generation of electricity and for various thermal applications, including space heating and industrial heat input. Total geothermal energy output in 2018 was estimated at 630 PJ[ii], with around half of this in the form of electricity (89.3 TWh).[1] Estimates of thermal energy consumption (also known as "direct use") are more uncertain than those for electricity, due to data collection challenges. Some geothermal plants produce both electricity and heat for various thermal applications.

An estimated 0.5 GW of new *geothermal power* generating capacity came online in 2018, bringing the global total to around 13.3 GW.[2] Turkey and Indonesia remained the leaders for new installations and accounted for about two-thirds of the new capacity installed.[3] Other countries that added capacity in 2018 (ordered by scale) were the United States, Iceland, New Zealand, Croatia, the Philippines and Kenya.[4] (→ *See Figure 21.*)

At year's end, the countries with the largest amounts of geothermal power generating capacity were the United States, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Italy, Iceland, Kenya and Japan.[5] (→ *See Figure 22* and ***Reference Table R15***.)

Turkey completed several geothermal power projects in 2018, raising its installed capacity by 21% (219 MW), to 1.3 GW.[6] Turkey ranks fourth globally for cumulative geothermal power capacity, having built up more than 1 GW of capability in only six years, between 2013 and 2018.[7]

The largest single unit completed in 2018 was the 65.5 MW Unit 2 at the Kizildere III plant, which became Turkey's largest geothermal power plant (165 MW) as a result.[8] Other projects completed during the year include the 19.4 MW Baklaci, the 13.8 MW Buharkent, the 25 MW 3S Kale, and the 32 MW Pamukören Unit 4.[9] A final addition, the 30 MW Alsehir Unit 3, joined Turkey's fleet in November.[10]

The majority of Turkey's geothermal power plants use binary-cycle[iii] technology, as do all of the country's plants under construction.[11] Conversely, most existing geothermal plants around the world use flash- or dry-steam technologies, which are suitable for high-temperature resources. Globally, binary-cycle technology has been the fastest-growing technology in recent years, due in part to rising use of relatively low-temperature resources.[12]

Indonesia continued to expand its geothermal capacity with 140 MW of additions – surpassing the Philippines by a small margin to rank second globally for installed capacity – and ended 2018 with 1.95 GW in operation.[13] In North Sumatra, the third and final 110 MW unit of the Sarulla plant was commissioned in 2018, following completion of the first two units in 2017.[14] The Sarulla

i In some markets, notably in North America, biomethane is called renewable natural gas.

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

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

plant is the country's first geothermal combined-cycle[i] unit, combining technologies from two manufacturers[ii] to utilise both steam and extracted brine from the geothermal field to increase the plant's efficiency.[15] Indonesia also started operation of its 30 MW Karaha Unit 1 in April 2018.[16]

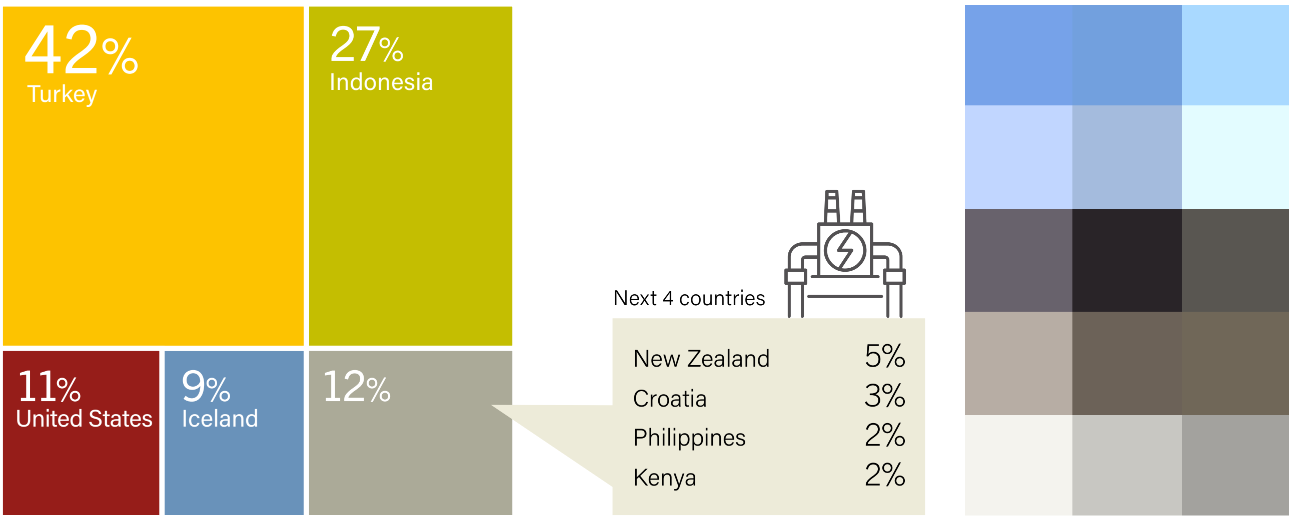
In the latter half of the year, the Indonesian government noted that it was not reaching its targets for accelerated geothermal investment, due largely to drilling delays by developers (→ *see Geothermal Industry section*).[17] Although the country's geothermal power potential is estimated at 29 GW, less than 7% of that has been developed due to high resource risk and high drilling costs.[18] Geothermal power supplies around 5% of the country's electricity.[19]

Many of the challenges facing Indonesia's geothermal industry are universal, namely economic risk stemming from long project

i A geothermal combined-cycle unit uses a binary system to extract residual energy from the steam exiting the high-pressure flash turbines, maximising energy extraction and overall plant efficiency.

ii These are Toshiba (Japan), which manufactures conventional steam turbines, and Ormat Technologies (United States), which manufactures binary-cycle turbines (for energy extraction from brine).

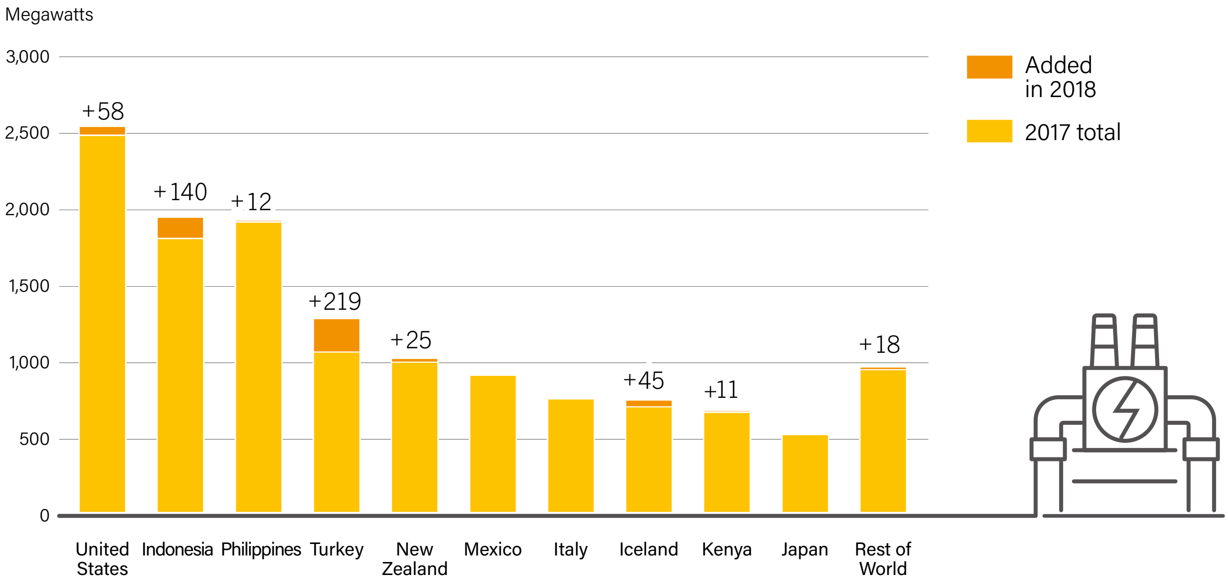
FIGURE 21. Geothermal Power Capacity Global Additions, Share by Country, 2018



Note: Total may not add up due to rounding.

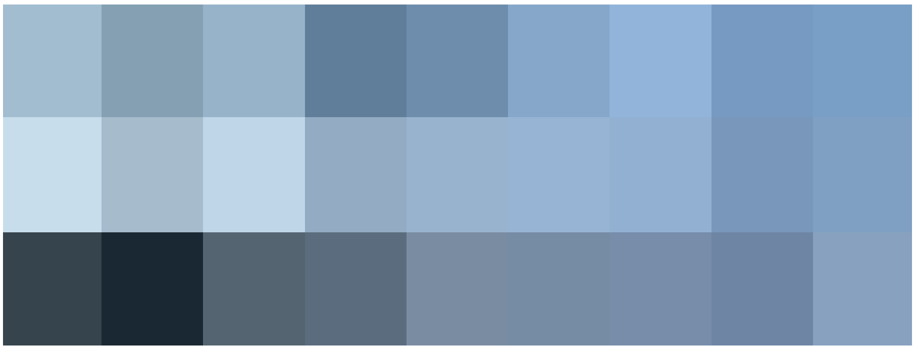
Source: See endnote 4 for this section.

FIGURE 22. Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2018



Source: See endnote 5 for this section.

Turkey and Indonesia accounted for around **two-thirds** of new geothermal power capacity in 2018.



lead-times, resource and exploration risk, and overall high development cost.[20] Due in part to such industry-specific barriers, some of the countries that pioneered geothermal energy use – such as Italy, New Zealand and the United States – have not seen significant growth in recent years. Nonetheless, both the United States and New Zealand completed new projects in 2018.

The United States remains the global leader for installed geothermal power capacity by a wide margin. In 2018, the country brought online at least 58 MW (net) in three facilities, for a total of 2.54 GW of net operating capacity[i].[21] One addition was the 48 MW third phase of the McGinnis Hills geothermal complex in Nevada, which is said to use two new-generation binary units – increasing plant efficiency and availability – where three units would have been required with earlier technology.[22] Also in Nevada, a Chinese technology developer repowered the Wabuska plant with 4.4 MW of capacity.[23]

In the US state of New Mexico, a 14 MW binary power plant was deployed to repower an existing 4 MW facility with improved and more-efficient binary technology.[24] Geothermal power capacity in the United States generated 16.7 TWh in 2018, a notable 5% increase over 2017, representing 0.4% of US net generation.[25]

New Zealand has seen only modest growth in its geothermal power capacity in recent years, due mostly to stagnant electricity demand and limited need for any new power generating capacity.[26] In 2018, the country commissioned the 25 MW Te Ahi O Maui binary-cycle plant. This relatively small power plant, like others of its kind, must move large quantities of geothermal fluid: three production wells and two reinjection wells retrieve and return up to 15,000 tonnes of fluid from the geothermal reservoir each day.[27] Originally considered a 22 MW project, it was subsequently uprated to 25 MW, which has reduced the project cost per megawatt to USD 5.45 million.[28] Geothermal power contributed 17% of New Zealand's electricity production in 2018.[29]

Iceland followed the United States for new capacity brought online during the year. The 90 MW Þeistareykir geothermal power plant was completed in 2018, with commissioning of the second of two 45 MW stages.[30] Iceland also saw initial electricity production from a set of low-temperature, binary-cycle power modules.[31] Historically, Iceland has been a major producer of geothermal energy (heat and power) from high-temperature sources; however, this project was designed to harness low-temperature resources of around 100 degrees Celsius (°C).[32] Iceland's 753 MW of operating geothermal power capacity (26% of total power capacity) – some of which also provides thermal co-generation for district water and space heating (see below) – accounted for around 31% of the country's electricity generation in 2018.[33]

Croatia completed its first geothermal power plant in 2018, ranking sixth worldwide for new capacity. The 17.5 MW Velika Ciglena plant generates electricity from a medium-enthalpy[ii] resource. The thermal reservoir was discovered in 1990 during an unsuccessful exploration for oil deposits.[34] Croatia plans further development of geothermal resources in an effort to boost the share of renewables in its energy mix.[35]

The geothermal sector of the Philippines has seen little development in recent years, but in 2018 the country completed its first new geothermal capacity since 2014, the 12 MW Maibarara-2 extension.[36] The Philippines ended the year with a total of 1.93 GW in operation.[37]

In 2018, Kenya had a modest upgrade to its geothermal facilities, with the last 11 MW stage of phased expansion of the Olkaria III complex, boosting the plant's capability to 150 MW.[38] The country's total installed capacity at year's end was 0.68 GW.[39]

Africa's geothermal activity is concentrated along the East Africa Rift System, extending from Djibouti on the Gulf of Aden south through Ethiopia, Kenya and Tanzania to Malawi, where the great lakes of Tanganyika and Lake Malawi outline some of the rift features that make the region rich in geothermal heat.[40] Several projects were under way in Kenya and Ethiopia during 2018.[41] However, development of geothermal resources in Eastern Africa, as in other geothermally rich regions, has been hampered by high cost and project risk. Other challenges include inadequate finance and grant support for exploration, inadequate trained human capacity, and a lack of clear and coherent policy and legislation across the region.[42]

i In general, a power plant's net capacity equals gross capacity less the plant's own power requirements. In the case of geothermal plants, net capacity also may reflect the effective power capability of the plant as determined by the current steam production of the field and running capacity, as opposed to the total nameplate capacity of its generator(s). The total gross nameplate generating capacity of US geothermal power plants was 3.77 GW at the end of 2018. See endnote 21 for this section.

ii 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.

Several islands in the Caribbean also hold significant untapped geothermal resources and have strong incentives to siphon the heat, but they lack the economic leverage to do so. Among them is the Commonwealth of Dominica, an island that is heavily reliant on diesel generators for electricity and that has one of the highest electricity rates in the world. Following a setback from Hurricane Maria in 2017, preparations for Dominica's 7 MW geothermal plant received renewed commitment of international support in 2018 and early 2019. The plant was backed by a EUR 2 million (USD 2.3 million) grant from the EU's Caribbean Investment Facility, a USD 27 million loan from the World Bank and other grants.[43]

On the nearby island of Nevis, exploratory drilling undertaken in 2018 revealed enough permeability and sufficient temperatures to suggest 10.5 MW of potential gross capacity.[44] This is enough to cover the island's current peak power demand of 9 MW.[45]

In Central America, Costa Rica was nearing completion of its 55 MW Las Pailas II plant by year's end and anticipated commissioning it in the first half of 2019.[46] The national utility expects that the plant will help decarbonise the country's energy sector and displace some of the imported power and thermal generation that has replaced hydropower during recent, unusually dry conditions.[47]

Direct extraction of geothermal energy for thermal applications – or *geothermal direct use*[i] – increased by an estimated[ii] 1.4 gigawatts-thermal (GW_{th}) of capacity in 2018, for an estimated global total of 26 GW_{th}.[48] These applications span a diverse set of uses. Space heating (including via district heating networks) is one of the largest and fastest growing applications, while swimming pools and public baths are about equal in scale but growing less rapidly.[49] Together, these applications represent an estimated 80% of both direct use capacity and consumption.[50] The remaining approximately 20% is for applications that include domestic hot water supply, greenhouse heating, industrial process heat, aquaculture, snow melting and agricultural drying.[51]

Europe is one of the most active markets for geothermal heat, although this market is highly localised and not very large in absolute terms. At the end of 2018, Germany had 37 relatively small (each at 40 megawatts-thermal, MW_{th}, or less) geothermal plants, totalling 336 MW_{th} of thermal capacity and 37 MW of power capacity.[52] These facilities use low-to-medium enthalpy resources (about 160°C or less), mostly for district heating, although seven of the plants use binary technology to produce electricity in addition to heat.[53]

New plants continue to come online in Germany. For example, in the Bavarian community of Holzkirchen, south of Munich, a 3.4 MW CHP plant started test operations in late 2018, supplying heat to the local district heating system, with power production expected to begin a few months later.[54] The plant uses binary-cycle technology to harness energy from two deep wells (5.1 kilometres of vertical depth) that supply geothermal brine at over 150°C.[55]

On the outskirts of Munich, the second of six planned boreholes was completed for what is expected to be Germany's largest geothermal plant at 50 MW_{th}, enough to provide heat for 80,000 city residents.[56] The borehole exceeded expectations, providing water at 108°C from a vertical depth of 3 kilometres.[57] This facility and five existing geothermal plants around the city are meant to help Munich achieve its goals of generating all district heating from renewable energy by 2040 and of becoming a carbon-neutral municipality by 2050.[58]

In France, geothermal district heating continued to expand in and around Paris, drawing on an expansive low-enthalpy aquifer. In 2018, the communities of Grigny and Viry Châtillon celebrated the inauguration of a joint geothermal network that serves 10,000 homes and public buildings.[59] In the Paris suburb of Cachan, two new boreholes replaced existing wells.[60]

In the Alsace region of France, geothermal drilling had great success in producing the hottest (200°C) well in continental Europe, outside of those in Tuscany.[61] Located in the Strasbourg metropolitan area, the French well is the continent's deepest (4.6 kilometres) and is expected to provide electricity and enough heat (via a district heating system) to supply 26,000 residents.[62] Further drilling was planned for 2019.[63]

To the east, Hungary saw expanded capacity in geothermal district heating with the completion of a new well for a district heating system that was established in 2017. The project's three wells serve nearly 24,000 dwellings in the city of Győr.[64]

In China, efforts are under way to replace coal-fired heating with renewable thermal energy – including geothermal energy – to achieve "smokeless cities".[65] Those efforts are being implemented by energy developers such as China Petrochemical Corporation (Sinopec, China), which launched its Green Action Plan to become a low-carbon enterprise by 2023.[66] While the emphasis is on increased use of natural gas and the build-up of pipeline infrastructure, the Plan also makes provisions for expanding the company's geothermal heating capacity to serve 2.1 million urban residents.[67] Engaged in a joint venture (formed in 2006) with Arctic Green Energy (AGE, Iceland) to advance geothermal development in China, the company announced in 2018 that it would replace energy derived from coal with geothermal energy in 20 cities nationwide by 2023.[68]

Europe
is one of the most active markets for geothermal heat.

i 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.*)

ii This estimate, based on extrapolation of 2014 and earlier data, is subject to high uncertainty.

GEOTHERMAL INDUSTRY

In 2018, the global geothermal industry continued to express measured optimism for geothermal development, tempered by ongoing concerns about various industry-specific challenges as well as by the perception of insufficient or wavering government support. International agencies and development banks explored opportunities to overcome some of these challenges and to fund new development.

Global investment in the geothermal sector in 2018 amounted to an estimated USD 2.2 billion.[69] This represents a very small portion (less than 1%) of all renewable energy investment for the year, excluding large hydropower projects.[70]

The Geothermal Development Facility for Latin America (GDF), founded in 2016 as the first multi-donor initiative to promote geothermal energy in the region, announced a second round of funding in October 2018. The EUR 13 million (USD 14.9 million) in grants will support surface studies and exploratory drilling in several countries.[71] The hope is that these grants, which are a part of GDF's original fund of EUR 55 million (USD 63 million), will seed new viable projects and catalyse additional investment in several hundred megawatts of capacity.[72]

In Mexico, the Inter-American Development Bank (IDB) approved a modification of a loan of nearly USD 109 million to stimulate private investment in geothermal development.[73] The loan is targeted at reducing investment risk at each stage of development, including exploration, drilling, field preparation, construction and operation. Over a 10-year period, the IDB's goal in Mexico is to finance up to 300 MW of geothermal power capacity and to leverage other public and private funds for a total of USD 4.2 billion invested in the development of proven geothermal reserves.[74]

Also during 2018, the World Bank, in co-ordination with several other development partners, initiated plans for the Indonesia Geothermal Resource Risk Mitigation (GREM) Project, designed to scale up investment in geothermal energy development in Indonesia.[75] The World Bank plans to provide USD 650 million in financing for risk mitigation of exploratory drilling in the country, and another USD 10 million for technical assistance.[76] The Bank expects that the project will leverage around USD 4 billion of commercial project finance by 2026, and that it will add around 1 GW of capacity by 2030.[77]

In November 2018, the Green Climate Fund[i] approved USD 100 million in financing (92.5% as grants) for the first USD 410 million tranche of the GREM Project; this is to be supplemented with World Bank loans of USD 225 million, with the remainder coming from private parties and the Indonesian government.[78] A key feature of GREM is that it is designed such that up to 50% of any loan will be forgiven if a project fails to find sufficient steam – a condition that reduces development risk considerably.[79]

The Asian Development Bank (ADB) set its sights on supporting geothermal energy development in China. The ADB signed USD 250 million in loans to Iceland's AGE and to Sinopec Green Energy (a joint venture of AGE and Sinopec) to support the development of geothermal district heating. Sinopec said that it hoped to replicate the collaboration across Asia.[80]

In addition to direct financial assistance, the availability of better and more complete information about geothermal resources helps to attract new investment and to generate new successful projects that otherwise might not occur. To that end, several international organisations and the World Bank joined forces to apply the UNFC[ii] Geothermal Specifications to generate a more holistic view of geothermal potential within a country.[81] The first effort of this collaboration was to share with the Indonesian government and investors how the UNFC system can help classify geothermal fields on the island of Flores, underscoring the need to differentiate between the technical feasibility and the economic viability of a project.[82]

Identifying region- or country-specific obstacles to geothermal development was the topic of two studies published in 2018. While regional in scope, both studies identified common themes. For one study, on the opportunities and challenges for expanded geothermal development in Latin America and the Caribbean, the key themes were:

- unmitigated geothermal resource risk in early project development;
- unfavourable policy and regulatory frameworks and insufficient market incentives;
- lack of institutional capacity in government and local technical capacity;
- lack of financing and access to risk-mitigating grants, cost sharing and insurance; and
- insufficient environmental and social safeguards and associated investment risk.[83]

The second study, focused on development barriers in Asian markets, touched on the same themes but identified some variability among countries. Technical barriers were found to be disproportionately large in the Republic of Korea, whereas in the Philippines fiscal challenges were most prominent. Meanwhile, Japan faces significant environmental and social barriers to expanded use of geothermal energy, including concerns about potentially adverse impacts on traditional geothermal baths.[84]

Tangible evidence of such industry-wide barriers was evident in Indonesia in 2018. As noted earlier, the country is not meeting its geothermal development targets, and the energy company Pertamina, which completed its 30 MW Karaha Unit 1 during the year, was circumspect about future developments.[85] At a total cost nearing USD 200 million (USD 6.7 million per MW),

i The Green Climate Fund is a global fund created to support the efforts of developing countries to respond to the challenges of climate change. In this regard, the Fund pays particular attention to the needs of highly vulnerable societies, including small island developing states. See endnote 78 for this section.

ii United Nations Framework Classification for Resources.

the project underscores the company's concern that geothermal development is expensive compared to competing technologies and carries both high development risk and high upfront costs.[86] While Pertamina has several projects in the pipeline, the company announced in late 2018 that it had greatly curtailed its planned near-term capacity additions, aiming for a total installed capacity of 1.1 GW by 2026 (up from the current 0.6 GW) instead of the previous target of 2.2 GW.[87]

In Europe, the geothermal industry was dismayed by a draft decree of the Italian government that would cut the country's public support for geothermal energy. The industry was concerned that such a move would undermine Italy's historic role in the development of the sector globally and would increase uncertainty and erode investor confidence. In addition, it was argued that the decree would be in violation of Italy's commitment to the EU's Renewable Energy Directive, in that it would amount to retroactive changes to Italy's renewable energy support.[88]

Work also continued on the research front during 2018. For example, the European Commission awarded the Geothermal Emission Control (GECO) project, a consortium of 17 partners across Europe, EUR 16 million (USD 18.3 million) to advance research into eliminating carbon dioxide (CO_2) and hydrogen sulphide emissions from open-loop[i] geothermal plants. One focus of the GECO project is the reinjection of these gases for subsequent mineralisation in underground rock deposits.[89]

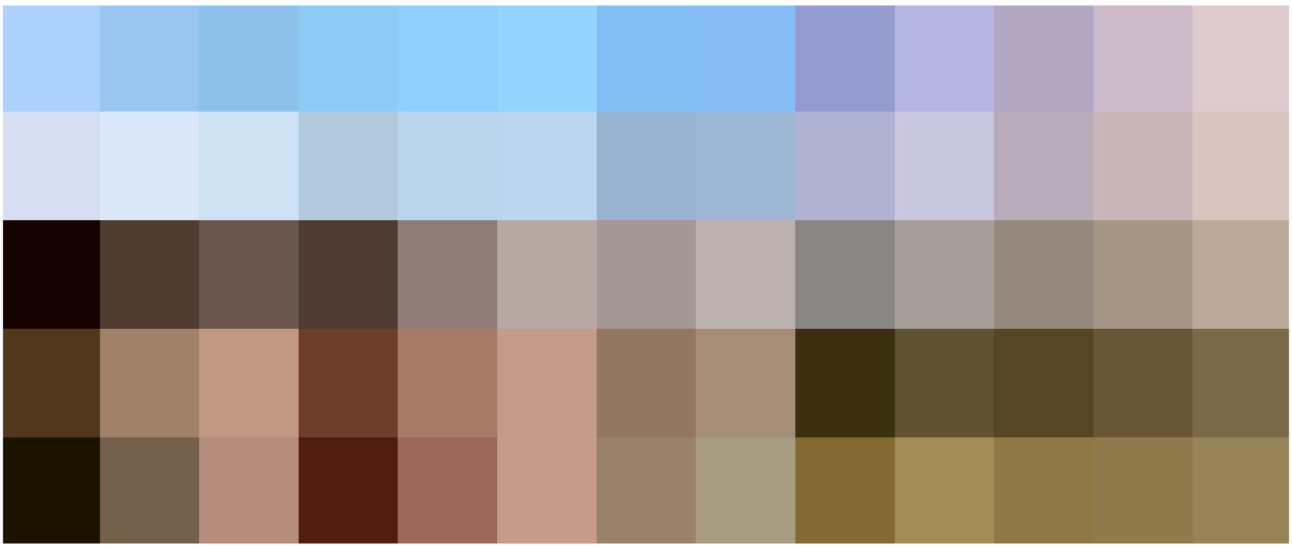
In addition, some notable ideas in geothermal energy utilisation emerged during the year. Algaennovation (Israel) signed a contract with an Icelandic utility, ON Power, to co-locate micro-algae production for aquaculture at the Hellisheidi geothermal power plant in southwest Iceland.[90] If successful, this effort to produce low-cost omega-3 supplements for humans would be a positive step towards further and more complete use of the geothermal resource, including its CO_2 stream.[91] The Hellisheidi plant also incorporated a hydrogen electrolyser in 2018, with a plan to serve a small but growing fleet of hydrogen fuel cell passenger vehicles and buses in Iceland with fuel generated through electrolysis using geothermal power.[92]

As noted earlier, binary-cycle geothermal power and heat technology is dominant in some markets, due in part to its suitability for relatively low-temperature resources. Among the key providers of this technology are Ormat Technologies (United States), Exergy (Italy) and Turboden (Italy, a subsidiary of Mitsubishi Heavy Industries of Japan). In Turkey, binary-cycle technology from Ormat and Exergy represented more than half of all installed capacity, and all capacity under construction as of 2018.[93]

Ormat manufactures turbines and other components in Turkey under a local subsidiary to qualify for local incentives, and installed its technology at 28 power plants in the country (totalling 523 MW) in the decade ending in 2018.[94]

In addition to Turkish installations, completed binary-cycle plants in 2018 include the Olkaria extension in Kenya (Ormat), the Velika Ciglena plant in Croatia (Turboden), the three new units noted in the United States (Ormat, Turboden and subsidiary of Chinese corporation Zhejiang Kaisan), the low-temperature project in Iceland (Climeon, of Sweden) and New Zealand's Te Ahi O Maui plant (Ormat).[95]

The availability of **better information** about geothermal resources helps to attract **new investment** and to generate new projects.



i Stand-alone closed-loop binary-cycle power plants can avoid significant venting of CO_2 and other pollutants from the geothermal fluid. Conventional open-loop power plants vent gases to the atmosphere.

HYDROPOWER

HYDROPOWER MARKETS

The global hydropower market in 2018 looked very similar to the preceding year in terms of capacity growth and concentration of activity, adding an estimated 20 GW to reach a total installed capacity of around 1,132 GW.[i,1] Given the large amount of hydropower capacity in place globally, the overall ranking of countries did not shift during the year. The top 10 countries for total capacity 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 23 and **Reference Table R16**.*)

Worldwide generation from hydropower, which varies each year with shifts in weather patterns and other local conditions[ii], was an estimated 4,210 TWh in 2018.[3] Global pumped storage capacity (which is counted separately) increased about 1% during the year.[4]

As in many preceding years, China led in commissioning new hydropower capacity, representing more than 35% of new installations in 2018.[5] Brazil came second, as in 2017, followed by Pakistan and Turkey, all adding more than 1 GW of capacity.[6] Other countries that added significant capacity included (in order of additions) Angola, Tajikistan, Ecuador, India, Norway and Canada.[7] (→ *See Figure 24.*) China also was home to most of the new pumped storage capability in 2018, with smaller additions completed in Austria and the United States.[8]

China added 7.0 GW of hydropower capacity in 2018 (excluding pumped storage) – similar to its additions in 2017 – for a year-end total of 322.3 GW.[9] Hydropower generation increased 3% to 1,234 TWh in 2018.[10] China's total completed hydropower projects during the year represented investment of CNY 67.4 billion (USD 9.8 billion), an increase of 8.4% over 2017.[11] While the country's growth in hydropower capacity (24%) was not in proportion to overall growth in electricity demand (28.6%) during the five-year period of 2013-2018, plant utilisation improved enough to raise hydropower's share of China's electricity generation from 16.9% to 17.4% during the period.[12]

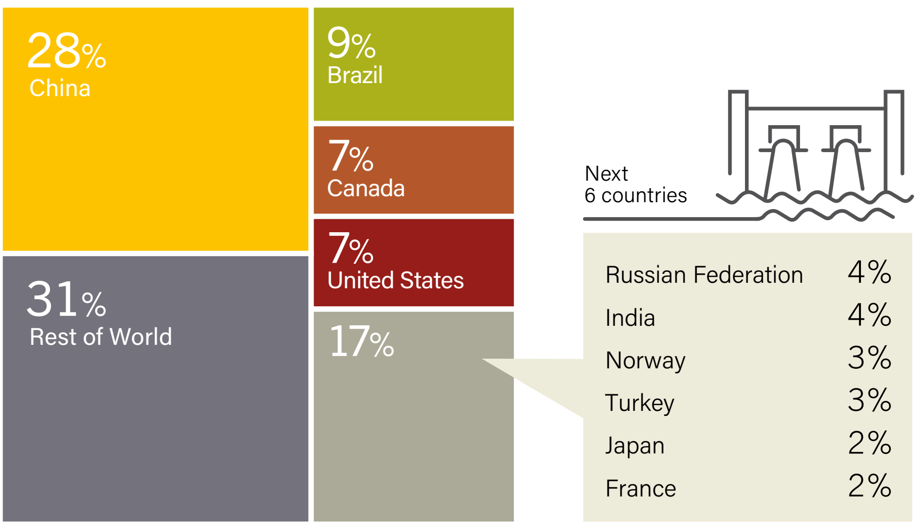
Pakistan reached a milestone in 2018 with the commissioning of three long-delayed projects. With a combined output of nearly 2.5 GW, these projects increased the country's total hydropower capacity by approximately a third, to nearly 9.8 GW.[13] The completed projects were the 108 MW Golen Gol plant, the 969 MW Neelum Jhelum plant and the 1,410 MW 4th Extension to the Tarbela Station, which now commands nearly 4.9 GW of capacity.[14] Progress also was made towards initiating construction of the decades-delayed 800 MW Mohmand Dam project, which, when completed, is expected to help with flood control, irrigation of existing and new farmland, and provision of drinking water to the city of Peshawar.[15]

Hydropower capacity in Turkey expanded by just over 1 GW in 2018, for a year-end total of 28.3 GW – or 32% of the country's overall generating capacity.[16] Following a drought in 2017, hydropower generation rebounded 5.5% to 60.9 TWh, providing more than 20% of Turkey's electricity supply for the year.[17]

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 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.

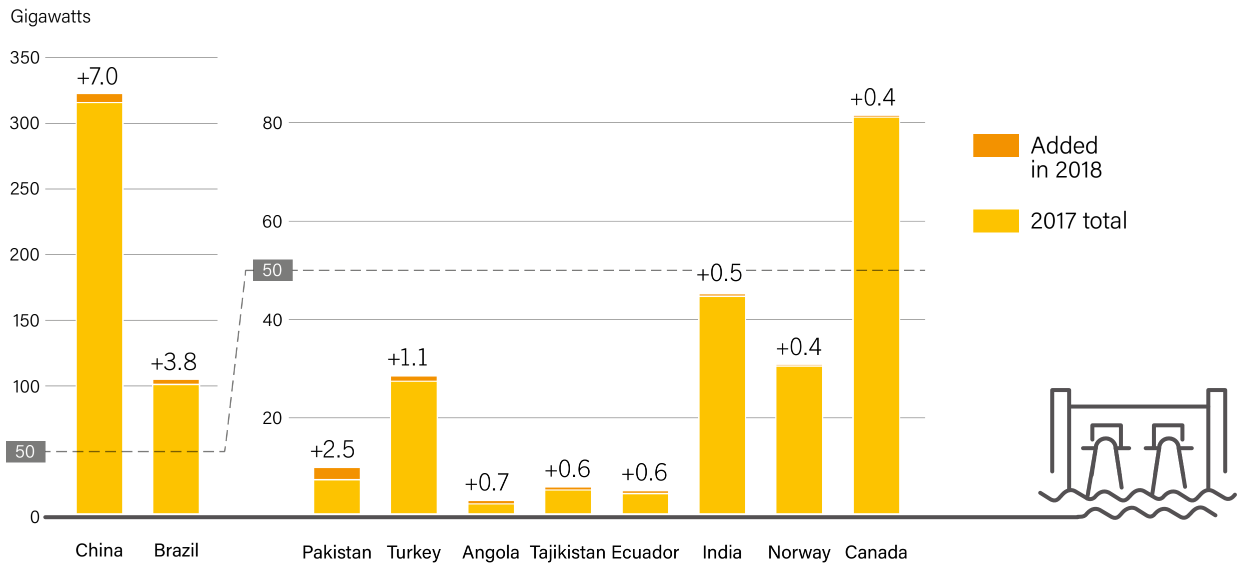
FIGURE 23. Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2018



Note: Total may not add up due to rounding.

Source: See endnote 2 for this section.

FIGURE 24. Hydropower Capacity and Additions, Top 10 Countries for Capacity Added, 2018



Source: See endnote 7 for this section.

India increased its hydropower capacity by 0.5 GW in 2018, for a year-end total of 45.1 GW.[18] The single-largest project to come into service in India was the Kishanganga plant, comprising three 110 MW units, in the northern state of Jammu and Kashmir.[19] The project drew on the local manufacturing and construction capacity of Bharat Heavy Electricals Ltd., as did the fourth and final 30 MW unit added at the Pulichintala plant in Telangana.[20] The 110 MW Pare hydropower plant in Arunachal Pradesh also was completed during the year.[21] India's remaining hydropower installations comprised relatively small facilities, totalling about 100 MW.[22] By year's end, India had a pipeline of 37 additional hydropower projects representing 12 GW of capacity, although 16 of those (6 GW) were stalled for various reasons, such as lack of funds as well as environmental concerns.[23]

Although annual additions in India continue to be significant in absolute terms, hydropower has ceded ground relative to solar PV and wind power capacity. Hydropower's share of the country's total installed capacity dropped by half between 2008 and 2018, to 13%, while the share of other renewables[i] doubled, to 21%.[24] As a result, hydropower's share of total generation in India declined from more than 16% in 2008 to about 10% in 2018.[25] Electricity generation from hydropower in India increased 2.7% during 2018 to nearly 140 TWh.[26]

In Central Asia, several notable hydropower developments occurred in 2018, including new construction as well as plant upgrades. In late 2018, Tajikistan started up the first of six 600 MW turbines at the Rogun facility, which resumed construction in 2016 after a hiatus extending back to the 1970s; a second unit was anticipated online in 2019.[27] The Rogun project is not expected to be fully completed until 2032, and if the dam rises to the planned 335 metres, it will be one of the world's tallest.[28] An earlier assessment by the World Bank highlighted the potential macroeconomic risks associated with such a costly project, as well as concerns about the required population resettlements and the potential impacts on downstream water flows.[29] Tajikistan also launched a project (with World Bank funding) to refurbish and modernise the 3 GW Nurek plant, which could boost the country's hydropower capacity 12%; the plant provides more than 70% of electricity demand nationwide and is the largest hydropower facility in Central Asia.[30]

> As in 2017, China and Brazil accounted for **more than half** of all new hydropower capacity installations.

To the north, the Kyrgyz Republic advanced ongoing upgrades of its four-decade-old Toktogul plant, awarding contracts for the facility's four generating units. The modernisation plan, with the support of regional development banks, will raise the plant's output from 1.2 GW to 1.44 GW while also improving plant safety, efficiency and reliability.[31] Also in the region, Kazakhstan completed modernisation of the first unit of the Shardarinsk plant, which has been in service for more than 50 years. When the work is complete, the plant is expected to experience a 26%

i Due to differences in average capacity factors among the different renewable energy technologies, these relative shifts in capacity shares do not accurately reflect changes in the share of generation.

gain in power (to 126 MW) and to be available for another 35-40 years of service, offering greater reliability and safety.[32]

Hydropower development in both Tajikistan and the Kyrgyz Republic has long been opposed by neighbouring Uzbekistan, on the grounds that such development might harm the latter's agricultural interests. However, Uzbekistan has softened its opposition and, in 2017, expressed its aspiration to harness more of its own hydropower potential (12 GW total, of which only 1.8 GW was being utilised as of 2018).[33] As of year's end, Uzbekistan was engaged in efforts to modernise its outdated hydropower facilities, which provide only 11% of the electricity needs of the fast-growing economy.[34]

Afghanistan restarted operation at its largest hydropower plant, the 100 MW Naghlu, which had been inoperable since 2012. Afghanistan is dependent on electricity imports but is relatively rich in hydropower resources, so it has focused its attention on rehabilitating existing facilities and building new ones as a means to achieve rapid and cost-effective access to environmentally friendly energy.[35]

In the southern Caucasus, Azerbaijan completed major modernisation and rehabilitation on the 425 MW Mingachevir station.[36] With the bilateral support of Iran, the country announced significant progress on two new hydropower dams in early 2019.[37]

Halfway around the globe, Brazil ranked second in the world for hydropower capacity and generation, as well as for new installations in 2018. Approximately 3.8 GW was added, somewhat more than in 2017, for a year-end total of 104.1 GW.[38] In the state of Mato Grosso, the last of four 175 MW units was installed at the São Manoel plant on the Teles Pires River, and the 300 MW Colíder plant was undergoing operational testing of its first unit in late 2018.[39] Another five 611 MW turbines were added to the Belo Monte plant – which is slated to total 11.2 GW when completed – reaching nearly 7.6 GW at year's end.[40] Brazil's hydropower output increased 4.2% during 2018, to 418 TWh, providing nearly 72% of the electricity generation in the country.[41]

Ecuador completed 0.5 GW of hydropower capacity to rank seventh globally in 2018 for new capacity.[42] Among the projects completed was the 180 MW Delsitanisagua project, two years behind schedule.[43] The plant represents 10% of the country's generating capacity and is expected to directly benefit more than 500,000 inhabitants in the country's south.[44] The project was plagued by cost overruns and contractual disagreements with Hydrochina, which was in charge of the construction.[45]

Also in Latin America, Colombia's largest infrastructure project, the still-incomplete 2.4 GW Ituango hydropower plant, had a major setback starting in April 2018. Blockage of a diversion tunnel used during construction caused the reservoir to fill rapidly, setting off an uncontrolled spill. The subsequent rapid changes in river flows forced the evacuation of thousands of people in communities downstream and caused the loss of infrastructure and homes. The dam was nearing completion at the time, but these events have caused a long delay for the project.[46]

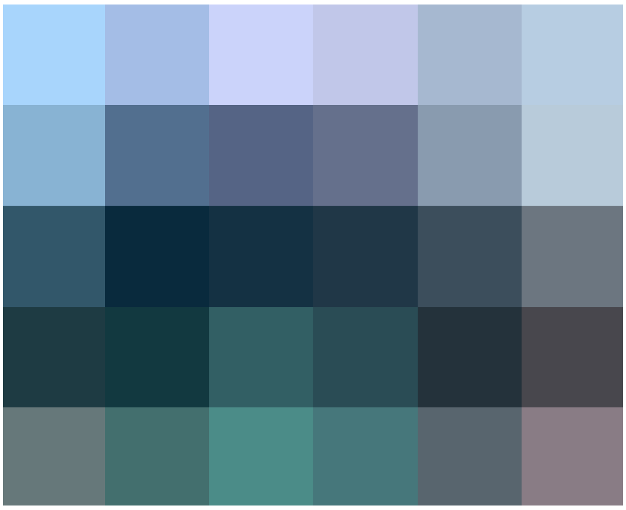
Relatively mature markets in North America and Europe are seeing a rising need for **plant modernisation.**

The United States ranked fourth in hydropower capacity in 2018, with 80 GW[i] in place at year's end.[47] The US market is relatively mature and has seen only modest growth in recent years, adding 0.9 GW (1.1%) during the period 2013-2018.[48] The country added four new hydropower plants in 2018 (three of them at or below 6 MW of capacity), retired a few small units and ended the year with net growth of 0.1 GW.[49] Proposed new hydropower projects in the United States with active permits amounted to less than 240 MW of capacity, and most were relatively small projects.[50] A study found that small-scale projects (less than 10 MW) are the most cost-efficient type of new hydropower development in the country because they typically use existing infrastructure.[51] Hydropower generation in the United States totalled 292 TWh, down marginally (2.9%) relative to 2017.[52]

The US west coast accounts for around half of the country's annual generation and was responsible for most of the decline in output in 2018. After a record snowpack improved hydropower output in the state of California in 2017, drier conditions the following year caused a 39% drop in generation.[53] Dam safety received heightened attention in the country following the spillway failure at California's Oroville Dam in 2017. In late 2018, the Federal Energy Regulatory Commission issued a report on the event and began reviewing the recommendations of its dam safety programme with an eye towards avoiding future incidents.[54]

Some Canadian provinces and their US counterparts have expressed interest in recent years in building new transboundary transmission lines, primarily to enable Canadian hydropower to serve US demand. In late 2018, Canada's National Energy Board approved the proposed Manitoba-Minnesota Transmission Project, involving a 500 kilovolt line connecting the networks of Manitoba Hydro (96% hydropower, with another 695 MW under construction) to Minnesota Power's Great Northern line, already under construction.[55] The Canada-US agreement envisions imports of 250 MW to Minnesota, but the interconnection is expected to have capacity for 885 MW.[56] A second project – the proposed 1,090 MW Northern Pass line between the Hydro Quebec territory and the US state of Massachusetts – was denied a permit in early 2018 by the New Hampshire siting authority, and the focus shifted to an alternate 1.2 GW line through the state of Maine.[57]

i This excludes nearly 23 GW of US pumped storage capacity.



All hydropower markets on the European continent have reached relative maturity, with few new large projects but a growing focus on modernisation as well as on pumped storage projects. Within the region, Norway ranks second only to the Russian Federation for installed capacity.[58] Norway added 0.4 GW of capacity, with nearly half of that being upgrades and expansions of existing facilities.[59] While the country's hydropower generation was within a normal range for 2018 as a whole, it fluctuated widely during the year, with very dry conditions in the summer months followed by extremely high rainfall in later months.[60] Norway's Lysebotn II plant was upgraded in 2018 to achieve greater efficiency and operational flexibility and to raise the plant's peak capacity 76% to 370 MW, increasing its annual production 15%.[61] Once new submarine cables are in place, the plant is expected to join similar facilities across Norway in providing fast-response, flexible generation to Germany and the United Kingdom, functioning as virtual storage.[62]

Iceland also increased its generating capacity with the commissioning of the 100 MW Búrfellsstöð II plant. This new power station was built adjacent to a facility originally constructed in 1969 (upgraded over time to 270 MW) to utilise surplus flow and increase efficiency during peak load periods.[63]

The Russian Federation has one of the most extensive fleets of hydropower facilities in the world, ranking fifth for capacity. But as in some other mature markets, the relative scale of new construction was modest in 2018, while retrofits and modernisation of existing stock continued. No new plants came into operation during the year, but the country's stated hydropower capacity increased about 57 MW, for a total of 47.1 GW.[64] Over the five-year period 2013-2018, installed capacity rose 4% (1.8 GW).[65]

Hydropower generation in the Russian Federation has risen in proportion to available capacity, representing close to 17% of all electricity generation on average during the 2013-2018 period.[66]

Much-improved hydrological conditions increased hydropower production in 2018 relative to the previous year, especially in Siberia, where the country's largest hydropower plant, the Sayano-Shushenskaya, set new output records.[67] The achievement was facilitated in part by modernised grid automation systems and expanded transmission infrastructure.[68] Multiple modernisation projects were under way during the year, including the 3.8 GW Ust-Ilimsk and the 6 GW Krasnoyarsk facilities in Siberia.[69]

Capacity additions on the African continent totalled 1 GW in 2018.[70] Angola, which is seeking to expand electrification and renewable energy supply in the near term, continued its rapid deployment of new hydropower capacity, adding another 0.7 GW for a total of 3 GW at year's end, ranking it third on the continent for capacity after Ethiopia and South Africa.[71] Angola's additions included two 334 MW units at the Laúca facility, where two similar units were completed in 2017 and where the total capacity will reach 2.1 GW upon the project's expected completion in late 2019.[72] Other African countries adding capacity included the Democratic Republic of the Congo and Zimbabwe (more than 0.1 GW each), as well as Egypt, Malawi and Uganda (each adding 32 MW or less).[73]

Pumped storage capacity increased 1.9 GW in 2018, for a year-end total of 160 GW[i].[74] New capacity was installed in China, Austria and the United States.[75] China's capacity grew more than 40% during the period 2013-2018, and an estimated 1.5 GW was added in 2018 for a total of 30 GW.[76] At year's end, the country had around 36 GW of additional pumped storage under construction. China considers pumped storage to be an important tool for minimising curtailment of variable renewable power, for grid stability, and for advancing national economic and environmental objectives.[77]

The Obervermuntwerk II project in Austria added 360 MW of pumping capacity at an existing network of reservoirs.[78] The project was optimised to allow precise control across the entire operating range of the two 180 MW reversible turbines, specifically to enhance frequency control and to provide fast response to better accommodate the growing use of variable renewable power technologies.[79]

The United States increased its pumped storage capacity, by 45 MW, during one stage of an extensive refurbishment at the state of Michigan's Ludington plant, one of the oldest and largest facilities of its kind in the country.[80] When completed, the staged project will raise the capacity of the facility around 16% to nearly 2.2 GW.[81] Most of the prospective hydropower projects in the United States incorporate pumped storage as their primary function: of the 18 projects issued preliminary permits in 2018, 12 were pumped storage (and 4 of those were pure pumped storage), for a total of 5 GW of capacity.[82] As of early 2019, preliminary permits had been issued for 16.3 GW of proposed pumped storage projects in the country.[83]

i 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.

HYDROPOWER INDUSTRY

A notable feature of the hydropower industry in 2018 was the swelling ranks of ageing facilities that require repairs and upgrades. More than half of all hydropower facilities worldwide have either already undergone, or will soon require, upgrades and modernisation.[84] Another trend was growing recognition of the value that hydropower facilities can offer for the effective integration of variable sources of renewable energy, such as solar PV and wind power, and of the potential synergies between hydropower and other renewable energy technologies, depending on local conditions.[85]

These two themes are interconnected. On the one hand, refurbishment and modernisation of hydropower plants may take on greater urgency and different priorities in evolving energy systems where flexibility in operation is paramount. Modernisation schemes can be designed and optimised to reflect the needs of power systems with high shares of variable renewable generation, just as they need to be optimised for changing climate conditions.[86] Even without storage pumping capability, reservoir hydropower plants – especially those using modernised controls and communication systems – can modulate output and provide passive storage and system balancing functions to better integrate variable generation.[87]

On the other hand, the rapidly rising share of variable renewables in the energy mix of many regions requires greater attention to the availability of energy storage and flexible supply – including hydropower, with pumped storage currently being the primary means of electricity storage globally. (→ *See Systems Integration chapter.*) New energy storage and additional opportunities for effective balancing of load and supply are receiving greater recognition as critical components of sector integration, allowing variable renewables to serve not only more of the general electricity demand but also transport and thermal applications.[88]

The hydropower industry continued to work on advancing the sustainability of hydropower development in 2018. Building on previous work in this area, including the 2011 Hydropower Sustainability Assessment Protocol (HSAP), the International Hydropower Association (IHA) launched two new tools. The first was the Hydropower Sustainability ESG Gap Analysis Tool (HESG Tool), which was developed under the mandate of the Hydropower Sustainability Assessment Council and helps developers and operators assess and close any gaps that projects might face with regard to established best practice in the environmental, social and governance arenas.[89] A key driver behind the project was to provide a more agile and low-cost (yet non-compromising) alternative to a full HSAP assessment.[90]

The second development from the IHA was the launch of the Hydropower Sustainability Guidelines on Good International Industry Practice. The 26 guidelines present definitions of the processes and outcomes relating to good practice in the planning, implementation and operation of hydropower projects, and may be specified in contractual arrangements to help ensure good project outcomes.[91] Both of these tools are aligned with the World Bank's new Environmental and Social Framework and the International Finance Corporation's Environmental and Social Performance Standards.[92]

> The hydropower industry noted intensifying **global competition** in 2018.

Certification of bond issuances on the basis of sustainability criteria can help advance renewable energy deployment. However, green bond standards have largely excluded hydropower.[93] In 2018, the Climate Bonds Initiative (CBI) updated its Climate Bonds Taxonomy, which provides guidance to help decision makers identify assets and projects that are aligned with the requirements of a low-carbon economy, and provides screening criteria consistent with the 2-degree Celsius global warming target set by the Paris Agreement. While hydropower facilities cannot yet receive certification from CBI (the eligibility criteria had not yet been finalised as of the end of 2018), the new Taxonomy indicates that any type of hydropower project may be "2-degree compliant" provided that specific criteria are met, including compliance with best industry practices in assessing and addressing environmental and social risks.[94]

Leading providers of hydropower technology reported mixed results in 2018 and growing competition in the global hydropower market. For example, GE (United States) reported higher losses for its hydropower segment as revenues contracted 3% in 2018.[95] The company noted competitive pressure from other turbine manufacturers and the need for continued investment to further improve the efficiency and flexibility of its hydropower technology through the use of digital solutions.[96] Spurred in part by the need for grid flexibility to accommodate growth in renewable energy, GE said that the hydropower industry continues to maximise value with new small-scale and pumped storage projects to support the expansion of both wind and solar power capacity.[97]

Voith Hydro (Germany) also reported significant growth in the market for pumped storage technology in the context of the expansion of both wind power and solar PV, with strong demand driven by China.[98] Voith noted Brazil's improving market conditions and a North American market focused on modernisation projects – but a constrained European market, due to preferential subsidies for wind power and solar PV.[99] Overall, Voith conveyed deterioration of its hydropower division in a challenging environment characterised by much higher-intensity competition in the global market.[100] Sales were strongest in Asia and North America but declined 20% overall due to low orders in preceding years and delays in the construction of major projects; new orders declined 27%.[101]

Andritz Hydro (Austria) reported sales being down 4% for the year, due primarily to a decline in order intake in previous years.[102] However, the company welcomed a 10% increase in new orders in 2018.[103]

OCEAN POWER

OCEAN POWER MARKETS

Ocean power[i] represents the smallest portion of the renewable energy market, with most projects focused on relatively small-scale demonstration and pilot projects of less than 1 MW.[1] Each year, various tidal and wave power projects under development undergo removals and redeployments. Net additions in 2018 were approximately 2 MW, with an estimated 532 MW of operating capacity at year's end.[2] Two tidal barrage facilities[ii] represent more than 90% of this total.[3] Development activity is found around the world but is concentrated primarily in Europe, and particularly off the shores of Scotland, where arrays of tidal turbines were being deployed in 2018. The resource potential of ocean energy is enormous, but it remains largely untapped despite decades of development efforts.[4]

Tidal barrage facilities use relatively mature and well-established in-stream turbine technologies, the same technologies used in some types of hydropower projects. Perhaps the most promising new facility of that type under consideration, located in the United Kingdom, was refused government backing in 2018 due to its projected high cost of energy.[5]

The two technology categories receiving the most development effort are tidal stream and wave energy conversion. Although tidal stream and wave power technologies have some elements in common, they are seen as two distinct sectors and have progressed at different rates.[6] Tidal stream technologies are closer to technological maturity and have shown a significant convergence around the use of horizontal-axis turbines, most being either mounted on the sea floor or attached to a floating platform.[7] At this point, tidal power devices have evolved to a level where they exhibit considerable predictability in performance.[8]

Conversely, wave power technology has not converged as much around just a few core approaches. This is due in part to the complexity of extracting energy from waves and to the variety of wave conditions that exist.[9] Therefore, wave power is still at a technology development stage, with at least eight different types of wave devices being pursued.[10]

> The **enormous potential** of ocean energy remains largely untapped despite decades of development efforts.

Ocean thermal energy conversion and salinity gradient technologies also remain well short of commercial deployment, and only a few pilot projects have been launched.[11]

OCEAN POWER INDUSTRY

The year 2018 was one of stark contrasts for the ocean power industry. On the one hand, manufacturers of tidal turbine arrays, in particular, indicated technological success and progression towards commercialisation.[12] On the other hand, a negative outlook prompted one industry leader to stop operation somewhat abruptly.[13]

In July, Naval Energies (France), parent company of the Irish tidal turbine manufacturer OpenHydro, announced that it would cease manufacturing and development of tidal turbine technology (thus closing OpenHydro's doors) and reserve its resources for the development of floating offshore wind power and ocean thermal energy conversion (OTEC).[14] The announcement came only two days after the installation of one of OpenHydro's turbines in Canada, and a month after the inauguration of its tidal turbine manufacturing plant in Cherbourg (France), which was to produce 2 MW turbines at a rate of up to 25 units per year.[15] The Cherbourg plant was expected to be a turning point for the tidal power industry, launching the commercialisation of the technology.[16]

The alleged reasoning behind the decision was the French government foreseeing only 100-150 MW of tidal power capacity installed in French waters by 2028 (equivalent to 50 to 75 OpenHydro turbines) and the UK government's 2016 decision to not proceed with tidal power tenders.[17] Further, Naval Energies said tidal power now has to compete with fixed-bottom (non-floating) offshore wind power, which the company claims is not possible due to the technologies' different levels of maturity.[18] (→ *See Wind Power section in this chapter.*)

Therefore, despite ongoing technological progress and development activity, with some tidal power technologies appearing to be near market-ready, the ocean power sector continues to require steady public support. A 2018 European Commission study on ocean power found that the industry remains highly dependent on public funding to leverage private investment.[19] Furthermore, while injection of public monies lowers the risk to private investors in funding projects, continuing revenue support is considered paramount to create relative investment certainty based on predictable returns until the industry achieves greater maturity. More than EUR 6 billion (USD 6.9 billion) had been invested in projects worldwide as of 2018, of which 75% was from private finance.[20] The industry is still awaiting clear market signals that reflect its significant potential contribution to decarbonising energy systems – signals that are considered vital for the industry to progress towards commercialisation.[21]

Even as OpenHydro's plans came to an end, other tidal stream projects progressed in 2018. In Canada, following the failed Cape Sharp Tidal project in Nova Scotia's Bay of Fundy (a partnership of OpenHydro and its Canadian partner Emera), the Canadian government announced CAD 29.8 million (USD 21.9 million) in support for a new tidal project.[22] This CAD 117 million

i 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.

ii These are the 254 MW Sihwa plant in the Republic of Korea (completed in 2011) and the 240 MW La Rance tidal power station in France (built in 1966).

(USD 85.8 million) project would install five 1.5 MW seabed-mounted tidal turbines manufactured by Andritz Hydro in the Bay of Fundy, alongside a 2 MW floating twin-turbine module developed by Orbital Marine Power (formerly Scotrenewables Tidal Power, United Kingdom).[23]

Also in Nova Scotia, Sustainable Marine Energy (United Kingdom) installed its PLAT-I tidal power floating platform equipped with four 70 kilowatt (kW) Schottel Hydro (Germany) tidal turbines.[24] By early 2019, in the wake of a successful collaboration between the two companies in both Scotland and Canada, Schottel and Sustainable Marine Energy made the strategic decision to merge their tidal power operations.[25]

In the United Kingdom, manufacturers made progress on several fronts. Scotland's MeyGen tidal stream array is the world's largest (6 MW), with four 1.5 MW horizontal-axis turbines in place since 2017.[26] In 2018, the project entered its 25-year operational phase; it ended the year having generated 10 gigawatt-hours (GWh), the amount of electricity that 2,800 Scottish households consume in one year.[27] Preparations were under way to install at least two new 2 MW turbines at the MeyGen site, with both incorporating larger generators and rotor diameters, as well as a common export cable – all designed to reduce the technology's levelised cost of energy.[28]

In the Bluemull Sound of Scotland's Shetland Islands, Nova Innovation (United Kingdom) and its partner organisations were granted a renewed lease for an expanded array of tidal turbines along with an approval for expansion from the European Commission, which provides financial support for the project.[29] The project includes three 100 kW direct-drive turbines, with plans to add another three units. The objective is to prove that the reliability and availability of tidal power arrays can be increased even as costs are reduced by at least 40%.[30] Also in 2018, Nova Innovation integrated on-shore battery storage to demonstrate the ability of tidal power to offer load-following dispatch.[31]

Orbital Marine Power continued successful tests of its 2 MW SR2000 twin-turbine tidal power device at the European Marine Energy Centre (EMEC) in Orkney, Scotland, generating more than 3 GWh in its first year of testing.[32] In 2018, Orbital Marine started preparations to launch a new version of the turbine (Orbital O2) at EMEC by 2020.[33] The new device will mimic the concept of the original, comprising a 73 metre long floating superstructure supporting two 1 MW turbines on each side, but adding new features such as 360-degree blade pitch control for bi-directional power capture.[34]

Off the coast of North Wales, Minesto of Sweden demonstrated the ability of its "energy kite" to harness relatively low-energy tidal streams and ocean currents.[35] A turbine integrated with a wing, the tethered device operates in a manner similar to an airborne kite. The device is said to enhance the energy conversion by "flying" faster than the actual tidal flow.[36]

In France, after two years in port for maintenance and optimisation, Sabella's (France) D10 turbine was re-immersed in the Fromveur Passage off the coast of Brittany, where it will supply electricity to the island of Ushant for a planned three-year term.[37]

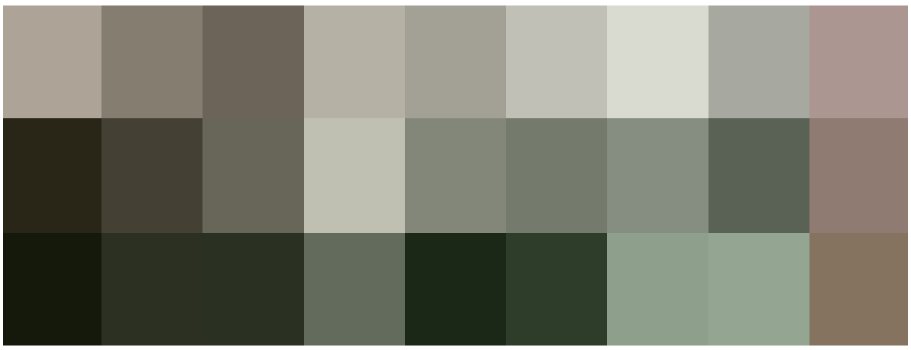
China had several tidal turbines under development in 2018. Building on smaller turbines installed earlier, Zhejiang University deployed one 600 kW horizontal-axis turbine near Zhairuoshan Island, and Guodian United Power went to sea trials on a 300 kW turbine nearby.[38] Hangzhou United Energy deployed both vertical- and horizontal-axis turbines, 400 kW and 300 kW each respectively; the company's combined installed capacity totalled 1.7 MW by year's end.[39]

Wave power development also continued in 2018, with several projects active around the globe. However, the industry showed some signs of financial distress and wavering government support.[40]

Australian wave power developer Carnegie received investment support from Enel Green Power (Italy) as Carnegie embarked on a government-backed plan to deploy its first full-scale 1.5 MW CETO 6 wave energy converter off the coast of Albany, Western Australia.[41] By early 2019, however, the Western Australia government had terminated its pending grant of AUD 15.8 million (USD 11.1 million) for the Albany project because of doubts that Carnegie would be able to fund its portion of the AUD 53 million (USD 37.3 million) development.[42] Driven in part by losses in unrelated subsidiaries, the company entered bankruptcy administration in early 2019 with hopes to recapitalise its core wave power business.[43]

Funding for ocean power in the United States continued in 2018, with a particular focus on wave power devices and associated technology. Ocean Energy (Ireland) constructed its wave power OE Buoy in the US state of Oregon. The device, which is 38 metres in length and has a potential power output of 1.25 MW, will be deployed in the Pacific at the US Navy test site on the island of O'ahu in Hawaii.[44] The USD 12 million project is funded in part under a collaborative agreement between the US Department of Energy (DOE) and the Sustainable Energy Authority of Ireland.[45]

The ocean power industry remains **highly dependent** on public funding to leverage private investment.



In early 2019, the US DOE announced that it had selected recipients for up to USD 25 million in grants to support ocean power technologies, with the aim of reducing capital costs and shortening project development times.[46] The three topic areas for funding were early-stage device design, advancement of new power take-off devices (PTOs[i]) and control systems, and the consolidation of scientific knowledge and understanding regarding potential environmental impacts of ocean power in order to reduce regulatory uncertainty.[47]

Across the Pacific, in China, a 260 kW floating hybrid wave (200 kW) and solar PV (60 kW) desalination platform was deployed for open-sea testing and was connected to the Wanshan Island grid through submarine cables.[48]

At the Biscay Marine Energy Platform (BiMEP) in Spain, Oceantec (now part of IDOM Group, Spain) redeployed its MARMOK-A-5 wave power device for a second phase of open-sea trials.[49] The upgraded device incorporates a bi-radial turbine developed by Kymaner (Portugal) that is driven by wave-induced compressed air, a technology known as an oscillating water column.[50] During its first deployment, the device demonstrated its survivability in winter seas as well as 85% availability to generate electricity.[51]

At the FaBTest facility in Cornwall (England), Marine Power Systems (United Kingdom) deployed its prototype quarter-scale WaveSub wave energy converter.[52] The WaveSub device harnesses the continuous orbital motion of waves through a PTO. AW-Energy (Finland) continued testing its WaveRoller wave energy converter in Northern Ireland, with the support of EU funding.[53] Late in the year, AW-Energy announced its collaboration with Enel Green Power (Italy) to further commercialise the technology.[54] At EMEC off the northern coast of Scotland, CorPower (Sweden) deployed and completed a demonstration of its half-scale C3 wave energy converter.[55]

Wave Energy Scotland (WES), a subsidiary of the Highlands and Islands Enterprise of the Scottish government, awarded more than GBP 4.5 million (USD 5.7 million) in 2018 for the development of wave power-related materials, controls and PTOs.[56] In early 2019, WES announced a further GBP 7.7 million (USD 9.8 million) in funding to Mocean Energy and AWS Ocean Energy (both United Kingdom) to launch half-scale prototype wave energy converters for testing in real ocean conditions.[57] In general, however, the industry momentum created by past public support in the United Kingdom is said to be slowing, with an adverse effect on private sector investor confidence.[58]

In that context, a 2018 study assessed the value of public support for the tidal and wave power industries against three government criteria: the appearance of a clear cost-reduction pathway for the technology; the prospect of the United Kingdom developing world-leading technology in a global market; and the ability of the technology to deliver maximum reduction in carbon emissions.[59] The study concluded that tidal power technologies had showed evidence of being able to deliver on all three fronts, while wave energy conversion was not advanced enough yet to demonstrate a cost-reduction pathway but could well meet the other two criteria.[60]

In 2018, the European Commission published an implementation plan for ocean power, outlining the necessary steps, timeline and estimated funding needs to commercialise tidal and wave power technologies in Europe by 2025 and 2030, respectively.[61] The plan acknowledges that much work is required to meet that timeline, not only in technology development but also in the establishment of a new industrial sector that allows the requisite economies of scale to meet the commercialisation target.[62]

An estimated EUR 1.2 billion (USD 1.4 billion) in funding is required between 2018 and 2030 to commercialise these technologies, with one-third each coming from industry / private equity, national and regional programmes, and EU funds (mainly Horizon 2020).[63]

Ongoing uncertainty regarding environmental risks to marine life associated with various ocean power technologies has prompted regulators in some locations to require individual developers to undertake significant data collection and assessment of potential impacts. A study released in 2018 on the current scientific knowledge in this area suggested that such case-by-case assessments may be costly enough to threaten the financial viability of projects and developers.[64] The study found that the deployment of single devices appears to pose very small risk to the marine environment.[65] However, because there are no large arrays in operation, the potential impacts of such projects are unknown.[66] Efforts continued during the year, led by the US DOE, to resolve, or put aside, environmental risks that continue to slow project consenting and hamper the development of ocean power.[67]

In 2018, there were more than 90 tidal power technology developers around the world, half of which were working on horizontal-axis turbines.[68] Other tidal power devices include vertical-axis turbines and tidal kites.[69] At least 200 companies were developing wave energy converters of various types, with nearly one-third of them developing point-absorber[ii] devices.[70] Other prominent wave power categories include attenuators, oscillating water columns, oscillating wave surge converters and overtopping/terminator devices.[71]

i A PTO (power take-off) is a device for transferring power from its source to deliver work. In the case of ocean energy conversion, the PTO transfers converted energy (i.e., from wave action) in a manner that is suitable for generating electricity.

ii Point-absorbers are wave energy converters that couple a floating element to a sea-floor base, converting the wave-driven motion of the floating top relative to the base into electricity, from European Marine Energy Centre Ltd. See endnote 70 for this section.

SOLAR PHOTOVOLTAICS (PV)

SOLAR PV MARKETS

The annual global market for solar photovoltaics (PV) increased only slightly in 2018, but enough to surpass the 100 GW[i] level (including on- and off-grid capacity) for the first time.[1] Cumulative capacity increased approximately 25% to at least 505 GW; this compares to a global total of around 15 GW only a decade earlier.[2] (→ *See Figure 25.*) Higher demand in emerging markets and in Europe, due largely to ongoing price reductions, compensated for a substantial market decline in China that had consequences around the world.[3]

Despite the single-digit growth rate of the global market in 2018, solar PV has become the world's fastest-growing energy technology, with gigawatt-scale markets in an increasing number of countries.[4] Demand for solar PV is spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of markets – for residential and commercial applications and increasingly for utility projects – even without accounting for the external costs of fossil fuels.[5]

Eleven countries added more than 1 GW of new capacity during the year, up from 9 countries in 2017 and 7 countries in 2016, and markets around the world have begun to contribute significantly to global growth.[6] By the end of 2018, at least 32 countries had a cumulative capacity of 1 GW or more, up from 29 countries one year earlier.[7]

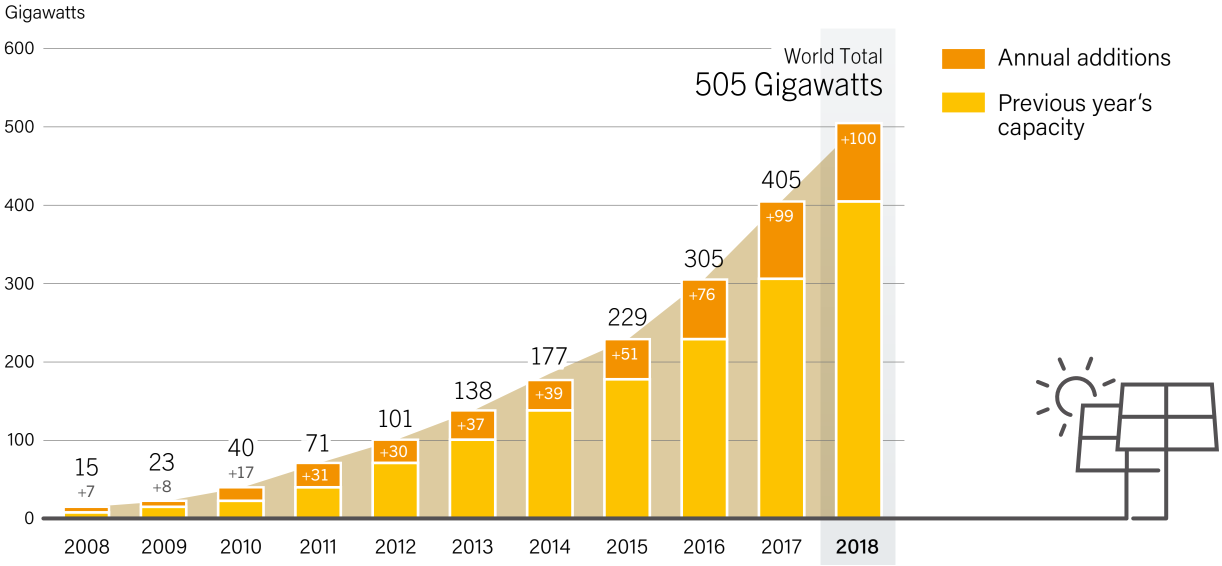
There are still challenges to address in order for solar PV to become a major electricity source worldwide, including policy and regulatory instability in many countries, financial and bankability challenges, and the need to integrate solar PV into electricity markets and systems in a fair and sustainable manner.[8] But solar PV already plays a significant and growing role in electricity generation in several countries.[9] In 2018, it accounted for 12.1% of total generation in Honduras and substantial shares also in Italy (nearly 8.2%), Greece (8.2%), Germany (7.7%) and Japan (6.5%).[10] By the end of 2018, enough capacity was in operation worldwide to produce close to 640 TWh of electricity per year, or an estimated 2.4% of annual global electricity generation.[11]

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.[12] Government policies – particularly tenders and, to a lesser extent, traditional FITs – continued to drive most of the global market in 2018.[13] Corporate purchasing of solar PV expanded considerably, and self-consumption was a significant driver of the market for new distributed systems in Europe and the United States.[14] Although still a negligible share of the annual market, a number of purely competitive ("unsubsidised") systems were being constructed in 2018; interest in this segment is significant and growing quickly.[15]

For the sixth consecutive year, Asia eclipsed all other regions for new installations, despite declines in the region's top three markets (China, India and Japan).[16] China alone accounted for around 45% of global additions, but this was down from nearly 54% in 2017.[17] Asia was followed by the Americas.[18] The top five national markets – China, India, the United States, Japan and Australia – were responsible for about three-quarters of newly installed capacity (down from about 84% in 2017); the next five markets were Germany, Mexico, the Republic of Korea, Turkey and the

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

FIGURE 25. Solar PV Global Capacity and Annual Additions, 2008-2018



Note: Data are provided in direct current (DC).
Totals may not add up due to rounding.

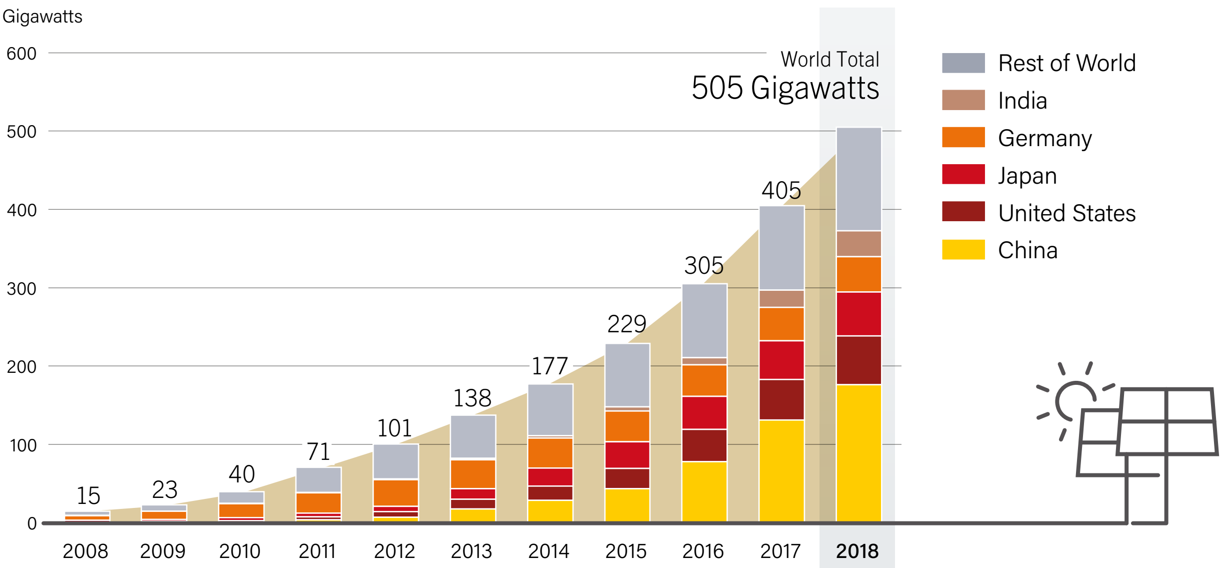
Source: Becquerel Institute and IEA PVPS.
See endnote 2 for this section.

Netherlands.[19] The annual market size required to rank among the top 10 countries continued to increase, reaching 1,330 MW in 2018 (up from 954 MW in 2017).[20]

At year's end, the leading countries for cumulative solar PV capacity were China, the United States, Japan, Germany and India.[21] (→ *See Figure 26.*)

China's annual solar PV market declined for the first time since 2014 but the country had its second-biggest year so far, with 45 GW newly installed.[22] While down more than 15% relative to 2017, the scale of new installations was greater than expected following significant subsidy reductions by the central government in May 2018, and the country's additions were more than four times those of the next-largest market.[23] (→ *See Figure 27* and ***Reference Table R17***.) By year's end, China's cumulative capacity of 176.1 GW was well beyond the national target of 105 GW by 2020 that was established in 2016.[24]

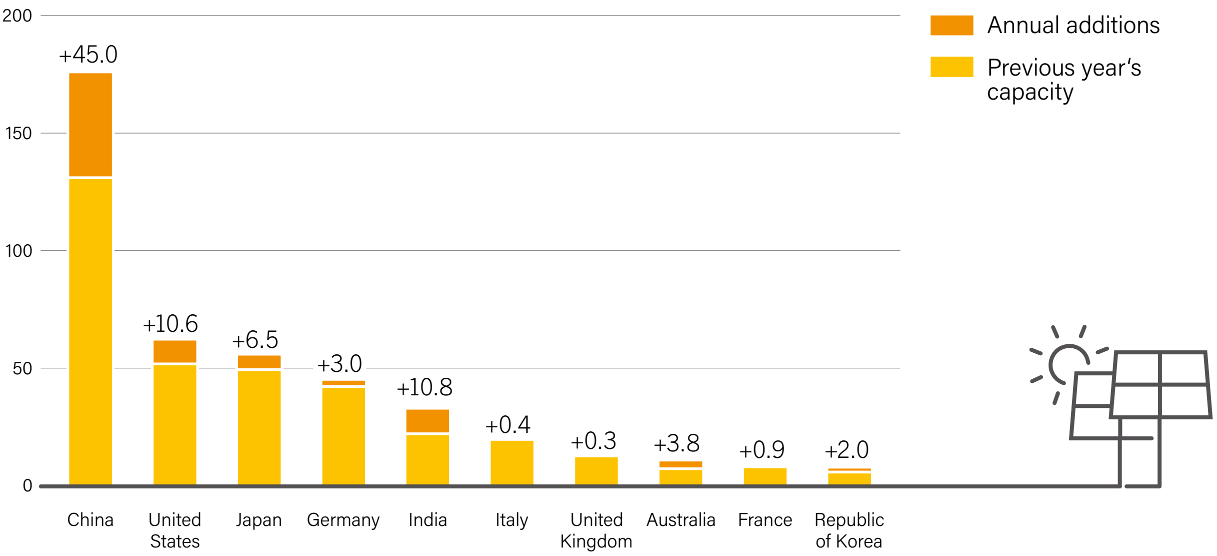
FIGURE 26. Solar PV Global Capacity, by Country and Region, 2008-2018



Note: Data are provided in direct current (DC).

Source: See endnote 21 for this section.

FIGURE 27. Solar PV Capacity and Additions, Top 10 Countries, 2018



Note: Data are provided in direct current (DC).
Data for India are highly uncertain.

Source: See endnote 23 for this section.

In 2018, solar PV generated
more than 12%
of Honduras' electricity and substantial shares in other countries.

These still-substantial additions came despite policy changes in China that reduced the FIT payment for solar generation, capped distributed projects at 10 MW for 2018, and ended approvals for new subsidised utility-scale plants (abolishing the 13.9 GW target for 2018), mandating that they go through auctions to set power prices.[25] The policy changes also shifted project approval to local governments.[26] Key factors driving China's policy revisions included a backlog in FIT payments and a growing deficit in the nation's renewable energy fund, as well as concerns about uncontrolled growth and a realisation that bids under the country's Top Runner[i] programme were much lower than the national FIT.[27] The changes reportedly signalled the central government's shift in focus from high-speed growth and dependence on subsidies, to high-quality development in order to reduce costs through technological improvements.[28]

China's market in 2018 was driven largely by the Top Runner and Poverty Alleviation programmes (and the FIT until late May).[29] Centralised utility power plants (above 20 MW) accounted for nearly 53% of the year's installations (and 71% of the year-end total); the remainder was in distributed[ii] systems, which were up considerably in both their capacity added in 2018 and their share of total additions relative to previous years.[30]

Curtailment of China's solar PV generation continued to decline, from a national average of 6% in 2017 to 3% in 2018, although curtailment rates remained far higher in the remote provinces of Gansu (10%, down 10 percentage points) and Xinjiang (16%, down 6 percentage points) due to insufficient transmission capacity.[31]

Reduced curtailment and rising capacity helped increase China's solar PV output 50%, to 177.5 TWh.[32] As a result, solar PV's share of total annual electricity generation in the country rose to 2.6% in 2018 (from 1.9% in 2017).[33]

The second-largest market in Asia was India, which added an estimated 10.8 GW for a total of around 32.9 GW[iii, 34] Installations were down relative to the previous year, for the first time since 2014.[35] The decline was due to several factors, including land and transmission constraints, a safeguard duty[iv] on imports from China and Malaysia (the sources of about 85% of India's imports of solar product), flaws in the tender scheme and uncertainty surrounding the Goods and Services Tax, all of which affected large-scale installations.[36] Investment in India's solar sector fell 27% by one estimate, despite an increase in investment in new manufacturing facilities, because of the decrease in installations and the decline in system costs.[37] (→ *See Investment chapter.*) Even so, solar PV was India's largest source of new power capacity for the second year running, and, for the first time, it accounted for more than half of the capacity added during the year.[38] India is targeting 100 GW of installed solar PV by fiscal year 2022.[39]

The Indian rooftop market continued to grow rapidly, up about two-thirds during 2018 by one estimate.[40] But total rooftop capacity remained relatively low, reaching as much as a few GW by year's end, a long way from the national target of 40 GW by 2022.[41] The rooftop market continued to consist mainly of large commercial and industrial companies, as well as government entities and educational institutions, all seeking to reduce their electricity bills; few residential customers can afford the upfront costs.[42]

As in recent years, most of India's newly installed capacity during 2018 was in large-scale installations, with the bulk of this in five states: Karnataka, Rajasthan, Andhra Pradesh, Tamil Nadu and Maharashtra.[43] At least three of these states (Andhra Pradesh, Karnataka and Tamil Nadu) continued to face curtailment challenges, in the range of 10-25%, which resulted in significant losses to project developers.[44] More than 40 GW of additional large-scale solar projects was tendered in India during 2018.[45] However, the gap expanded between tenders issued and auctions completed. Many auctions were cancelled retroactively, and several gigawatts of awarded capacity were annulled during the year.[46]

The market in Japan also contracted (down about 13%), for the third consecutive year, with 6.5 GW added for a total of 56 GW.[47] Japan's market continued to suffer from high prices of solar generation (Japan's prices are some of the highest worldwide),

i China's PV Top Runner programme, introduced in 2015, provides economic incentives to Chinese companies to invest in new and innovative technologies and to achieve minimum performance criteria for cells, modules and inverters. The programme, based on auctions, was created to promote the application of advanced, high-efficiency solar PV products and to close outdated production facilities. See endnote 27 for this section.

ii "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 30 for this section.

iii Data for India are highly uncertain. See endnote 34 for this section.

iv Members of the World Trade Organization may take safeguard action, which includes placing temporary duties or restrictions on imports, while they adjust in order to become more competitive with foreign producers.

land shortages, grid constraints and high labour costs.[48] The country's first three tenders, held in late 2017 and 2018, resulted in relatively high bid prices and were undersubscribed.[49]

Even so, the number of large solar plants in Japan continued to grow, raising some conflicts between developers and local citizens and their governments due to concerns that include potential negative impacts on landscapes and the natural environment.[50] By early 2019, the national government was considering covering solar PV projects larger than 40 MW under a revised national environmental assessment law.[51]

Japan's residential rooftop sector remained fairly stable, and interest expanded in the use of solar-plus-storage for self-consumption.[52] The market for larger rooftop systems also has grown as falling solar costs relative to electricity from the grid have increased the commercial sector's interest in self-consumption.[53] Community power movements in Japan continued to make progress in their financing and business models.[54]

For the year, solar PV accounted for an estimated 6.5% of Japan's total electricity generation (11% in the Kyushu region), up from 5.7% nationally in 2017.[55] Late in the year, Japan's first curtailment of solar PV (and wind) generation occurred on the island of Kyushu due to periods of high shares of variable renewable output combined with inflexible nuclear generation, which also increased its share in the electricity mix in 2018.[56]

Elsewhere in Asia, the Republic of Korea added more than 2 GW to end 2018 with 7.9 GW.[57] The market has been driven primarily by a renewable portfolio standard (RPS).[58] Turkey followed, installing 1.6 GW for a total of 5.1 GW, already surpassing the national target for 2023.[59] However, Turkey's additions were down 37% relative to 2017 due to several factors, including uncertainties regarding national support schemes, issues related to land acquisition, permission and financing, as well as delays as project developers await further cost reductions.[60]

Others in Asia to add capacity included Chinese Taipei (almost 1 GW), driven by a FIT and a target of 20 GW by 2025, as well as Pakistan (0.5 GW) and Malaysia (0.4 GW).[61] Several countries in the region held tenders, including Bangladesh and Kazakhstan, which held its first solar auction; in the Philippines, solar PV (and wind power) competed favourably against coal, and several solar PV projects were approved for construction.[62]

The Americas accounted for around 14.5% of the global market in 2018, due largely to the United States.[63] The United States added an estimated 10.6 GW for a total of 62.4 GW.[64] California again led all states in added capacity (3.4 GW), and during the year it became the first US state to mandate solar installations on most new homes (starting in 2020).[65] California was followed by Texas (added 1 GW) and North Carolina (0.9 GW). Overall, a geographic shift in capacity additions continued, with progress in many states that previously did not have significant markets.[66]

The US market as a whole was relatively stable (down 2%) compared to 2017. The residential sector expanded 7%, driven by emerging state markets, but the non-residential and utility-scale sectors contracted by 8% and 3%, respectively.[67] The decline in new utility-scale capacity commissioned during the year was reportedly due largely to new federal duties on imported solar cells and modules, which led to project cancellations and delays (timelines shifted based on the tariff schedule); the

California
became the first US state to mandate solar installations on most new homes.

effects of import tariffs were countered somewhat by a global oversupply of modules (resulting from China's policy changes and subsequent decline in module demand), which drove down prices.[68]

Late in the year, the US market also was buoyed by increased interest from corporations, including utilities, eager to begin construction of new projects before the federal investment tax credit begins to phase out in 2020.[69] Companies signed a total of 13.2 GW of utility-scale solar power purchase agreements (PPAs), pushing the pipeline of contracted projects to the highest level ever, at 28.3 GW.[70] While commercial and industrial off-takers were responsible for only 153 MW of capacity additions during 2018, they accounted for 21% (2.8 GW) of new deals signed, or 1 GW more than in all previous years combined.[71] Innovations such as aggregation[i] are helping to open the market for smaller businesses as well.[72]

US companies, including utilities, signed
13.2 GW
of utility-scale solar PPAs in 2018.

A few of the US projects contracted in 2018 included energy storage; large-scale solar-plus-storage projects are already undercutting new gas plants in some markets (with the help of federal tax credit support).[73] Interest in solar-plus-storage is increasing in the US residential market as well.[74] (→ *See Systems Integration chapter.*)

To the south, several countries in Latin America and the Caribbean are seeing a rapid expansion of annual installations, thanks to an abundance of solar resources and a favourable political climate.[75] Large companies are flocking to the region with expectations of massive expansion.[76]

The region's top country for additions in 2018 was Mexico, which ranked among the top 10 globally for the first time.[77] (→ *See Figure 28.*) Mexico added more than 2.7 GW (up from 285 MW installed in 2017), boosting its total capacity five-fold to nearly 3.4 GW.[78] This substantial growth in capacity resulted from the grid connection of several very large projects (a result of auctions as well as private PPAs) and from a significant increase in distributed projects under Mexico's net metering scheme.[79]

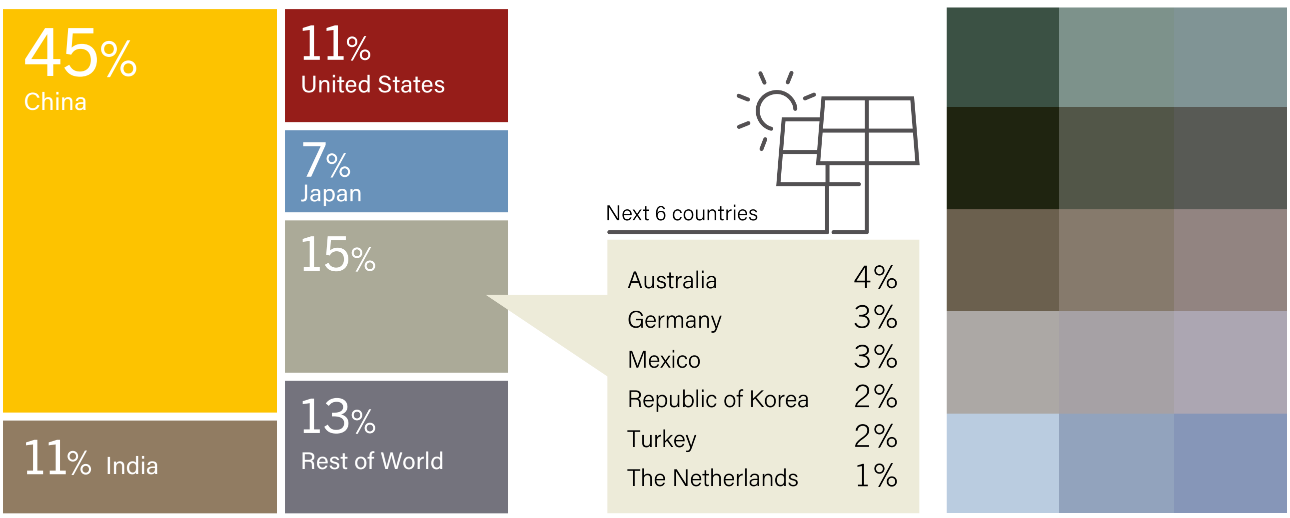
Chile followed Mexico in the region for cumulative capacity, with almost 0.5 GW installed for a total of 2.6 GW.[80] Most of Chile's capacity is in large-scale projects, many of which support mining operations and other major energy consumers.[81]

Much of the capacity installed in Latin America has occurred via large-scale PPAs, with many new ones announced in 2018, and the region is home to a good portion of the world's merchant[ii] solar plants.[82] But distributed solar PV has begun to see significant growth, particularly in Brazil, where cumulative

i Aggregation can occur when, 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 72 for this section.

ii Merchant solar plants are facilities financed by investors built with the intention of selling electricity into the wholesale market, rather than through a PPA, which includes an agreed purchase price for electricity that is generated by a plant over several years.

FIGURE 28. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2018



Note: Totals do not add up due to rounding.

Source: See endnote 77 for this section.

distributed capacity surpassed 0.5 GW in 2018.[83] Nearly 0.4 GW of this total was added during the year, thanks to the extension of Brazil's national net metering programme as well as to a rising number of state-level incentives, falling module prices, rising electricity tariffs and increased environmental awareness.[84] In total, Brazil added more than 1.1 GW in 2018, doubling its capacity to nearly 2.3 GW.[85]

Access to financing remains a challenge in much of Latin America for projects of all sizes due in part to volatile interest rates and currency instability.[86] To overcome these challenges, several developers have turned to green bonds, which have been issued for projects in Argentina, Chile, Colombia, Peru and Uruguay.[87]

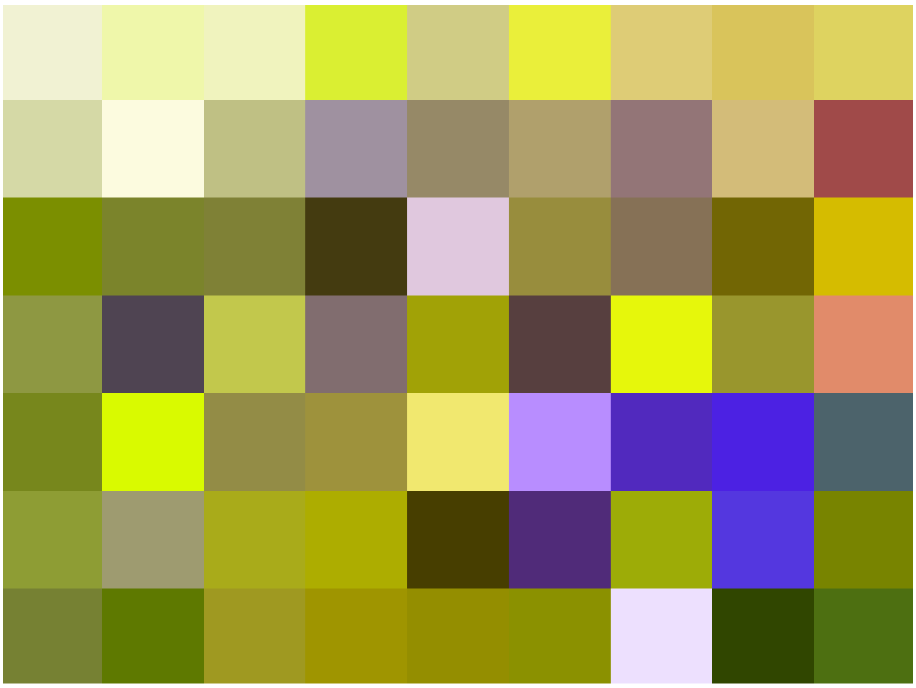
Europe was the third-largest region for new installations (9.7 GW) but maintained its second-place ranking for total operating capacity.[88] The region continues to represent a shrinking portion of cumulative global capacity as emerging economies with rapidly growing electricity demand deploy more and more solar PV.[89] In 2018, however, demand increased significantly within the EU and beyond, with the cost-competitiveness of solar energy stimulating investment also in Belarus, the Russian Federation and Ukraine.[90] Ukraine installed more than 0.7 GW to nearly double its total capacity (1.6 GW), thanks to a FIT for large-scale installations and net metering for smaller systems enacted in part to address energy security concerns.[91]

The EU added around 8.3 GW of grid-connected solar PV in 2018, up 36% over the previous year's additions, bringing total capacity to 115 GW.[92] Relative to 2017, 22 of the 28 EU countries recorded higher installations, driven by national binding targets for 2020, which many member states have yet to meet.[93] Other drivers included the removal of tariffs on Chinese solar panels in September; rising emissions prices in the EU's Emissions Trading System, which improved the competitiveness of solar PV relative to fossil fuels; and a continuing decline in solar PV system prices.[94]

A significant development in the EU in 2018 was the emergence of direct bilateral PPAs for solar PV.[95] Developers have begun to build projects with plans to sign long-term PPAs with large industrial consumers (or even to sell electricity to utilities at the market price).[96] One estimate shows PPA activity in the region increasing from 360 MW in 2017 to 2.4 GW in 2018.[97] By late 2018, about 15 projects that did not rely on direct government subsidies to make a profit were under way in the EU, and banks had begun to provide funding for such projects in Italy, Spain and elsewhere.[98]

Germany was the EU's largest market, regaining the region's top spot for the first time in five years.[99] The annual market was up more than 70% relative to 2017, to nearly 3 GW, bringing total capacity to 45.3 GW.[100] The main drivers of the increase were self-consumption and feed-in premiums for medium- and large-scale commercial systems.[101] By the end of 2018, Germany had more than 1.7 million solar PV systems.[102] More than half of all new systems were installed with storage, and approximately 120,000 solar-storage systems were in operation by year's end.[103] It also was a successful year for lining up future capacity: solar tenders were over-subscribed, and solar PV won all the capacity in Germany's first joint auctions for solar and onshore wind power.[104] The country's solar output increased more than 17% in 2018 (to 46.2 TWh), due largely to unusually dry and sunny summer weather, and amounted to 7.7% of annual gross electricity generation.[105]

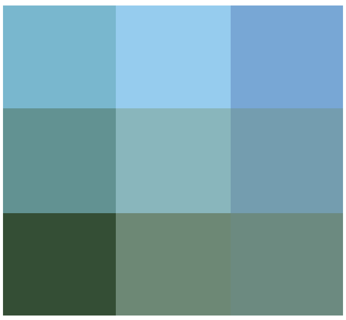
The Netherlands has seen steady market growth since 2014 and, in 2018, added a record 1.4 GW to close the year with 4.3 GW.[106] While more than 40% of additions were installed on residential rooftops, the market is driven increasingly by utility-scale projects in the commercial sector, where additions were up 90% relative to 2017.[107]



The EU added 8.3 GW of grid-connected capacity,

up 36%

over 2017 installations, for a total of 115 GW.



France ranked third in the region for new installations (0.9 GW), despite a slight contraction relative to 2017.[108] France was followed by Italy (which pushed its total capacity over 20 GW), Belgium, Hungary and Spain, all of which installed around 0.4 GW.[109] The United Kingdom, which in 2017 ranked second in the region and ninth worldwide for installations, saw its market continue to decline, to below 0.3 GW, due to the removal of support policies.[110] In Italy and Spain, installations rose slightly in 2018, following several years of negligible installations; both markets have been driven predominantly by self-consumption in recent years.[111]

Self-consumption is playing an important role in Australia as well. Solar energy is already cheaper than electricity from the grid in most of the country, thanks to the falling price of solar PV generation, existing subsidies for small-scale installations, and high wholesale electricity prices.[112] By late 2018, more than 2 million Australian homes and businesses were powered by rooftop solar PV, meaning that one in five households in Australia generates at least some of its electricity with solar energy.[113]

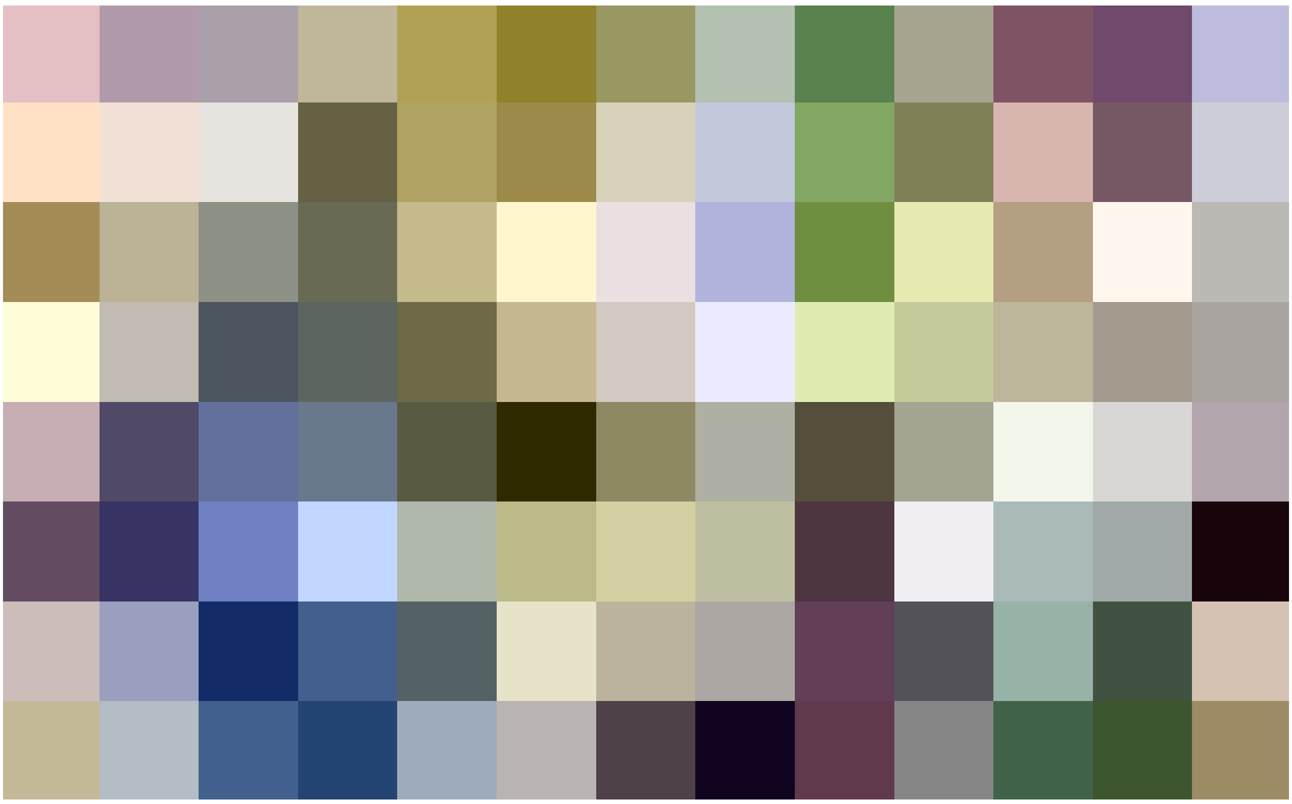
Australia's capacity additions nearly tripled relative to 2017, to about 3.8 GW, raising total capacity to more than 11.1 GW.[114] Every state and territory but Tasmania broke records for new capacity in 2018.[115] Residential and commercial rooftop installations were up more than 40% (to nearly 1.6 GW), for a total of around 8 GW.[116] Capacity additions of large-scale utility projects surpassed annual additions of rooftop systems for the first time: more than 2.4 GW was added, up from 0.1 GW in 2017, increasing the total capacity of utility projects to 3.1 GW.[117] At year's end, more than 3 GW of additional large-scale capacity was under construction.[118]

The corporate PPA sector in Australia is still at an early stage, but in 2018 it accounted for contracts worth hundreds of megawatts of future capacity.[119]

Generation from Australia's rooftop systems was boosted an estimated 22% during the year due to the installation of additional capacity, but also as a result of greater understanding among system owners of how to maximise system output, as well as the use of smart energy management systems and monitoring equipment; rooftop systems accounted for 4.2% of the country's total electricity consumption.[120] Overall, Australia's solar PV output increased more than one-third in 2018, at the expense of coal and gas, to 11.7 TWh, or 5.2% of total generation.[121]

The rising penetration of rooftop and large-scale solar PV (and wind power) continued to reshape Australia's grid during the year, challenging electric utilities.[122] In Queensland, where about half of the new large-scale capacity was installed, solar generation has depressed wholesale power prices.[123] The dramatic increase in large projects in 2018 began to cause network constraints; by year's end, the greatest concerns for project developers were delays and changing rules for grid connections, which have resulted in cost-overruns and have undermined investor confidence, slowing the project pipeline.[124]

The Middle East and Africa saw substantial progress in 2018, with an estimated 2.6 GW added for a year-end total of at least 6.7 GW.[125] In the Middle East, most of the new capacity was in the United Arab Emirates (as much as 0.6 GW), Israel and Jordan (both adding around 0.4 GW).[126] However, many countries across the region have begun to take advantage of falling solar PV prices to diversify away from fossil fuels, or to power their oil and gas



extraction industries.[127] Tenders were held during 2018 and early 2019 in several countries, including Jordan, Kuwait, Oman and the United Arab Emirates (Dubai and Abu Dhabi), and Lebanon held a 300 MW solar-plus-storage tender.[128] Distributed solar PV generation remains a nascent market outside of Jordan and Dubai, but in 2017 and 2018, several countries in the Middle East and North Africa – including Egypt, Morocco, Oman, Saudi Arabia and Tunisia – launched rooftop solar PV programmes to help reduce energy costs and to secure reliable electricity in areas where supply does not meet peak loads.[129]

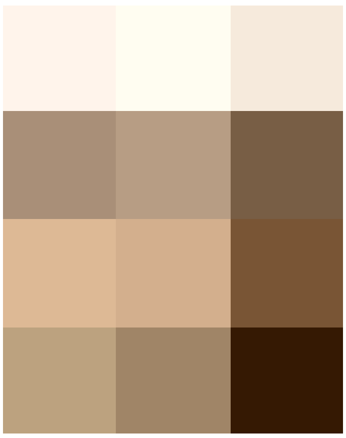
From northern Africa to the continent's southern tip, solar PV is viewed increasingly as a means to diversify the energy mix, meet rising demand and provide energy access.[130] (→ *See Distributed Renewables chapter.*) Egypt inaugurated the first phase of its planned 1.8 GW Benban solar park in early 2018 and was Africa's top installer for the year.[131] A former gas exporter, Egypt now imports liquefied natural gas at great expense, and solar (in addition to wind) power represents part of the country's plan to expand energy options and reduce blackouts.[132]

At year's end, Africa's top countries for cumulative capacity were South Africa with 1.8 GW (added 60 MW), Egypt with nearly 0.7 GW (added at least 0.5 GW) and Morocco, which added the vast majority of its 0.6 GW capacity during 2018.[133] Several other countries on the continent held solar PV tenders or had large plants being planned, under construction or commissioned in 2018.[134]

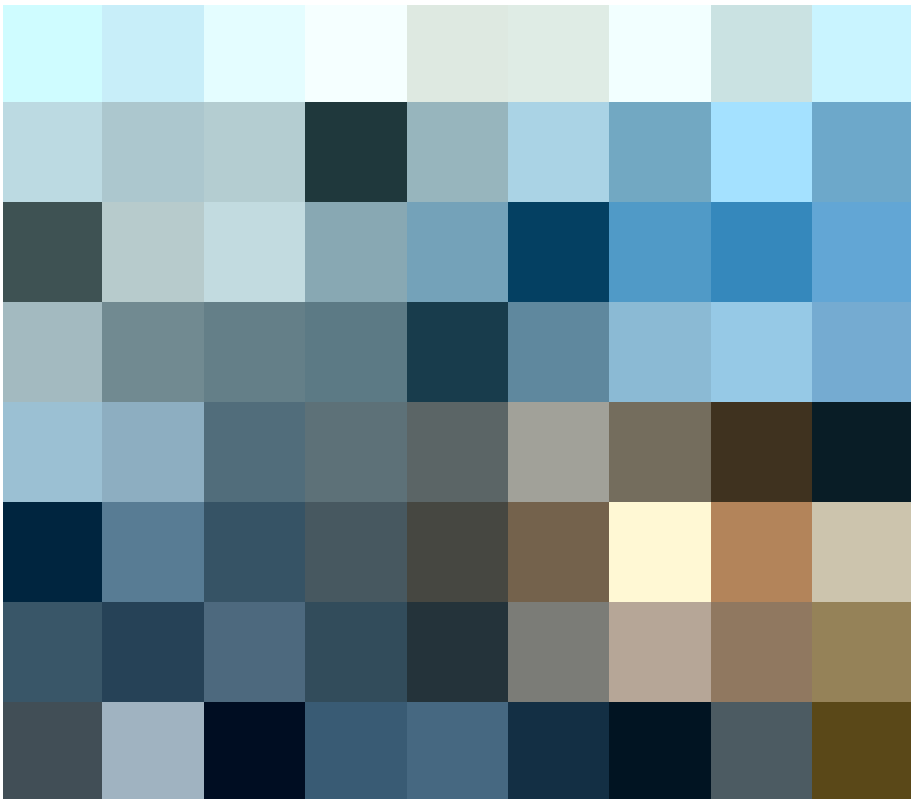
Across Africa and around the world, companies are erecting solar PV plants to power their operations for mining, manufacturing and fossil fuel extraction.[135] Motivating factors include economics as well as favourable regulations, environmental considerations and the flexibility of solar power systems.[136] A firm in Zimbabwe announced plans in 2018 to construct a 300 MW solar PV facility rather than the originally planned 600 MW coal plant for platinum mining operations.[137] In August, a US long-term electricity contract was signed for a 240 MW project to provide electricity for a steel manufacturer, reportedly the largest behind-the-meter solar PV project to date.[138] Soon thereafter, two of the world's largest coal mining companies announced a joint venture to invest more than USD 1.6 billion in 3 GW of solar power capacity in India.[139] Mining companies in Canada, Chile and elsewhere also have invested in solar PV (and wind power) capacity.[140]

The size and number of large projects continued to grow during 2018, with a total of at least 235 solar PV plants of 50 MW and larger operating in at least 37 countries (up from 28 in 2017) by year's end.[141] Newly commissioned plants included the 828 MW Villanueva park in Mexico, the largest solar PV project in the Americas; the 750 MW Rewa project in India, from which a quarter of the generation will be used to power the Delhi Metro; and Jordan's largest project to date (105 MW), which is expected to provide enough electricity for 50,000 homes.[142] Planning or construction began on very large projects in nearly every region of the world.[143]

Large-scale plants can cover vast areas, raising concerns about potential environmental impacts, grid-connection challenges and the use of agricultural lands.[144] Interest in floating solar PV is increasing rapidly due in part to some of the concerns linked to land-based projects.[145] Hybrid solar PV-hydropower systems are at an early stage, but they provide mutual benefits and have been proven at scale.[146] (→ *See Sidebar 3.*)



Around the world, **companies** are building solar PV plants to power their operations.



SIDEBAR 3. Floating Solar PV

The number of floating solar photovoltaic (FPV) installations has increased exponentially in recent years, due to strong interest from regions that lack available land for solar deployment and driven by the rapid development of large-scale projects in China. The first FPV installation was a 20 kW pilot system completed in Japan in 2007, and the first non-research installation was a 175 kilowatts-peak system in the US state of California in 2008. Just over a decade later, floating systems exist in at least 29 countries in nearly every region of the world and are under consideration or development in several more countries.

In 2018, installed capacity of FPV crossed the 1 GW mark, the same milestone that ground-mounted solar PV reached in the year 2000. Global installed capacity more than doubled during 2018, with an estimated 786 MW added to reach a cumulative total of some 1,314 MW by year's end. (→ *See Figure 29.*) New capacity additions included two 150 MW projects in China (both in Anhui Province), the world's largest floating solar PV projects to date. China dominates the FPV market with about 75% of the global installed capacity (more than 950 MW), followed by Japan.

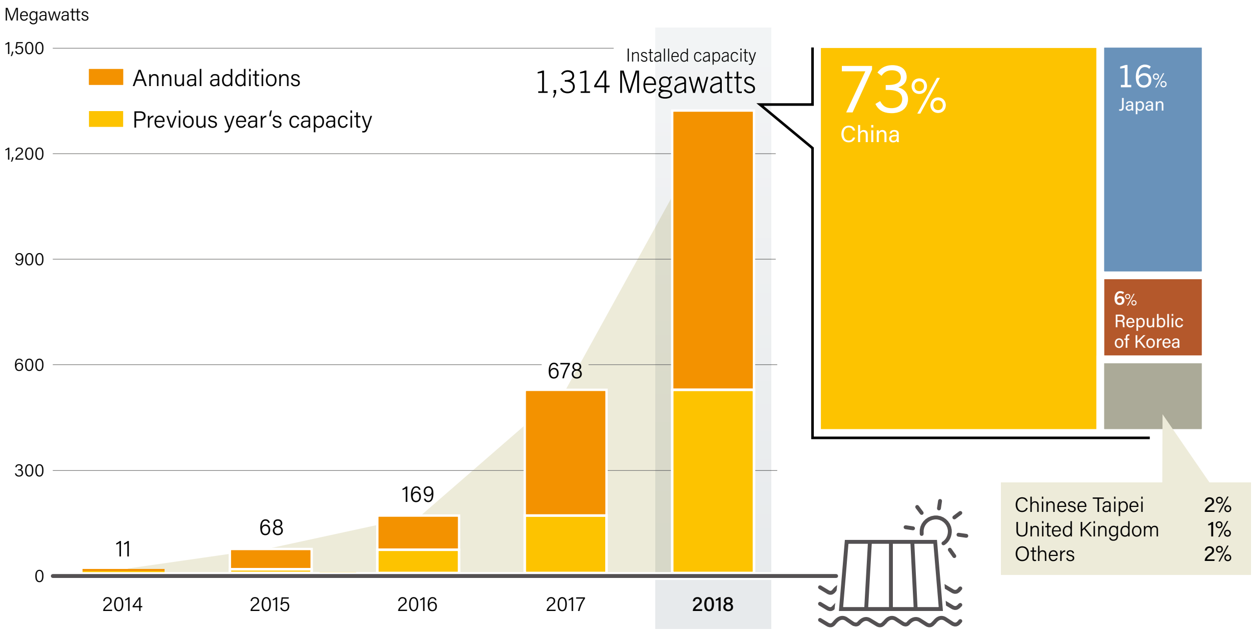
The third-largest FPV market, the Republic of Korea, commissioned its first megawatt-size installation in 2018 – an 18.7 MW system in North Jeolla.

FPV installations open new opportunities for the deployment of solar PV, especially in countries with high population density and competing uses for available land, such as Japan, the Republic of Korea, Singapore and parts of India, where FPV deployment has been driven largely by land constraints. Floating installations offer several benefits in addition to increased potential for solar PV in countries with limited land availability, including improved energy yield, elimination of the need for major site preparation, improved output (due to the cooling effect of water and less dust on panels), reduced evaporation from water reservoirs and the use of existing electricity transmission infrastructure at hydropower sites.

Industrial basins, irrigation ponds and drinking water reservoirs have been the preferred locations for FPV installations, although a variety of artificial water bodies and near-shore sites also have been used. In China, spurred by the national Top Runner programme, developers are transforming some of the country's dozens of existing flooded coal mines by installing floating solar PV systems: in Anhui Province, such systems range from 20 MW to 150 MW per site.

The rise of FPV is also opening opportunities for combining solar PV technology with hydropower stations. The world's first hybrid FPV and hydropower system was installed in 2017 in Portugal (220 kW at the Alto Rabagão Dam). However, the use of solar PV-plus-hydropower has already been proven at scale with ground-mounted solar systems: for example, the Longyangxia project in Qinghai, China combines 1,280 MW of hydropower and 850 MW of ground-mounted solar PV.

FIGURE 29. Floating Solar PV Global Capacity and Annual Additions, 2008-2018, and Top Countries, End-2018



Source: World Bank Group, ESMAP and SERIS. See endnote 146 for this section.

In solar-hydro hybrid systems, the hydropower can be used to reduce the effects of solar resource variability. Meanwhile, the solar PV can boost the energy yield and help manage periods of low water availability (for example, in places with dry and rainy seasons, the generation from hydropower and from solar PV can be complementary). The use of solar PV also can make water available for other purposes, such as irrigation. Such hybrid plants can make better use of existing transmission assets as well, opening opportunities in particular for countries where grids are weak or are constrained by inflexible generation technologies.

In some countries and regions, FPV installations are promoted through financial incentives. For example, Chinese Taipei offers a feed-in tariff for floating systems that is higher than that for ground-mounted systems; the Republic of Korea gives extra renewable energy certificates for projects that are floating; and the US state of Massachusetts increases the incentive value for solar projects that use floating solar PV, as part of the state's SMART Program that was implemented in 2018. Preferential FITs for solar PV typically include floating projects as well, as is the case in Japan, Malaysia and Vietnam (which extended the term of its FIT scheme for another 12 months in 2018).

In places such as China, Chinese Taipei, India, Japan, the Republic of Korea and Singapore, where population density is high and land is scarce or has a high opportunity cost, governments have shown interest in using floating solar PV to help reach ambitious renewable energy targets. In India and Singapore, experience gained from demonstration or pilot plants that were deployed in recent years led to commercial tenders in 2018.

The levelised cost of electricity (LCOE) of floating solar PV installations does not differ greatly from that of ground-mounted, fixed-tilt systems. On a per watt basis, the capital costs of FPV are still slightly higher, owing chiefly to the need for floats, moorings and more resilient electrical components. However, these costs are balanced by a higher expected energy yield of floating solar PV relative to ground-mounted systems (yields are conservatively estimated to be 5% higher for floating systems, with gains potentially as high as 10-15%[i] in hot climates, leading to a comparable LCOE. Nevertheless, FPV systems have seen reductions in capital costs, reflecting economies of scale as the market expands.

i As measured in the floating PV test-bed run by the Solar Energy Research Institute of Singapore (SERIS).

Source: World Bank Group, ESMAP and SERIS. See endnote 146 for this section.

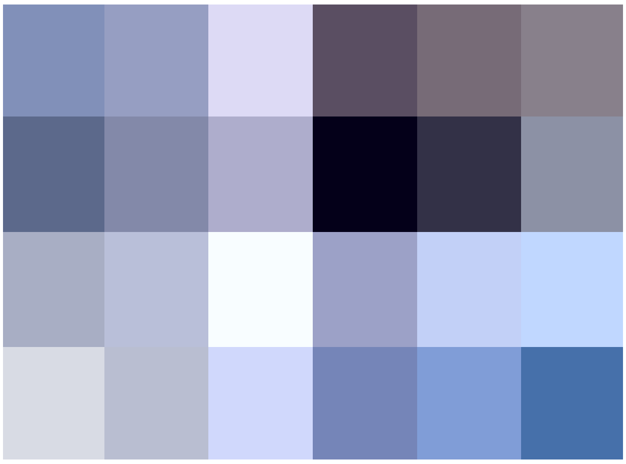
SOLAR PV INDUSTRY

The solar PV industry experienced significant growing pains in 2018. China continued to dominate global manufacturing as well as the world market for solar PV; as a consequence, the country's decision to constrain domestic demand led to turmoil in the industry as Chinese modules flooded the global market.[147] The resulting oversupply of cells and modules drove down prices and helped to open significant new markets, which counteracted the decline in China's installations.[148] Meanwhile, cell and module production capacity continued to increase.[149] Record-low auction prices, driven by lower panel prices and intense competition, brought further consolidation in the industry.[150] Trade disputes also affected the industry, weakening project pipelines in India and affecting growth in the United States.[151] Overall, manufacturers had a challenging year with slim margins, and many manufacturers sold panels at below the cost of production.[152] Nonetheless, competition and price pressures also led to investment in new, more-efficient production capacity and to continued advances in solar PV technology, particularly in China.[153]

Module prices declined about 29% in 2018, to a global average of 22.4 cents per watt, with the greatest decrease occurring after China's policy changes in May.[154] By one estimate, this helped lower the cost of installing 1 MW of solar PV by an average of 12%.[155] As of late 2018, the LCOE from plants in operation was at levels close to or below the retail electricity price in some countries, and in some cases even below wholesale electricity prices.[156]

Record PPAs and tenders continued during 2018, with some announcements of prices in the range of USD 20 per MWh.[157] Very low bid prices[i] were seen in several countries, including Brazil, India and Egypt (under USD 30 per MWh).[158] Saudi Arabia announced the winning bid from its 2017 tender (USD 23.4 per MWh), and a PPA was signed in Dubai at a new low for the United Arab Emirates (USD 24 per MWh).[159] Germany held an auction for large-scale projects that attracted bids below EUR 40 (USD 45.8) per MWh for the first time, and solar PV beat wind energy in joint auctions, although average bid prices inched up during the year.[160] The United States[ii] also saw long-term PPAs signed at record low prices for solar generation (the lowest being under USD 24 per MWh) and for solar PV-plus-storage (median bid price of USD 36 per MWh).[161]

Some in the industry consider tariffs in the USD 20 per MWh range to be a "new normal" for winning tenders under ideal conditions (for example, high solar irradiation, stable policy environment), although the average solar PV LCOE remains somewhat higher.[162]



There is a concern that tenders have been favouring the most cost-competitive options and not necessarily the most advanced or innovative technologies and designs.[163] Even so, tenders have driven a shift to market-oriented conditions in many countries and to the introduction of new business models.[164]

Trade policies[iii] also influenced the industry in 2018, with two of the top three country markets (India and the United States) placing new tariffs on China, the world's largest manufacturer and exporter of solar products.[165] Mid-year, the government of India placed a safeguard duty of 25% on solar products imported from China and Malaysia.[166] Indian developers responded by stalling project construction or sourcing imports from other countries in the region, particularly Singapore, Thailand and Vietnam.[167] Along with a general slowdown in Indian demand during 2018, the duty contributed to a reported 37% reduction in solar cell and module imports relative to 2017.[168] By some accounts, however, it also led to additions to domestic manufacturing capacity.[169]

The United States imposed tariffs on nearly all major sources of solar PV imports in early 2018.[170] The prospect of tariffs led to domestic stockpiling in 2017 and drove up panel prices in the country, making domestic production more profitable and spurring some new manufacturing plant construction.[171] In 2018, however, the import tariffs reduced demand for US solar installations, a trend that was partially offset by a flood of Chinese panels entering the global market.[172] Three additional sets of US tariffs (on Chinese inverters and non-lithium batteries, on steel and on aluminium) adopted during 2018 also affected the US solar industry.[173]

Meanwhile, in September the EU ended anti-dumping and anti-subsidy measures that had been in force since 2013 on cells and modules imported from China.[174] The European Commission

i Note that bid prices do not necessarily equate with energy costs. Also, energy costs vary widely according to solar resource, project size, regulatory and fiscal framework, 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 (although not wholesale prices) in many locations. See, for example, Galen Barbose and Naïm Darghouth, *Tracking the Sun VIII: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States* (Berkeley, CA: Lawrence Berkeley National Laboratory, September 2017), p. 2, https://emp.lbl.gov/sites/default/files/tracking_the_sun_10_report.pdf, and IEA PVPS, *Trends in Photovoltaic Applications 2018: Survey Report of Selected IEA Countries Between 1992 and 2017* (Paris: 2018), pp. 71, 73, http://www.ieapvps.org/fileadmin/dam/public/report/statistics/2018_iea-pvps_report_2018.pdf.

ii These prices reflect the US Investment Tax Credit, which applies to residential and commercial solar systems. The tax credit is for 30% of installed system cost through 2019; it steps down to 26% in 2020, 22% in 2021 and 10% (commercial only) from 2022 onwards.

iii In addition, in several countries measures were in place to encourage local production or to penalise the use of foreign-made products, from IEA PVPS, *2019 Snapshot of Global PV Markets* (Paris: April 2019), p. 15, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_T1_35_Snapshot2019-Report.pdf.

determined that it was in the EU's best interest to allow the measures to lapse, given the region's goal of increasing the supply of renewable energy.[175] In turn, China ended anti-dumping and countervailing duties on solar-grade polysilicon from the EU.[176]

China dominated global production in 2018 for the 10th year running.[177] Seven of the top 10 manufacturers, and all of the top three, were Chinese-based companies: JinkoSolar maintained the lead, followed by JA Solar, Trina Solar and LONGi Solar (all China); Canadian Solar (China/Canada), Hanwha Q-CELLS (Republic of Korea), Risen Energy, GCL-SI and Talesun (all China) and First Solar (United States) rounded out the top 10.[178] Most of these companies also were among the top 10 for cell production.[179] First Solar is the only top 10 company that manufactures thin films and that produces all of its modules.[180] The top 10 module suppliers[i] shipped nearly 60% of the total in 2018.[181]

Despite subsidy reductions and falling demand in China, several Chinese companies made significant investments during 2018 to increase their manufacturing capacity and announced plans for further expansion, with the aim of achieving lower production costs through advanced technologies.[182] China's cell production volumes were estimated to be up more than 21% over 2017, to 87.2 GW, while module production rose 14.3%, to 85.7 GW.[183] Beyond China, new manufacturing capacity (mostly for modules, and largely Chinese-owned) was completed or under construction in several countries, including India, Morocco, Nigeria, Saudi Arabia, South Africa, Sri Lanka and the United States (where expansion has followed tax reform and trade tariffs).[184]

Non-Chinese manufacturers have found it increasingly difficult to compete due to challenges they face in mobilising funding as well as to the growing focus in China on high-tech manufacturing. As a result, many non-Chinese manufacturers have turned to differentiation through products for niche markets, specific technology add-ons and other developments that provide added value.[185]

While some companies in China have made significant investments in manufacturing capacity and in research and development in recent years, elsewhere around the world in 2018 most of the capital flowing into solar PV went to downstream companies and projects.[186] The year broke records for solar project acquisitions, with large projects attracting even conservative investors such as insurance companies and pension funds, and some 29 GW worth of solar projects traded hands.[187] Leading utilities have acquired significant portfolios of solar PV projects; in China, India and the United States, power companies have substantial domestic capacity, whereas European multinationals are developing global portfolios.[188]

Companies upstream and downstream were affected by cut-throat pricing that was not necessarily reflective of cost, as well as by shrinking or shifting markets in some countries.[189] The year saw several bankruptcies, perhaps most notably in China, following the policy changes mid-year, and in Japan.[190] Since 2013, Japan has seen a steady rise in bankruptcies due to reductions in FIT payments and falling profits for solar companies: an estimated 95 Japanese solar companies went bankrupt in 2018.[191] In India, very low energy prices from tenders made it difficult for developers to get financing and to find equipment, particularly as the industry remained highly dependent on imports.[192] Even operations and maintenance (O&M) companies felt the bite of price pressure, with a notable increase in consolidation in India.[193] In response to such pressures, O&M companies around the world continued investing in labour-saving innovations and expanding into new service areas, including energy storage.[194]

The drive to increase efficiencies and reduce the LCOE has pushed manufacturers to develop advanced technologies, and new record cell and module efficiencies were achieved throughout the year.[195] Silicon-based solar cells, which account for about 90% of the market and are ahead of the competition for stability and efficiency (20-22% for typical solar cells in the marketplace), are close to reaching their maximum theoretical efficiency.[196] Researchers are working to overcome these limits by stacking cells of different types and developing new cell technologies.[197]

Passivated Emitter Rear Cell (PERC)[ii] technology has become the new standard for the monocrystalline silicon solar cell variety because it increases efficiencies with modest investment.[198] PERC cell production capacity increased from a few pilot lines in 2013 to more than 35 GW in 2017, and was expected to exceed 60 GW by the end of 2018.[199] The large and rapid ramp-up has been driven in part by policy, with China leading the way.[200] Although mono PERC is the focus of most capacity expansions, several manufacturers are converting factories to production of heterojunction cell technology (HJT)[iii], which offers higher efficiencies and can be manufactured at relatively low temperatures and with fewer production steps than other high-efficiency cell technologies.[201]

Researchers also advanced perovskite[iv] technology during the year, working to increase efficiency and reduce costs, improve long-term stability and replace lead content with more environmentally friendly materials.[202] UK-based Oxford PV announced a record 28% power conversion efficiency for a perovskite-silicon tandem solar cell in late 2018, exceeding the efficiency record for a single junction silicon solar cell (26.7%).[203] The company aims to make its technology commercially available by late 2019 or early 2020.[204]

i The solar PV value chain also includes manufacturers upstream (e.g., polysilicon, wafers, solar glass, chemicals, backsheets and balance of systems components) as well as downstream actors, including engineering, procurement and construction companies, project developers, and operations and maintenance providers.

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. Its efficiency potential is higher, it can be manufactured at relatively low temperatures, and it requires fewer production steps than do other high-efficiency solar cells.

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 in recent years.

Module manufacturers have continued to develop advanced technologies, such as multi-busbars[i] and half-cut cells[ii], which were first used in China under the country's Top Runner programme but increasingly are seen elsewhere as well.[205] By one estimate, at year's end there were at least 15 technology options for modules, and the field was only expanding.[206] Bifacial modules, which can capture light on both sides, also offer significant potential gains in output that are expected to more than make up for their additional cost.[207] Large projects with bifacial modules already were being deployed in 2018, although quality-related uncertainties remained.[208] First Solar took a giant step forward with its transition to the Series 6 thin film module, and in 2018 the company announced plans to triple its US manufacturing capacity.[209]

Improvements in geographic information systems are helping developers identify locations with high solar resource potential for large-scale projects, and other advances are helping to reduce time requirements for project construction and commissioning.[210] More and more large projects are using single-axis trackers[iii], which flatten the production curve and increase yield.[211] In 2018, global tracker shipments jumped an estimated 40%.[212]

Once projects are in operation, improved inverter[iv] reliability, remote technologies and advanced cleaning options are helping to reduce labour-related costs and outage times.[213] Digitalisation is improving plant monitoring processes, and new technologies such as aerial drones, combined with artificial intelligence, are helping with preventative maintenance, speeding up procedures, increasing plant efficiency and reducing associated costs.[214]

Despite tremendous steps forward in solar PV technologies, the need to drive down manufacturing and project development costs has raised concerns that manufacturers and developers could be pushed to cut corners, and that quality could be compromised.[215] Already, poor quality – from product manufacturing and shipping, to project design and construction, to commissioning and O&M stages – is an issue of concern in a number of countries.[216] In India, as a result of price pressure, inexperience, extreme climatic conditions and weak government requirements, many firms have cut corners on quality in order to operate on thin margins, so that they can bid low and win projects.[217] Smaller rooftop systems in India have experienced quality challenges as well.[218] Other countries, from Australia to Pakistan, also have faced component quality issues due to the desire for cheap imported modules and to a lack of testing and standards.[219]

In turn, such developments have prompted developers of large-scale projects to invest increasingly in rigorous quality assurance programmes to secure return on their investment in the medium and long term.[220] Governments and non-profit organisations, as in Australia, for example, have stepped up efforts to test and certify panels and other components in order to protect consumers.[221] As new technologies emerge, not only do they make decisions more complex for developers (for example, which module type to use, trackers or not), but there also is a need for new benchmarking tests.[222] Quality assurance companies, such as DNV GL of Norway, are working with universities and research institutions to advance and extend reliability and performance tests for modules.[223] In 2018, DNV GL issued the world's first project certificate for a solar PV plant to a 100 MW facility in Telangana, India.[224] At the time, the company's service specification was believed to be the world's only global guideline for certifying solar PV projects.[225]

To help reduce uncertainty related to solar projects, large insurance companies have begun guaranteeing output from solar farms. A new product sold by Swiss Re AG, called a Solar Revenue Put, reportedly can guarantee as much as 95% of a solar plant's expected output.[226]

Other developments in 2018 included the opening in France of what was believed to be the first non-pilot facility in Europe – and possibly the world – dedicated to recycling solar panels.[227] In early 2019, Sembcorp and Singapore Polytechnic signed a collaborative agreement to commercialise Singapore's first solar panel recycling process.[228]

The linkages between solar PV, storage and electric vehicles (EVs) continued to expand during the year. Solar cell and module manufacturer Hanwha Q Cells announced plans to enter the solar rooftop market with solar-plus-storage for residential customers.[229] In early 2019, the Dutch oil giant Shell purchased Sonnen, the leading manufacturer of home batteries in Germany, with an eye towards becoming the utility of the future – focused on clean energy, EVs and distributed electricity generation with storage.[230] China's BYD, which began by manufacturing batteries and later expanded into EVs, has begun manufacturing solar panels as well.[231] In 2018, BYD and Kostal (Germany) signed a deal to provide storage solutions for residential and commercial solar PV systems.[232] In Germany, companies like Enerix, Sonnen and Solarwatt, which were once struggling due to a shrinking domestic solar PV market, are thriving thanks to the growing demand for energy storage systems.[233] (→ *See Systems Integration chapter.*)

i Busbars are the thin strips of copper or aluminium between cells that conduct electricity. The size of the busbar determines the maximum amount of current that it can carry safely.

ii Half-cut cells are fully processed solar cells cut in two pieces to reduce cell-to-module losses during assembly, which increases efficiency and boosts power.

iii Trackers enable panels to track the movement of the sun.

iv Inverters convert direct current electricity from solar panels to alternating current for the grid.

CONCENTRATING SOLAR THERMAL POWER (CSP)

CSP MARKETS

An estimated 550 MW of concentrating solar thermal power (CSP)[i] came online in 2018, increasing cumulative global capacity more than 11% to just under 5.5 GW.[1] (→ *See Figure 30* and ***Reference Table R18***.) This annual increase represents the largest gain since 2014, and it occurred despite delays in several projects that had been scheduled to begin operation in 2018.[2] By year's end, the pipeline of CSP projects under construction reached around 2 GW in 10 countries across Africa, Asia, the Middle East and South America, with most of this capacity being built in the United Arab Emirates (0.7 GW) and China (just over 0.5 GW).[3] All but 3 of the 23 plants[ii] under construction by the end of 2018 planned to include thermal energy storage (TES).[4]

For the third consecutive year, new capacity came online only in emerging markets. This trend is expected to continue because nearly all commercial CSP capacity under construction by the end of 2018 was in emerging countries.[5] China and Morocco led the market in new additions, followed by South Africa and Saudi Arabia.[6]

Parabolic trough and tower technologies continued to dominate the market. Parabolic trough plants represented around 70% of new capacity additions in 2018, with the balance made up by tower plants.[7] By year's end, the plants under construction included just over 1 GW of trough systems, 0.8 GW of tower systems and 65 MW of Fresnel plants (at two facilities in China).[8]

In China, three new CSP plants with a combined capacity of 200 MW entered operation in 2018: the 100 MW Shouhang Dunhuang Phase II tower project (11 hours TES[iii]), the 50 MW Supcon Delingha tower project (7 hours TES) and the 50 MW CGN Delingha parabolic trough project (9 hours TES).[9] These projects form part of a national strategic plan to build local experience in the implementation of CSP by targeting more than 5 GW of capacity by 2022.[10] Under this plan, China's central government in 2018 reduced the number of planned CSP projects qualifying for preferential FITs from 20 to 16; in addition, the government reduced FITs for plants that were initially targeted for completion in 2018 but delayed into 2019 and 2020.[11]

India was the only other country in Asia to have CSP capacity under construction by the end of 2018.[12] The 25 MW Gujarat Solar One facility (9 hours TES) was expected to enter operation in late 2019, and the 14 MW Dadri Integrated Solar Combined-Cycle plant also was under construction.[13]

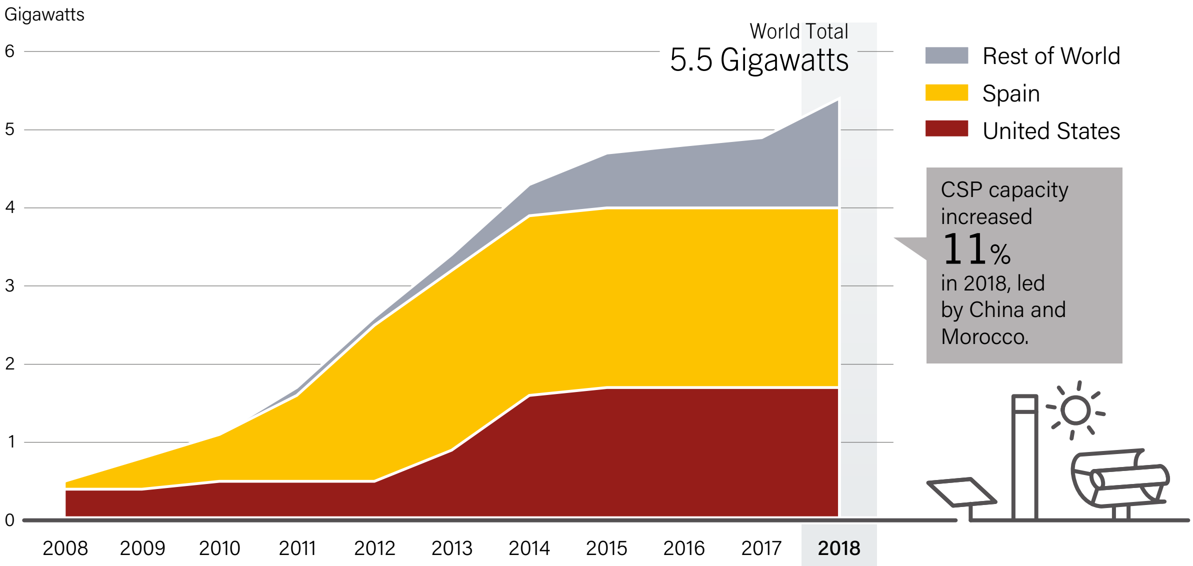
In North Africa, Morocco brought capacity online with the completion of the 200 MW Noor II facility (7 hours TES), and the adjacent 150 MW Noor III plant (7 hours TES) was at an advanced stage of construction by year's end; once the plant is operational, Morocco's total CSP capacity will exceed 0.5 GW.[14]

i CSP is also known as solar thermal electricity (STE).

ii Two of these plants without TES are integrated solar combined-cycle (ISCC) facilities, hybrid plants that use both solar energy and natural gas to produce electricity.

iii Storage capacity for CSP facilities with TES is typically reported in "hours" of storage. For CSP plants that incorporate TES, the thermal storage capacity is provided, in parentheses, in hours.

FIGURE 30. Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2008-2018



Source: See endnote 1 for this section.

South Africa ranked third for capacity additions in 2018. The commissioning of the 100 MW Ilanga-1 plant (4.5 hours TES) increased the country's total operating CSP capacity by just over 30%, to 400 MW.[15] In addition, the 100 MW Kathu Solar Park (4.5 hours TES) was commissioned in early 2019, bringing much-needed dispatchable power onto the country's grid during a period of capacity shortages and rolling blackouts.[16] Nonetheless, the long-term future of CSP in South Africa is uncertain: an updated draft Integrated Resource Plan, released by the government in early 2019, included no allocation for CSP beyond plants that already were under construction.[17]

In Saudi Arabia, operations commenced at the 50 MW Waad al Shamal Integrated Solar Combined Cycle (ISCC) plant, and construction continued at the country's 43 MW Duba 1 ISCC facility.[18] Construction on CSP facilities also was under way elsewhere in the Middle East. Kuwait's 50 MW (10 hours TES) Shagaya plant was expected to reach commercial operation in 2019, and construction began on the United Arab Emirates' 700 MW CSP plant at the Mohammed bin Rashid Al Maktoum Solar Park.[19] In Israel, work continued on the 110 MW (4.5 hours TES) Ashalim Plot A parabolic trough facility, which entered commercial operation in April 2019, and on the 121 MW Ashalim Plot B tower facility, expected to come online later in the year.[20] In total, just over 1 GW of CSP capacity was under construction in the Middle East at the end of 2018.[21]

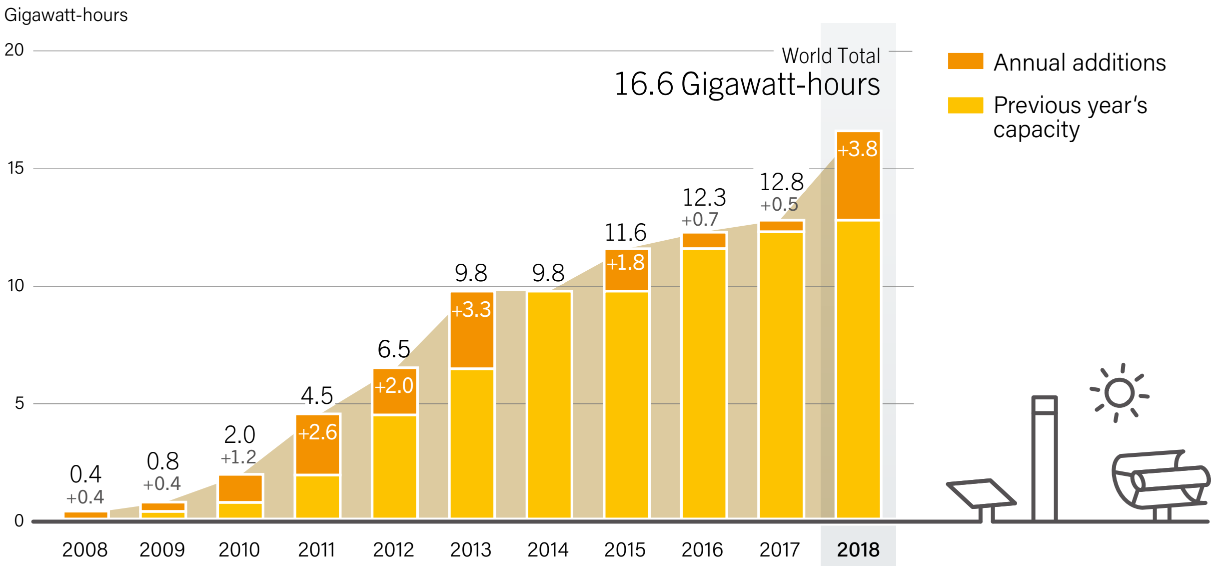
Elsewhere, construction restarted at Chile's 110 MW (17.5 hours TES) Cerro Dominador CSP plant, which was expected to be operational in 2020.[22] Construction had been delayed due to financial challenges at the project's developer and contractor, Abengoa (Spain).[23] In France, the 9 MW eLLO Fresnel facility, under construction at the end of 2018, entered operation in early 2019.[24]

Spain remained the global leader in existing CSP capacity, with 2.3 GW in operation at the end of 2018, followed by the United States, with just over 1.7 GW.[25] These two countries accounted for around 75% of the global CSP capacity in operation at year's end, but no new capacity has entered commercial operation in Spain since 2013 and in the United States since 2015.[26] Neither country had new facilities under construction as of the end of 2018; however, in early 2019 Spain's government announced a target of 5 GW of new CSP capacity by 2030.[27]

Almost 17 GWh[i] of thermal energy storage, based almost entirely on molten salts, was operational in conjunction with CSP plants across five continents by the end of 2018.[28] (→ *See Figure 31.*) With the exception of ISCC plants, all CSP plants that entered operation between the end of 2014 and the end of 2018 incorporated a TES system.[29] TES continues to be viewed as central to the operational value of CSP by enabling it to be a dispatchable source of power, increasing its capacity factor, providing a source of grid flexibility and allowing for the integration of higher shares of variable renewable energy in power systems.[30] (→ *See Systems Integration chapter.*)

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 2018. Individual TES capacities are calculated by multiplying the reported hours of storage for each facility by their corresponding rated/net power capacity in MW.

FIGURE 31. CSP Thermal Energy Storage Global Capacity and Annual Additions, 2008-2018



Source: See endnote 28 for this section.

CSP INDUSTRY

The CSP industry continued to diversify geographically in 2018, with developers and construction companies from a broader range of countries and regions involved in active projects. This followed several years of industry growth outside the traditional CSP markets of Spain and the United States.[31]

The capital costs of building new CSP systems fell sharply between 2016 and early 2018, according to an analysis of 16 CSP deals concluded during this period.[32] Costs declined due to the wider deployment of both tower projects (which offer cost benefits under certain market conditions[i]) and TES, as well as to ongoing innovations in technology and project design, an increase in project size and the emergence of more CSP suppliers (particularly in China), which is driving greater market competition.[33] Procurement mechanisms, including competitive auctions, also have helped reduce costs.[34]

In China, FITs for CSP (which the central government sees as a key energy technology) have supported the development of local CSP skills and processes and allowed for the rapid growth of a new national industry.[35] In 2018, Chinese projects under construction were estimated to be 40% cheaper than facilities being built elsewhere in the world.[36]

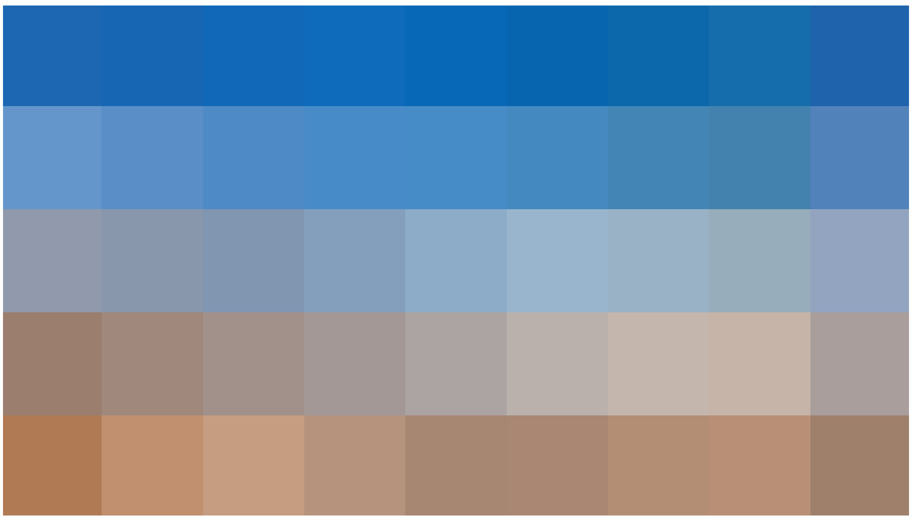
CSP developers have focused on TES due to its potential to improve the operational value of CSP plants.[37] While solar PV with battery storage became increasingly cost-effective in 2018, a study released in early 2019 showed that CSP with TES may be more competitive for long-duration (greater than four hours) storage applications.[38]

No new tenders or auctions for new CSP capacity were finalised in 2018, although the construction contract for what is expected to be the world's largest CSP plant (700 MW) upon completion, in Dubai, was awarded by the Saudi developer ACWA Power to the Chinese firm Shanghai Electric.[39] ACWA Power was the leading CSP project developer globally in 2018, with just over 1 GW of projects either brought into operation or under construction during the year.[40]

At least 14 other developers – including 7 from China and others from France, Israel, Kuwait, Saudi Arabia, South Africa, Spain and the United States – were active on projects completed or under construction in 2018.[41] The leading CSP contractors (ranked in terms of MW completed and/or under construction) included Shanghai Electric (China), Sener (Spain), Abengoa (Spain), Acciona (Spain), SEPCO3 (China), GE Renewable Energy (United States) and TSK (Spain).[42]

Several CSP plants are being built or developed in parallel with solar PV facilities. Hybrid projects that include both CSP and solar PV can allow for lower levelised costs of electricity by using relatively low-cost solar PV generation during daylight hours and CSP with TES for power dispatch at night, or during daylight hours with poor irradiance.[43] Examples include the Mohammed bin Rashid Al Maktoum Solar Park in the United Arab Emirates, where the 700 MW CSP facility is being built next to just over 1 GW of solar PV capacity; and the Cerro Dominador facility in Chile, which is under construction adjacent to an existing 100 MW solar PV plant.[44] In Australia, developers of the Aurora CSP plant applied for a permit in 2018 to build 70 MW of solar PV alongside their planned CSP facility.[45]

Several CSP-related research and development activities were under way during the year, many of which focused on achieving higher operating temperatures in CSP heat exchangers, allowing for higher efficiency and lower running costs. New research support announced in 2018 included USD 72 million in funding from the US Department of Energy for research aimed at developing three competing heat-transfer mediums (liquid, solid and gaseous) intended to work in conjunction with a high-temperature CO_2 power cycle.[46] An alternative to conventional steam-driven power generation, the CO_2 power cycle offers the potential to raise thermal power cycle efficiency as much as 10%.[47] The DOE also announced USD 12.4 million in funding for 15 research projects focused on developing high-temperature components for CSP systems.[48]



The **capital costs** of building new CSP systems fell sharply between 2016 and early 2018.

i For example, tower plants typically can achieve higher specific yield values and hence greater cost efficiency at higher and lower latitudes (greater than approximately 30° to 35° south or north). See endnote 33 for this section.

SOLAR THERMAL HEATING AND COOLING

SOLAR THERMAL HEATING AND COOLING MARKET

Solar thermal technologies are used extensively in all regions of the world to provide low-temperature heat for hot water, space heating and drying. Increasingly, industries, hospitals, hotels, laundries and other large heat consumers are turning to solar thermal systems to meet their needs for high-temperature heat, steam and refrigeration.

By the end of 2018, residential, commercial and industrial clients in 130 countries benefited from solar heating and cooling systems.[1] Glazed (flat plate and vacuum tube) and unglazed solar thermal systems combined provided around 396 TWh (1,426 PJ) of heat annually – equivalent to the energy content of 233 million barrels of oil.[2] Cumulative global operating capacity for these collector types reached an estimated 480 GW_{th} at year's end, up almost 2% from the previous year's total of 472 GW_{th}.[3] (→ *See Figure 32* and ***Reference Table R19***.)

Globally, 33.3 GW_{th} of solar thermal capacity was added in 2018, down 4% from the 34.6 GW_{th} newly installed in 2017.[4] The decline is attributed to reduced demand for residential systems in China, which continued to be the world's largest national market for solar thermal systems.[5] Although China still dominated gross additions (accounting for 74%), the country's demand for residential solar water heaters – the core sales segment of the solar thermal sector for at least a decade – dipped 44% between 2015 and 2018 because of market saturation and reduced construction activities.[6] The growth in China's so-called engineering segment, which includes hot water systems in multi-family homes, public buildings, and tourism and industrial facilities, did not offset the strong decrease in the residential market.[7]

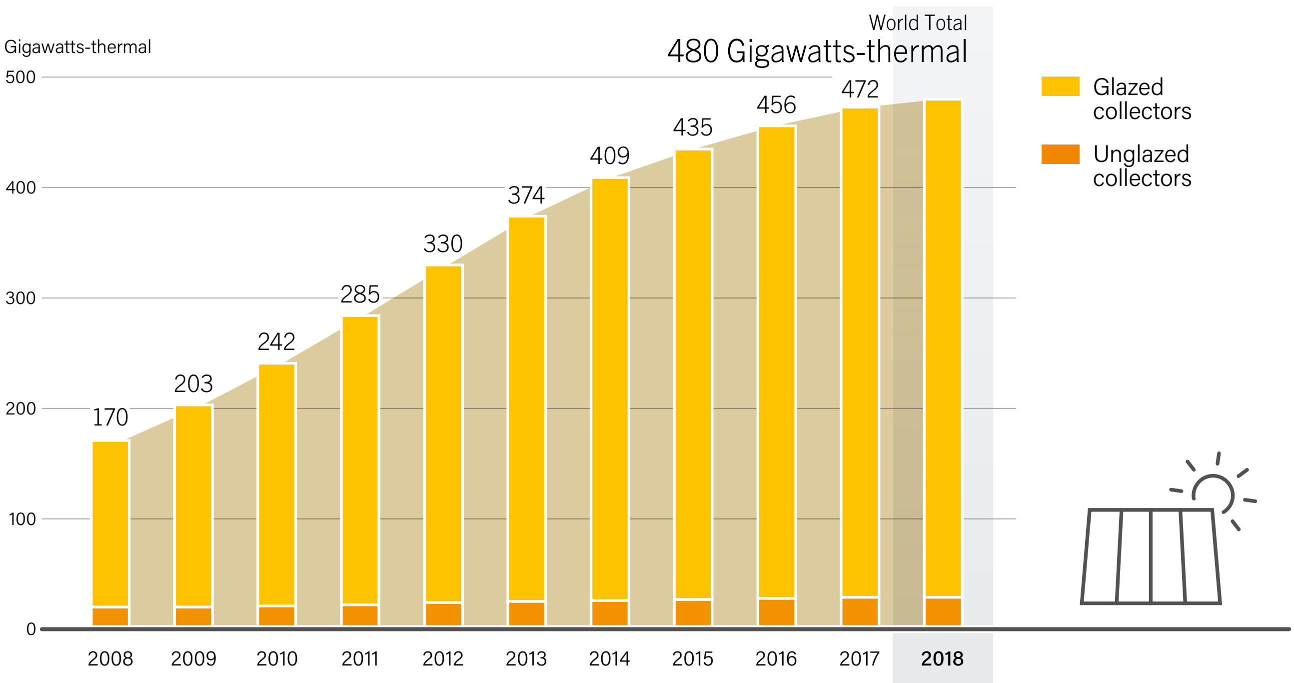
Gross additions in China during 2018 were 24.8 GW_{th}, down 5% from the previous year (26.1 GW_{th}).[8] (→ *See Figure 33.*) The remaining countries among the top 20 for newly installed solar thermal capacity added a combined total of 6.5 GW_{th}, 4% more than the 2017 volume of 6.3 GW_{th}.[9] The top 20 countries for new installations comprised around 94% of the global market in 2018.[10]

While China's market continued to contract, important markets in several regions increased their annual installations relative to 2017. These markets included Australia (up 2%), India (17%), Mexico (4%), South Africa (2%) and, more notably, several countries in Europe: Cyprus (5%), Denmark (128%), France (2%), Greece (4%), Poland (179%) and Spain (2%).[11] Overall, annual installations in 2018 rose in 10 of the world's 20 largest markets – a positive development compared with 2017, when only 6 of the largest markets reported sales increases.[12]

Turkey, India, Brazil and the United States were again the leaders in new solar thermal installations, after China[i,13] Australia overtook Germany to rank sixth, and Germany fell to seventh place due to a steadily shrinking national market.[14] The list of the top 20 national solar thermal leaders remained largely unchanged in 2018, with

i Year-end 2018 data for cumulative capacity in operation are not available for countries other than China.

FIGURE 32. Solar Water Heating Collectors Global Capacity, 2008-2018



Note: Data are for glazed and unglazed solar water collectors and do not include concentrating and air collectors.

Source: IEA SHC. See endnote 3 for this section.

some exceptions: Denmark and Cyprus (despite its small size) joined the ranks of the top 20 countries, while Chinese Taipei and Japan dropped off the list.[15]

Vacuum tube collectors accounted for 72% of the capacity added globally in 2018 (down from 73% in 2017); they represented more than 80% of new installations in China and India, and 50% of the market in Turkey.[16] Flat plate collectors had a 24% share (up from 23% in 2017) and were the dominant technology in the largest European countries.[17] Unglazed collectors, which are commonly used to heat swimming pools, remained unchanged at 4% of the market and accounted for more than a third of new installations in Australia, Brazil, South Africa and the United States.[18]

The Chinese market continued to transition from vacuum tube collectors towards flat plate systems, even though vacuum tubes still accounted for most of the newly installed capacity.[19] China's market for vacuum tube collectors contracted a further 7% relative to 2017, while new flat plate collector area was up 3%.[20] Sales of flat plate collectors have been driven by building codes that mandate the use of solar thermal systems (and heat pumps) in new construction and major renovations as means to reduce local air pollution.[21] These regulations have increased the demand for façade- and balcony-integrated applications, where flat plate collectors have been a preferred solution compared to vacuum tube collectors.[22]

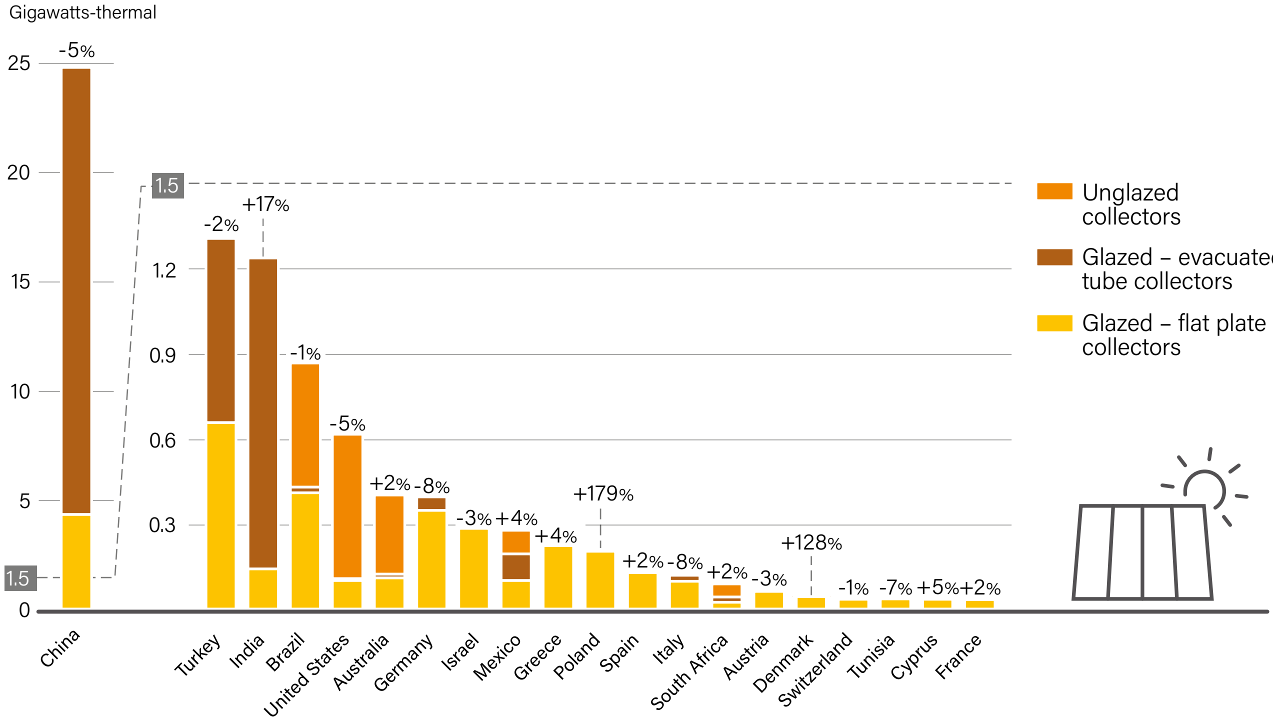
Solar space heating and solar process heat are among the technologies explicitly mentioned in China's 13th Five-Year Plan (2016-2020) as options for combatting air pollution. Northern provinces, including Beijing, Hebei and Shandong, responded by implementing subsidies that target the deployment of residential and commercial solar thermal systems.[23] Incentives are linked to the volume of hot water that a given solar thermal system can produce, and cover 20-40% of investment costs, greatly shortening payback periods and driving demand for solar thermal systems in construction and manufacturing.[24]

China's market for
solar industrial heat
is driven by policies to combat air pollution.

At the end of 2018, China's cumulative solar thermal operating capacity was an estimated 338 GW_{th}, or around 70% of the world's total.[25] China's cumulative capacity increased only 1% in 2018 because replacement of the systems (87%) dominated gross additions.[26] A typical Chinese-made system lasts around 10 years, so only 13% (3.1 GW_{th}) of China's 2018 sales contributed to increasing total operating capacity.[27]

In Turkey, uncertainty about the economy, the national currency and the domestic construction market slowed market growth.[28] Installations were down 2%, to 1.3 GW_{th}, following a modest increase of 4% in 2017.[29] A 48% decline in construction permits as well as relatively high interest rates resulted in lower sales of solar thermal collectors in 2018.[30] The volume was down

FIGURE 33. Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2018



Note: Additions represent gross capacity added.

Source: See endnote 8 for this section.

Sales increased in most of the largest solar thermal markets outside China.

for both vacuum tube collectors, which were used in Turkey´s colder regions (such as middle and eastern Anatolia), and flat plate collectors, which were installed in commercial projects at schools, dormitories, military stations and prisons.[31]

For the second year in a row, India ranked third globally for new installations.[32] The volume of sales was up significantly (17%) over 2017, bringing new solar thermal installations to just below 1.3 GW_{th} in 2018.[33] Market development remained below expectations, however, in part because the Indian government prioritised the deployment of solar power capacity during 2018, and new policies to support solar thermal systems were lacking.[34]

India's demand for vacuum tubes rose in 2018, with imports[i] from China reaching 5.8 million tubes, up 27% over 2017.[35] This increase was due to low prices of raw materials and to the resulting cost advantages of vacuum tubes compared to flat plate collectors. By contrast, flat plate collector sales in India dropped 46% (147 MW_{th}) from their peak in 2017 (278 MW_{th}).[36] The reduced demand for flat plate collectors was attributed to price increases that resulted from rising prices for copper and glass covers, both of which are key system components.[37]

Brazil added 0.88 GW_{th} of solar thermal capacity in 2018, slightly below 2017 levels.[38] The main reason for the decline (of roughly 1%) was a slowdown in implementation of the country's social housing programme, due to a lack of public funding.[39] From 2009 to 2015, before Brazil's financial crisis, the programme effectively drove the country's solar heat sector by mandating the installation of solar water heaters in housing constructed for low-income families.[40] The market contraction also was due to uncertainty surrounding Brazil's 2018 presidential campaign and the election process, which constrained spending in private households, still the country's dominant market segment for solar thermal systems.[41]

The Brazilian city of Belo Horizonte, which has installed more than 3,500 solar water heating systems in blocks of flats over the past two decades, further strengthened its position in 2018 as the country's solar city.[42] In August, Brazil's largest tennis and sports club, located in Belo Horizonte, commissioned a flagship 2.3 MW_{th} project that is expected to provide 70% of the club's water-heating demand.[43]

The United States ranked fifth for solar thermal sales in 2018 (totalling 623 MW_{th}) and remained the world's largest market for unglazed collectors, followed by Brazil (439 MW_{th}) and Australia (280 MW_{th}).[44] The unglazed segment accounted for 82% of US additions during the year, with 511 MW_{th} added (down 5% from 2017).[45] Both glazed and unglazed collector segments fell short of their 2017 volumes due to relatively low oil and gas prices and an increasing focus on solar electricity instead of heat.[46]

For the first time, Australia rose to rank sixth among the largest global markets. Unglazed collectors continued to dominate the Australian solar thermal market, which has fluctuated at around 280 MW_{th} every year since 2013.[47] Preliminary numbers suggest a modest upward trend in the market for glazed collectors, with new installations totalling around 128 MW_{th} (up 6%).[48] The key market driver was again the national renewable energy target, which allows electric utilities to purchase small-scale renewable technology certificates to meet their obligations.[49] Residential and commercial solar hot water systems with glazed collectors of any scale are eligible for these certificates, and thus system owners can reap benefits beyond energy cost savings.[50]

Germany, Greece, Poland, Spain and Italy were Europe's top five solar thermal markets in 2018.[51] Germany's solar thermal additions of 401 MW_{th} were down 8% relative to 2017.[52] The market decrease was a result of the generally low rate of refurbishment of old heating systems, the still relatively high cost of residential solar thermal systems and the high demand for heat pumps, particularly in new construction.[53]

Poland broke all records with its 179% increase in solar thermal installations relative to 2017, which was a weak year due to delays in tender processes.[54] New installations of 217 MW_{th} in Poland in 2018, approached the level of Greece.[55] Poland's emissions reduction programme – which aims to improve local air quality – drove the country's solar thermal market by providing municipalities with support for the installation of more-efficient solar thermal and biomass heating systems.[56] Several municipalities awarded contracts for tenders that were issued under the policy in 2017, yielding hundreds of new residential solar water heater installations.[57] However, the tenders also spurred fierce competition in system prices and did not achieve sustainable market development for solar thermal systems.[58]

i In an early-2018 consultation with policy makers, solar thermal industry representatives pointed out that India's increasing reliance on imported solar thermal technologies undercut the government's ongoing "Made in India" campaign and reduced domestic employment. The government had yet to introduce any measures to address the issue as of end-2018.

Greece, meanwhile, has seen steady growth year-on-year. In 2018, Greece added more systems than ever before with an added capacity of 230 MW_{th}.[59] Market growth has been based on attractive product pricing of solar thermal systems relative to other water heating technologies (driven by electricity and fossil fuels), as well as on a building regulation that stipulates a minimum 60% solar share in hot water production for new buildings.[60] Another driver in 2018 was the Energy Savings in Households programme, which provided low-income families with grants that cover 60% of the investment costs of solar water heaters.[61]

Export volumes of the Greek solar thermal industry also reached a new record in 2018 (391 MW_{th}), benefiting from increasing demand in emerging markets worldwide.[62] Top export regions included southern Europe (Italy and Spain), North Africa (Egypt, Morocco and Tunisia), the United Arab Emirates and the Caribbean.[63]

The United Arab Emirates remained an attractive market – the result of continuing regulations in some emirates that require solar thermal installations on new construction.[64] For example, Dubai's solar thermal obligation had a positive impact on local demand[i] for solar water heating systems in 2018.[65] The emirate mandates that solar energy provide at least three-quarters of the annual hot water needs in any new building owned by a single individual, including hotels, worker dwellings, private villas, shopping malls and public buildings.[66]

Several other Arab states and parts of Africa – including Kenya, Morocco, Saudi Arabia, South Africa and Uganda[ii] – also have thriving residential solar thermal markets.[67] Morocco's high reliance on imported fossil fuels, which supply 95% of the country's energy needs, and its rapidly increasing energy demand have sparked interest in solar thermal and other renewable energy options.[68]

Kenya first grabbed the attention of solar water heater manufacturers in 2012, when it introduced a favourable new building regulation.[69] Kenya imported more than 1,360 solar water heaters in 2016 and early 2017 under this rule, which stipulated that building owners and contractors must purchase solar thermal systems to supply at least 60% of the hot water in new, expanded, or renovated commercial or residential buildings that use more than 100 litres of hot water per day.[70] Demand slowed in the second half of 2018 because Kenya's parliament suspended the regulation in August as a consequence of several weaknesses in the rules.[71]

To the west, Rwanda's long-standing SolaRwanda programme kept the country on the industry's radar in 2018. The subsidy programme reduces the cost of solar hot water heaters via a combined investment grant and loan.[72] Between 2011 and the end of 2018, SolaRwanda supported 3,400 installations, and in 2018 the government began the process of renewing the programme for a second phase.[73]

Around the world, customers are increasingly demanding better system design and overall quality for tank and collector units placed on roofs.[74] In response to customer demand, a growing number of solar thermal manufacturers now equip their products with electric elements, guaranteeing hot water in all weather conditions.[75]

Although most solar thermal capacity continued to be installed as solar water heaters in individual buildings, large commercial and industrial clients around the globe showed an increasing interest in solar heat during 2018. At least 37 new large-scale solar thermal systems plus 6 extensions (each greater than 350 kilowatts-thermal (kW_{th}), or greater than 500 square metres (m^2) with glazed and concentrating collectors were commissioned in 2018 to feed heat to district heating networks or to provide space heating for large residential, commercial and public buildings.[76] This represented a significant increase compared to 17 systems plus 3 extensions of this type reported a year earlier.[77] (→ *See Figure 34.*) The number of new large-scale systems in Europe was up from 10 in 2017 to 16 in 2018, and installations in the rest of the world increased from 7 (2017) to 21 (2018).[78]

i Sales data for solar water heaters in the United Arab Emirates were unavailable as of end-2018.

ii These countries were named most frequently by solar water heater suppliers when asked for the key export markets in Africa and the Gulf region in the next few years.

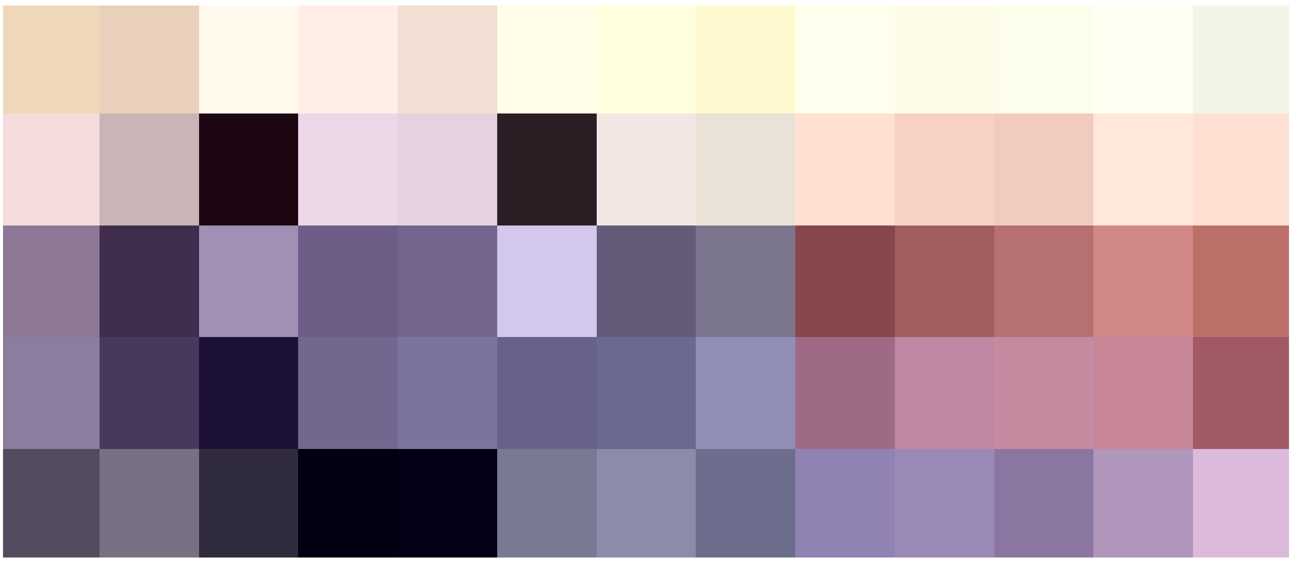
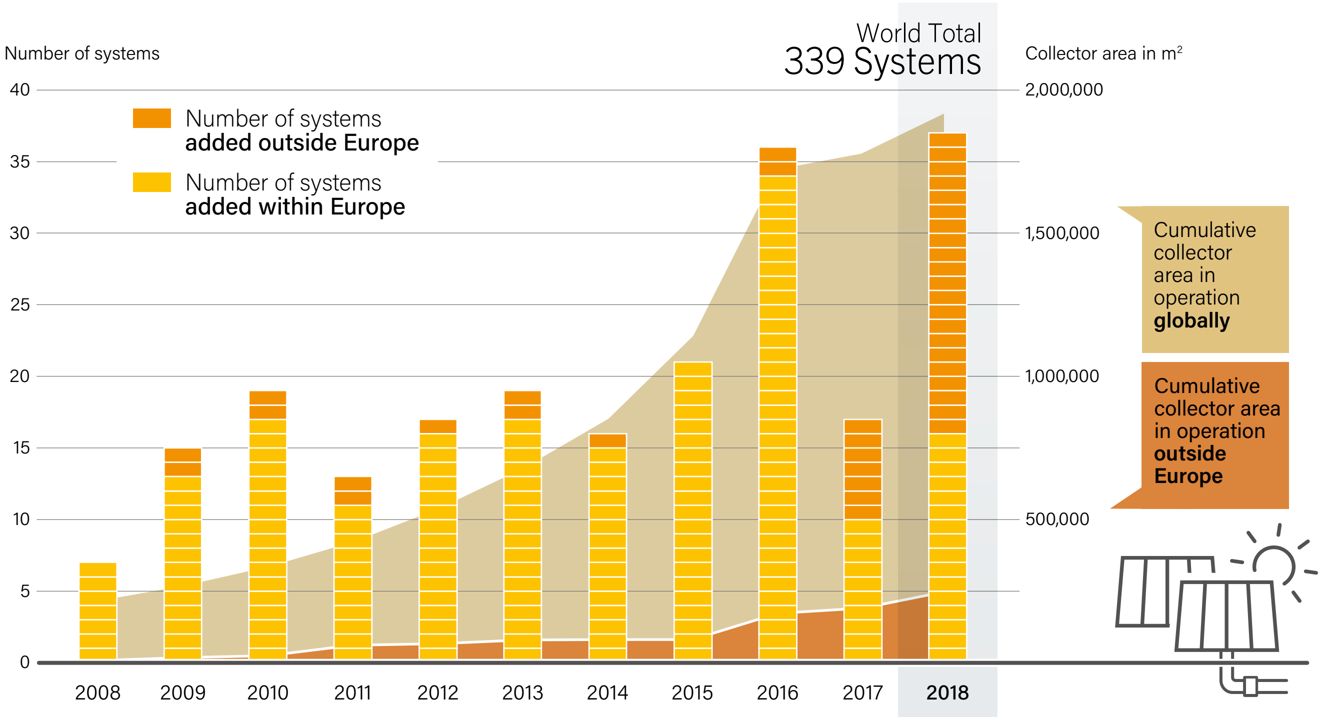


FIGURE 34. Solar District Heating Systems, Global Annual Additions and Total Area in Operation, 2008-2018



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 77 for this section.

These numbers include only projects reported by the larger technology suppliers. The actual market volume in 2018 for megawatt-sized systems in 2018 was likely much larger for two reasons: some investment subsidy schemes did not publish data about commissioned systems that received public funding, and new large-scale solar thermal systems in Turkey were not tracked[i] because they were realised on a purely commercial basis, without subsidies.[79] Globally, at least 339 large-scale solar thermal systems were in operation by the end of 2018, for a total of 1.35 GW_{th}.[80]

In 2018, most large-scale systems were installed with the help of investment subsidy programmes, such as those in Germany, the Netherlands, Jordan and some Chinese provinces (for example, Tibet and Shandong).[81] In Germany, five villages added solar fields (totalling 5.9 MW_{th}) to new or existing mostly biomass-fired district heating systems, a significant increase over the years 2017 and 2016, each of which saw only one large field commissioned.[82] In the Netherlands, large heat consumers have been attracted to solar thermal in response to the renewable feed-in tariff scheme, and in 2018 the first phase of a large-scale collector field (4.9 MW_{th}) was commissioned to heat the greenhouses of a freesia grower.[83] In Jordan, the first demonstration plant (0.8 MW_{th}) for a public hospital began operating in June; the system is expected to provide 10% of the hospital's annual heat requirement.[84]

The Chinese central government provided 100% funding for at least two solar district heating plants in Tibet, following feasibility studies in more than 20 Tibetan counties and towns during 2017.[85] One of these plants was a 14 MW_{th} flat plate collector field (with 15,000 cubic metres (m^3) of pit storage) that began operating in late 2018; it is expected to meet 90% of the space heating requirements in the connected households, with a combined floor area[ii] of at least 82,000 m^2.[86] By year's end, construction was under way on a second such plant in Tibet, using parabolic trough collectors (12.6 MW_{th}).[87]

Recognising that solar thermal district heating is one of the most cost-effective ways to decarbonise the heating sector, sustainability-conscious utilities have started planning or constructing megawatt-sized plants in new markets. In Latvia, for example, a 15 MW_{th} solar collector plant combined with a biomass boiler was under construction to provide sustainable heat for nearly 15,000 inhabitants in the town of Salaspils.[88] In Alcalá de Henares, Spain, some 12,000 families should benefit from stable heat prices guaranteed by a new concentrating solar heat plant (14 MW_{th}).[89] Both the Latvian and Spanish plants were expected to be commissioned in 2019.

Also in 2018, an important milestone was reached for the project Big Solar, a planned 154 MW_{th} solar field with 0.9 million m^3 of seasonal storage for district heating that will be constructed in the Austrian city of Graz.[90] Land-use restrictions around densely populated cities represent some of the greatest barriers to development of solar systems for district heating. In Graz, the

i A 3.2 MW_{th} installation for a prison in Ankara is the only new installation in Turkey that is included in Figure 34.

ii In China, demand in district heating networks usually is described by heated floor area, whereas in Europe demand generally is described by the number of households/buildings connected to the network.

The **top markets** for concentrating heat technologies in 2018 were China, Mexico, India and Turkey.

local utility was able to secure 11 hectares of land for the seasonal storage, and another 30 hectares (in a water protection zone near the city) was contracted for the collector field.[91]

In addition to providing heat for buildings, solar thermal energy is being used increasingly for production processes in factories. In 2018, at least 104 manufacturing businesses commissioned solar heat for industrial processes (SHIP) installations, raising the world total by 16% to at least 736 SHIP systems in operation by year´s end.[92] The leading markets in the number of new installations were Mexico (51 systems), China (15), India (10) and Germany (9).[93] SHIP systems were installed in an additional 13 countries worldwide during the year.[94]

The SHIP capacity added in 2018 was much smaller (40 MW_{th}) than in the previous year (134 MW_{th}), in part because US-based project developer Glasspoint postponed the commissioning of additional parabolic trough collector arrays, which it had intended to install during 2018 in greenhouses at the solar steam plant near the Aman West oilfield in Oman.[95] In 2017, the company brought online the first four units with 100 MW_{th} of capacity and announced another 200 MW_{th} to be put online at a later date.[96]

In 2018, demand from manufacturing businesses in Shandong (China) was driven by the provincial subsidy scheme covering 20-40% of the investment costs of large-scale solar thermal systems for industry, hospitals and schools.[97] Among the 146 subsidy applications submitted as of March 2018, there were proposals for 34 new SHIP plants.[98] These plants included the largest SHIP system commissioned in 2018, with 4.2 MW_{th} supplying process heat to a poultry factory.[99]

Despite the growing interest in new SHIP plants, the number of sales contracts for SHIP installations that were concluded in 2018 remained below industry expectations.[100] Factors stalling growth included the challenge of achieving cost-competitiveness against still low oil and gas prices in many countries, difficulty in obtaining financing and a lack of awareness of solar thermal technology among manufacturing businesses.[101]

To produce heat or steam for processes above 100°C, as well as for steam networks in hospitals or district heating, solar thermal systems require the use of concentrating collector technologies. In 2018, the capacity of new installations with concentrating collectors fell sharply, to 27 MW_{th}, down from 143 MW_{th} in 2017 (when Oman added 100 MW_{th} in just one project).[102] The top markets for concentrating heat technologies in 2018 were China (13 MW_{th}), Mexico (4 MW_{th}), India (3 MW_{th}, including 1.9 MW_{th} for commercial cooking) and Turkey (3 MW_{th}).[103] Parabolic trough collectors were the dominant technology, with a market share of 85% of the new concentrating solar thermal capacity; only a few systems were installed with dish technology (all in India) and two with linear Fresnel collectors.[104]

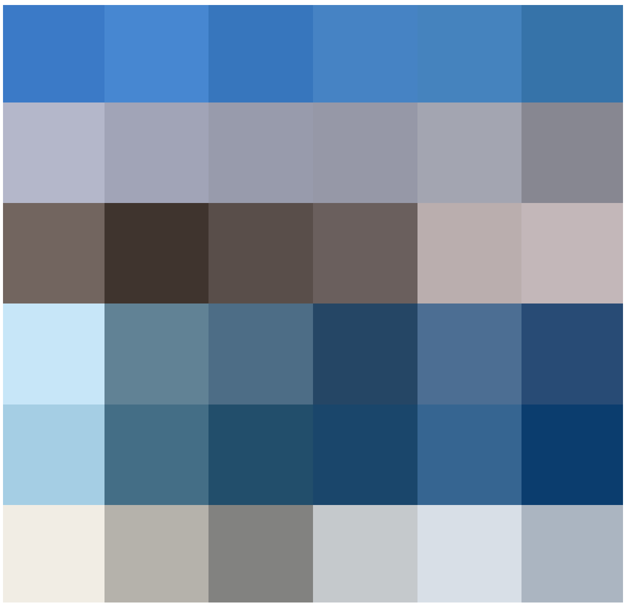
SOLAR HEATING AND COOLING INDUSTRY

The solar thermal industry includes companies that manufacture a range of different technologies (glazed flat plate and vacuum tube, and unglazed) as well as companies that offer different system types, such as small hot water systems for buildings, large fields for district heating, integrated solutions for industrial process heat, and solar cooling systems. Business development in 2018 depended largely on companies' portfolios and locations.

The handful of unglazed collector manufacturers around the world experienced another year of flat sales and continued to focus on the same countries as in past years – primarily Australia, Brazil, Mexico and the United States. The manufacturers of glazed collectors focused mainly on China and India for the production and sale of vacuum tube collectors (which accounted for more than 80% of glazed collector sales in those countries) and on all other large markets for flat plate collectors.

China's ongoing transition from vacuum tube technologies to flat plate collectors resulted in increased production volumes for domestic flat plate collector manufacturers in 2018, and ongoing consolidation for manufacturers of vacuum tube collectors.[105] At year's end, the number of manufacturers of solar thermal collectors as well as producers of related components was estimated to be 450, a large decline from the approximately 2,000 solar thermal manufacturers that were counted in 2012.[106]

For the second consecutive year, Chinese companies dominated the ranking of the world's largest manufacturers of flat plate collectors, holding the top five positions. Heading the list was Sunrise East Group (including the Sunrain and Micoe brands), followed by Haier[i], Jinheng Solar (with its export Brand BTE Solar), Five Star and Linuo Paradigma.[107] The key market for flat plate collectors is the residential high-rise construction industry, which mounts the collectors on the balconies of buildings.[108] In response to the high demand in China for these systems, both Jinheng Solar and Linuo Paradigma upgraded their automated production lines for flat plate collectors in 2018.[109]



i Haier has been the majority owner of the Austrian company GREENoneTEC since May 2017.

In Europe, for the largest flat plate collector manufacturers, business development depended largely on location. Although the three German manufacturers (Bosch, Viessmann and Vaillant) reported declining sales (down 8% on average) due to the continuing contraction of the German solar thermal market, large solar collector manufacturers based in Greece, Poland and Spain had a strong year.[110]

Dimas, the top Greek manufacturer, enlarged its production volume 13% due to rising demand in the Middle East and to new markets in Latin America (particularly in Central America).[111] Total exports from Greece's collector industry rose 20% in 2018, to 391 MW_{th} (following a 41% increase in 2017), due to cost-competitiveness as well as good quality and product reputation.[112] Exports of Greek collectors far exceeded domestic sales (230 MW_{th}).[113]

Favourable market conditions benefited the Polish flat plate collector manufacturer Hewalex, which more than doubled its sales in 2018 compared to the previous year.[114] The company delivered around 4,300 residential solar water heater systems to seven municipalities that were included in Poland's Clean Air priority programme.[115] Spain's three leading collector manufacturers (BDR Thermea/Baxi, Delpaso Solar and Termicol) increased their exports in 2018, to 95 MW_{th} (up 8%), profiting from rising demand in southern Europe, Morocco and the United Arab Emirates.[116]

Arcon Sunmark of Denmark, despite being in a low position among all flat plate collector manufacturers, regained its lead as a developer of solar district heating installations in 2018, following a financially difficult year in 2017. In addition to the above-mentioned 15.6 MW_{th} solar district heating plant in Tibet, the company commissioned seven systems in Denmark and one each in Germany and Austria (totalling 41 MW_{th}).[117]

Beyond the flat plate collector industry, several developers of concentrating solar thermal projects secured new deals in 2018. US-based Glasspoint, which first developed the 1 GW_{th} Miraah project in Oman in 2016 and the 850 MW_{th} Belridge project in California in 2017, signed a memorandum of understanding with the oil producer Occidental of Oman in 2018 to deliver a solar steam-producing system. For this second project in Oman, Glasspoint will install parabolic trough collectors with a total capacity of 2 GW_{th} in greenhouses (to protect the collectors from sand and dust) at Oman's Mukhaizna oil field.[118]

On a smaller scale, the parabolic trough collector manufacturer Rackam (Canada) signed a contract in 2018 to develop Brazil's first medium-temperature large-scale solar heat installation, a 8.3 MW_{th} collector field based at a farm.[119] Parabolic trough collectors were the dominant technology for solar process heat in 2018, offered by at least 16 collector manufacturers, followed by linear Fresnel (7) and dish (3) technologies.[120]

Around the world, solar thermal companies announced a number of new megawatt-size systems in 2018, pointing to the rising interest in solar thermal energy as a source of heat for large commercial and industrial clients.[121] A key challenge that the industry has faced with this customer group, however, is the expectation that such systems will have short payback periods.[122]

To respond to this challenge, several technology suppliers began offering solar heat supply contracts in 2018, rather than selling turnkey hardware solutions.[123] This business model, in which technology suppliers become energy service companies (ESCOs), avoids the high upfront costs to clients and reduces the client risk associated with a new industrial solar heat solution. The ESCO retains ownership of the solar thermal system and operates and maintains the installation over a specific contract period.[124]

Solar heat **supply contracts** are a favoured business model for commercial clients.

Three key trends drove the growth of ESCOs in the solar thermal supply chain in 2018. First, several established suppliers of solar thermal technologies – such as Modulo Solar (Mexico), Linuo Paradigma (China) and Millennium Energy Industries (Jordan) – added heat supply contracts to their portfolios.[125] Second, a number of start-up companies emerged with a focus on the contracting of commercial and industrial heat supply, and, third, renewable financing facilitators broadened their sales strategies beyond electricity to include thermal energy.[126]

The French start-up newHeat, founded in December 2015, secured two ESCO solar heat projects in 2018. After signing a 20-year contract to supply solar process heat to a paper mill in Dordogne (France), newHeat began operating a 2.9 MW_{th} collector field at the site in late 2018.[127] In the second project, newHeat developed a 12 MW_{th} industrial heat supply system together with Kyotherm, a French third-party equity investor that recently broadened its portfolio to include heat supply contracts. The project received pre-approval for funding in 2018, and newHeat signed a 20-year heat purchase agreement with the industrial client, a malting factory in France.[128]

Elsewhere in Europe, the start-up company SWA Solar Wärme Austria developed its first ESCO project in September 2018, installing a solar heat collector field on the roof of a golf club in southern Austria.[129] The solar heat ESCOs have noted that the existence of standardised heat supply contracts is an important means to increase deployment of this business model.[130]

Reducing system costs is one of the most urgent challenges facing the solar thermal industry, especially in western Europe, where these costs are still relatively high. During 2018 and early 2019, collector manufacturers and system suppliers launched several innovations that improve the cost-effectiveness and design of their products. For example, Dutch-based HRsolar began manufacturing a completely black collector on a fully automated production line.[131] The panel is insulated with noble gas (rather than an insolation material at the back of the collector) between the glass and the absorber, allowing for a reduction in thickness (to 40 millimetres), and the panel can be combined aesthetically with solar PV panels on rooftops.[132] The Spanish startup Solatom started marketing a transportable, pre-assembled linear Fresnel collector (20 kW_{th}) that provides steam at up to 300°C.[133] Early in 2019, Austria's GREENoneTEC launched a new integrated storage collector (Sunpad) that minimises material costs, enabling the company to reduce the retail price by one-third compared to its previous model.[134]

Prices of installed commercial and industrial systems have declined in recent years due to scale and standardisation in the supply chain, as some best-practice examples from 2018 demonstrate. In Denmark, investment costs for collector fields larger than 7 MW_{th} and on green spaces were benchmarked at EUR 200 (USD 229) per m^2 in 2018.[135] The Swedish manufacturer Absolicon optimised its parabolic trough collector at a field price of EUR 220 (USD 252) per m^2, and the system delivers steam up to 150°C.[136] Solutions that were engineered to meet the specific needs of commercial customers – including storage tanks and the integration of solar systems into existing heat supply networks – were realised at EUR 630 per m^2 (USD 721 per m^2) (Sunoptimo, Belgium) and USD 618 per m^2 (Millennium, Jordan).[137]

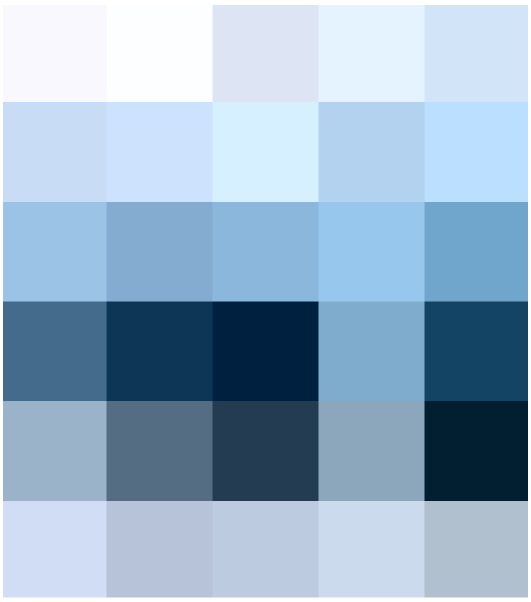
Cost-saving strategies of solar thermal manufacturers concern not only product design, manufacturing and installation, but also certification, which increasingly is being driven by government incentive programmes. Membership in the Global Solar Certification Network (GSCN), which launched in 2016, enables collector producers to receive certification in more than one region based on the same test report, thus saving them time and money.[138] During 2018, the number of GSCN applications from industry, certification bodies and test labs continued to rise.[139]

GSCN's work is based on the global standard for collector testing, which was approved in 2013. The standard marked a milestone for the solar thermal sector because it formalised globally accepted collector testing procedures and included testing methodologies for a number of additional collector types, such as air heating collectors and concentrating medium-temperature collectors. The Solar Keymark, which is based on the global standard, issued its first certificate in 2018 for a concentrating solar collector panel produced by Absolicon.[140]

In addition, the Solar Heating Arab Mark and Certification Initiative (SHAMCI), one of the recognised certification schemes within the GSCN, signed a co-operation agreement with Jordan in 2018 to promote the SHAMCI quality mark in the country.[141] As a result, the Jordan Standards and Metrology Organization became the second certification body in the 17-country Arab region to accept the SHAMCI quality mark for solar thermal products (the first was the Egyptian General Organization for Standardization and Quality (EOS), in 2017).[142]

Suppliers of solar thermal cooling systems had another difficult year in 2018, due to low demand. Solar heat-driven cooling systems in many cases were not cost-effective compared to gas-driven heat pumps or electricity-driven compression chillers, both of which are established technologies for air conditioning.[143] Even so, a handful of solar thermal cooling system suppliers established a market presence and commissioned several commercial systems around the world.[144] Among these system suppliers are S.O.L.I.D. (Austria), VSM Solar (India), Shuangliang (China), Maya (joint venture with Yazaki, Japan) and Solarinvent (both Italy) as well as three German companies, Fahrenheit, Industrial Solar and Invensor.[145]

Italy was the most attractive market for solar cooling solutions in 2018, due to the high investment subsidies under the national Conto Termico 2.0, and the country saw a total of five new systems installed in office buildings and relatively large residential buildings during the year.[146] Yet, some solar system suppliers realised publicly effective reference projects in new markets around the world. For example, in February, S.O.L.I.D. inaugurated the largest solar thermal cooling system of the year (880 kW of cooling) at IKEA in Singapore.[147] In April, the German-Indian joint venture VSM Solar delivered and installed the first-ever solar cooling system (528 kW of cooling) mounted on an Indian government building.[148] Also in 2018, Fahrenheit successfully deployed seven new sorption cooling systems in several countries, including Austria, Germany, the Netherlands, Saudi Arabia and Spain.[149] At the end of 2017, Industrial Solar started operating a 700 kW_{th} Fresnel collector field for air conditioning and process heat at the pharmaceutical company Ram Pharma in Jordan.[150]



WIND POWER

WIND POWER MARKETS

The global wind power market continued to be fairly stable in 2018, with about 51 GW of capacity installed worldwide (including nearly 47 GW onshore and 4.5 GW offshore), down approximately 4% from 2017.[1] Onshore installations accounted for all of the market decline.[2] This was the fifth consecutive year with annual additions exceeding 50 GW, but also the third year of decline following the peak in 2015, when China alone installed more than 30 GW in advance of policy changes.[3] The additions in 2018 pushed cumulative capacity up 9% to 591 GW, with about 568.4 GW onshore and the rest operating offshore.[4] (→ *See Figure 35.*)

Following a record year for wind power in Europe and India in 2017, both markets contracted in 2018, but notable growth occurred in several other regions and countries.[5] Emerging markets across Africa, Southeast Asia, Latin America and the Middle East together accounted for nearly 10% of new installations, up from 8% the previous year.[6] New wind farms reached full commercial operation in at least 47 countries during 2018, and at least 3 countries (Bosnia and Herzegovina, Indonesia and Kosovo) brought online their first commercial projects.[7] By year's end, the number of countries that had developed some level of commercial wind power capacity was at least 103, and 33 countries – representing every region – had more than 1 GW in operation.[8]

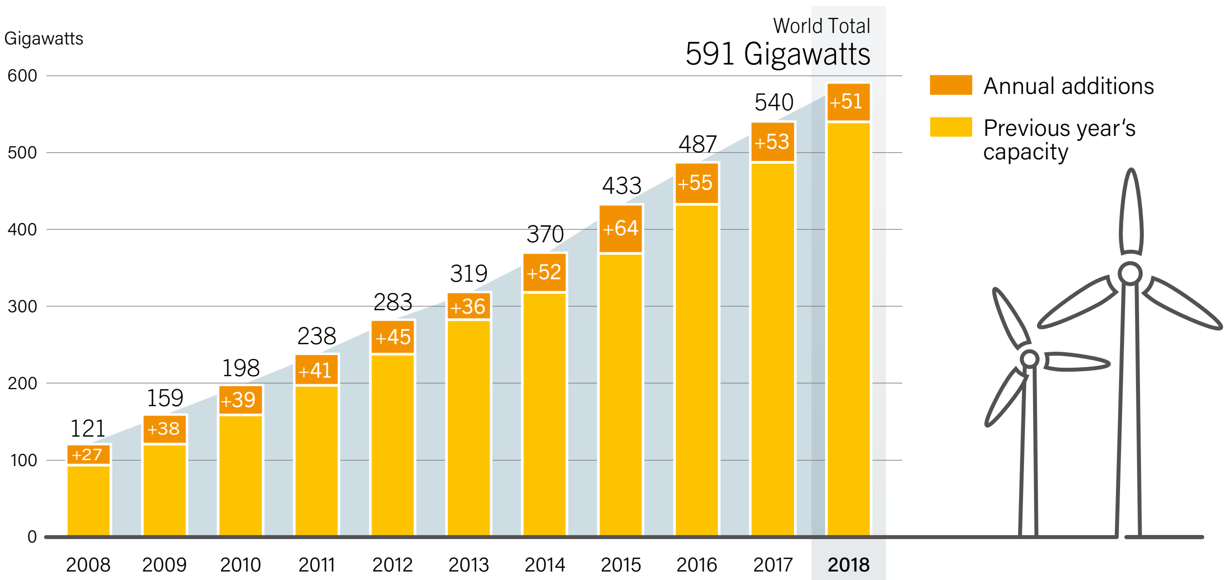
Rapidly falling costs per kilowatt-hour (both onshore and offshore) have made wind energy the least-cost option for new power generating capacity in a large and growing number of markets around the world.[9] As a result, the economics of wind energy have become the primary driver for new installations.[10] Outside of China (with a FIT) and the United States (tax credits), most of the global demand in 2018 resulted from tenders and other market-based policies.[11]

Targets for renewable energy and for reductions in CO_2 emissions also continue to be important drivers of wind power deployment, as they are for other renewable sources.[12] Also significant is the need for bulk power at a low price to meet rapidly rising electricity demand or to replace coal and nuclear power capacity as it comes offline.[13] Corporate PPAs are playing an important role in mature markets: new PPAs during 2018 – mostly in North America (60%) and northern Europe – were up more than 64% compared with 2017, to nearly 6.4 GW.[14]

Wind power provides a substantial share of electricity in a growing number of countries. In 2018, wind energy covered an estimated 14% of the EU's annual electricity consumption and equal or higher shares in at least six individual member states, including Denmark, which met 40.8%[i] of its annual electricity consumption with wind energy.[15] At least 12 countries around the world met 10% or more of their annual electricity consumption with wind energy in 2018, and some – including Costa Rica, Nicaragua and Uruguay – have seen rapid increases.[16] In Uruguay, the share of generation from wind energy rose more than five-fold in just

i Wind power accounted for 48% of net generation in Denmark during 2018 (see endnote 15). There is a difference between generation (electricity produced within a country's borders) and consumption due to imports and exports of electricity and to transmission losses.

FIGURE 35. Wind Power Global Capacity and Annual Additions, 2008-2018



Source: GWEC. See endnote 4 for this section.

At least 103 countries have commercial wind power capacity and **33 countries** have **more than 1 GW** in operation.

four years, from 6.2% in 2014 to 33% in 2018.[17] Shares also were high at the sub-national level in several countries (see below). By year's end, global wind power capacity in operation was enough to contribute an estimated 5.5% of total electricity generation.[18]

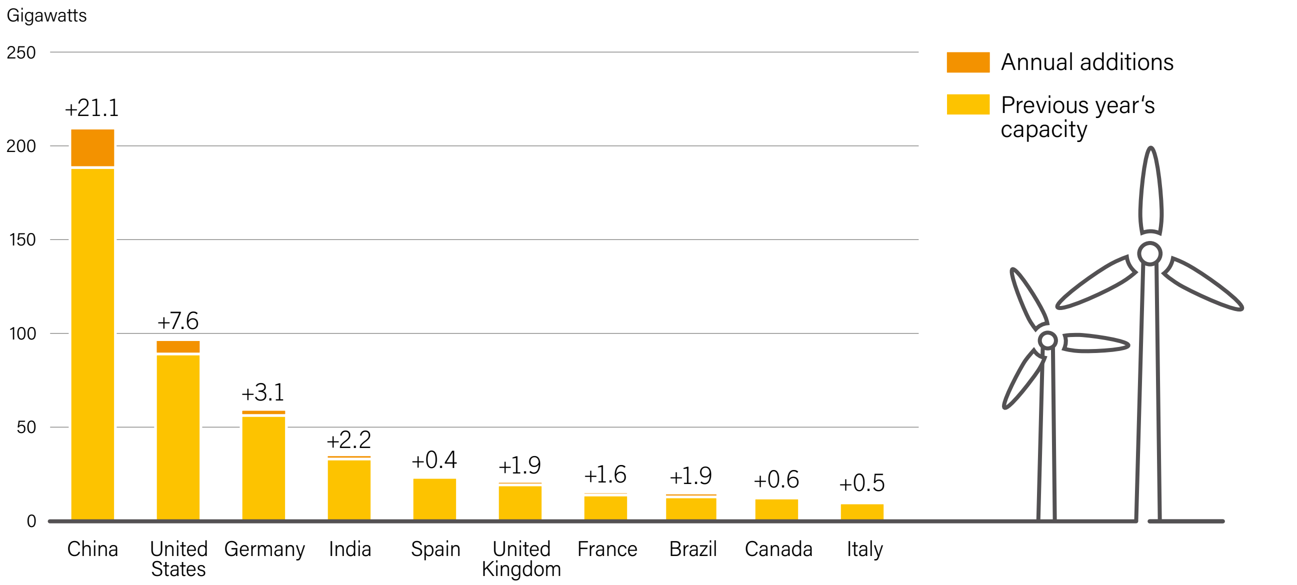
For the 10th year running, Asia was the largest regional market, representing nearly 52% (up from 48%) of added capacity, with a total exceeding 262 GW by year's end.[19] Europe (nearly 22%), North America (almost 16%) and Latin America and the Caribbean (over 7%) accounted for most of the rest of 2018 installations.[20] China retained its lead for new capacity (both onshore and offshore) and was followed distantly by the United States, Germany, India and Brazil, with the United Kingdom close behind. Other countries in the top 10 for capacity additions were France, Mexico, Sweden and Canada.[21] For cumulative capacity, the top 10 countries were unchanged from 2017.[22] (→ *See Figure 36* and ***Reference Table R20***.)

China in 2018 became the first country to exceed 200 GW of wind power capacity, and saw an increase in new installations (up 7.5%) following two years of decline.[23] Approximately 21.1 GW was added (19.5 GW onshore and nearly 1.7 GW offshore), bringing total installed capacity to approximately 210 GW.[24] Around 20.6 GW was integrated into the national grid and started receiving the FIT premium in 2018, with approximately 184.3 GW[i] considered officially grid-connected by year's end.[25]

Although the northern and western provinces were still home to a large share (72%) of China's cumulative capacity by the end of 2018, nearly half (47%) of new installations were in the country's central and eastern regions.[26] The top provinces for additions during the

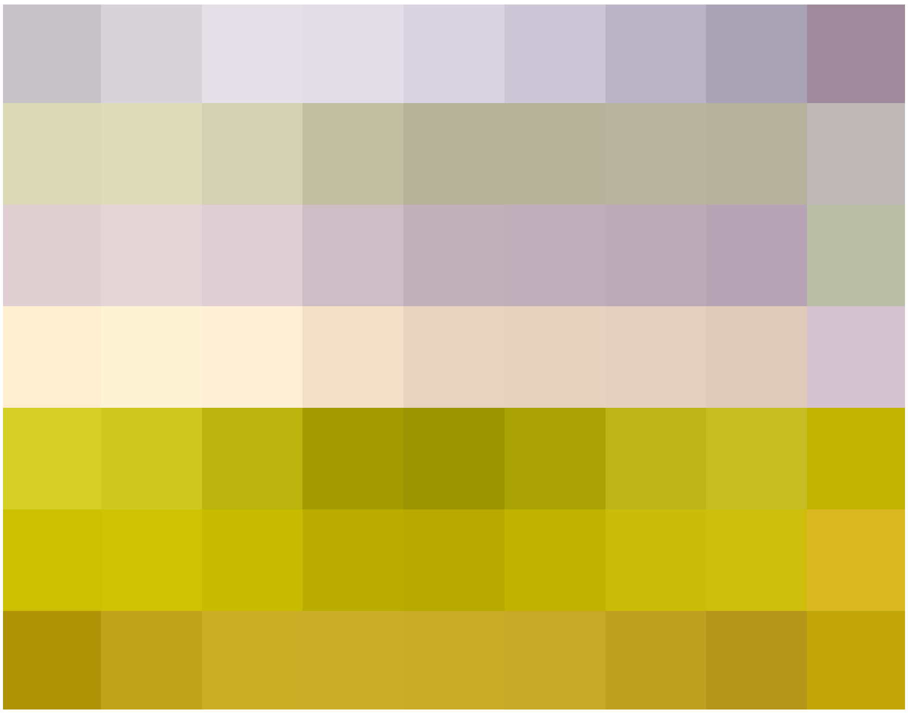
i Statistics differ among Chinese organisations and agencies as a result of what they count and when. See endnote 25 for this section.

FIGURE 36. Wind Power Capacity and Additions, Top 10 Countries, 2018



Note: Additions are net of decommissioning.

Source: See endnote 22 for this section.



Curtailment of wind decreased

5 percentage points

in China, down to 7% on average.

year were Henan (2.4 GW), Hebei (2.1 GW) and Jiangsu (2.1 GW), all of which are relatively close to demand centres.[27] The curtailment situation continued to improve as a result of policies to expand electrification (especially of heating in industry), to encourage direct trade in renewable energy among large consumers and to construct new transmission lines, as well as limitations on new wind (and solar) power capacity in problem areas.[28]

Overall, an estimated 27.7 TWh of potential wind energy was curtailed in China – a national average of 7% for the year, down from 12% (41.9 TWh) in 2017 and 17% in 2016.[29] Curtailment remained concentrated mainly in three provinces (Gansu, Inner Mongolia and Xinjiang), but all three saw significant reductions relative to 2017.[30] In late 2018, China re-emphasised its aim to keep curtailment of wind generation below 10% in 2019 and 5% in 2020.[31] Even with curtailment, China's generation from wind energy was up 20% (to 366 TWh) in 2018, and wind energy's share of total generation continued its steady rise, reaching 5.2% (up from 4.8% in 2017).[32]

India was the only other Asian country to rank among the top 10 for 2018 installations. The country climbed from fifth to fourth place, even though additions fell nearly 50% from the record high in 2017.[33] India added 2.2 GW in 2018, bringing the year-end total to 35.1 GW.[34] Another 9.2 GW or more was in the pipeline, but many wind (and other) power projects have been delayed by problems in obtaining land and accessing transmission lines.[35]

Elsewhere in Asia, Turkey's annual installations were down for the second year in a row, with 0.5 GW added for a total approaching 7.4 GW at year's end.[36] Fourth in the region was Pakistan, which added 0.4 GW, bringing its total to 1.2 GW, followed by Japan (nearly 0.3 GW, for a total of 3.7 GW).[37] Other countries in Asia that added capacity included the Republic of Korea; Indonesia, which added its first commercial wind farm during the year; and Mongolia.[38]

The EU installed roughly 10.1 GW of new capacity (7.4 GW onshore and 2.7 GW offshore), or net additions of 9.7 GW (accounting for decommissioning), for a year-end total of 178.8 GW (160.3 GW onshore and 18.5 GW offshore).[39] Additions were down 35% relative to the record high in 2017, when developers rushed to install significant capacity ahead of regulatory changes that required competitive auctions for the allocation of support.[40] As a result, the EU saw the lowest amount added since 2011, although most of the reductions occurred in Europe's largest markets, Germany and the United Kingdom.[41]

In spite of the absolute market contraction, wind power in the EU did not give up much in relative market share. Wind power accounted for around half of the EU's net capacity additions in 2018 (55% in 2017), and by year's end it represented nearly one-fifth (18.8%, up from 18% in 2017) of the region's total installed power capacity.[42] Wind energy's share of EU electricity generation increased two percentage points over 2017 – even though 2018 was a less windy year – due to increased wind power capacity as well as lower electricity demand.[43] Onshore wind energy met approximately 12% of the region's total electricity demand, and offshore wind energy met 2%.[44]

In total, 16 EU countries added wind power capacity during 2018. However, the market was quite concentrated, with the top five countries – Germany, the United Kingdom, France, Sweden and Belgium – accounting for about 80% of net additions.[45] The leading EU countries for cumulative capacity were Germany, Spain, the United Kingdom, France and Italy.[46]

Germany was again the top installer in the region and the third largest globally, adding 3.4 GW (more than 3.1 GW net, including almost 2.2 GW onshore and nearly 1 GW offshore) for a cumulative total of around 59.3 GW at year's end (with 52.9 GW onshore and 6.4 GW offshore).[47] Annual installations were about half those in 2017, ending a five-year period of rapid expansion.[48] Germany's market contraction reportedly was due to onerous permitting procedures, local opposition and the shift from FITs to auctions, which initially favoured citizen projects that were granted an extended period (4.5 years) for completion and thus were not yet in operation by year's end.[49] Wind output increased 5.6% relative to 2017, accounting for 18.6% of Germany's total net electricity consumption in 2018.[50]

The United Kingdom also saw a significant market contraction (down 55% relative to 2017) with the transition away from its Renewables Obligation – 1.9 GW was added (69% offshore) for a total approaching 21 GW.[51] Wind energy set new highs (onshore and offshore) for the year, generating 17.1% of UK electricity.[52] The increase was due largely to capacity additions and to a new transmission line between Scotland and Wales, which greatly reduced curtailment of wind generation.[53]

France added nearly 1.6 GW for a total of 15.3 GW, and was followed by Sweden (plus 0.7 GW for a total of 7.4 GW) and Belgium (plus 0.5 GW; total 3.4 GW), which installed 60% of its new capacity offshore.[54] Spain added 0.4 GW in 2018, the country's largest capacity increase since 2012, and continued to rank second in the EU for cumulative capacity (23.5 GW).[55]

Outside the EU, Norway was the largest European installer (adding 0.5 GW) in 2018, followed by Serbia, which increased its total capacity almost 20-fold to nearly 0.4 GW.[56] Bosnia and Herzegovina (51 MW) and Kosovo (32 MW) added their first commercial wind capacity.[57] The Russian Federation commissioned its first commercial wind farm early in the year, and the first firm orders from the country's wind power auction in 2017 were announced in late 2018.[58] Across all of Europe, 9.3 GW of new capacity was awarded during the year through government auctions and tenders – including 2.3 GW offshore – and corporate deals were signed for 1.5 GW of new wind power capacity (0.8 GW of it in Norway) by firms ranging from aluminium and auto manufacturers to pharmaceutical companies.[59]

On the other side of the Atlantic, the Americas accounted for more than 23% of the world's newly installed capacity in 2018, with the United States alone installing nearly 15% of the global total.[60] The United States maintained its second-place ranking after China for annual additions, with 7.6 GW of capacity newly commissioned in 2018 (78% in the last quarter), an 8% increase over 2017.[61] By year's end, 96.5 GW of capacity was in operation across 41 US states, with another 16.5 GW under construction.[62] Texas continued to have a wide lead over other states for total capacity (24.9 GW), and South Dakota became the 19th US state to have more than 1 GW of capacity in operation.[63]

The United States is enjoying a relatively prolonged period of policy certainty following more than two decades of one- to two-year extensions of the federal production tax credit.[64] State policies also have helped influence where deployment occurs, but wind power growth has outpaced state mandates and targets in recent years.[65] Corporate purchasing has played a significant role in this trend, and US wind power PPAs had a record year in 2018: utilities signed contracts for 4.3 GW, and non-utility customers committed to purchase the generation from an additional 4.2 GW of wind power capacity.[66]

Wind power set short-term generation records in several regions of the United States, including in Texas.[67] For the year as a whole, utility-scale wind power accounted for more than 30% of annual electricity generation in three US states (with Kansas in the lead at 36.4%) and more than 20% of annual generation in six states; in total, utility-scale wind power accounted for 6.6% of US electricity generation.[68]

Latin America and the Caribbean added nearly 3.4 GW of capacity in 2018, up more than 18% relative to 2017.[69] The region ended the year with about 25.6 GW of wind power capacity operating in at least 26 countries.[70] Brazil was home to more than half of the region's total at year's end and continued to rank among the global top 10 for both additions and cumulative installations.[71] The country added around 1.9 GW in 2018, for a year-end total approaching 14.7 GW.[72] Wind power accounted for 8.3% of Brazil's electricity generation in 2018 (up from 7.4% in 2017).[73]

Mexico was among the world's top 10 installers for the first time, adding more than 0.9 GW for a total of nearly 5 GW.[74] Other significant markets in the region included Argentina, one of the world's fastest-growing wind power markets (adding 0.5 GW for a total exceeding 0.7 GW), Chile (0.2 GW; 1.7 GW) and Peru (0.1 GW; 0.4 GW).[75] Auctions and tenders have driven much of the wind power deployment in the region.[76]

Canada's market expanded more than 60% relative to 2017, to nearly 0.6 GW, putting it in 10th place for additions.[77] Wind power has been the country's largest source of new electricity generation for a decade, and the 12.8 GW in operation at the end of 2018 was enough to meet approximately 6% of Canada's electricity demand.[78] The province of Ontario continued to lead in cumulative capacity (5 GW), followed by Québec (3.9 GW), while Prince Edward Island had the country's highest share of wind energy in the electricity mix (28%).[79]

Wind energy is also playing an increasingly important role in Australia, which saw records for both installations and output in 2018.[80] The country brought online more than 0.5 GW of new large-scale capacity, for a total approaching 5.4 GW.[81] During the year, wind energy supplied 7.1% of the country's electricity, with far higher shares in South Australia (35%), Victoria (28%) and New South Wales (19%).[82]

The rapid increase in the number and capacity of large wind (and solar) power projects in Australia is challenging the country's grid, resulting in project delays.[83] By year's end, an additional 5.7 GW of capacity was under construction or financially committed.[84] Other parts of Oceania had little wind power activity in 2018.[85]

Africa and the Middle East also saw a significant market increase (50%) from 2017, with most of the nearly 1 GW of new capacity coming online in Egypt (380 MW), Kenya (310 MW) and Morocco (120 MW).[86]

Across Europe,
9.3 GW
of new wind power capacity was awarded through government auctions and tenders.

Kenya's Lake Turkana Wind Power (LTWP) project finally began supplying electricity to the national grid[i] in September 2018, upon completion of a 436-kilometre transmission line.[87] LTWP's capacity factor has been very high, averaging 80% over the first two months of 2019.[88] Iran and Jordan also installed capacity during 2018, and Saudi Arabia held its first wind power tender.[89] Construction was expected to begin on Saudi Arabia's first utility-scale project in 2019.[90] At year's end, 12 countries in Africa and 4 in the Middle East had a cumulative capacity of 5.7 GW of onshore wind power capacity, with South Africa (2.1 GW), Egypt (1.2 GW) and Morocco (1 GW) accounting for most of the total.[91]

In the offshore segment, seven countries in Europe and two in Asia connected a total of 4.5 GW in 2018 (the same as in 2017), increasing cumulative global capacity by 24%, to 23.1 GW.[92] Wind turbines operating offshore represented only 4% of total global wind power capacity at year's end, but offshore additions in 2018 accounted for 8% of all new capacity.[93] China had a record year and led the sector for the first time, installing 1.7 GW for a total of 4.4 GW.[94] The country is well within sight of its national target, which calls for 5 GW of offshore capacity by 2020.[95] At least three Chinese provinces also have offshore targets, including Fujian (2 GW by 2020), Guangdong (30 GW by 2030) and Jiangsu (3.5 GW by 2020).[96] Elsewhere in Asia, the Republic of Korea commissioned turbines offshore (35 MW) during 2018.[97]

Europe continues to be home to most of the world's offshore wind power capacity. In 2018, the region added more than 2.6 GW (down 16% from 2017), for a regional total of 18.5 GW, most of which is in the North Sea.[98] Leading countries for additions were the United Kingdom (1.3 GW), which completed the world's largest offshore project (the 657 MW Walney Extension), Germany (nearly 1 GW) and Belgium (0.3 GW).[99] Spain installed its second offshore turbine, which has a self-installing telescopic substructure for crane-less installations, and three floating turbines were grid-connected off the UK and French coasts.[100] Although Europe's offshore capacity additions were below the record installations in 2017, investment in offshore capacity (including projects under construction) was up 37% in 2018 to its third-highest level.[101]

By the end of 2018, 17 countries (11 in Europe[ii], 5 in Asia and 1 in North America) had offshore wind capacity.[102] The United Kingdom maintained its lead for total capacity (8 GW), followed by Germany (6.4 GW), China (4.4 GW), Denmark (1.3 GW) and Belgium (1.2 GW).[103] Europe was home to about 79% of global offshore capacity (down from 84% in 2017, and 88% in 2016), with Asia accounting for nearly all the rest.[104] (→ *See Figure 37.*)

The success of offshore wind power in Europe – based on a well-developed supply chain, advances in installation and in O&M, several years of experience and the low cost of capital, all of which have made offshore wind power competitive in the region going forward – has sparked interest in almost every other region.[105] In 2018, studies continued for Australia's first proposed wind farm, off the coast of Victoria, and Brazil moved closer to seeing its first offshore wind project.[106] Chinese Taipei held a tender for 1.6 GW of capacity on top of previously allocated capacity (towards its target of 5.5 GW by 2025), and India set offshore targets of 5 GW by 2022 and 30 GW by 2030.[107] Poland committed to 8 GW by 2035, and Turkey announced plans to hold an auction for the world's largest offshore wind farm (1.2 GW), which was later postponed.[108]

The United States has added no new offshore capacity since its first project (30 MW) was completed in late 2016, but several states had supportive policies or ambitious plans in place by early 2019 – including New Jersey (mandate for 3.5 GW by 2030) and New York (goal of 9 GW by 2035).[109] In December, the winning bids for lease areas off the coast of Massachusetts were far below the previous US record.[110] The country's first large-scale offshore wind farm, the 0.8 GW Vineyard Wind project, was expected to begin construction off the Massachusetts coast in 2019.[111]

As the global offshore market continued to expand, the market for small-scale land-based turbines contracted further. Small-scale[iii] turbines are used for a variety of applications

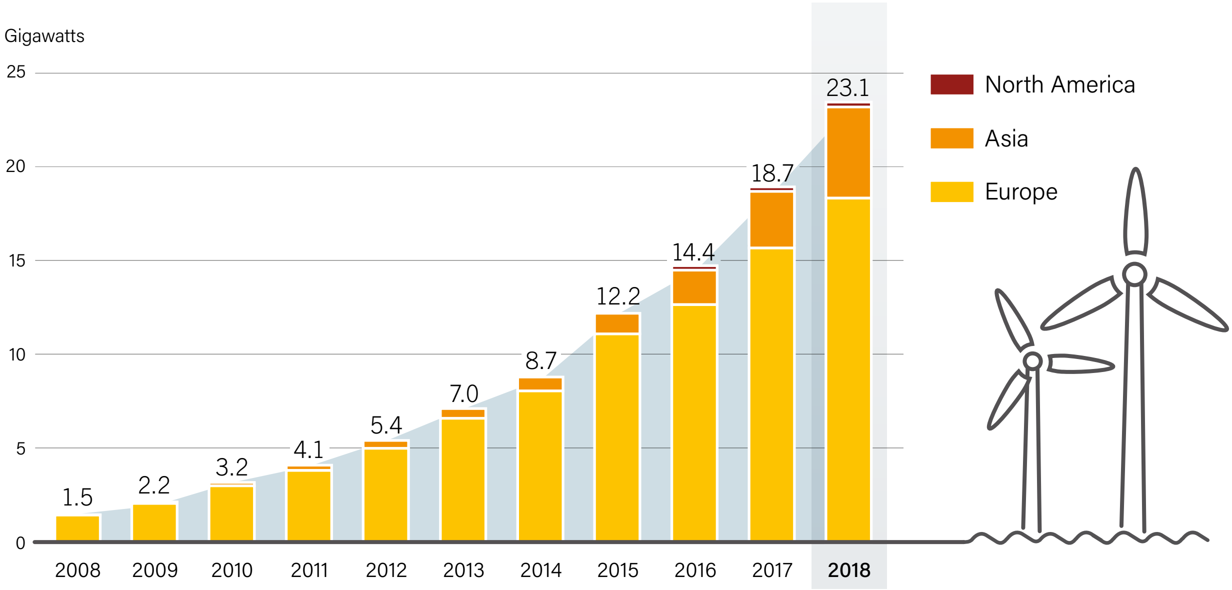
The success of offshore wind power in Europe has sparked interest in almost every other region.

i Electricity from the LTWP project bypasses local communities because all output must be sold to the state-owned power company, and local populations are not connected to the grid. See endnote 87 for this section.

ii 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 102 for this section.

iii 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 (WWEA) and the American Wind Energy Association 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. For more information, see, for example, WWEA, *2017 Small Wind World Report Summary* (Bonn: June 2017), http://www.wwindea.org/wp-content/uploads/filebase/small_wind_/SWWR2017-SUMMARY.pdf.

FIGURE 37. Wind Power Offshore Global Capacity by Region, 2008-2018



Source: See endnote 104 for this section.

> The wind industry is meeting new challenges with **technology advances** that are increasing output and reducing the levelised cost of electricity.

(both on- and off-grid), including defence, rural electrification, water pumping and desalination, battery charging, telecommunications and increasingly to displace diesel in remote locations.[112] The global market continued to slow in 2017 (latest available data) in response to unfavourable policy changes and ongoing competition from relatively low-cost solar PV.[113]

By one estimate, 114 MW of new small-scale wind power capacity was installed in 10 countries during 2017, down from an estimated 122 MW in 2016.[114] Deployment was down significantly even in markets that were growing until recently, including China and the United Kingdom.[115] The United States deployed an estimated 1.7 MW (3,269 units) in 2017, continuing the country's downward trend for turbines smaller than 100 kW.[116] By year's end, approximately 1 million small-scale turbines, or at least 1.1 GW, were operating worldwide.[117]

Wind turbines of various sizes, totalling almost 0.5 GW of capacity, were decommissioned in 2018.[118] Decommissioning continued to occur primarily in Europe, home to some of the oldest wind power markets. Germany accounted for the largest number of decommissioned turbines, followed by the Netherlands.[119] Several 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.[120] Yet, while falling prices are helping to move wind power into new markets and driving up sales, the highly competitive environment is causing a decrease in the number of turbine manufacturers.[121] The global transition from FITs to more-competitive mechanisms, such as auctions and tenders, has resulted in intense price competition that is squeezing the entire value chain and challenging wind turbine manufacturers and developers alike.[122] Further, wind power's success is coming with new challenges, including some inadequately planned projects resulting from poorly designed and executed tenders, as well as limitations of power systems and markets that were designed for centralised, large-scale fossil power.[123] (→ *See Systems Integration chapter.*) The industry is meeting these challenges with ongoing technology advances (including larger turbines) that are increasing energy production per turbine, improving plant efficiency and output, and reducing the levelised cost of electricity from wind energy.[124]

Auctions and tenders were held in more than 15 countries, and a total of 17.8 GW of wind capacity contracts (14.5 GW onshore and 3.3 GW offshore) were allocated in 2018.[125] It was another year of highly competitive auctions, although there was a slowdown in the decline in bid levels and equipment prices relative to the previous two years.[126] Average winning bid levels[i] for onshore wind energy were close to USD 20 per MWh (down from around USD 30 per MWh in 2017) in several countries – including Brazil, India and Saudi Arabia.[127]

i 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.

In Europe, tenders in Denmark, Greece and Poland saw extremely low prices (for example, in Denmark, EUR 21.5 (USD 24.6) per MWh) due to a strong pipeline of permitted projects.[128] By contrast, France and Germany both held onshore wind power tenders that were under-subscribed, with France's second tender of the year bringing in only 118 MW of the 500 MW on offer (due to legal uncertainty regarding permitting authorisations), and Germany's bid prices[i] increased during the year (due to frequent rule changes and permitting challenges).[129] Germany saw some "zero-subsidy" bids for offshore auctions (capacity due online starting in 2024), and the Netherlands held successful "subsidy-free" tenders for offshore capacity (due online starting in 2023).[130] In these cases, winning projects would receive only the wholesale price of electricity and in-kind support[ii], and no direct government subsidies; however, zero-subsidy bids remain the exception.[131]

In the US state of Colorado, record-low PPA bids[iii] were set for stand-alone onshore wind power projects (median price of USD 18.1 per MWh) as well as for wind-storage hybrids (median price of USD 21 per MWh) for projects scheduled to come online in 2023.[132] Contract prices for US offshore wind energy fell 75% between the Block Island (Rhode Island) project in 2014 (USD 244 per MWh) and the 800 MW Vineyard Wind project in 2018.[133]

In response to the decline in bid prices over the past few years, several governments and state-owned utilities (for example, in Chinese Taipei, France and India) have sought to renegotiate wind energy purchase agreement price levels (onshore and offshore) that were set under tender contracts or PPAs.[134] These developments are a sign of the rapid speed at which prices have fallen (without a similar decrease in costs along the wind energy value chain); but there is also concern that they risk undermining investor confidence and stalling domestic markets.[135]

The global shift to auctions has fundamentally altered the economics of the wind industry, with orders based on government timelines and developers pushed to compete harder to win projects.[136] These changes have accelerated a race to the bottom on price, which forces equipment makers to adapt quickly or lose out on contracts.[137] As prices fall (often faster than costs) and as increased competition squeezes the margins for turbine manufacturers, even some of the biggest manufacturers are seeing smaller profits, despite increasing unit sales, and are seeking ways to cut costs further in both operations and turbine production.[138] Those with the means are developing new revenue streams, moving into project development, acquiring new subsidiaries and expanding into new services (such as O&M, where margins are higher) and even moving beyond their core business (into areas such as electric vehicle charging).[139] At the same time, many service providers are expanding into new areas, such as distribution of spare parts.[140]

Severe competition is causing further consolidation among turbine manufacturers, and it pushed seven small turbine equipment manufacturers out of the market in 2018.[141] And while 37 manufacturers[iv] in 2018 delivered wind turbines to the global market, the top 10 companies captured an 85% share (up from 80% in 2017 and 75% in 2016).[142] (→ *See Figure 38.*)

The top five manufacturers alone accounted for nearly two-thirds of the turbines delivered in 2018.[143] Vestas (Denmark) again led the pack, with more than one-fifth of the global market, due in part to the company's wide geographic spread, with sales in 36 countries.[144] Vestas was followed by China-based Goldwind, which traded spots with Siemens Gamesa (Spain), and by GE Renewable Energy (United States) and Envision (China), which replaced Enercon (Germany).[145]

Of the top 10 turbine manufacturers, half are based in China, although Chinese manufacturers continued to rely almost entirely on their home market in 2018.[146] German-based Senvion, which ranked ninth globally in 2017, filed for insolvency in early 2019, following project delays, a shrinking home market, falling prices and increased competition.[147]

While most wind turbine manufacturing takes place in China, the EU, India and the United States, the manufacture of components (such as blades), the assembly of turbines and the locations of company offices are spreading to be close to growing wind energy markets – including Argentina, Australia and the Russian Federation – as companies seek to reduce transport costs and to access new sources of revenue.[148] For example, Argentina's Newsan partnered with Vestas to convert an existing manufacturing facility in Buenos Aires into an assembly plant for wind turbines.[149]

Major manufacturers, including GE Renewable Energy and Siemens Gamesa, are focused increasingly on the repowering market segment.[150] 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).[151] Such partial repowering can extend turbine lifetime while greatly increasing a wind farm's performance.[152] Siemens Gamesa, for example, makes blade tip extensions to improve the output of existing turbines in lower-wind areas and has developed upgrades to make the company's turbines more aerodynamic.[153] Nearly every major turbine manufacturer offers various upgrading services.[154]

During 2018, repowering took place at several of Europe's onshore wind farms where turbines were decommissioned, even though there are no government programmes for repowering.[155]

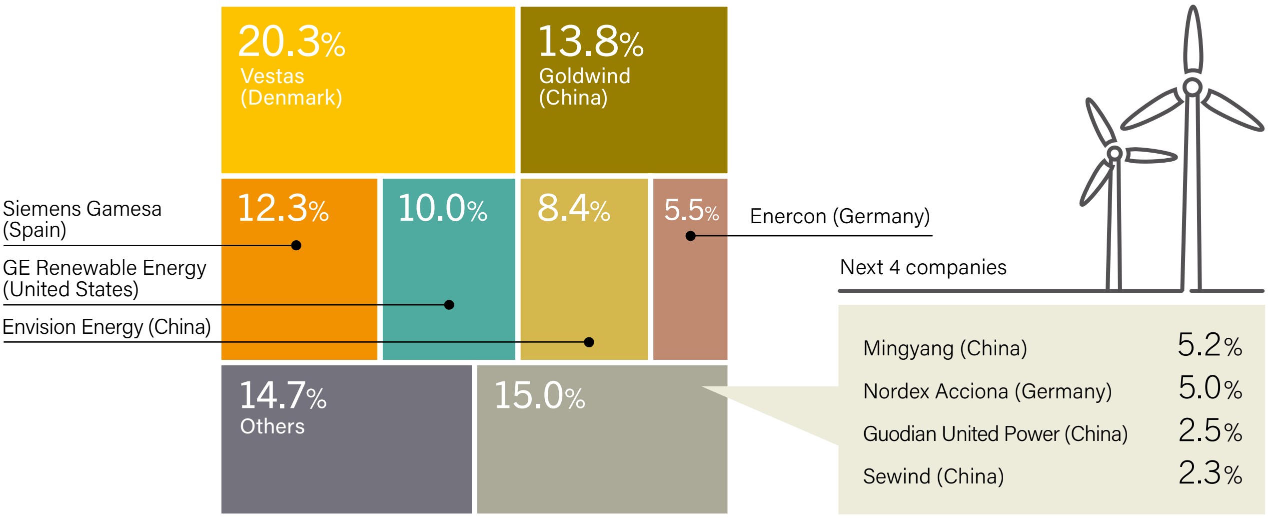
i Even so, in Germany, the difference between the FIT for onshore wind energy in 2016 and an auction for onshore capacity in February 2019 was a decline of 31%, from Karin Ohlenforst, Global Wind Energy Council, personal communication with REN21, 22 April 2019.

ii For example, in the Netherlands, the Dutch government covers the cost of supplying the grid connection and some of the preparatory work. See endnote 131 for this section.

iii Prices in the United States reflect the US Production Tax Credit, which applies to commercial wind power systems.

iv This is down from around 100 manufacturers a few years earlier. See endnote 142 for this section.

FIGURE 38. Market Shares of Top 10 Wind Turbine Manufacturers, 2018



Note: Based on total sales of approximately 50.6 GW.

Source: GWEC. See endnote 142 for this section.

By one estimate, 460 MW of Europe's capacity was repowered, mostly in Germany but also in Austria, France, Portugal and Spain.[156] In the United States, the extension of federal tax credits – enabling project owners to extend turbine lifetime, increase output and reduce O&M costs, while also qualifying for another decade of credits – has incentivised (partial) repowering of existing assets.[157] An estimated 1.2 GW of US capacity was partially repowered and 0.1 GW was replaced during 2018.[158]

Severe competition is causing further consolidation among turbine manufacturers.

Turbine manufacturers are speeding the pace of innovation to reduce their machines' LCOE in order to compete, particularly in offshore wind auctions, and to help manage wind energy's integration into electricity grids.[159] Technology advances continue to be made in several types of turbines (to match available wind resources), which are customised to meet various conditions, as well as in tower and blade materials, logistics and transport to move ever-larger turbines and components, and digital and other advanced technologies for designing, operating and maintaining wind farms – all advances that can help improve efficiencies and drive down costs.[160]

During 2018, GE Renewable Energy launched a new system that uses thermal imaging and acoustic spectral analysis to check for defects in blades, and MHI Vestas launched a set of next-generation smart tools for design assessment, turbine monitoring and real-time decision making.[161] Manufacturers continued to announce new turbine models for specific markets, both onshore and offshore.[162] Most large manufacturers are focusing on tested and well-proven turbine platforms that provide flexibility and that enable them to more easily develop turbines for specific markets while minimising costs.[163] In early 2019, for example, Vestas introduced a single turbine platform that can produce customised solutions for low, medium and high wind speed conditions.[164]

To address the increasing need to balance energy supply with grid demand, turbine manufacturers and project developers continued to develop hybrid projects, combining wind power with other renewable technologies as well as storage systems.[165] (→ *See Systems Integration chapter.*) In several countries, aggregators are combining portfolios of wind power with solar PV and other renewable technologies.[166]

Developers also are increasingly looking to hedge against the variability of wind (and solar) energy, purchasing insurance to insure their revenue and attract better financing. In 2018, investment manager Nephila Holdings Ltd (Bermuda) and insurance giant Allianz SE (Germany) joined together to offer a new insurance policy to wind farm developers. The risk is spread across a global portfolio of renewable energy projects.[167]

The general trend continued towards larger machines – including longer blades, larger rotor size and higher hub heights – as turbine manufacturers aimed to boost output and to gain or maintain market share. The average size of turbines delivered to market in 2018 was 2% larger than in 2017, at 2.45 MW.[168] By country, the largest averages were seen in the United Kingdom[i] (nearly 4 MW), Germany and Denmark (nearly 3.8 MW)

i Averages were high in the United Kingdom and Germany due in part to the significant portions of their additions that were installed offshore, where turbines tend to be larger.

and Canada (3.3 MW), with averages exceeding 2 MW in all other established markets.[169] Significant differences in average turbine ratings can occur within regions; on land in Europe, for example, differences result from regulatory restrictions on height, age of projects and/or wind speeds.[170]

Offshore, developers are taking advantage of larger turbines as soon as they become available.[171] Larger turbines mean that fewer foundations, converters, cables and other resources are required for the same output; this translates into faster project development, reduced risk, lower grid-connection and O&M costs, and overall greater yield.[172] The size of turbines as well as projects has increased rapidly in order to reduce costs through scale and standardisation.[173]

Across Europe, the average per-unit capacity of newly installed turbines offshore was 6.8 MW in 2018, 15% larger than the average in 2017; the largest turbines installed in 2018 were 8.8 MW machines connected off the UK coast.[174] Turbines are set to get only bigger, with several major manufacturers announcing machines of 10 MW and up, scheduled for sale and delivery starting in 2021.[175] This trend comes with new challenges related to design, manufacturing, logistics and installation.[176]

The offshore wind power industry also continued to make advances towards the deployment 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.[177] Several configurations for floating substructures continued to be developed and demonstrated in 2018, with a few floating structures commissioned (in the United Kingdom and France) during the year, including a new type of substructure for France's Floatgen Project.[178]

Also in 2018, the European Investment Bank granted a EUR 60 million (USD 68.7 million) loan to a joint venture for construction of a 25 MW floating wind farm in Portuguese waters, a vote of confidence for a technology that is still in the early stages; the venture, Windfloat Atlantic, is the first project-financed floating wind farm.[179] In addition, a consortium of companies was selected to develop a project off the US coast of northern California; and innogy SE (Germany), Shell (Netherlands) and Steisdal Offshore Technologies (SOT, Denmark) partnered to build a demonstration project off Norway using SOT's modular floating foundation concept, which can be fully industrialised and deployed without installation vessels.[180]

Turbine manufacturers are moving production facilities to port areas to address transport challenges caused by ever larger, heavier turbine components for offshore projects. This has led to a variety of dedicated facilities and vessels for handling and transport, such as purpose-built roll-on/roll-off ships with extendable ramps controlled by hydraulic systems, and the offshore jack-up vessel with large capacity cranes to lift heavy nacelles.[181] Siemens Gamesa fully implemented its roll-on/roll-off concept in early 2018 and believes that this technology, which eliminates the need for cranes to move heavy components on and off of ships, can reduce logistics costs by 20%.[182] Increasingly, drones are being used in combination with artificial intelligence to monitor and service turbines offshore and on land to reduce costs, improve safety of workers and boost performance.[183]

New offshore markets still face challenges that Europe and China have addressed, including developing supply chains and associated infrastructure such as ports, rail links and installation vessels, as well as technology for electrical connections.[184] But there are efforts to change that. In Japan and the Republic of Korea, local turbine suppliers are investing in the development of new, larger turbines to advance a local offshore industry and supply chain, and, in early 2019, Norway's Equinor (formerly Statoil) and state-run Korea National Oil Corporation agreed to jointly pursue commercial floating offshore wind power off the Korean coast.[185]

In the United States, major energy, marine transport and other related businesses are competing to participate in harnessing offshore wind energy at scale.[186] In 2018, for example, Siemens Gamesa and Denmark's Ørsted signed a contract for the first offshore wind project to be built in US federal waters (off Virginia), EDF (France) and Shell formed a joint venture to acquire a lease area (off New Jersey), and Equinor won a lease auction to build a 1 GW wind farm (off New York).[187] The marine transport company Reinauer Group (United States) formed a unit dedicated to supporting the US offshore wind industry, and Aeolus Energy Group (United States) announced plans to build a fleet of vessels capable of installing 10-12 MW turbines.[188] Interest also increased among US oil and gas companies, many of which are exploring how they can play a role in the offshore wind energy sector.[189]

Even as the offshore industry has begun to take off in many regions, contraction in the global market for small-scale turbines has continued to have negative impacts on that industry. The number of producers of small-scale machines in China and the United States has declined sharply in recent years, with manufacturers of small-scale wind turbines relying heavily on export markets, which also are in decline.[190] In 2018, UK-based Gaia-Wind entered liquidation, and US-based Northern Power Systems temporarily suspended activities following the expiration of the FIT in Italy, the company's primary market.[191]

In response to declining markets, manufacturers of small-scale turbines are exploring new business opportunities.[192] US-based United Wind partnered on an initiative that enables organic farmers in the United States to lease small-scale turbines with long-term fixed monthly electricity rates.[193] Some companies are promoting their expertise in providing electricity access in remote and rural areas in the developing world, while others are looking to energy storage and other options to expand or realign their business models.[194]

→ *See Sidebar 4 and Table 3* on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.[195]

SIDEBAR 4. Renewable Electricity Generation Costs, 2018

In many parts of the world, renewables represent the least-cost source of new power generation technology. The global weighted average levelised cost of electricity (LCOE)[i] from all commercially available renewable power generation technologies declined in 2018, including concentrating solar thermal power (CSP) (down 26% from 2017), bioelectricity (down 14%), solar PV and onshore wind (both down 13%), hydropower (down 11%), and geothermal and offshore wind (both down 1%)[ii]. The decline is due in part to technology improvements and to reductions in installed costs, but also to increasing market competition. For example, major suppliers of turbines and associated technology for hydropower plants noted strong and increasing competition in the global marketplace, contracting sales, and declining or even negative margins. (→ *See Market and Industry chapter.*)

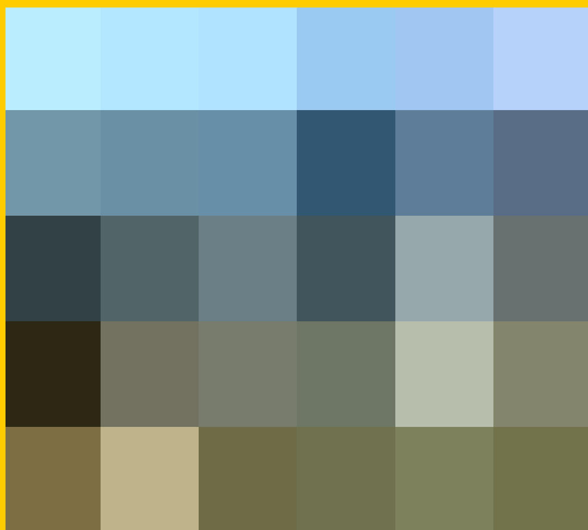
Because the LCOE of different technologies can vary greatly by country and region (→ *see Table 3*), the global weighted average LCOE is an imperfect measure; however, trends in this metric give a sense of overall movement. In 2018, the global weighted average LCOEs for hydropower (USD 47/MWh), onshore wind (USD 56/MWh) and bioelectricity (USD 62/MWh) were all at the lower end of the LCOE range for fossil fuel generation technologies (at USD 49/MWh to USD 174/MWh). These renewable technologies were able to compete head-to-head with fossil fuels, while geothermal projects (at USD 72/MWh) were not far behind. As LCOE reductions have continued, solar PV has started to compete directly with fossil fuels. Offshore wind and CSP are less widely deployed, although their costs also continue to fall. Offshore wind has become competitive with fossil fuel generation technologies as well as some CSP projects.

Onshore wind now represents a competitive source of electricity in most parts of the world. Between 2010 and 2018, the global weighted average LCOE of onshore wind power fell 35%. In 2018 alone, it fell 13% compared to 2017, as total installed costs declined and as improvements in wind energy technology (for example, higher hub heights, larger swept areas, increased rotor diameters and increased turbine size) helped increase the average capacity factor of new wind projects. (→ *See Wind Power section in Market and Industry chapter.*) Wind turbine prices fell by between 10% and 20% from 2017, depending on their size and market, helping to reduce installed costs for projects around the world.

A significant number of onshore wind power projects were commissioned in 2018 with an LCOE of between USD 30/MWh and USD 40/MWh, much lower than the cost of new fossil fuel power plants and even rivalling the variable costs of fossil fuels in some regions. The global weighted average LCOE of offshore wind declined 20% between 2010 and 2018, from USD 159/MWh to USD 127/MWh, and declined 1% in 2018 from the 2017 value. These reductions have been influenced by improvements in wind technology that drive higher wind capacity factors and reduce operations and maintenance costs, even as projects were increasingly developed in deeper waters and farther from ports.

Solar PV has experienced the most rapid cost declines, as module prices have fallen more than 90% since 2010. In 2018, crystalline silicon module prices fell by between 26% and 32% from 2017 levels due to competition, continued improvements in module efficiency, as well as manufacturing improvements that have reduced process costs and raw materials needs. As a result, the global weighted average LCOE of utility-scale solar PV projects commissioned in 2018 fell to USD 85/MWh, 13% lower than in 2017. A number of utility-scale solar PV projects commissioned in 2018 had an LCOE between USD 40/MWh and USD 50/MWh, but most (between the 5th and 95th percentiles) projects spanned USD 58/MWh to USD 219/MWh.

With the least total installed capacity of the renewable technologies discussed here, the weighted average LCOE for new CSP projects commissioned in 2018 was USD 185/MWh. This represents a 26% decline from 2017 and a 46% reduction from 2010. Recent reductions have been driven by China's involvement as a key player in supply chain and project development.

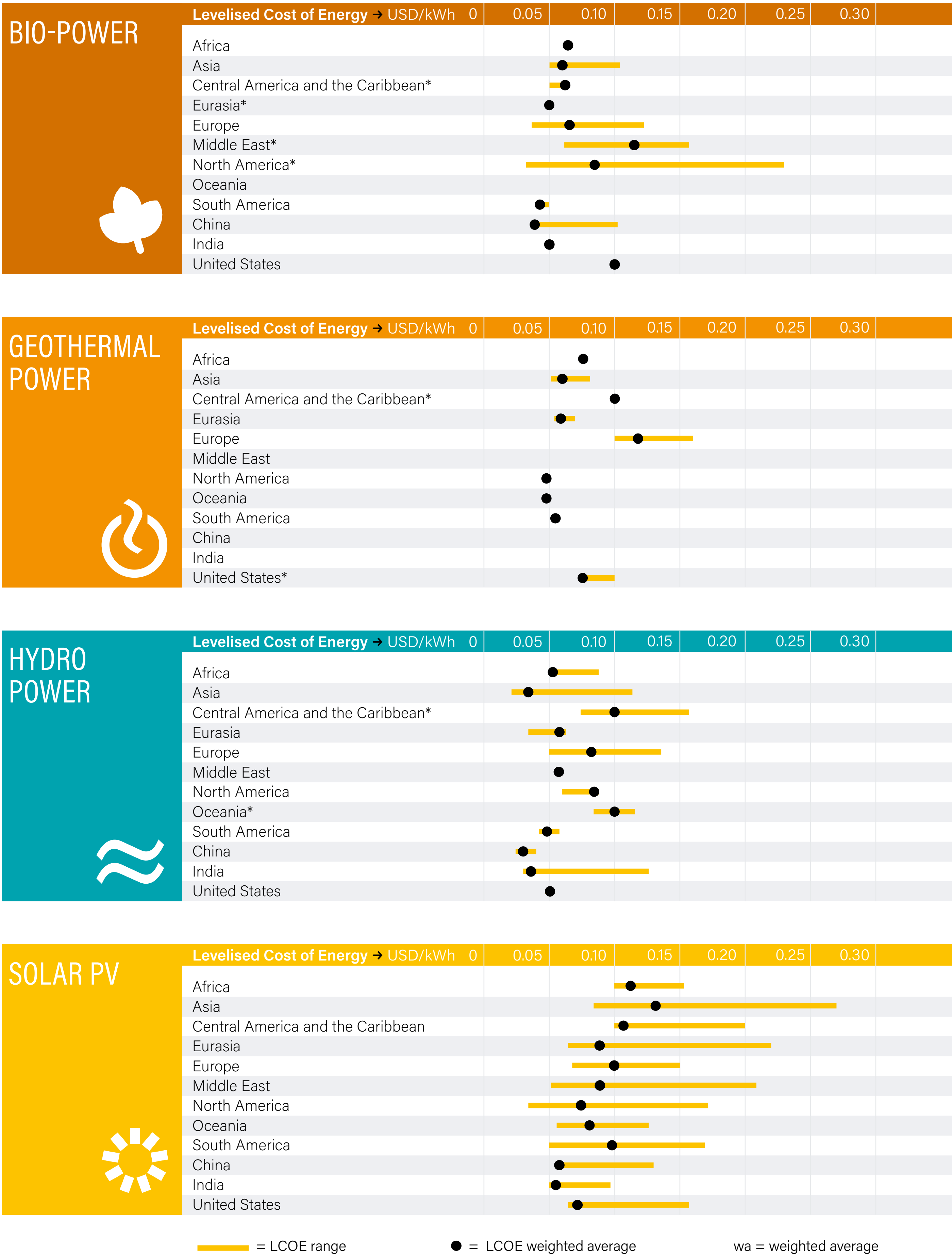


i All references to LCOE in this sidebar exclude the impact of any financial support policies, so the cost to final consumers will be lower than quoted here in markets where this support is material. The other key assumption is that the weighted average cost of capital is 7.5% in the OECD and China and 10% (real) elsewhere. LCOE numbers presented here are therefore conservative given the current low interest rate environment. More details on the LCOE methodology can be found in IRENA, *Renewable Power Generation Costs in 2018* (Abu Dhabi: 2019), https://irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018.

ii All data in this sidebar are from the IRENA Renewable Cost Database 2019, which contains cost data on more than 17,000 renewable power generation projects, accounting for around half of all deployment to 2018.

Source: IRENA. See endnote 195 of Wind Power section in this chapter.

TABLE 3. Renewable Electricity Generating Technologies, Costs and Capacity Factors, 2018



Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	1,220	1,220	1,220		0.41	0.41	0.41
Asia	1,350	5,347	2,408		0.54	0.90	0.78
Central America and the Caribbean	1,512	2,393	1,768		0.27	0.80	0.60
Eurasia	1,378	1,414	1,401		0.83	0.83	0.83
Europe	1,158	6,873	2,917		0.67	0.93	0.81
Middle East	3,424	4,454	4,022		0.46	0.92	0.64
North America	532	7,690	3,877		0.16	0.96	0.84
Oceania	2,450	2,450	2,450				
South America	891	1,897	1,081		0.53	0.83	0.58
China	1,350	4,935	1,383		0.53	0.94	0.75
India	1,350	1,350	1,350		0.75	0.75	0.75
United States	2,370	2,370	2,370		0.42	0.42	0.42

Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	4,612	4,612	4,612		0.80	0.80	0.80
Asia	3,045	5,150	3,612		0.64	0.89	0.83
Central America and the Caribbean	3,688	3,688	3,688		0.57	0.57	0.57
Eurasia	4,507	4,869	4,793		0.77	0.98	0.92
Europe	5,142	10,599	7,192		0.72	0.75	0.74
Middle East							
North America	3,833	3,833	3,833		0.91	0.91	0.91
Oceania	3,794	3,794	3,794		0.90	0.90	0.90
South America	3,140	3,140	3,140		0.80	0.80	0.80
China							
India							
United States	5,382	7,007	5,555		0.80	0.80	0.80

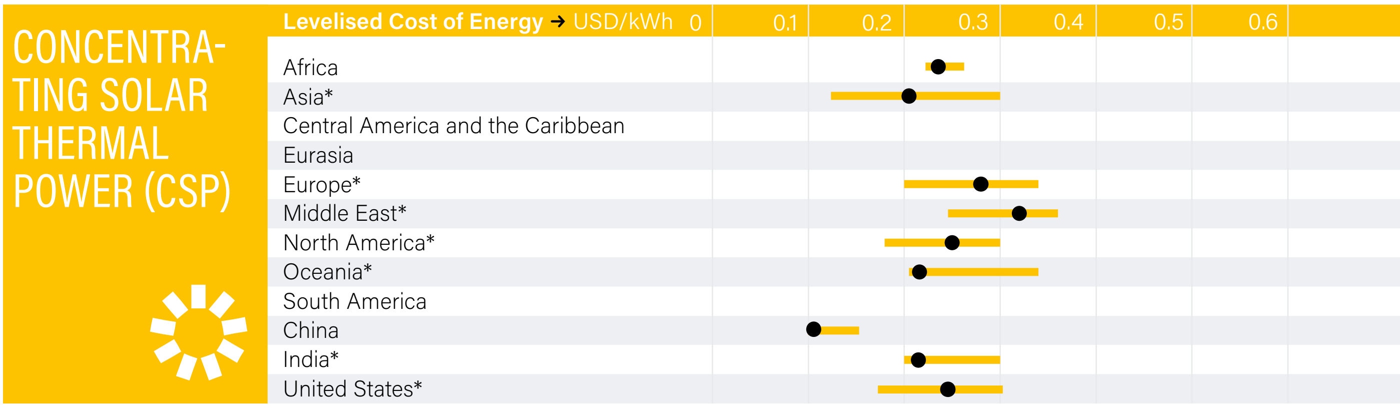
Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	1,937	3,405	2,265		0.47	0.81	0.56
Asia	657	4,540	1,350		0.33	0.64	0.46
Central America and the Caribbean	1,720	4,665	3,549		0.32	0.55	0.53
Eurasia	1,864	2,606	2,462		0.52	0.61	0.53
Europe	877	4,820	1,488		0.16	0.44	0.24
Middle East	1,255	1,255	1,255		0.27	0.27	0.27
North America	3,366	5,843	5,665		0.42	0.73	0.71
Oceania	3,886	3,888	3,888		0.31	0.50	0.45
South America	1,519	2,248	2,029		0.50	0.59	0.53
China	975	1,286	1,184		0.40	0.51	0.49
India	1,105	2,446	1,489		0.28	0.57	0.49
United States	2,232	3,028	2,490		0.54	0.64	0.57

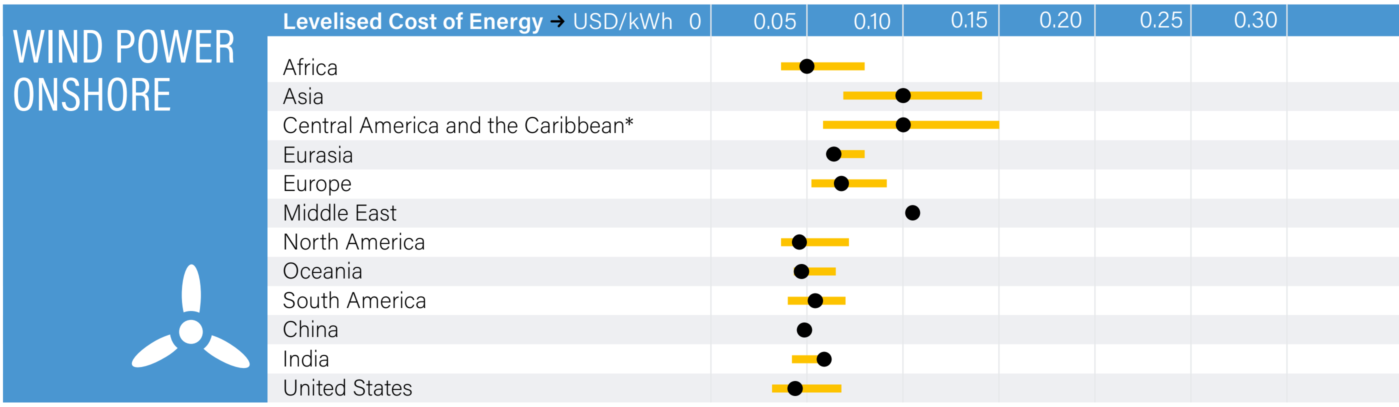
Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	1,299	2,889	1,621		0.17	0.23	0.18
Asia	1,161	3,595	1,921		0.12	0.18	0.16
Central America and the Caribbean	1,336	2,304	1,402		0.14	0.21	0.16
Eurasia	1,138	2,444	1,287		0.14	0.19	0.16
Europe	903	1,756	1,098		0.11	0.19	0.14
Middle East	836	3,195	1,342		0.19	0.22	0.20
North America	916	2,481	1,557		0.14	0.27	0.22
Oceania	1,188	2,336	1,554		0.17	0.24	0.20
South America	936	2,086	1,542		0.13	0.31	0.20
China	878	1,512	879		0.13	0.18	0.17
India	656	1,098	793		0.16	0.22	0.19
United States	1,414	2,362	1,549		0.14	0.27	0.22

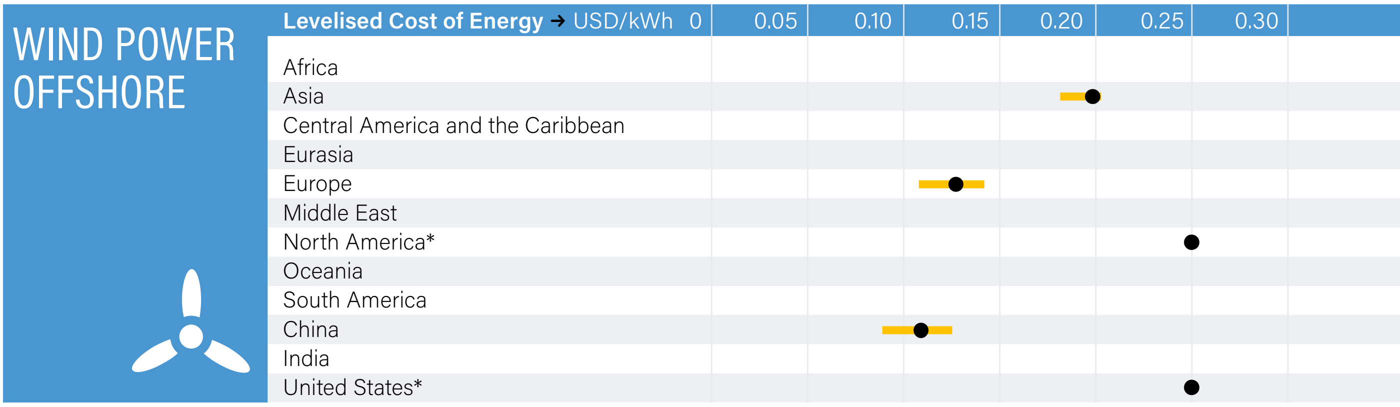
* Data for projects in 2018 are not available. Values shown here are for projects commissioned in 2017.

Source: IRENA. See endnote 195 of Wind Power section in this chapter.

TABLE 3. Renewable Electricity Generating Technologies, Costs and Capacity Factors, 2018 (continued)







= LCOE range ● = LCOE weighted average wa = weighted average

Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	5,711	7,204	6,181		0.34	0.36	0.35
Asia	3,183	7,794	4,285		0.21	0.54	0.28
Central America and the Caribbean							
Eurasia							
Europe	6,237	9,353	7,718		0.23	0.41	0.32
Middle East	6,485	6,965	6,645		0.24	0.39	0.29
North America	6,645	8,084	7,301		0.27	0.52	0.35
Oceania	6,957	6,958	6,958		0.11	0.23	0.12
South America							
China	3,272	5,695	4,228		0.32	0.62	0.55
India	3,183	7,794	4,408		0.21	0.54	0.28
United States	6,645	8,084	7,301		0.27	0.52	0.35

Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	1,149	2,438	1,451		0.34	0.49	0.41
Asia	1,783	2,565	2,237		0.22	0.35	0.29
Central America and the Caribbean	2,066	3,404	2,277		0.24	0.54	0.33
Eurasia	1,972	2,001	1,998		0.32	0.35	0.35
Europe	1,483	2,362	1,950		0.25	0.43	0.33
Middle East	2,313	2,313	2,313		0.29	0.29	0.29
North America	1,287	2,180	1,546		0.33	0.46	0.39
Oceania	1,472	1,973	1,638		0.31	0.48	0.37
South America	1,345	2,265	1,763		0.33	0.54	0.47
China	1,099	1,261	1,173		0.26	0.29	0.29
India	1,086	1,337	1,201		0.25	0.37	0.28
United States	1,341	2,346	1,659		0.36	0.52	0.44

Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa							
Asia	4,832	4,847	4,843		0.28	0.30	0.29
Central America and the Caribbean							
Eurasia							
Europe	3,775	5,597	4,922		0.40	0.50	0.47
Middle East							
North America	10,080	10,080	10,080		0.48	0.48	0.48
Oceania							
South America							
China	2,130	2,995	2,747		0.24	0.31	0.29
India							
United States	10,080	10,080	10,080		0.48	0.48	0.48

Source: IRENA. See endnote 195 of Wind Power section in this chapter.

* Data for projects in 2018 are not available. Values shown here are for projects commissioned in 2017.

Note: All monetary values are expressed in USD_{2018}. LCOE is computed using a weighted average cost of capital of 7.5% for OECD countries and China and 10% for the rest of the world, and excludes subsidies and/or taxes. Minimum and maximum values are based on 5th and 95th percentiles. Where only the weighted average is shown for specific regions/countries and technologies (i.e., without minimum and maximum amounts for LCOE, investment cost or capacity factor), there is only one project in the IRENA Renewable Costing Database. Readers should note that methodologies for calculating LCOE and capacity factors may vary across organisations. The data methodology and regional groupings used here are defined in IRENA, *Renewable Power Generation Costs in 2018* (Abu Dhabi: 2019), www.irena.org/costs. Data for North America exclude the United States. Data for Asia exclude China and India. When there are no data for the associated region or country, data from either country or region are used to represent data for that category. For example, if there are no data for the United States for geothermal power but there are data for North America, then the North America data are used for the United States.

04

Project and City:
Solar panels at Epe Healthcare and Maternity Centre, Epe, Lagos State, Nigeria

Technology:
Solar PV

Epe, Lagos State, Nigeria

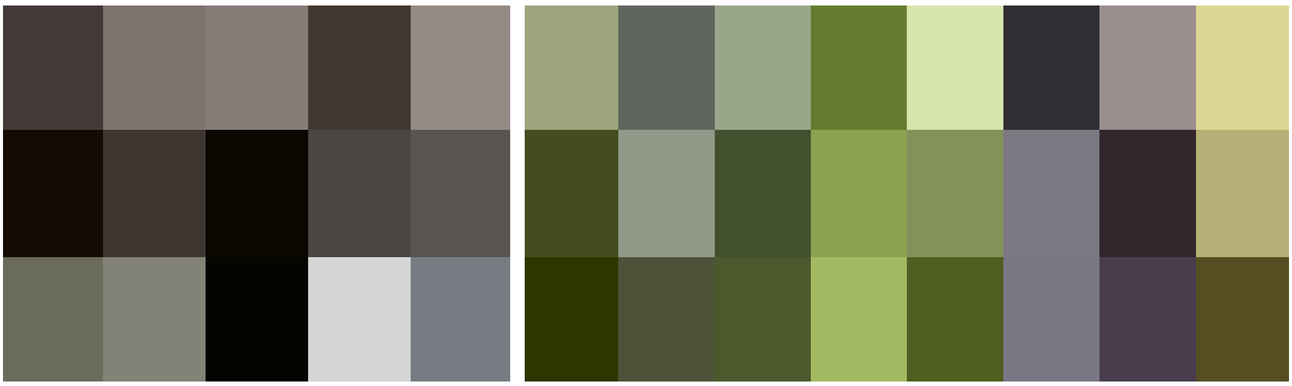
The Lagos Solar project aims to provide 5 megawatts of solar power to education and healthcare facilities and is jointly funded by the state government of Lagos and the UK Department for International Development. Construction on the project began in 2015 with the establishment of a 10 kilowatt solar PV installation at Epe maternity hospital, and since then 172 schools and 11 public health centres have gained new or improved access to electricity from renewable sources. However, funding challenges are preventing solar PV projects from being implemented at all similar facilities in the state.

DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

Distributed renewables for energy access (DREA)[i] systems are renewable-based systems (stand-alone and off-grid systems as well as micro- or mini-grids) that can generate and distribute energy independently of a centralised electricity grid. DREA systems provide a wide range of services – including lighting, electricity for appliances, cooking, heating and cooling – in both urban and rural areas of the developing world. They can play a key role in fulfiling energy needs and improving the livelihoods of millions of people living in rural and remote parts of the world.

Already, an estimated 5% of the population in Africa and 2% of the population in Asia – or nearly 150 million people across these two regions – benefit from energy access through off-grid solar systems.[1] Among the 20 so-called high-impact countries[ii], Bangladesh has an off-grid solar access rate of around 9%, Mongolia of 8% and Nepal of 6%.[2] (→ *See Figure 39.*)

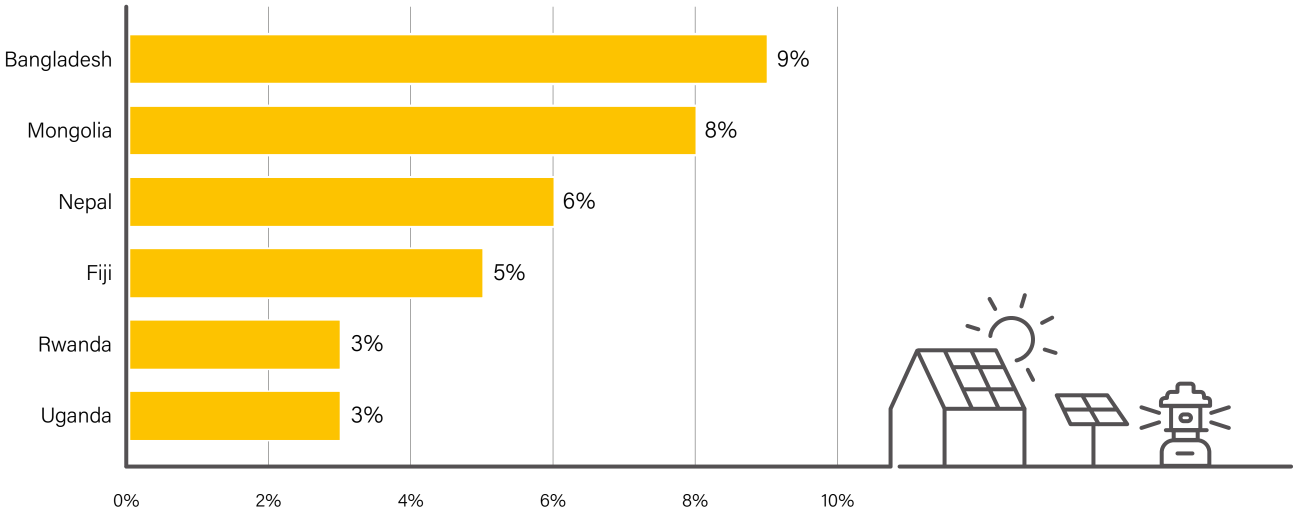
Nearly
150 million
people across Africa and Asia benefit from energy access through off-grid solar systems.



i See Sidebar 9 of 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.

ii 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. The high-impact countries, as identified in the World Bank's *Global Tracking Framework* report, are Afghanistan, Bangladesh, Burkina Faso, the Democratic People's Republic of Korea, the Democratic Republic of the Congo, Ethiopia, India, Indonesia, Kenya, Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, Pakistan, the Philippines, Sudan, Tanzania and Uganda.

FIGURE 39. Top 6 Countries with Highest Off-Grid Solar PV Access Rate (Tier 1 and Above), 2016



Note: Tier 1 access, as defined in the World Bank's Multi-tier Framework for measuring access to household electricity supply, equals a minimum of 3 watts or 12 watt-hours per day of peak capacity, lighting of 1,000 lumen hours per day, and a minimum four hours per day or one hour per evening of electricity supply.

Source: World Bank. See endnote 2 for this chapter.

DREA systems traditionally have provided basic services such as lighting and cooking to off-grid communities. However, because of their reliability, short installation time, improved cost-benefit ratio and the emergence of financial schemes that reduce upfront cost, DREA systems are being considered increasingly as either a complement to or, in some situations, a substitute for centralised power generation. DREA systems have the added benefit of reducing dependence on fossil fuel imports. In remote areas with low population densities, DREA systems are often the fastest and most cost-effective means for providing people with electricity, making these systems a compelling proposition for rapidly achieving energy access goals.[3]

DREA systems offer an opportunity to accelerate the transition to modern energy services in remote and rural areas while also offering social, environmental and economic co-benefits, such as:

- reduced chronic and acute health effects, especially for women and children;
- improved lighting quality for households;
- increased school retention and improved grades for children;
- increased income for small and medium-sized businesses (including farmers); and
- reduced negative impacts on forests.[4]

This chapter reviews the current status of and trends in DREA in developing countries and presents an overview of the major programmes and initiatives launched or operational in 2018.

OVERVIEW OF ENERGY ACCESS

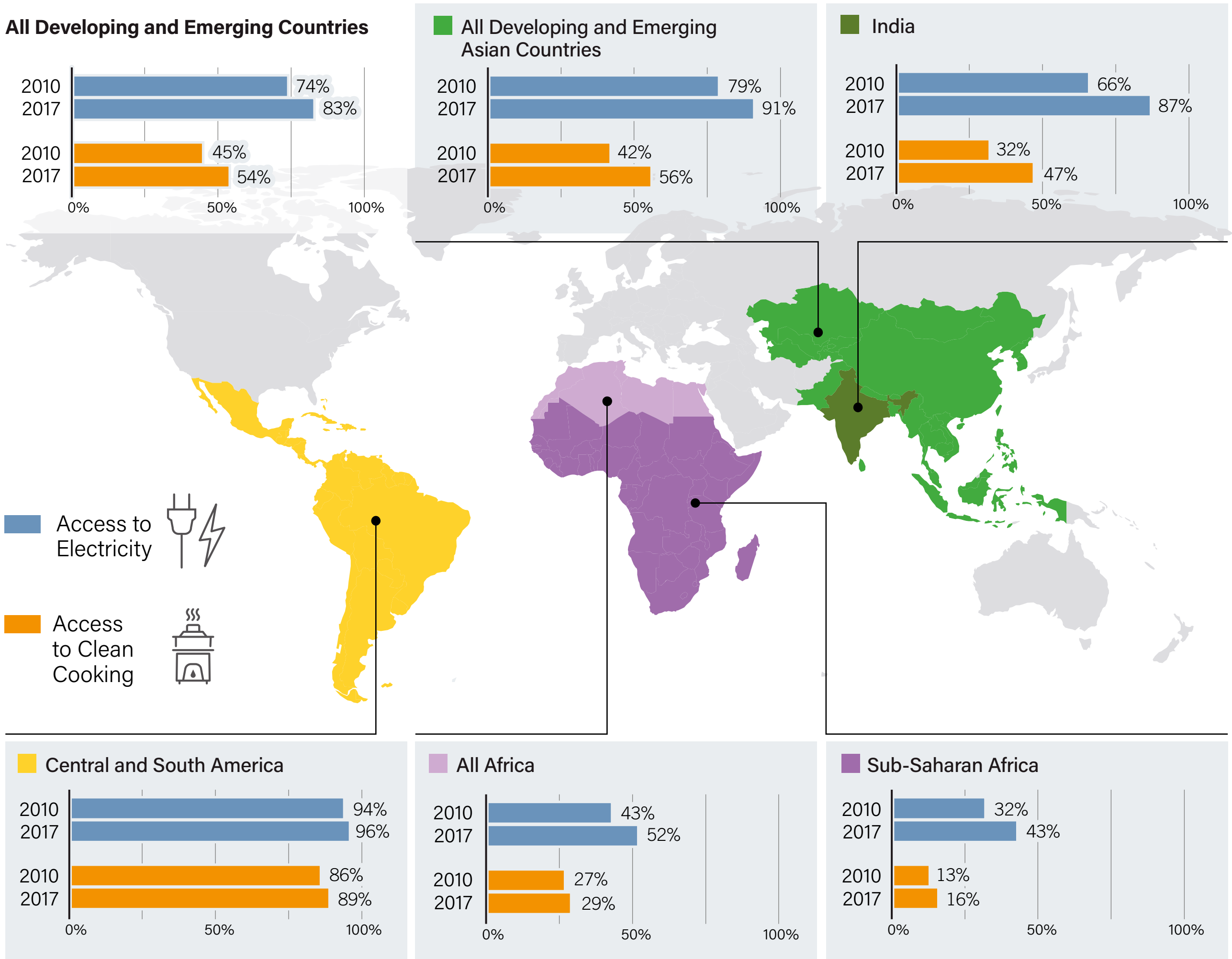
In 2017, about 122 million people worldwide gained access to electricity, reducing the global population without electricity access to below the 1 billion mark.[5] Approximately 992 million people, or 13% of the world's population, lacked access to electricity in 2017 – down from 14% in 2016.[6] An estimated 2.7 billion people (36% of the global population and 46% of the population in developing countries) were living without clean[i] cooking facilities in 2017, down from 2.8 billion in 2016.[7] (→ *See Figure 40.*).

The vast majority of people lacking access to energy are in Africa and in the Asia-Pacific region, with most of them living in rural areas. In 2017, 61% of the people without electricity access lived in sub-Saharan Africa and around 35% lived in developing Asia.[8] ***(→ See Reference Table R21.)*** In Africa, nearly half of the people on the continent, or around 600 million people, lacked access to electricity, with the majority living in sub-Saharan Africa.[9]

Although the electrification rate in sub-Saharan Africa increased from 23% in 2000 to 43% in 2017, progress since 2011 has been concentrated in four countries: Ethiopia, Kenya, Nigeria and Tanzania.[10] Access rates vary widely across Africa. Whereas North African countries have electrification rates close to 100%, in 12 countries on the continent more than 80% of the population is without electricity access.[11] The countries with the highest share of the population lacking electricity access in 2017 were

i "Clean" in this chapter refers to clean and/or efficient cook stoves as per the methodology of the Clean Cooking Alliance. Stoves/fuels that meet Tier 2 for efficiency or higher are counted as efficient; stoves/fuels that meet Tier 3 for indoor emissions or higher are counted as clean as it relates to potential health impacts; and stoves/fuels that meet Tier 3 for overall emissions or higher are counted as clean as it relates to potential for environmental impacts. This definition of clean encompasses only the health and environment impacts of cooking as indicators, regardless of the type of stoves/fuels being used (for example, liquefied petroleum gas (LPG) is counted alongside modern renewable fuels, and LPG cook stoves continue to make up the majority of clean cook stoves on the market).

FIGURE 40. Rates of Access to Electricity and Clean Cooking, by Region, 2010 and 2017



Source: OECD/IEA. See endnote 7 for this chapter.

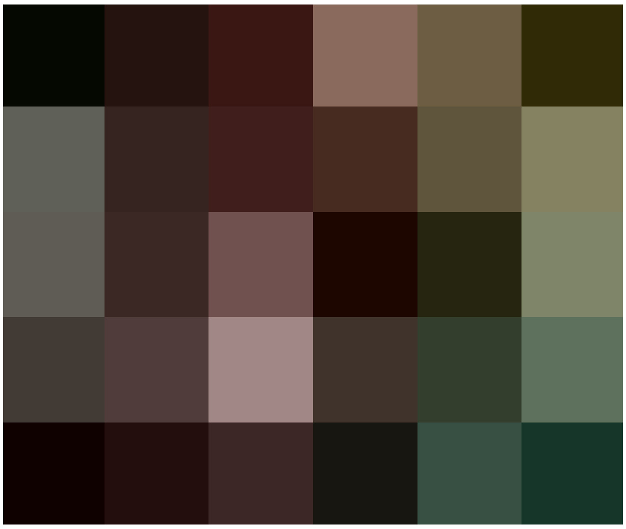
South Sudan (99%, with 12 million people lacking access), the Central African Republic (97%; 5 million people) and Chad (92%; 14 million people).[12]

In developing Asia, in contrast, 91% of the population had access to electricity in 2017.[13] Of the 550 million people worldwide who gained access to electricity between 2011 and 2017, 75% lived in Asia.[14] India and Indonesia doubled their electrification rates during this period, and by 2017 Bangladesh was providing electricity to 80% of its population, up from only 20% in 2000.[15] Nevertheless, more than 350 million people in the region still lacked access to electricity in 2017, including 168 million people in India (13% of the population), 52 million in Pakistan (26%), 33 million in Bangladesh (20%) and 24 million in Myanmar (44%).[16]

In Central and South America, 96% of inhabitants had access to grid electricity in 2017; however, several countries had high shares of people without access, including Haiti (70% of the population; 8 million people), Honduras (25%; 2 million) and Nicaragua (10%; less than 1 million).[17] In the Middle East, 92% of the population had access to electricity in 2017.[18] Yemen, however, lags in electricity access, with 53% of the population (15 million people) lacking access to electricity that year.[19]

With regard to energy for clean cooking, although millions of people have gained access in recent years, progress continues to be distributed unevenly both within and across regions.[20] In 2017, 64% of people without access to clean cooking energy lived in developing Asia, and 33% lived in sub-Saharan Africa.[21] ***(→ See Reference Table R22.)***

In Africa, nearly 895 million people (71% of the population) lacked access to clean cooking facilities in 2017, with 893 million of them living in the sub-Saharan region.[22] Only 68 million people in sub-Saharan Africa gained access to clean cooking facilities between 2000 and 2017, and in some 26 countries in the region more than 90% of the population still relied on traditional biomass[i], coal or kerosene for cooking in 2017.[23] These countries include Nigeria



(93% of the population; 178 million people), Ethiopia (93%; 98 million) and the Democratic Republic of the Congo (DRC) (95%; 79 million).[24]

In Asia, where most of the progress in the clean cooking sector has occurred, some 1.7 billion people (44% of the population) still lacked access to clean cooking facilities in 2017.[25] In China and India, the populations without access in each country dropped 15 percentage points between 2010 and 2017 (from 45% to 30% in China and from 68% to 53% in India).[26] The number of people relying on traditional biomass, coal or kerosene to meet their household cooking needs in 2017 totalled more than 703 million (53% of the population) in India, 409 million (30%) in China, 132 million (80%) in Bangladesh, 130 million (66%) in Pakistan and 79 million (30%) in Indonesia.[27]

Around 56 million people in Central and South America (11% of the population) did not have access to clean sources of cooking in 2017.[28] In Haiti, 94% of the population (10 million people) was dependent on traditional cooking fuels and devices, and in Honduras and Nicaragua less than 50% of the population had access to clean cooking solutions (5 million and 3 million people, respectively).[29]

In the Middle East, where 95% of the population had access to clean cooking facilities in 2017, Yemen lagged with an estimated 39% of its population (11 million people) lacking access to modern cooking fuels and technologies.[30]

TECHNOLOGIES AND MARKETS

Distributed renewable energy systems such as mini-grids and off-grid solutions are the most cost-effective means for providing electricity access in rural and remote regions.[31] Yet there is no one-size-fits-all solution for bringing modern energy services to the millions of people worldwide who lack access to them. Underserved populations can be provided with electricity through grid extension and connections, off-grid devices and systems such as mini-grids. Various tools and fuels can be used to provide clean cooking energy, based on the use of biomass, biogas, ethanol or liquefied petroleum gas (LPG). All of these options have a role to play depending on the local circumstances – including the existing infrastructure, enabling environment and market readiness.

This section discusses developments in 2018 with regard to distributed renewable energy options for energy access, with a specific focus on off-grid solar systems, renewable energy-based mini-grids, productive off-grid energy systems and clean cooking facilities.

ACCESS TO ELECTRICITY

Sales of larger affiliated solar home systems increased

77%

in 2018, highlighting an increasing demand from individuals for more power.

The number of people who obtained electricity access through DREA systems increased substantially between 2011 and 2017, from around 20 million to more than 152 million.[32] The two largest regional markets for DREA systems were Asia, with some 95 million people connected in 2017, and Africa, with approximately 55 million served.[33] Solar-based off-grid systems – such as solar lights/lanterns, solar home systems and solar mini-grids – accounted for around 95% of the connections to DREA systems.[34]

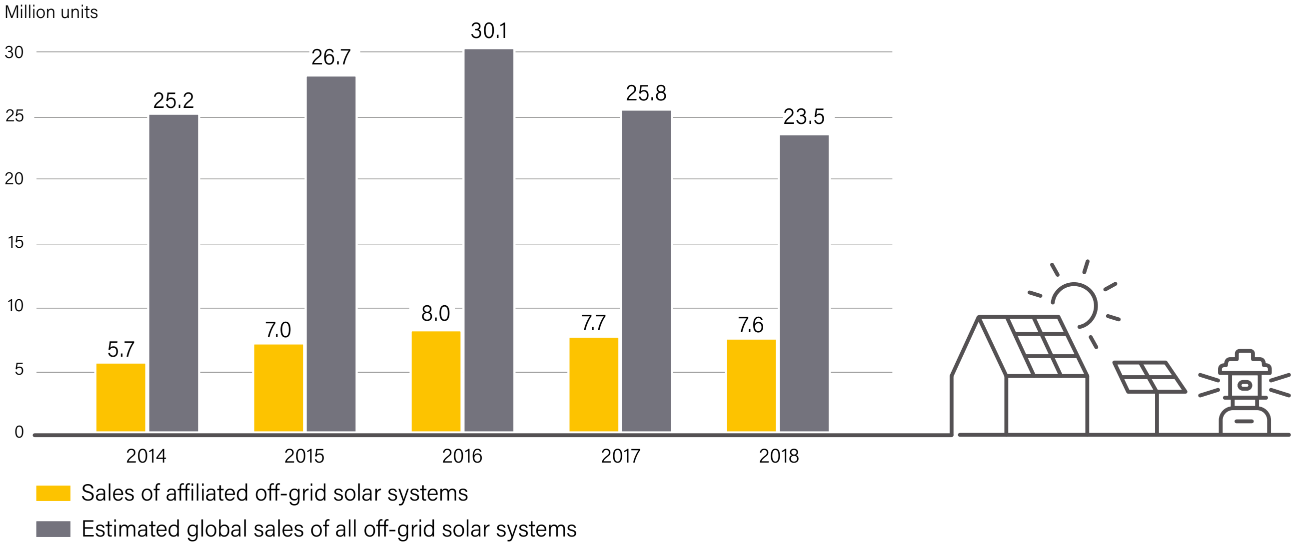
The market for off-grid solar systems has grown exponentially over the past decade, with estimated sales reaching 23.5 million in 2018, up from only 0.9 million in 2010.[35] Around 7.6 million affiliated off-grid solar products[ii] were sold globally in 2018, comparable to the sales volume of the previous year; however, sales in 2018 resulted in a 45% increase in the total installed capacity of affiliated off-grid solar products, to around 58.8 megawatts (MW) (up from 40.7 MW in 2017).[36] (→ *See Figure 41.*) This reflects a change in the dynamics of the off-grid solar market: whereas sales volumes of affiliated pico-solar systems (0-10 watts, W) fell 9% in 2018, sales of larger affiliated solar home systems (above 11 W) increased 77%.[37] Pico-solar systems still represented around 88% of total sales in 2018, however.[38]

i See Glossary for definition.

ii Based on GOGLA and Lighting Global (LG) Global Sales Data Collection, covering companies that are GOGLA members, LG affiliates and, since the second half of 2018, also affiliates of the Efficiency for Access Coalition. Affiliated off-grid solar systems/products in this chapter refer to all sales figures reported by these affiliates, which are defined as complete systems that include a panel, a battery and at least one light point. This means that these sales volumes do not include products sold as components (solar panels, batteries) or top-up products. Counterfeit and sub-standard products are reported to be present in a number of markets, regardless of the level of penetration of quality-assured products. The size of the market for counterfeit and sub-standard products is difficult to quantify, and no data exist at the regional or global level.

Sales of affiliated off-grid solar products grew in the two main regional markets of East Africa (16% increase compared to 2017) and South Asia (9% increase), as well as in the East Asia and the Pacific region (32% increase).[39] However, sales decreased in the fast-growing Central and West African markets, by 43% and 21%, respectively.[40] Across the top five country markets for affiliated off-grid solar products, the sales volume grew more than 30% in Kenya, Ethiopia and Nigeria, and also increased in India, but it decreased in Uganda.[41] (→ *See Figure 42.*)

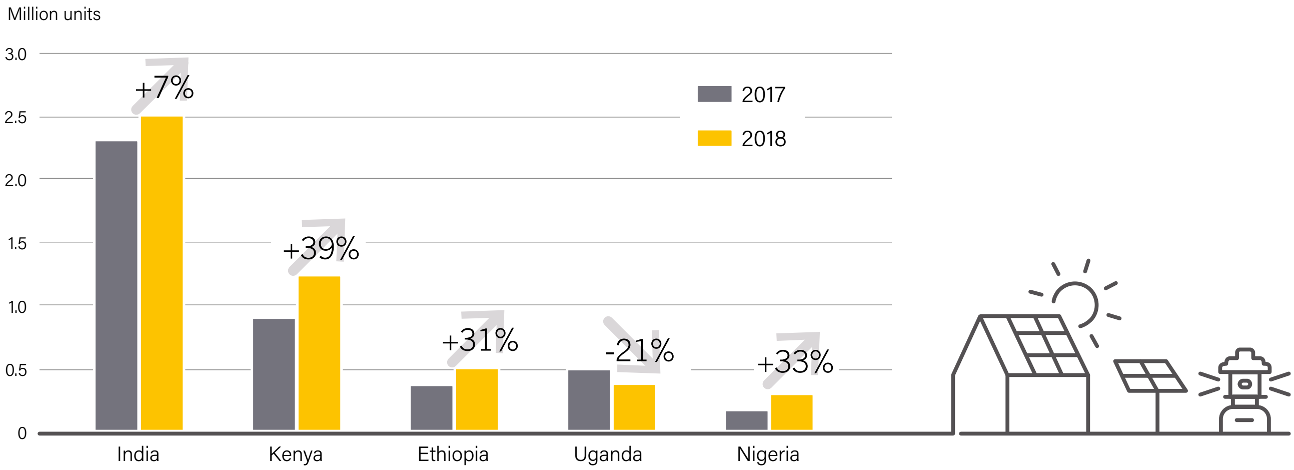
FIGURE 41. Annual Global Sales of Off-Grid Solar Systems, 2014-2018



Note: Estimated global sales of all off-grid solar systems from 2014-2017 based on data from Dalberg Advisors and Lighting Global, *Global Off-Grid Solar Market Trends Report 2018*, and estimated global sales of all off-grid solar products for 2018 are extrapolated from devices sold by GOGLA- and Lighting Global-affiliated companies in 2018. Sales data for affiliated companies represent around 30% of all global sales of small systems (<11 Wp) and 60-80% of sales of solar kits with larger solar panels (11 Wp and above). Estimated global sales of all off-grid solar systems in 2018 do not include sales of component-based systems which are largely dominant in South Asia.

Source: GOGLA/Lighting Global. See endnote 36 for this chapter.

FIGURE 42. Number of Affiliated Off-Grid Solar Systems Sold in Top 5 Countries, 2017 and 2018



Note: Figure drawn from dataset in which only countries where more than three companies have provided data are included.

Source: GOGLA/Lighting Global. See endnote 41 for this chapter.

The market for affiliated off-grid solar products is still dominated by sales in cash. Of the total volume of affiliated products sold in 2018, around 78% of the sales were in cash, compared to only 22% using pay-as-you-go (PAYG) systems (for example, mobile payments).[42] The main market for cash sales was India, where nearly 2.5 million products were sold through this method.[43] In contrast, East African countries accounted for more than 60% of all PAYG sales, with Kenya, Uganda and Rwanda among the main markets for affiliated off-grid solar products that year.[44]

Momentum for renewable energy-based mini-grids has built in recent years. As data on the performance and cost structure of solar and other renewable-based systems become more available, the bankability of mini-grids is improving, and they are attracting interest from governments and investors. A growing number of developers have passed the stage of proof of concept and are now expanding their operations with the backing of commercial financiers. Mini-grids provided electricity access to an estimated 8.6 million people worldwide in 2016.[45]

Asia had the largest installed mini-grid capacity in 2018, with an estimated 2,000 solar mini-grids in operation, compared to around 800 solar mini-grids in Africa.[46] The general outlook for the sector appears positive: in the second half of 2018, more than 500 mini-grid projects – with a total capacity of 150 MW and targeting some 275,000 people – were reportedly under development across Africa, Asia and Latin America[i].[47] Nigeria alone plans to develop 10,000 mini-grids to support rural electrification.[48] Among the projects announced in Asia in 2018 were three solar PV micro-grid projects (1.2 MW total capacity) in Indonesia, a 2 MW solar PV micro-grid in the Philippines, two new solar mini-grids (about 200 kilowatts-peak total capacity) in Pakistan and about a dozen systems in Myanmar.[49]

The use of biogas has increased in recent years, providing electricity access to an estimated 276,000 people in 2017.[50] Global biogas production for off-grid electricity access surged from only 1.7 million cubic metres in 2010 to around 31 million cubic metres in 2017.[51] An estimated 65% of this biogas was produced in Asia (mainly in the Philippines and India), and about 33% was produced in Latin America.[52]

As both the installed capacity of DREA and the diversity of products have grown, greater attention is being placed on the potential for DREA systems to directly enable productive use of energy. Typical productive use applications enabled by DREA systems (such as mini-grids and stand-alone solar systems) include water pumping, milling, ice making, woodworking and egg incubation. Emphasis also is being placed on the potential for DREA-powered appliances to provide income-generation opportunities. Low-wattage DREA systems such as solar home systems enable users to power LED lights, televisions, phone chargers, refrigerators and fans, for example in small shops and restaurants, as well as in people's homes after sunset. Growing evidence confirms that even small-scale DREA systems can help users generate income.[53]

Studies on mini-grids in Tanzania suggest that productive use of energy harbours opportunities for operators to grow demand, increase revenue and lower costs.[54] Although data on the deployment of productive use applications and appliances that can be powered by DREA systems remain limited, this is likely to change as governments and development finance institutions show growing interest in promoting DREA and productive use or income-generation applications. Some estimates suggest that by 2022, around 50% of the solar home systems deployed worldwide could be bundled with a television, and 60% with a fan.[55]

A policy push in India has led to the deployment of more than

177,000

solar pumps for irrigation and drinking water, compared to 11,626 in 2014.

Entrepreneurs in India, with the support of the government, have been leading efforts to promote DREA systems such as solar water pumps. Between 2014 and 2018, the number of solar pumps installed in the country for irrigation and drinking water purposes increased from 11,626 to 177,000.[56] A tender announced in 2018 to establish a 10 MW solar facility for agricultural purposes in the state of Maharashtra is expected to further boost the technology.[57] An Indian company also has installed 100 solar cold storage units to help farmers keep their produce cool.[58] In Africa, productive use efforts in 2018 included the piloting of solar mills in East Africa, the installation of solar pumps in Tanzania and the installation of 30 solar-powered hammer mills in Zambia.[59]

ACCESS TO CLEAN COOKING FACILITIES

The market for clean cooking solutions continued to grow in 2018, with key milestones achieved at both the country and industry levels. By year's end, Bangladesh had distributed more than 1.6 million improved cook stoves under its national Improved Cook Stove programme, surpassing the initial target of 1 million.[60] In Honduras, more than 150,000 efficient cook stoves have been installed in rural areas through the Proyecto Mirador project.[61] At the industry level, companies such as Burn Manufacturing and Envirofit announced that they had sold some 500,000 and 1.6 million clean cook stoves, respectively, as of the end of 2018.[62]

Overall, however, the market for clean cooking solutions continues to be dominated by liquefied petroleum gas. In India, an estimated 70 million LPG connections have been added in poor regions of the country since 2015, and in Africa an estimated 50% of the urban population of Sudan and 24% of urban residents in Kenya use LPG for cooking purposes.[63]

An estimated 125 million people worldwide used biogas for cooking in 2017, mainly in China (111 million) and India (9 million).[64] Around 15.5 billion cubic metres of biogas was produced for cooking purposes that year, with around 13.1 billion cubic metres

i Based on reports from Odyssey Energy Solutions Platform, which connects mini-grid developers and investors. The projects are located in 21 countries: Cabo Verde, Cameroon, the Democratic Republic of the Congo, Ethiopia, Ghana, Haiti, India, Kenya, Lesotho, Myanmar, Niger, Nigeria, the Philippines, Rwanda, Sierra Leone, Somalia, South Africa, Tanzania, Uganda, Zambia and Zimbabwe.

produced in China and 1.7 billion cubic metres in India.[65] Although the production of biogas for cooking decreased between 2012 and 2017 in the traditional markets of China and India, it increased greatly in other Asian countries such as Bangladesh, Cambodia, Indonesia and Nepal.[66] On the African continent, biogas production increased nearly 200% during that period to around 44 million cubic metres, mainly in the five countries engaged in the Africa Biogas Partnership Programme: Burkina Faso, Ethiopia, Kenya, Tanzania and Uganda.[67] (→ *See Figure 43.*)

By the end of 2018, more than 3.2 million solar cookers were estimated to have been distributed worldwide.[68]

BUSINESS MODELS

The success of DREA systems in recent years is due in part to innovative business models that have made many of the systems more affordable than fossil fuel-based solutions such as diesel generators and kerosene lighting. These business models have enabled more people in poor and remote areas to gain access to energy. To overcome challenges in reaching customers, companies have had to innovate in every aspect of business, from raising capital, through operations management, to customer acquisition.

Companies are benefiting from a wide range of finance opportunities. In recent years, they have used grants from development organisations and philanthropic foundations to greatly leverage investments from patient[i] as well as commercial investors. Companies also are making use of impact investing and crowdfunding to raise capital: between 2015 and 2018, fundraising for DREA activities from crowdfunding platforms increased almost nine-fold from USD 3.4 million to USD 30.5 million.[69] In addition to mobilising financing, some PAYG companies are seeking to cut the technology investments linked with payment terminals. In 2018, for example, M-KOPA, a leading PAYG company in Africa, piloted with Mastercard a QR code payment system for off-grid solar customers in Uganda.[70]

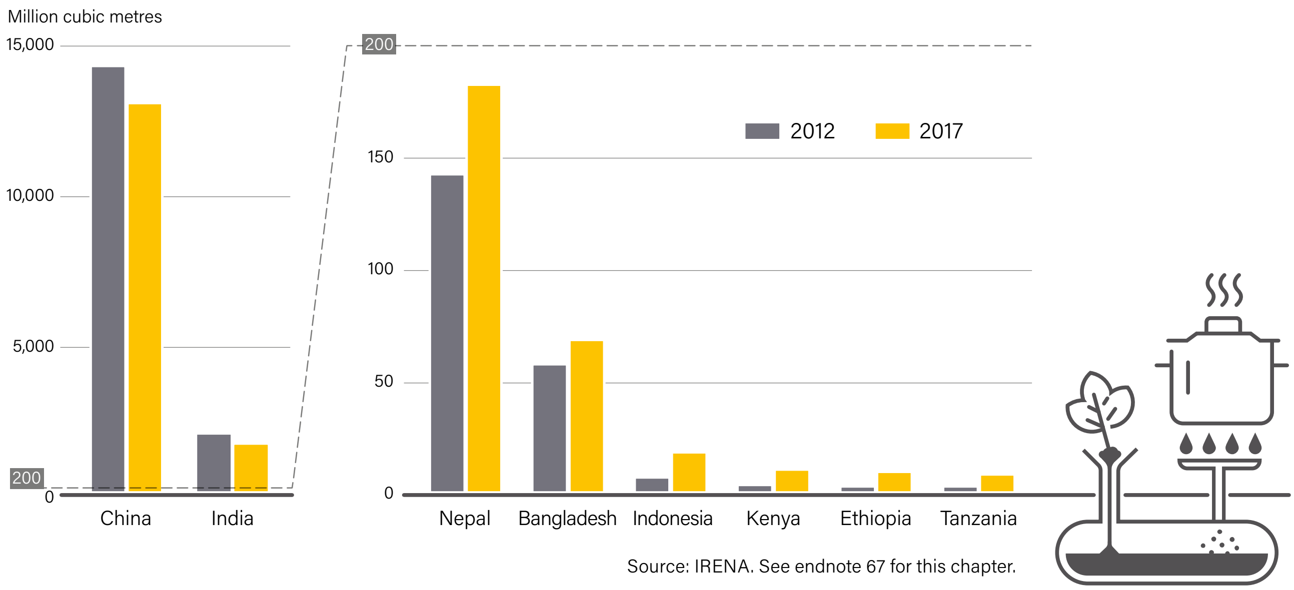
Technology innovations have enabled larger-scale deployment of DREA systems. Companies that are commercialising solar home systems have adopted intelligent components and custom-designed cloud-based software platforms to automate tasks related to customer account management, logistics monitoring, system control and real-time analytics. Several of the software platforms developed initially for internal use were launched in 2018 as commercial services and are now available to other companies seeking to optimise their operations when deploying DREA solar home systems.[71] Similar tools are available for the mini-grid sector as well.[72]

In countries with a relatively high penetration of mobile money, the PAYG model has been a key enabler of the mainstreaming of off-grid solar systems. More than 30 companies in at least 30 countries worldwide are now using the PAYG business model, with the majority of sales concentrated in Kenya, Uganda and Tanzania.[73] To maximise the effectiveness of customer acquisition, companies have leveraged existing networks of mobile operators or microfinance institutions. For example, in 2018 the French mobile network operator Orange partnered with PAYG solar companies such as BBOXX and d.light to scale up its off-grid solar distribution in the DRC and Madagascar.[74]

The increased demand for larger off-grid systems has created opportunities for many companies to offer their customers household applications beyond lighting and mobile phone charging, such as energy-efficient refrigerators, fans and televisions. Since 2017, more companies also have explored the possibility

i Patient investors refer to investors willing to make a financial investment in a business with no expectation of turning a quick profit, in anticipation of more substantial long-term returns.

FIGURE 43. Production of Biogas for Cooking in Selected Countries, 2012 and 2017



Source: IRENA. See endnote 67 for this chapter.

of providing energy services targeting income-generating activities, so-called productive use applications. Some of the more popular appliances and equipment deployed for productive uses include solar water pumps, mobile phone chargers and refrigerators.[75]

DREA companies are adapting their business models with the increasing demand for **energy-efficient appliances** and productive use of electricity.

Productive use is especially important with mini-grid applications, as these grids can be scaled to optimise both the load on the grid and the revenue of the operator. To develop new productive uses and sustain existing ones, mini-grid companies are increasingly providing finance to facilitate the adoption of productive applications, to train users on how to operate the machines and appliances, and to extend support to the productive micro-enterprises to ensure their long-term viability.[76] Although this can complicate the business models being used, it is seen as fundamental to increase the commercial viability of otherwise small and economically unattractive communities.

Some mini-grid operators are exploring a shift in their sales models away from selling individual kilowatt-hours to selling energy as a service at a flat rate. In recognition of the importance of productive use, the African Development Bank (AfDB) announced in 2018 that its loan to stimulate rural electrification in Nigeria would include a USD 20 million component dedicated specifically to incentivising the provision of productive use.[77]

As the off-grid energy sector matures and as competition increases, many PAYG companies are reviewing their business models to either sell additional services to their customers or target new customers. Zola Electric, for example, launched a new product in 2018 targeting populations living in wealthy areas in urban and peri-urban regions that are frequently affected by power shortages.[78]

The commercialisation of clean cooking systems has yet to be scaled to the level of off-grid solar systems. However, many companies are piloting various delivery models focused mainly on an integrated approach that includes sales of both the stove and the associated fuel (the "tool and fuel" business model).[79] In recent years, companies such as Inyenyeri (Rwanda) and Emerging Cooking Solutions (Zambia) have secured significant investment to demonstrate the financial viability of their model, which includes distributing ultra-clean gasifier stoves as well as pellets that the companies produce from wood and agricultural feedstocks.[80]

Other companies are applying the tool and fuel model with ethanol as the fuel. For example, KOKO Networks, which operates in India (manufacturing) and East Africa (retail), sells high-efficiency ethanol stoves with cartridges that can be refilled using mobile money at fuel automatic teller machines installed at small businesses.[81] By using the existing fuel infrastructure and capitalising on a last-mile distribution model, the company has been able to reduce the price of the ethanol fuel by up to 50%, making it a cost-effective substitute for charcoal.[82]

In 2017, nearly USD 6 million was raised to support initiatives seeking to demonstrate the commercial viability and scalability of pre-fabricated biogas systems.[83] Companies such as Sistema Biobolsa, ATEC and Home Biogas are coupling the production and sale of these systems with PAYG financing or with microfinance loans, with a view towards penetrating the African, Asian and Latin American markets.[84]

Various actors are testing the use of PAYG financing with different models. Since 2017, KopaGas in Tanzania has commercialised a PAYG distribution model for LPG that is similar to the PAYG off-grid solar systems.[85] KopaGas leases its customers a PAYG kit that includes an LPG cylinder coupled with a smart meter that allows for prepayment (using mobile money) of the quantity of gas to be used.[86] Similar approaches are being tested using biogas fuel in Cambodia and biogas gasifiers in Cambodia, Lesotho and Uganda.[87]

POLICY DEVELOPMENTS

As part of efforts to provide access to modern energy for rural populations, an increasing number of countries are turning their attention to distributed renewable energy technologies and are introducing specific policy measures to promote them.

One of the more common types of policy measures is to include DREA in national strategies and commitments. In 2018, several countries integrated DREA in their rural electrification strategies and plans. For example, Togo's new electrification strategy aims to provide electricity access by 2030 to 3 million people by installing 300 solar PV mini-grids and providing solar kits to some 550,000 households, among other efforts.[88] Kenya plans to provide universal energy access by 2022 through the use of off-grid systems such as mini-grids and stand-alone solar systems alongside grid extension efforts.[89]

An emerging trend in electrification planning is the use of geospatial least-cost models, which help electrification planners choose among the different electrification solutions for specific locations and sequence the implementation of electrification projects. Nigeria, Tanzania and Zambia are among the countries that have benefited recently from the use of such tools.[90]

Governments are extending policy measures to implement DREA projects through specific delivery instruments. For example, Kenya launched a tendering process in early 2019 for the construction of 1.4 megawatts of solar PV plants with associated power distribution networks as part of its plan to increase rural electricity access through mini-grids.[91] Madagascar updated its system of calls for proposals for private sector implementation of off-grid projects and established regular dialogues between the private and public sectors.[92] In the Philippines, the government approved a new competitive process for selecting power supply providers in off-grid areas.[93]

Some countries also focused on developing specific regulatory support and rules for DREA systems. For example, Sierra Leone's Electricity and Water Regulatory Commission drafted comprehensive mini-grid regulations that were set to be adopted in 2019.[94] The US territory of Puerto Rico issued a new regulation defining the different classes of micro-grids, the types of generation that they can use, and the role of utilities and municipalities in overseeing them.[95] Such steps are in line with similar developments in previous years in countries like Tanzania and Nigeria, which adopted detailed mini-grid regulations addressing challenging issues such as the tariffs that operators are allowed to charge or the arrangements around the interconnection of mini-grids in the case of grid arrival.[96]

Some countries adopted specific incentives to create a more supportive enabling environment for DREA. The DRC issued an import tax exemption on solar equipment, and India approved Phase III of its Off-grid and Decentralised Solar PV Applications Programme, which targets an additional 118 MW of off-grid solar PV capacity by 2020.[97]

In the clean cooking sector, an important development was the adoption of a new ISO standard for laboratory testing of cook stoves.[98] In India, a new National Biogas and Organic Manure Programme – launched in 2018 as the continuation of an earlier biogas programme – aims to implement at least 250,000 biogas plants with capacities ranging from 1 to 25 cubic metres per day by early 2020.[99]

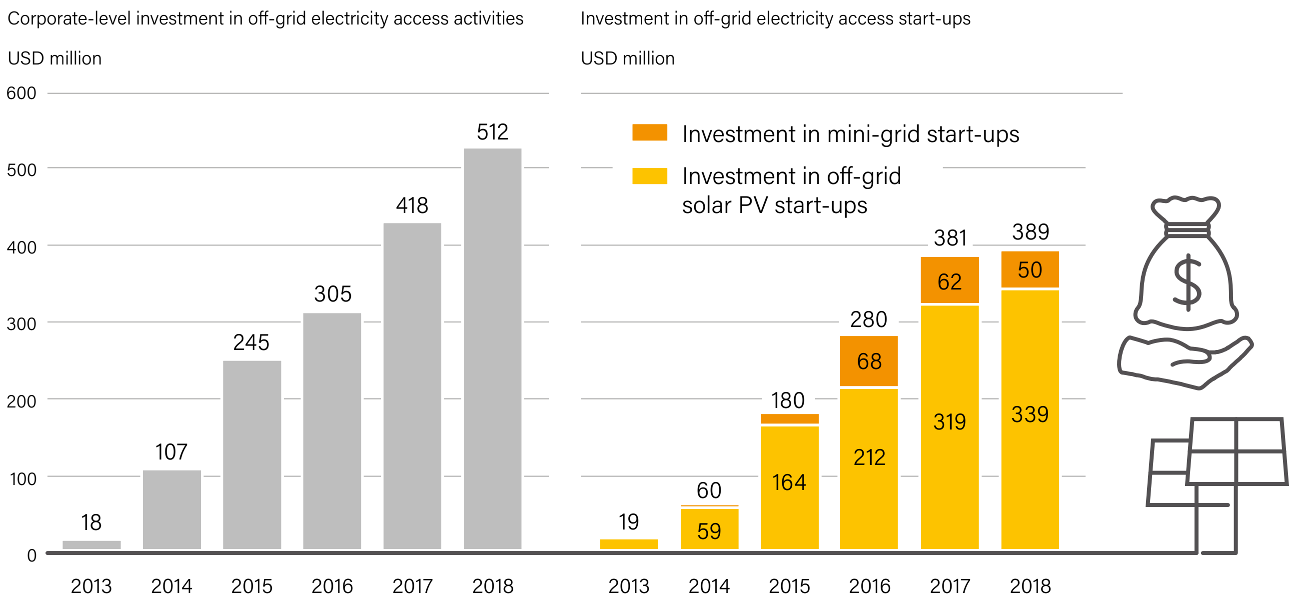
INVESTMENT AND FINANCING

The year 2018 set another record for energy access investment, with an estimated USD 512 million in corporate-level investment flowing into off-grid electricity access companies – a 22% increase from the USD 418 million invested in 2017.[100] (→ *See Figure 44.*) Cumulative corporate-level investments in the off-grid sector totalled USD 1.7 billion by the end of 2018, with 81% of the capital flowing to companies commercialising solar home systems and pico PV systems.[101]

Since 2010, the bulk of the investment has been directed towards off-grid electricity companies operating in Africa, with East Africa accounting for 58% of the investment mobilised, West Africa for 17% and Southern Africa for 4%.[102] By comparison, the Asia-Pacific region accounted for 15% of cumulative investment and Latin America for 6%.[103]

Investment continued to flow to DREA start-ups involved in providing electricity access. Off-grid electricity start-ups (including off-grid solar and mini-grid companies) raised an estimated USD 389 million in 2018, a 2% increase from the USD 381 million raised the previous year.[104] Investment in the sector was driven mainly by the stable growth of off-grid solar start-ups, particularly PAYG companies. Off-grid solar startups attracted a record USD 339 million in capital flows in 2018, up 6% from the USD 320 million raised in 2017.[105] (→ *See Figure 44.*)

FIGURE 44. Global Investment in Off-grid Electricity Access Activities, 2013-2018



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 100 for this chapter.

Although 2018 was not a landmark year for large, single-investment transactions in energy access start-ups, the average value of investment deals surged as the industry shifted to a focus on profitability rather than growth.[106] Reflecting the rising average value of transactions, 6 of the top 10 investments made in off-grid electricity companies since 2011 occurred in 2018[i],[107]

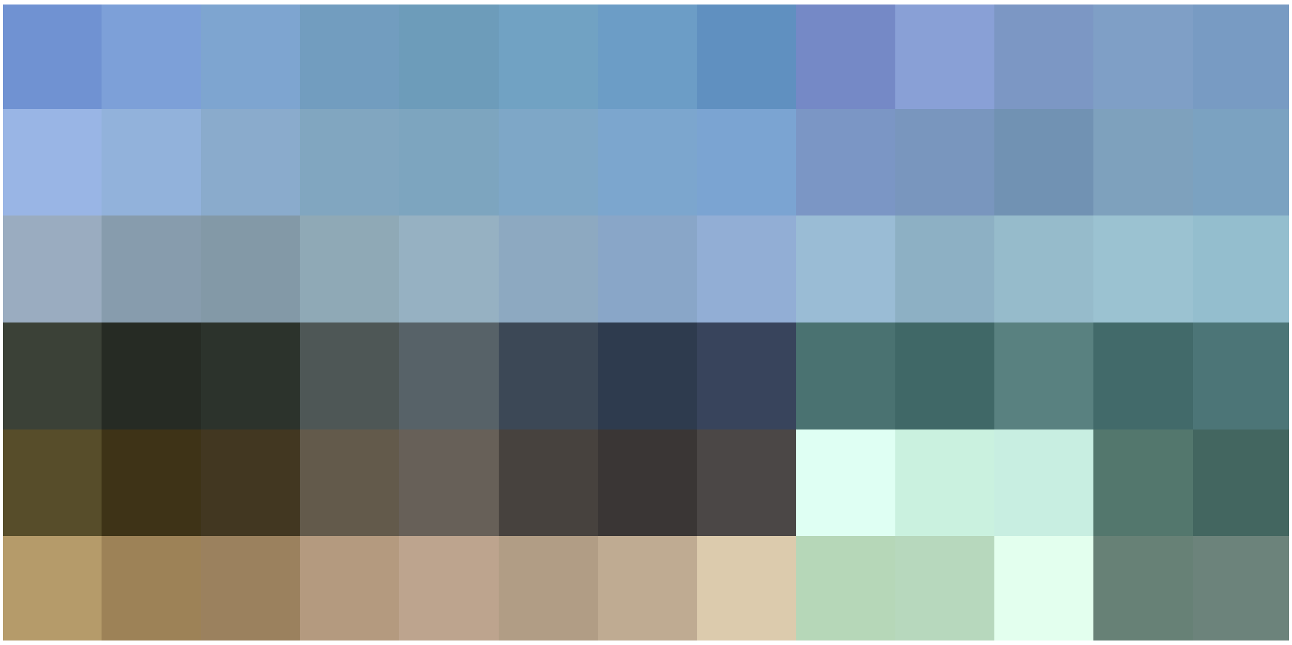
81%
of cumulative corporate-level investment flowed to companies commercialising solar home systems and pico solar devices.

Africa (particularly East Africa) remained the main recipient of capital inflows for off-grid solar systems. Zola Energy, formerly known as Off Grid Electric, raised more than USD 108 million to expand its activities in Africa, with the aim of reaching at least 25,000 new customers.[108] d.light secured USD 90 million in funding from several investors – including USD 25 million from the European Investment Bank and USD 41 million from a consortium that includes the Dutch Development Bank FMO and the government-sponsored investment funds Swedfund International and Norfund – to expand in Ethiopia, Kenya, Nigeria, Tanzania and Uganda.[109] M-KOPA attracted USD 10 million in financing from FinCanada to help the company consolidate its activities in East Africa.[110] BBOXX secured a partnership with EDF and USD 4 million in financing from a local bank in Togo to expand its activities in the country.[111]

Investments also continued to flow to Asia and to Central and South America. The PAYG start-up SolarHome raised USD 15 million to install some 28,000 solar home systems in Myanmar and to expand its activities in Cambodia and Indonesia.[112] Kingo, which was very active in 2017, secured another USD 15.5 million in 2018 to expand its services to around 250,000 people in Guatemala.[113] In an undisclosed transaction, the French energy utility ENGIE acquired a 90% stake in Simpa Network's India operations.[114]

An estimated USD 289 million in corporate-level investments flowed into the mini-grid sector from 2010 to 2018, representing around 17% of the total corporate-level investment in energy access during that period.[115] Mini-grid start-ups attracted around USD 51 million in investment in 2018, down 18% from the USD 62 million raised in 2017.[116] Husk Power Systems raised USD 20 million from Shell, ENGIE and Swedfund International to scale up its mini-grid business in Asia.[117] SunFunder launched a USD 1.2 million facility with mini-grid developer PowerGen to install 20 mini-grids in Kenya and serve some 2,400 households.[118] RVE.SOL raised USD 2.9 million (EUR 2.5 million) to deploy its PAYG mini-grid model in Kenya, benefiting some 15,000 people.[119]

Several investment vehicles for DREA systems were either set up or secured capital inflows in 2018. For example, the BEAM platform, organized by BBOXX and the private equity firm Bamboo Capital Partners, aims to invest around USD 50 million in equity in DREA service companies.[120] Solar Frontier Capital and SIMA Funds launched a dedicated USD 175 million debt facility for the distribution of off-grid solar systems.[121] The Solar Energy Transformation Fund of SunFunder secured USD 25 million from the US Overseas Private Investment Corporation (OPIC) to invest in more than 50 off-grid solar companies.[122] The Off-Grid Energy Access Fund (OGEF), which



i The top six investments were Zola Electric (USD 55 million; January 2018), d.light (USD 50 million; April 2018); d.light (USD 41 million; December 2018), Zola Electric (USD 32.5 million; January 2018), Starsight Power (USD 30 million; February 2018) and Yoma Micro Power (USD 28 million; April 2018).

aims to provide debt financing to companies providing off-grid energy services, received funding of USD 58 million.[i,123] Also in 2018, Africa's first project financing facility, CrossBoundary Energy, was launched with initial capital of USD 16 million, with the aim of providing electricity to some 170,000 people through mini-grids in Nigeria, Tanzania and Zambia.[124]

Crowdfunding also continued to be an important source of financing for off-grid companies. Solar Home secured USD 10 million from investors, including from the crowdfunding platforms Crowdcredit and Trine.[125] BBOXX raised USD 1.1 million (EUR 1 million) from Trine to scale up its activities in Kenya.[126]

In the clean cooking sector, an estimated USD 40 million was invested in clean cooking companies in 2017, a 36% increase compared to 2016.[127] (→ *See Figure 45.*) Nearly 70% (USD 27 million) of this investment was raised by companies that have an integrated business model (deploying both clean cooking stoves and the associated fuels), highlighting the financial viability and scalability of this model and its attractiveness to potential investors.[128] By comparison, 25%, or USD 10 million, was raised by clean cook stove manufacturers and 5% by fuel producers.[129]

Companies commercialising renewable energy-based stoves and/or fuels attracted 90% of the sector's investment in 2017.[130] (→ *See Figure 46.*) Companies dealing in biomass pellets and gasifier stoves raised around 31% of the total investment for that year, while companies involved with biogas systems raised about 15%.[131] In contrast, companies commercialising LPG stoves and fuel through consumer finance and PAYG approaches attracted only 7%[ii] of the capital flows in 2017.[132]

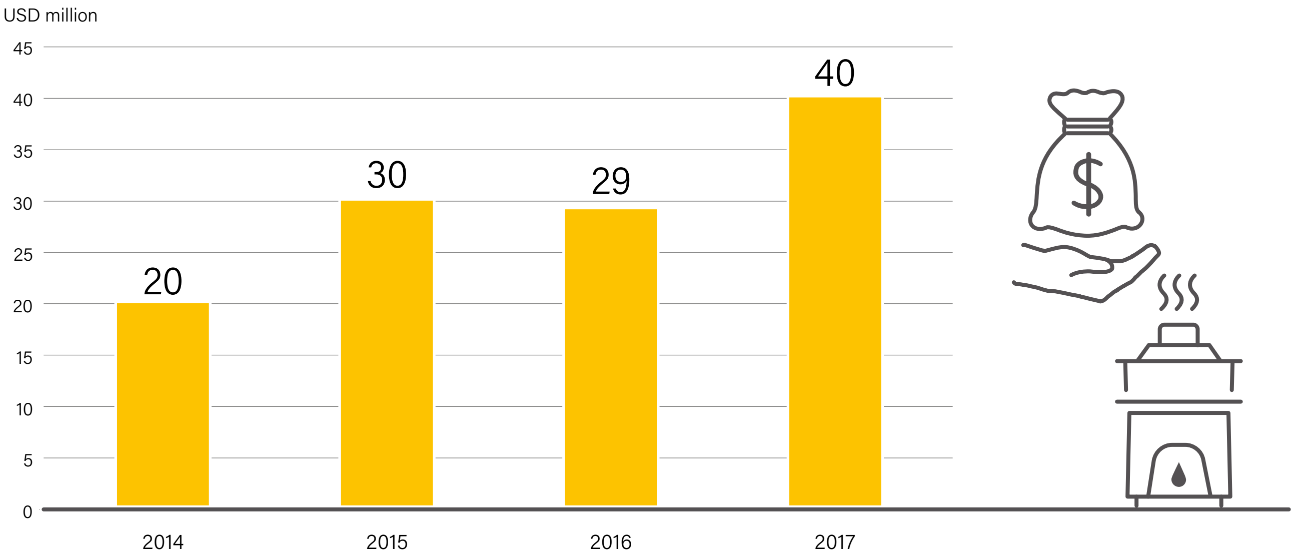
With the emergence of viable business models, the clean cooking sector is gradually attracting more institutional investors. In 2017, commercially oriented institutions such as banks, venture funds and family offices invested a total of USD 21 million, or more than half of total investment.[133] Given the small number of commercially viable players on the market, 90% of these investments were concentrated in just three companies.[134]

The clean cooking sector continued to attract early-stage investments in 2018 to finance and demonstrate innovative business models, but scale-up capital is yet to be mobilised. For example, Inyenyeri attracted USD 1.1 million (EUR 1 million) from Oikocredit to expand its business in Rwanda and to achieve its goal of serving 150,000 households by 2020, up from 3,000 as of mid-2018.[135] PayGo Energy raised USD 3.5 million to expand its business in Kenya.[136]

i Among the main financing institutions were the AfDB, the Nordic Development Fund, the Global Environment Facility, Calvert Impact Capital and All On, an off-grid energy impact investment company backed by Shell.

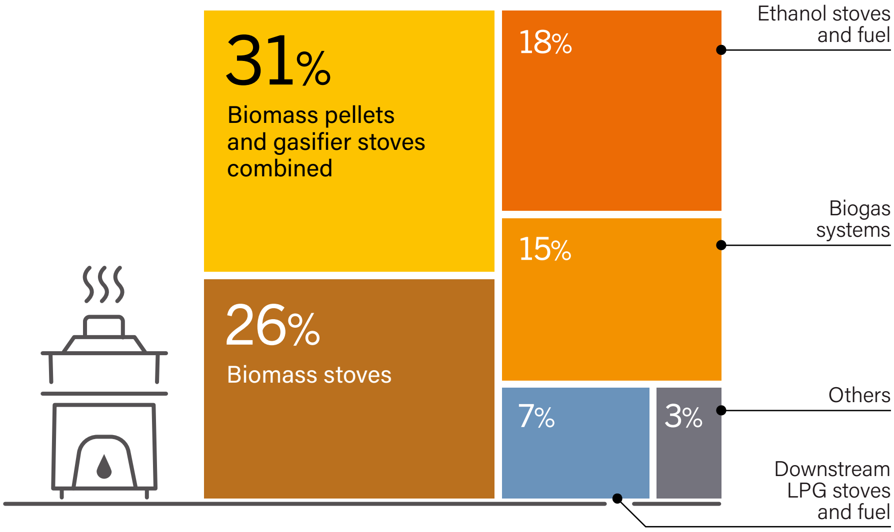
ii Based on data provided to the Clean Cooking Alliance by a handful of LPG distributors and stove manufacturers as well as a few PAYG-oriented LPG players. The broader universe of LPG sector players has undoubtedly attracted far more finance which is, as of yet, untracked.

FIGURE 45. Global Investment in Clean Cooking Companies, 2014-2017

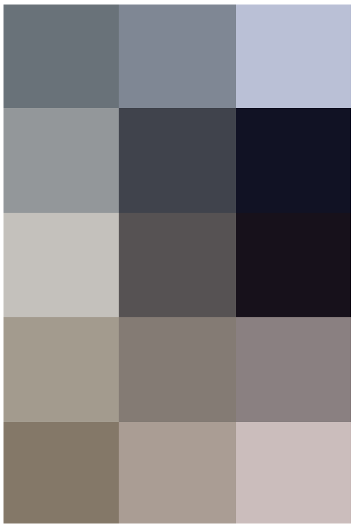


Source: see endnote 127 for this chapter.

FIGURE 46. Share of Capital Raised by Clean Cooking Companies, by Technology and/or Fuel Type, 2017



Source: see endnote 130 for this chapter.



INTERNATIONAL INITIATIVES AND PROGRAMMES

International actors and donors continued to support the deployment of DREA systems in 2018 by providing finance and technical assistance but also by facilitating partnerships and organising networking and advocacy events. (→ ***See Reference Tables R23 and R24.***) Since 2010, development financial institutions (DFIs) have played an important role in financing off-grid energy access activities and catalysing private investment. For example, 4 of the top 10 investors in corporate off-grid energy access were public DFIs: the Dutch Development Bank FMO (USD 149.4 million), Norfund (USD 129 million), the CDC Group (USD 100.6 million) and OPIC (USD 85 million).[137]

In 2018, DFIs committed nearly USD 1 billion (USD 989 million) towards off-grid systems, representing about 7% of these institutions' total investment in energy projects that year (USD 13.5 billion).[138] Typically, DFIs have committed between 1% and 5% of their total energy portfolio investments to off-grid systems; however, in the fourth quarter of 2018 this share rose to 17%.[139]

For example, the World Bank provided USD 55 million to the Second Rural Electrification and Renewable Energy Development (RERED II) project in Bangladesh to support the installation of 1,000 solar irrigation pumps, 30 solar mini-grids and some 4 million clean cook stoves in rural areas.[140] The World Bank also committed more than USD 510 million to four new projects promoting the use of distributed renewable energy in Nigeria, Pakistan, the Solomon Islands and Yemen, while the International Finance Corporation provided advisory services and invested in companies promoting off-grid technologies in Myanmar, Yemen and Zambia.[141]

Also in 2018, the AfDB granted a loan of USD 266 million to Rwanda for energy access activities including the promotion of off-grid systems.[142] The AfDB plans to give Ethiopia USD 100 million for the development of a facility that will provide off-grid electricity to more than 5 million households by 2025.[143] In addition, the AfDB announced that it would guarantee a local currency debt facility in Côte d'Ivoire that would allow Zola Energy to mobilise USD 28 million to finance some 100,000 solar home systems in the country.[144]

The Asian Development Bank (ADB) approved USD 45 million in financing (USD 25 million in the form of grants and

USD 20 million as a loan) for the installation of at least 2,000 solar PV pumping irrigation systems in Bangladesh, with a total installed capacity of 19.3 MW.[145] The ADB also approved two new projects aimed at promoting DREA in Nepal and Tonga.[146]

On a bilateral level, the European Union provided a grant of around USD 68 million (EUR 60 million) to the government of the Philippines for the installation of 40,500 solar home systems in off-grid communities.[147] With financing from the Millennium Challenge Corporation, the Off-Grid Clean Energy Facility of Benin would provide USD 20 million towards developing and operating off-grid energy systems.[148] The US-backed initiative Power Africa granted Uganda USD 500,000 for its off-grid solar expansion programme.[149] The Republic of Korea announced that it would provide some 500,000 clean cook stoves to rural dwellers in Ghana.[150]

The Green Climate Fund approved funding for three DREA projects in 2018: USD 20 million to the Clean Cooking Program in Bangladesh, USD 21 million to the Green Mini-Grid Program in the DRC and USD 24 million to the Yeleen Rural Electrification Project in Burkina Faso (through a private sector-driven green mini-grid model).[151] Meanwhile, the Global Environment Facility approved funding for projects aimed at advancing DREA in Angola, Djibouti, Guinea-Bissau, Myanmar, Nigeria and the Solomon Islands.[152]

Several initiatives and programmes are targeting the promotion of appliances that are specifically designed to be powered by off-grid systems and that in many cases can generate income for end-users. Most of these initiatives are implemented by organisations that are part of the Efficiency for Access coalition, relaunched in early 2018.[153] The aim of the coalition is to scale up and bring together programmes and support mechanisms striving to accelerate the uptake of energy efficiency in energy access efforts. Specific initiatives supported by the coalition include the Low-Energy Inclusive Appliances programme, the Global LEAP Awards, the Off-Grid Cold Chain Challenge and the Efficiency for Access Investor Network.

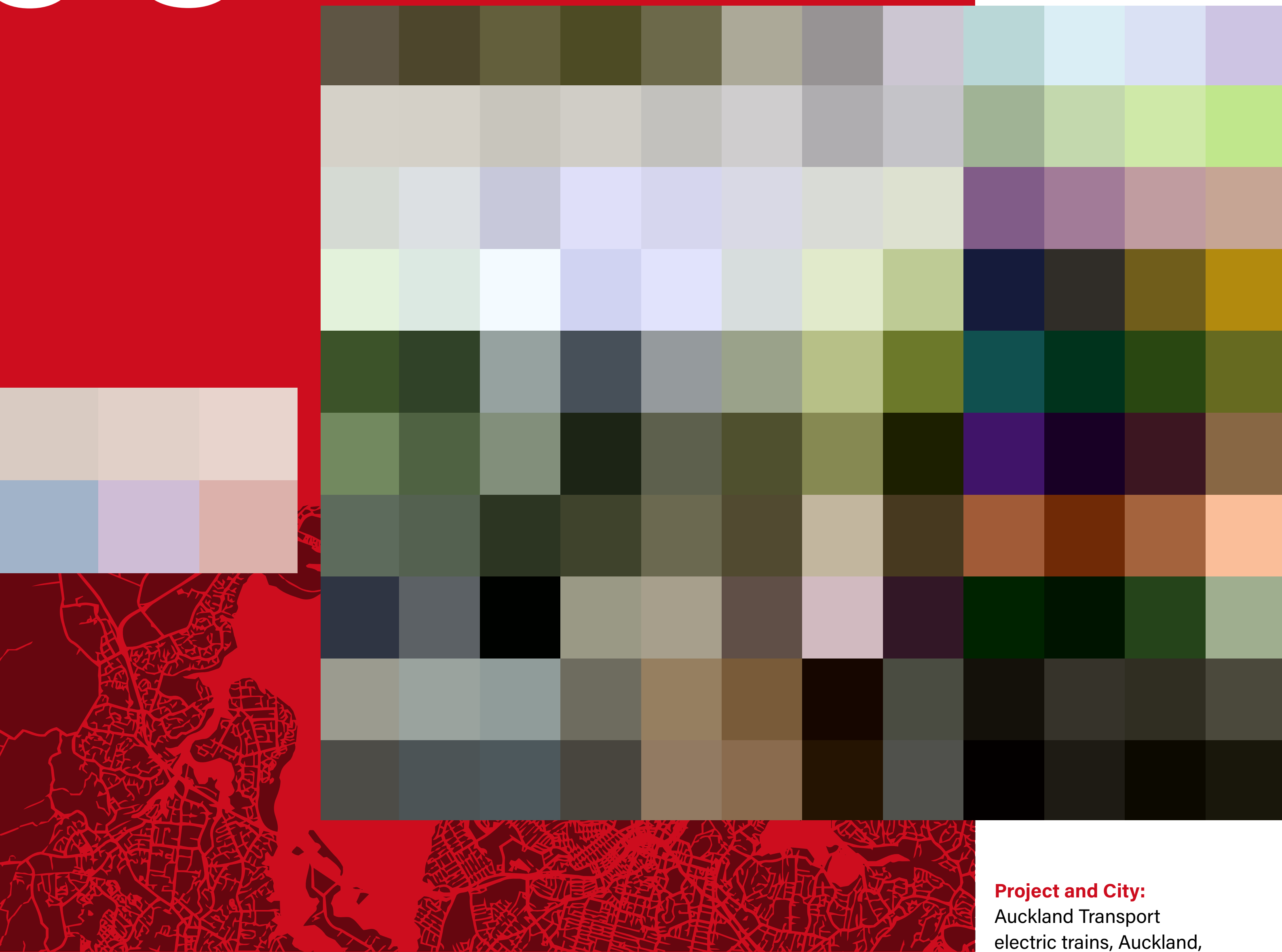
OUTLOOK

Overall, 2018 was a positive year for DREA systems. On the electricity access side, governments and the international community were increasingly considering the spectrum of opportunities provided by DREA systems. Off-grid solar systems, backed by the PAYG model, continued to attract the interest of stakeholders and investments as they became established as the most cost-effective and fastest option to provide electricity access to rural and remote populations. Mini-grids also are gaining momentum to become the much-anticipated game-changer in the sector as the appropriate enabling ecosystem is established with regard to technology, regulations, financing and business models.

On the clean cooking access side, in light of the huge financing gap needed to meet the 2030 goal of universal access, much emphasis has been put on addressing the key barriers and challenges that impede the required investment flows in the sector. Promising business models are being developed and tested, building on lessons learned from the success of off-grid solar. The year 2018 was one of strengthened partnerships among different stakeholders, both within and across sectors.

However, reaching the desired goals in both electricity access and clean cooking would require that DREA systems become mainstream in national strategies, including by establishing the appropriate enabling environment to build capacity and attract the private sector. Meaningful ways to build collaborations between utilities and DREA players have yet to be developed and will be central to the continued scale-up of these sectors beyond the handful of countries now benefiting from their presence.

05



Project and City:
Auckland Transport electric trains, Auckland, New Zealand

Technology:
Electric trains

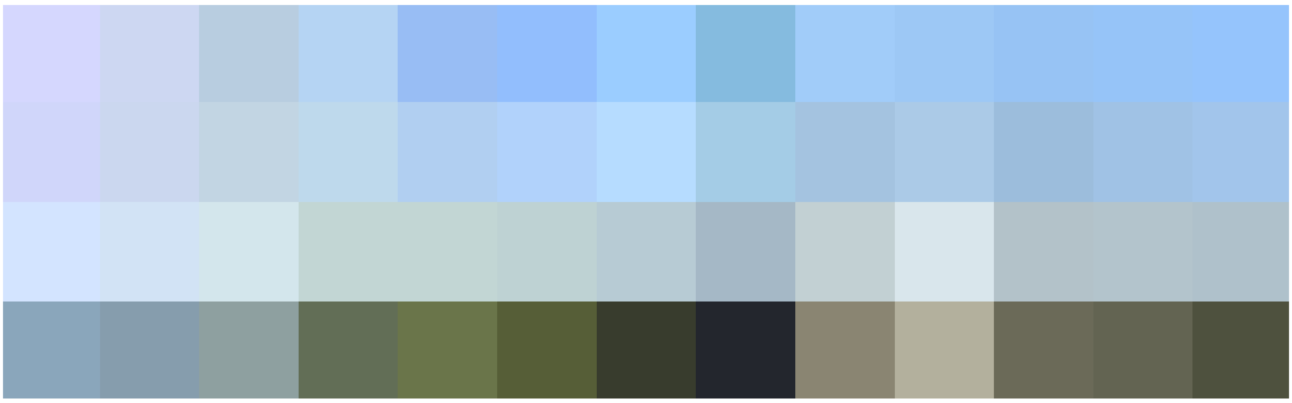
Auckland, New Zealand

In 2018, Auckland Council issued green bonds that raised NZD 200 million (USD 134 million) to fund electric trains and associated infrastructure. The first electric train entered into service in April 2014, and today more than 3,000 electric rail services operate to and from downtown Auckland each week. KiwiRail sources the power from the main electricity grid and will use the funding to operate the service and purchase additional trains. In 2018, around 84% of New Zealand's electricity was generated from renewable resources, with hydropower accounting for more than 60% of net generation.

INVESTMENT FLOWS

Global investment in renewable power and fuels (not including hydropower projects larger than 50 megawatts (MW)) totalled USD 288.9 billion in 2018, as estimated by BloombergNEF (BNEF)[i]. This was 11% less than the USD 326.3 billion invested in 2017. However, 2018 was the ninth successive year in which investment in renewables exceeded USD 230 billion, and the fifth in which it topped USD 280 billion. (→ *See Figure 47* and ***Reference Table 25.***) In addition, an estimated USD 16 billion was invested in large hydropower projects in 2018, down from USD 40 billion in 2017[ii].

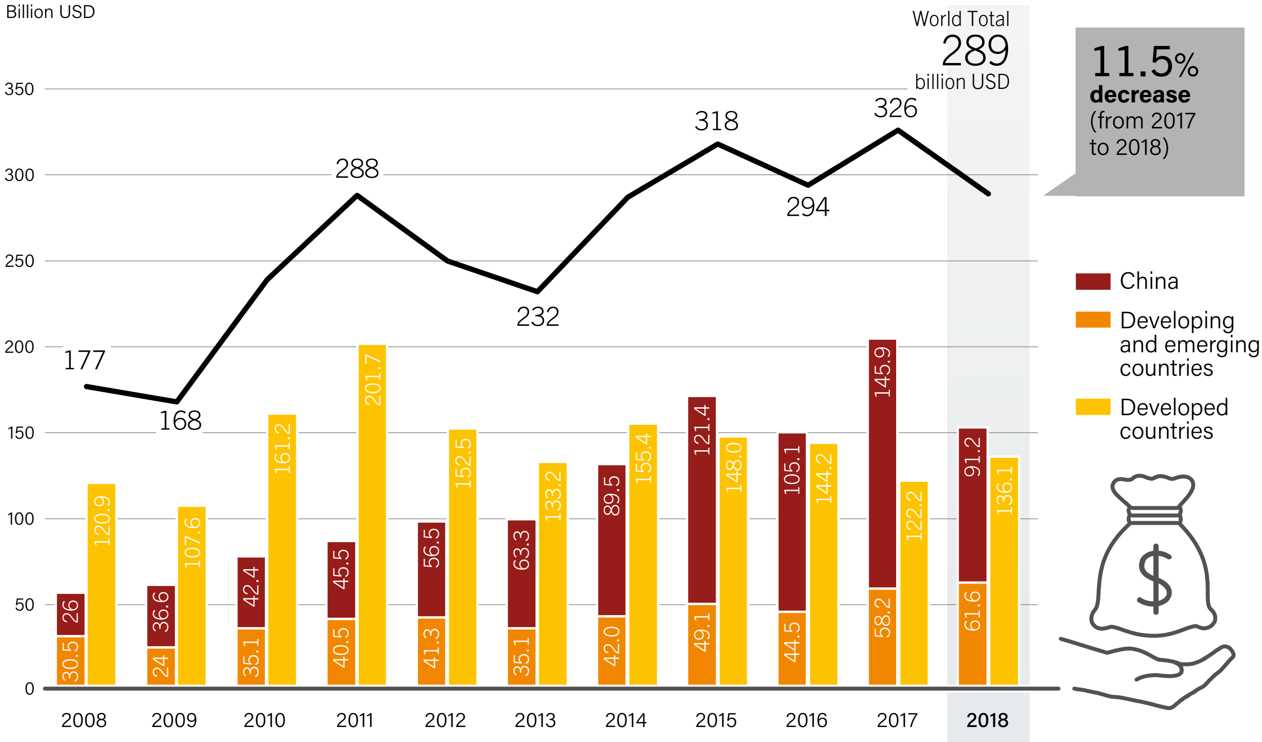
Global investment in renewable power and fuels reached
288.9
billion USD
in 2018.



i Data in this chapter are based on the output of the BNEF Desktop database 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 megawatt (MW); all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately and referred to as small-scale projects or small-scale distributed capacity; all ocean power projects; and all biofuel projects with an annual production capacity of 1 million litres or more. Where totals do not add up, the difference is due to rounding.

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 chapter figures, unless otherwise mentioned.

FIGURE 47. Global New Investment in Renewable Power and Fuels in Developed, Emerging and Developing Countries, 2008-2018



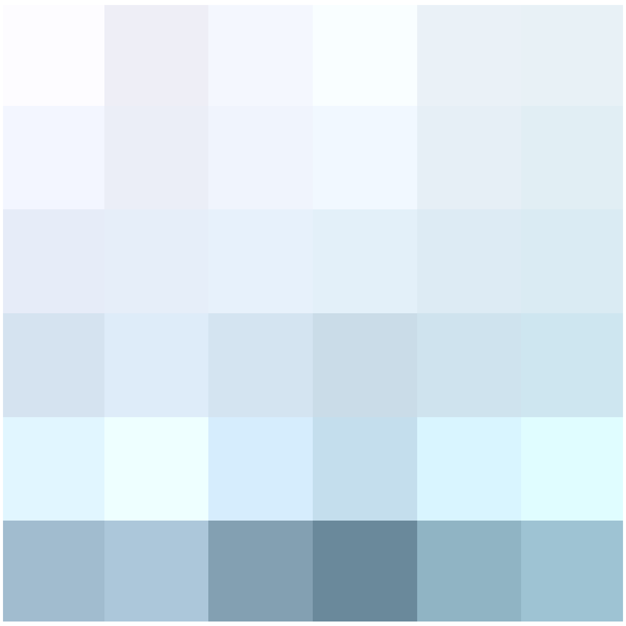
Note: Figure does not include investment in hydropower projects larger than 50 MW. Investment totals have been rounded to nearest billion. Data for previous years have been revised since the publication of the *Global Trends in Renewable Energy Investment 2018* report. See BNEF for data methodology and regional groupings.

Source: BNEF.

The overall investment in renewable power capacity (including all hydropower) in 2018 once again far exceeded that in fossil fuel and nuclear power capacity. The total dollar amount invested in renewable power was almost exactly three times higher than the amount invested in new coal- and gas-fired generators combined.

Investment in renewables continued to focus on solar power, which secured USD 139.7 billion in 2018. This was down 22% from 2017, due largely to lower unit costs for solar power and to changes in China's photovoltaic (PV) market[i]. Although wind power investment continued to lag behind solar power, it increased 2% in 2018, to USD 134.1 billion. The other sectors were further behind, although investment in biomass and waste-to-energy increased 54%, to USD 8.7 billion.

Investment in China, the country that attracts the most renewable energy investment by far, fell sharply from its record high in 2017. The next-largest investments were in the United States, Japan and India. A total of 19 countries had investments of more than USD 2 billion each, including, for the first time, Ukraine and Vietnam.



i Note that declining costs of some renewable energy technologies (particularly solar PV and wind power) have a downward influence on total dollar investment (all else being equal). Thus, changes in monetary investment do not necessarily reflect changes in capacity additions.

INVESTMENT BY ECONOMY

Renewable energy investment in developed countries increased 11% in 2018, to USD 136.1 billion[i]. Excluding China, which saw steep declines, investment in the developing world increased 6% to USD 61.6 billion, a record high. This reflects a broadening of investment activity in wind and solar to more countries in Asia, Eastern Europe, and the Middle East and Africa.

Trends varied by region, with investment rising in Europe, in the Middle East and Africa, in Asia (except China and India) and in the United States, and falling in the Americas (excluding the United States but including Brazil) as well as in China and India[ii]. (→ *See Figure 48.*) Considering all financing of renewable energy (but excluding hydropower larger than 50 MW), China accounted for 32% of the global total, down from 45% in 2017, followed by Europe (21% in 2018), the United States (17%) and Asia-Oceania (excluding China and India; 15%). Smaller shares were seen in India (5%), the Middle East and Africa (5%), the Americas (excluding Brazil and the United States; 3%) and Brazil (1%).

China accounted for the bulk of investment worldwide for the seventh successive year, at USD 91.2 billion in 2018, although this was down 37% from 2017 and was the lowest annual figure since 2014. The dip was due largely to a mid-year change in the government's feed-in tariff policy, which halved investment in solar power (to USD 40.2 billion, down from USD 89 billion in 2017). By comparison, investment in wind power in China decreased only 6% to USD 50.1 billion.

Investment in Europe jumped 39% to USD 61.2 billion, the highest level in two years. The increase is attributed to three main factors. In Scandinavia, a surge in financings of onshore wind projects occurred in Sweden and Norway, backed by corporate power purchase agreements (PPAs). In Spain, where electricity prices were secured through auctions or through PPAs with companies or utilities, investment in solar PV plants increased. Finally, the region experienced a rebound in offshore wind investment, with five offshore wind projects totalling more than USD 1 billion reaching financial close in the waters off Belgium, Denmark, the Netherlands and the United Kingdom.

In the United Kingdom – Europe's largest national investor in renewable energy in 2018 – investment jumped 23% to USD 8.3 billion, due mainly to the financing of two offshore wind power projects and one coal-to-biomass conversion plant. Investment in Germany was down 45% to USD 7.5 billion, reflecting a sharp contraction in the onshore wind power market. Investment in other European countries increased substantially: Spain was up 10-fold to USD 7.5 billion, the Netherlands was up 170% to USD 5.1 billion, and Sweden was up 117% to USD 4.6 billion, its highest level to date. Investment in France declined 4% to USD 4.5 billion.

In the United States, investment edged up 1% to USD 48.5 billion, the highest level since 2011. This was due largely to a 15% increase in wind power investment, which reached USD 24.6 billion. Developers stepped up efforts to finance large wind power projects that qualify for the country's Production Tax Credit before the incentive expires. Solar power investment in the United States was down 8% to USD 21.8 billion.

Despite steep declines in its overall investment in renewables, **China** still accounted for the largest single share of investment worldwide, with USD 91.2 billion in 2018.

i Developed-country volumes are based on OECD countries, excluding Chile, Mexico and Turkey.

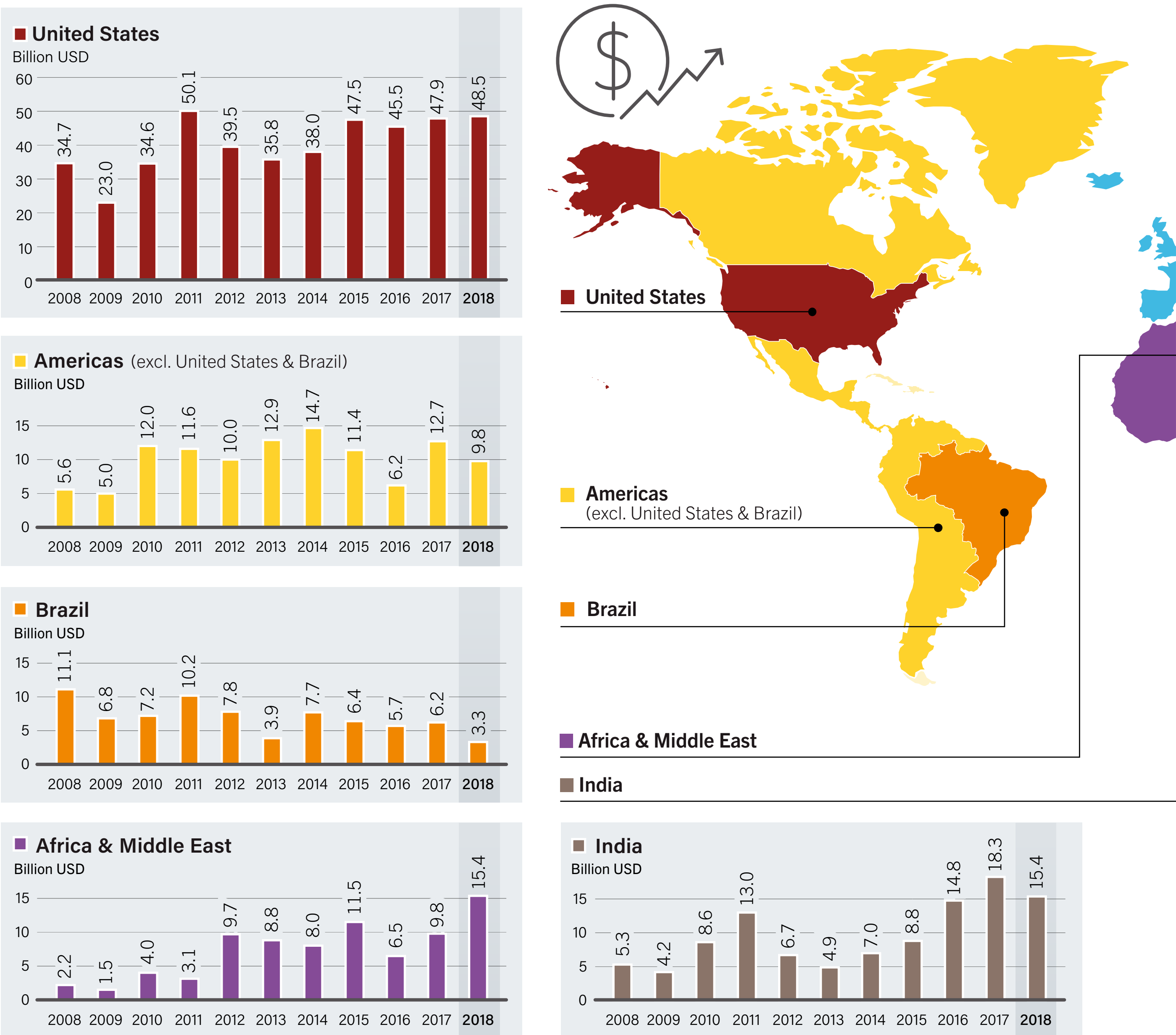
ii Regions presented in this chapter reflect those as presented in the BNEF Desktop database and differ from the regional definitions across the rest of the GSR, which can be found at www.ren21.net/GSR-Regions.

Investment in the Asia-Pacific region (excluding China and India) increased 6% to USD 44.2 billion, the highest level in three years. Investment varied widely by country, however. It increased 32% in Australia, to USD 9.5 billion (the highest level to date) and reached USD 4.1 billion in Vietnam, up seven-fold from 2017. For the first time, Vietnam emerged as a multibillion-dollar market for solar PV. In Japan, renewable energy investment was down 19% to USD 18.3 billion, and investment in solar power reached a seven-year low as costs fell and as developers struggled to secure land and grid connections.

Investment in India fell 16% to USD 15.4 billion, although this was the country's second-highest annual total to date. The investment decline reflected uncertainty in import tariffs and exchange rates. Investment in wind power equalled its 2016 record, at USD 7.2 billion, but investment in solar power declined 27% to USD 8.2 billion.

In the Middle East and Africa – an up-and-coming region for wind and solar power – investment jumped 57% to a record USD 15.4 billion. Egypt, Kenya, Morocco and South Africa were all billion-dollar markets. South Africa led with USD 3.9 billion in investment, up 33-fold from 2017, as the

FIGURE 48. Global New Investment in Renewable Power and Fuels, by Country or Region, 2008-2018

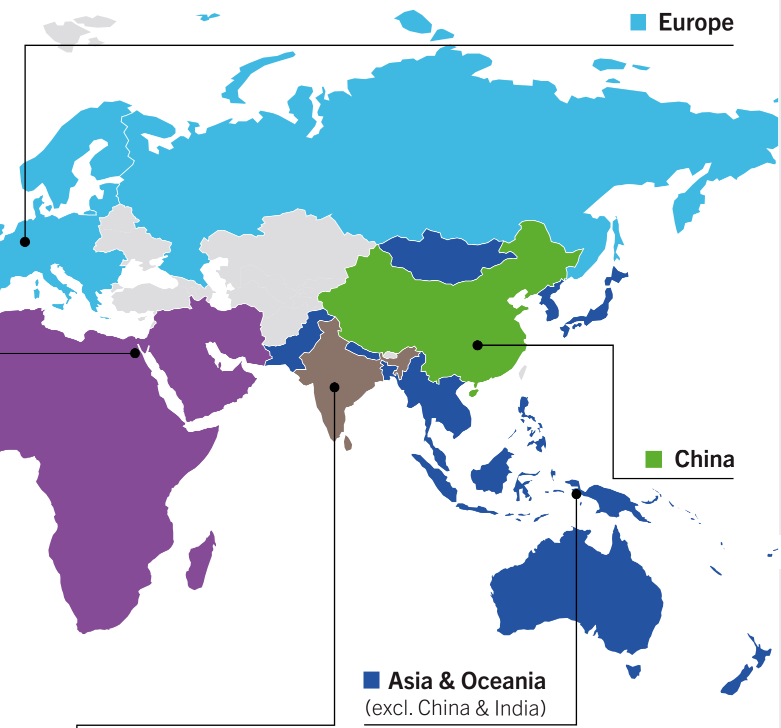


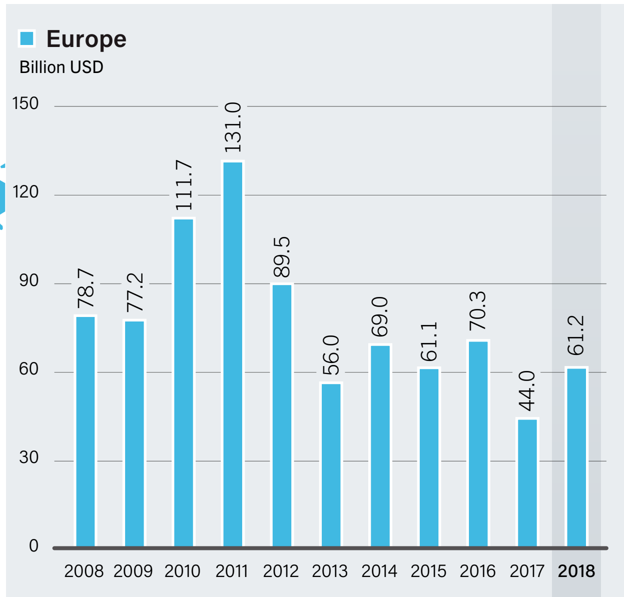
Note: Data are in current USD and include government and corporate research and development (R&D).

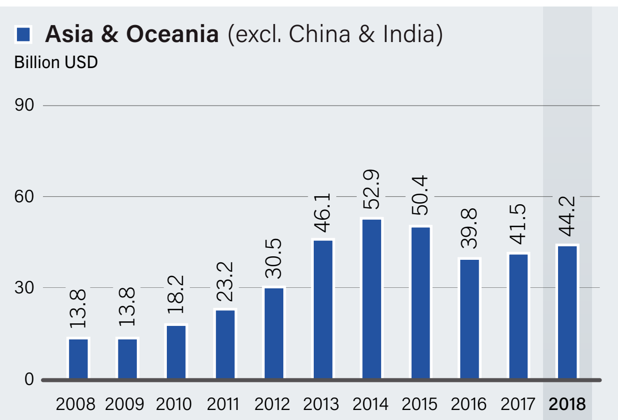
country's renewable energy auction programme led to a series of project financings, ending two years of delays. Morocco followed with USD 2.9 billion, up 157% from 2017. Across the region, solar power was the largest recipient of project financing, with a record USD 9.8 billion, and wind power investment reached USD 4.7 billion, an all-time high.

In the Americas (beyond Brazil and the United States), investment declined 23% (excluding large hydropower), to USD 9.8 billion. Of the billion-dollar markets, Argentina and Canada both saw modest increases in funds committed. Investment in Argentina was up 18% to USD 1.9 billion, its highest level to date. Investment in Canada was up 17% to USD 1.6 billion. Investment declined in both Chile (down 41% to USD 1.2 billion) and Mexico (down 38% to USD 3.7 billion); wind power suffered hard in both countries.

Brazil also experienced substantial declines in investment, which dropped 47% to USD 3.3 billion in 2018. Both wind and solar power struggled with the impact of a weak economy and the timing of the country's renewable energy auction programme.







Source: BNEF.

INVESTMENT BY TECHNOLOGY

Solar PV and wind power continued to dominate new investment in renewable energy in 2018. (→ *See Figure 49.*) Whereas in 2017, investment in solar PV was much higher than that in wind power, the gap narrowed sharply in 2018, with solar PV accounting for 48% of investment and wind power for 46%. This was due mainly to a 22% decline in dollar commitments to solar power, to USD 139.7 billion, the lowest level since 2013. The main factors contributing to the decline were the slowdown in solar power investment in China and falling capital costs for solar PV projects in most markets, which meant that fewer dollars were needed to finance a given amount of capacity.

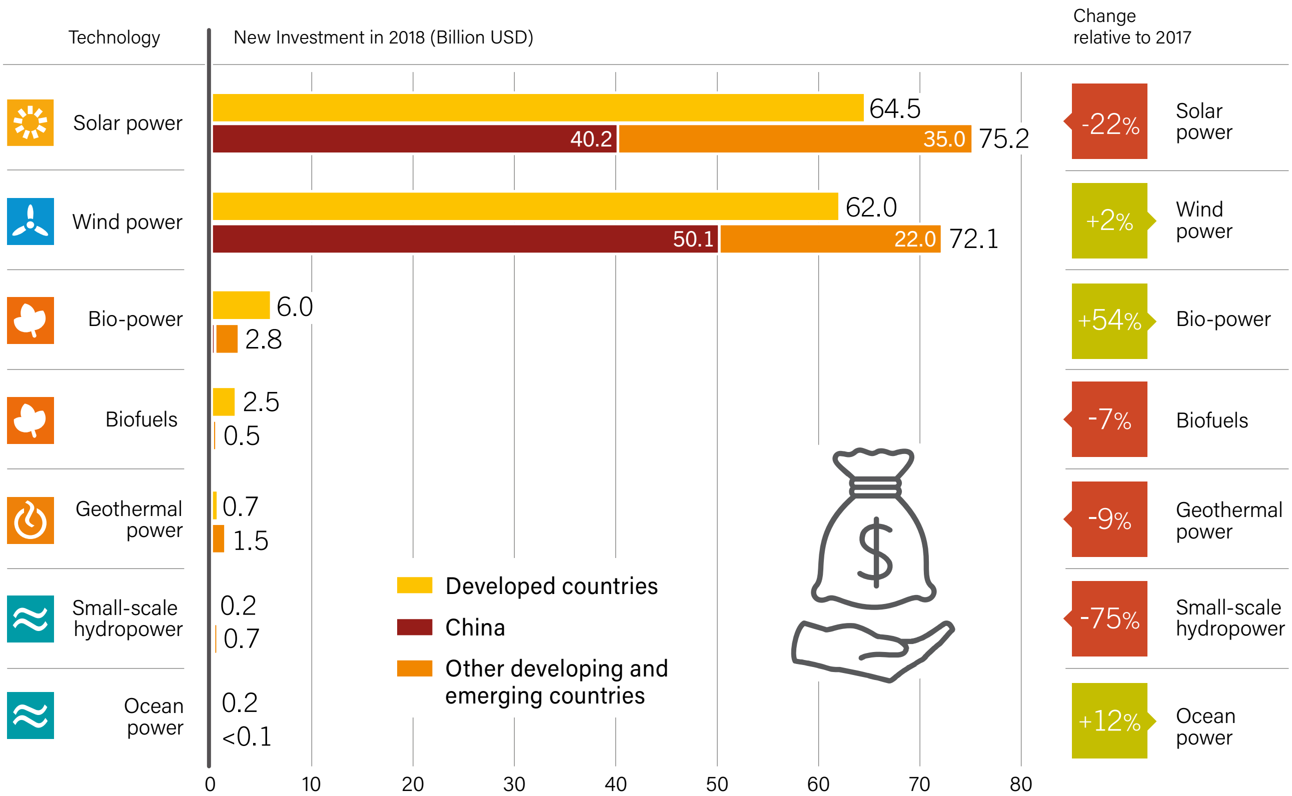
Investment in wind power edged up 2% to USD 134.1 billion, its highest level ever. This was due largely to the financing of large onshore wind power projects in China, the United States, South Africa, India and Sweden, as well as to a number of offshore project deals in Europe. Overall, investment in onshore wind power was up 2% for the year, to USD 109.8 billion (a record high), and investment in offshore wind power was up 7%, to USD 24.6 billion (the second-highest level on record).

Developed economies led in both solar and wind power investment in 2018, followed by China. Other developing and emerging economies invested significantly more in solar power than in wind power during the year.

Although investment in biomass and waste-to-energy was comparatively small, it was up 54% in 2018, to USD 8.7 billion. Several sizeable biomass projects in Japan received financing, and investments in large waste-to-energy plants were approved in Serbia, the United Arab Emirates and the United Kingdom.

Investment in **solar power** continued to lead investment in renewable energy, albeit by a smaller margin in 2018.

FIGURE 49. Global New Investment in Renewable Energy by Technology in Developed, Emerging and Developing Countries, 2018



Note: Total values include estimates for undisclosed deals as well as estimates for small distributed capacity and corporate and government R&D.

Source: BNEF.

Investment in biofuels was down 7% in 2018, to USD 3 billion. Much of the total was R&D spending and venture capital deals, although two ethanol plants were financed in the United States, for a total of several hundred million dollars.

Despite decisions to invest in two new generating plants in Indonesia and Kenya, investment in geothermal power fell 9%, to USD 2.2 billion. Investment in small hydropower plants plummeted 75%, to USD 901 million, reflecting a general slowdown in the sector. Although investment in ocean power increased 12%, the total dollar amount remained small, at only USD 203 million. Some ocean power technology developers have run into financial difficulty, and the outlook for policy support in key markets such as France and the United Kingdom is unclear. (→ *See Ocean Power section in Market and Industry chapter.*)

Financing for large hydropower projects of more than 50 MW (excluded from BNEF's renewable energy investment total) was weaker than earlier in the decade. Investment totalled an estimated USD 16 billion in 2018, down 60% from 2017. The large difference reflects the fact that no multi-gigawatt dams were financed in 2018, whereas in 2017 the go-ahead for the 16 gigawatt, USD 28 billion Baihetan project in China boosted the investment total significantly.

INVESTMENT BY TYPE

Asset finance accounts for the vast majority of total investment in renewable energy – including the financing of utility-scale wind farms, solar parks, biomass and waste-to-energy plants, biofuel production facilities, small hydropower dams, geothermal plants and ocean power stations. Asset finance totalled USD 236.5 billion in 2018, down 12% from 2017 and its lowest level since 2014. New asset finance deals were led, in dollar terms, by a USD 3.3 billion (950 MW) offshore wind farm in the United Kingdom and a USD 2.4 billion (800 MW) plant in Morocco that combines solar PV and concentrating solar thermal power.

Small-scale distributed capacity investment, or investment predominately in solar PV systems smaller than 1 MW, totalled USD 36.3 billion in 2018, down 15% from 2017. In the United States – the biggest market for small-scale solar – investment was down 15% to USD 8.9 billion. Germany, Australia, India, Japan and the Netherlands (in descending order) remained significant markets at over USD 1 billion each.

In total, capacity investment in asset finance and small-scale distributed installations (excluding large hydropower) came to USD 272.8 billion in 2018. Excluding biofuels, a total of USD 272.3 billion was invested in renewable electricity capacity, down 12% from 2017.

Other types of renewable energy financing that contributed to the investment total in 2018 included global R&D, public market investment, and venture capital and private equity (see dollar breakdowns below), as well as USD 4.8 billion in re-invested equity.

Both **corporate and government R&D** increased in 2018: corporate R&D was up 12% to a record USD 7.5 billion, and government R&D was up 8% to USD 5.5 billion. The largest percentage increases in R&D overall came in China and in the Asia-Pacific region (excluding China and India). Total R&D for solar power increased 12% from 2017, and for wind power increased 9%.

Public market investment in new equity issued by specialist renewable energy companies was up 6%, to USD 6 billion, but remained well below the double-digit billions reached in 2007 and 2014. The biomass and waste company China Everbright International raised the most equity in 2018, at USD 1.3 billion.

Venture capital and private equity investment (VC/PE) in renewable energy reached USD 2 billion in 2018, up 32% but far below the record USD 9.9 billion a decade earlier. The US biofuels company World Energy led the list of VC/PE deals, with a USD 345 million expansion capital round.

Asset finance	Small-scale distributed capacity investment	Corporate and government R&D	Public market investment	Venture capital and private equity
237 billion USD	36.3 billion USD	13.0 billion USD	6.0 billion USD	2.0 billion USD

RENEWABLE ENERGY INVESTMENT IN PERSPECTIVE

In 2018, significantly more investment dollars flowed to renewable power technologies (excluding large hydropower) – an estimated USD 272.3 billion[i], or 65% of the total of all new generating capacity – than to other technologies, including fossil fuel or nuclear power generating plants. If hydropower projects larger than 50 MW are included (an additional USD 16 billion), investment in renewable power would reach USD 288.3 billion, or 69% of the total for all generation technologies. This compares to approximately USD 33 billion committed to nuclear power capacity – largely new capacity in China and the Russian Federation – and USD 95 billion committed to fossil fuel generating capacity (including USD 50 billion for new coal-fired power stations and USD 45 billion for gas-fired generators). (→ *See Figure 50.*)

Investment in renewable power technologies accounted for

65%

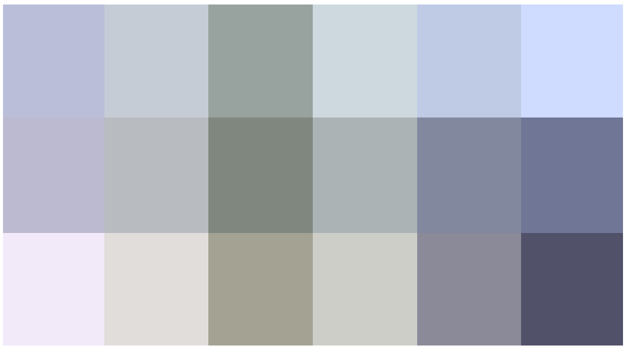
of the total of all new generating capacity.

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.[1] (→ *See Box 1.*)

EARLY INVESTMENT TRENDS IN 2019

Global investment in renewable energy – including global asset finance, small-scale solar, public market equity, and VC/PE – was USD 45.4 billion in the first quarter of 2019, down 29% from the same period in 2018 (USD 64.6 billion)[ii].

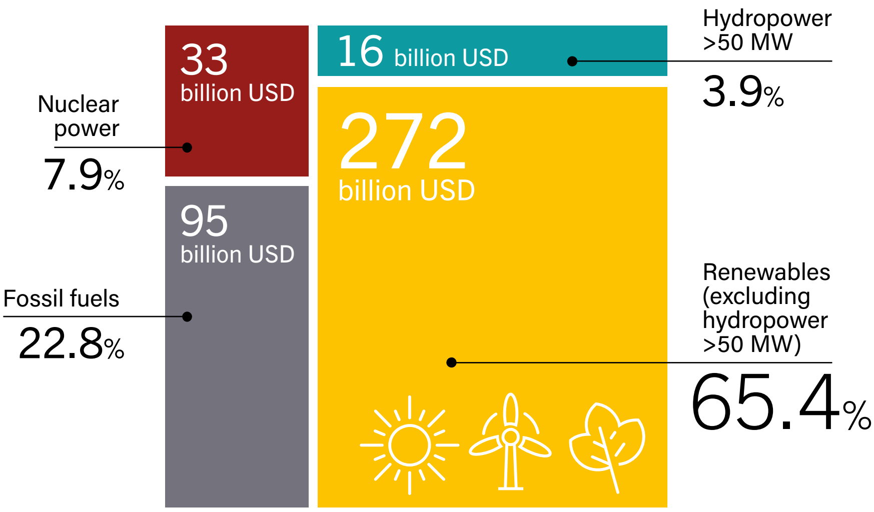
Leading the list of big deals in the first quarter of 2019 was the final investment decision on the USD 4.2 billion, 700 MW Al Maktoum IV solar thermal project in the United Arab Emirates. For wind power, the largest financing committed was USD 650 million for Torrent Power's 500 MW project in India, awarded in an auction conducted by Solar Energy Corporation of India. In other technologies, the biggest transaction for new capacity was USD 634 million for the 60 MW Lostock waste-to-energy project in the United Kingdom.

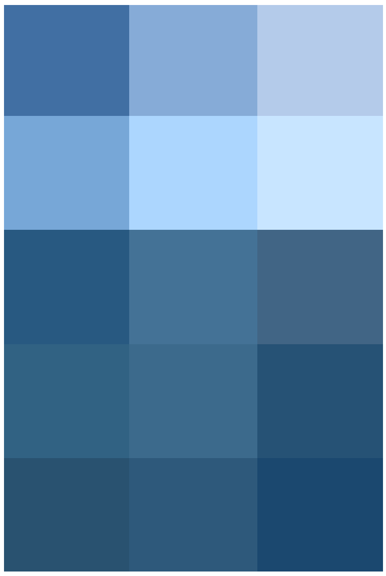


i This number is for renewable power asset finance and small-scale projects. It differs from the overall total for renewable energy investment (USD 288.9 billion) provided elsewhere in the chapter because it excludes biofuels and some types of non-capacity investment, such as equity-raising on public markets and development R&D.

ii This figure is too preliminary to indicate broader trends for the 2019 total. The first quarter total is likely to be revised upwards as more information becomes available, including the exact timing of large transactions.

FIGURE 50. Estimated Global Investment in New Power Capacity, by Type (Renewables, Fossil Fuels and Nuclear Power), 2018





Note: Renewable investment data in figure exclude biofuels and some types of non-capacity investment.

Source: BNEF.

BOX 1. Fossil Fuel Divestment Trends

Since 2011, a growing number of institutions have divested from, or sold off their financial interests in, fossil fuel companies. To divest, they may make 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[i] companies. Others divest based on criteria that may include a company's willingness to engage in meaningful efforts to curb emissions.

By 2018, around 1,000 institutions spanning 37 countries had committed to divesting from fossil fuels, with estimates of total asset values ranging from USD 6.2 trillion to USD 8 trillion. The set of institutions undertaking this divestment is diverse and spans insurance companies (which account for roughly 55% of total assets divested), pension funds (around 33%), banks (around 6%), as well as smaller shares from governments, non-governmental and faith-based organisations, and health, cultural or educational institutions, among others.

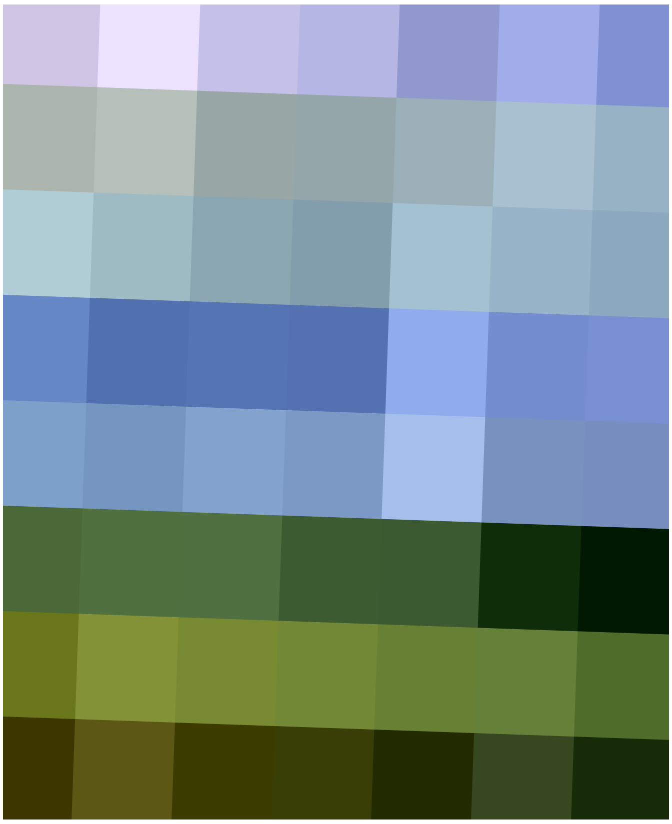
Insurance companies are increasingly divesting from coal company equities and bonds and, in some cases, are ceasing to underwrite coal projects. Around 20% of the insurance industry's global assets were covered by divestment policies in 2018, up from 13% in 2017. This includes at least 19 major insurance companies worldwide, many of which are based in Europe; very few insurance companies in the United States or the Asia-Pacific region have taken similar steps.

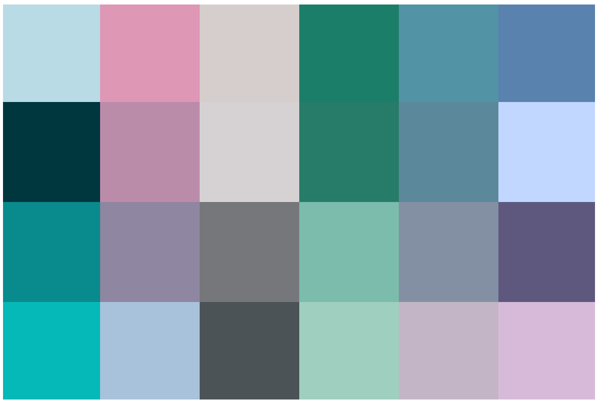
By the end of 2018, 144 self-managed public pension funds had committed to divesting from fossil fuels, including those of major cities such as Berlin (Germany), Copenhagen (Denmark), Dunedin (New Zealand), Paris (France) and Sydney (Australia). The mayor of New York City (United States) announced plans in 2018 to divest around USD 140 billion of the city's pension funds within five years, and the mayor of London (United Kingdom) pledged to divest the London Pension Fund Authority of its remaining fossil fuel investments by 2020. Ireland became the first country to pass legislation divesting all of its public funds (around USD 355 million) from fossil fuels.

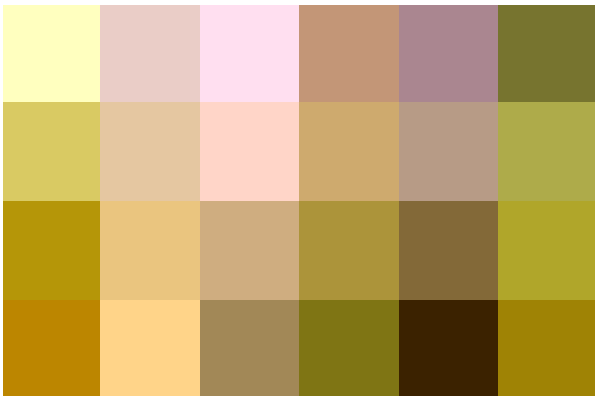
Funds divested from fossil fuel companies are not necessarily reinvested in companies associated with renewable energy. However, there is a network of individuals and organisations that links the two together, DivestInvest. As of 2018, 175 foundations in this network had committed to investing at least 5% of their portfolios in climate solutions such as renewable energy.

i Tar sands, also known as oil sands, are unconventional petroleum deposits in which a mixture of sand, clay and water is saturated with a thick petroleum, bitumen.

Source: See endnote 1 for this chapter.







06

Project and City:
Hydrogen Bus Project, Aberdeen, Scotland, UK

Technology:
Renewable hydrogen

Aberdeen, Scotland, UK

The Aberdeen Hydrogen Bus Project is the world's largest demonstration of hydrogen fuel cell buses. The Aberdeen City Council sources renewable electricity from the grid through a green supply tariff. During periods of low demand, the surplus electricity is used to run a 1 megawatt electro-lyser to produce hydrogen. The project provides flexibility to the power grid in Scotland's wind-rich north, helping to balance the grid and minimise curtailment. In 2017, the buses saved an estimated 460 metric tonnes of carbon dioxide in well-to-wheel emissions.

ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

Ongoing deployment of renewable energy is driving a transformation of energy systems around the world.[1] Spurred in part by rapid declines in the generation costs of solar photovoltaic (PV) and wind power, many countries have seen significant growth in installed capacity and generation from variable sources of renewable energy. In 2018, at least nine countries supplied more than 20% of their electricity generation from variable renewable energy (VRE)[i].[2] This transformation continues to be limited primarily to the electricity sector, however, as growth in the use of modern renewables in the heating, cooling and transport sectors remained minimal in 2018.[3] (→ *See Global Overview chapter.*)

Renewable energy can facilitate more efficient, sustainable and economical operation of suitably designed energy systems.[4] However, varied technical, physical, organisational and legal barriers may slow or halt the growth of renewable energy.[5] As shares of renewables grow in energy systems, additional challenges may emerge that require systems-focused approaches and strategies.[6] Energy systems integration, as defined here, is the significant elimination of the impediments to higher penetration of renewable energy (in particular VRE) in energy systems – including in power grids, heating and cooling systems, and transport fuelling systems[ii].

This integration is advanced through:

- appropriate design of the operations, regulations and markets that govern energy systems;
- infrastructural improvements or enhancements that aid access to renewables or facilitate their uptake; and
- increased flexibility in energy demand and supply to accommodate VRE.

Energy systems integration is also advanced through technologies that promote the linking of energy supply and demand across electricity, thermal and transport applications. These so-called enabling technologies – such as energy storage, heat pumps and electric vehicles (EVs) – can expand or unlock markets for renewables by allowing renewable energy to supplement or replace fossil fuels, for example through the electrification of heating end-uses that traditionally are served by non-renewable resources.[7] Some of these technologies are already commercially mature and widely deployed, while others are still emerging but experienced rapid growth in 2018.

This chapter focuses on efforts to integrate VRE into existing energy systems and to steer the evolution of power systems to better accommodate renewable energy[iii]. It also reviews the status of selected technologies that enable system integration of renewable energy in the heating, cooling and transport sectors.

i Defined more broadly, VRE also can include some forms of ocean power and hydropower. This chapter focuses primarily on solar PV and wind power, as these represent the fastest-growing VRE markets that are having the greatest impacts on energy systems. See Glossary for an extended definition of VRE.

ii See Chapter 6 of GSR 2018 for a more detailed overview of challenges related to renewable energy integration.

iii This chapter focuses on system planning and design but does not aim to provide a detailed overview of policy interventions for advancing renewables. See Policy Landscape chapter for an overview of developments in policies to integrate VRE in 2018.

ADVANCES IN THE INTEGRATION OF VARIABLE RENEWABLE ENERGY

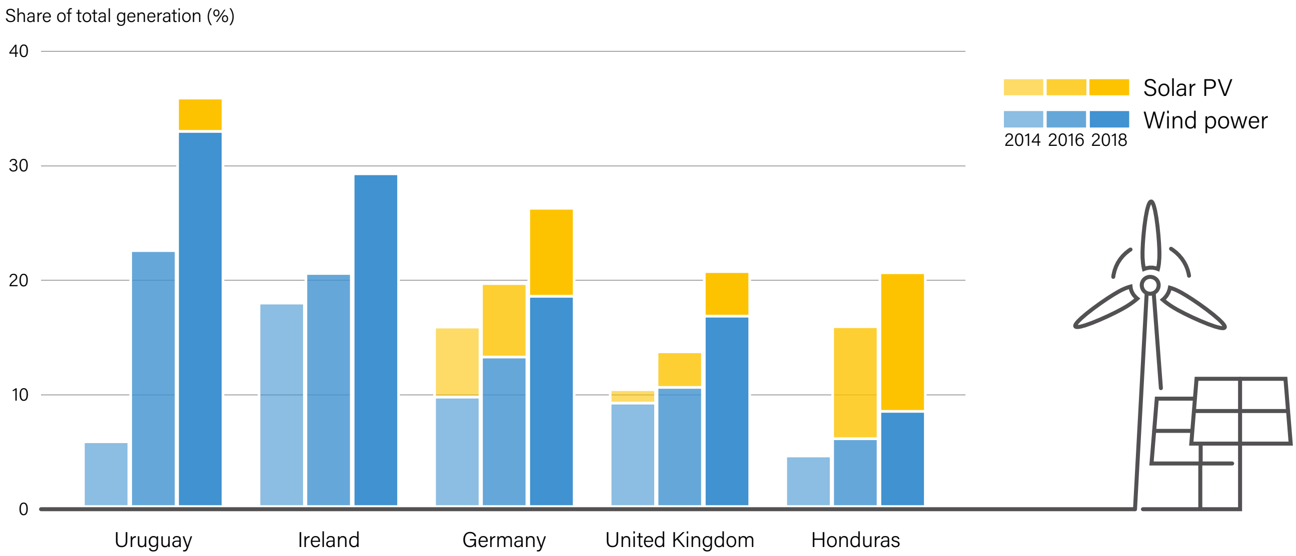
In numerous countries around the world, the power sector has experienced significant transformation, driven primarily by the rapid increase in penetration of variable wind and solar generation. This growth is due in part to quickly declining costs for solar PV and wind power, which have made these renewable energy sources the most economical options for new power-generating capacity in an increasing number of markets.[8] Variable renewables already have seen high levels of penetration in power systems around the world, with average compound annual growth rates of more than 10% between 2014 and 2018 in countries such as Uruguay, Ireland, Germany, the United Kingdom and Honduras.[9] (→ *See Figure 51.*)

Improving overall power system flexibility is central to advancing the integration of VRE.[10] Conventional sources of flexibility exist in all power systems, and most can accommodate 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.[11] (→ *See Table 4 in this chapter.*) Integration of higher shares of VRE may require strategic power market design, planning and linkages; the evaluation, improvement and enhancement of power systems and grid infrastructure; accurate resource forecasting; and improved flexibility in both generation and demand.

The physical or operational linkage of electricity systems allows surplus generation in a given market or region to be used in another market that has a generation deficit. It also can help aggregate VRE generation across larger geographical regions to mitigate the effects of localised variability of solar insolation and wind availability, reducing curtailment and operational system costs.[12] In 2018, Uruguay planned to manage high levels of wind penetration by increasing regional power trading with Argentina and Brazil.[13] Meanwhile, in the United States, several utilities joined or planned to join the Electricity Imbalance Market, which links power systems across eight western US states with the dual objectives of minimising system costs and optimising the use of clean energy sources.[14]

The design of appropriate power market rules is an important lever for increased participation of VRE in electricity markets and trading. In China, a national carbon emissions trading scheme for power markets, announced in late 2017, is expected to allow renewables to be more competitive in merit-order wholesale electricity markets being developed under the country's 13th Five-Year Plan (2016-2020).[15] In the European Union, new electricity rules provisionally approved in late 2018 aim to increase VRE shares through greater integration of regional electricity markets as well as increased competition and consumer participation.[16]

FIGURE 51. Share of Electricity Generation from Variable Renewable Energy, Selected Countries, 2014, 2016, 2018



Note: This figure includes selected countries with high shares of variable renewable energy according to the best available data at the time of publication. Factors including annual weather variations may significantly impact generation from VRE in a particular year. Trends shown are not meant to imply assumed future growth of generation shares.

Source: See endnote 9 for this chapter.

Tools for wind and solar forecasting continued to advance in 2018, driven in large part by rising shares of VRE generation in power systems.[17] In the United States, the independent system operator in Texas introduced intra-hour wind forecasting in five-minute intervals to more accurately manage wind gusts and lulls, better manage reserves and increase reliability.[18] Similarly, in Australia, pilot project funding was announced for solar and wind forecasting with intervals of five minutes.[19]

The deployment of digital technologies (digitalisation[i]) also can help reduce curtailment of VRE, by improving the operational efficiency and flexibility of generation assets.[20] Significant advances are being made in optimising fleets of renewable generation assets to reduce lifetime costs, improve flexibility and better forecast operational requirements.[21] For example, the multinational technology firm GE is creating virtual versions of its wind turbines to allow for virtual testing, forecasting of operational conditions and better turbine management.[22]

The expansion and interconnection of grid infrastructure allows for the aggregation of VRE resources over larger geographical areas and for the connection of remote sources of renewable generation with major electrical load centres; this increases system flexibility and improves the overall cost-effectiveness of the system.[23] Grid infrastructure upgrades to support VRE growth were under way or planned in several countries in 2018. For example, the South African utility Eskom obtained a USD 100 million loan facility for transmission upgrades to connect 27 new renewable energy projects (including 24 solar PV and wind projects) to the country's grid.[24] In Australia, plans were announced to accelerate the development of AUD 2.6 billion (USD 1.8 billion) in required transmission upgrades to accommodate planned wind and solar projects.[25] In Jordan, the public utility secured funding to improve grid capacity and connect solar regions with demand centres in the capital city Amman.[26]

The modernisation of grid infrastructure has been one element of China's multifaceted push to reduce curtailment of solar PV and wind generation. Average VRE curtailment in the country for generation from solar PV and wind power reached 3% and 7%, respectively, in 2018, down from 17% and 12% in early 2017.[27] Other initiatives in China included the introduction of wholesale electricity markets and demand response, the implementation of pumped (hydropower) storage and the roll-out of EVs.[28]

As VRE shares in power systems increase, flexibility of both demand and generation becomes central to ensuring reliable grid operations[ii],[29] A range of demand response[iii] technologies, incentives and penalties are being applied to shape grid loads to more closely match generation profiles, particularly in Europe and the United States.[30] In mature demand response markets, specialised service providers are emerging that manage consumer participation in such programmes, enabling participants to profit from incentives and/or minimise the effects of penalties.[31] In 2018 and early 2019, large utilities in Canada, Ireland, Poland and the United States were procuring demand response capacity from these service providers.[32]

In many regions of the world, the flexibility of VRE generators continues to be enhanced through ongoing research and development (R&D), advances in resource forecasting and power electronics, and the parallel deployment of VRE and energy storage.[33] Some countries, such as Denmark, Germany and Italy, have also made significant efforts over the past decade to improve the generation flexibility of fossil fuel power plants in response to rising shares of VRE, or to increase VRE shares.[34]

ENABLING TECHNOLOGIES FOR SYSTEMS INTEGRATION

ENERGY STORAGE

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.[35] While energy storage technologies are not always an imperative for driving higher shares of VRE, they can enable higher penetration of VRE in some power systems by improving system flexibility, reducing curtailment of VRE and, in some cases, driving down overall system costs.[36]

Working across end-use sectors, energy storage can facilitate temporal shifts in supplies of renewable electricity and thermal energy to meet heating and cooling loads when needed, and can allow (surplus) renewable electricity to serve thermal loads.[37] Certain thermal energy storage technologies are well-suited to long-term or seasonal storage applications that can facilitate greater uptake of renewables in district heating and cooling systems.[38] (→ *See Box 2 in this chapter.*) Hot water storage systems in buildings and industry also can be used as thermal reservoirs that can be coupled with VRE through the use of electric heat pumps.

Energy Storage Markets

Markets for energy storage continued to grow in 2018. Mechanical storage in the form of pumped (hydropower) storage accounts for the vast majority of global energy storage capacity. Global pumped storage capacity reached some 160 gigawatts (GW)[iv] in 2018, with 1.9 GW of new capacity added over the course of the year, down from the more than 3 GW commissioned the previous year.[39] (→ *See Figure 52.*)

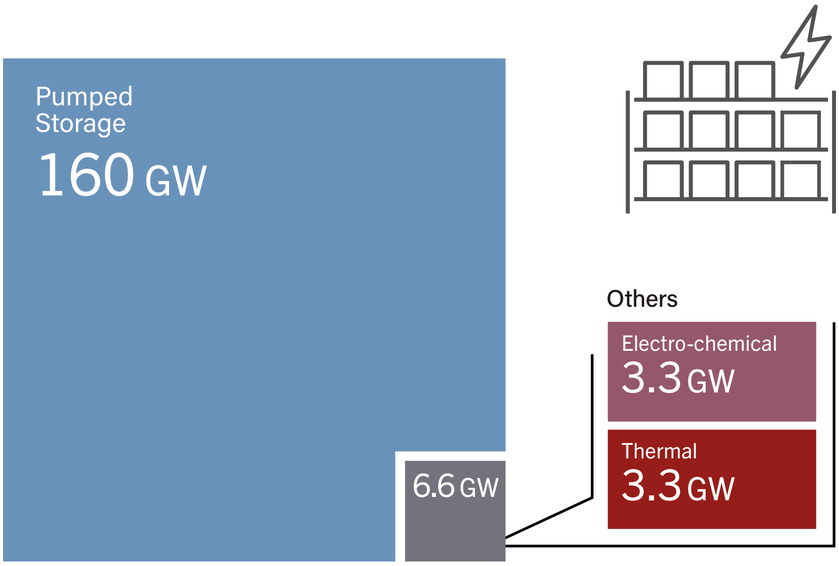
i For an overview of digitalisation and how it impacts energy systems, see Sidebar 3 in GSR 2018.

ii This includes the mitigation of excessive or uneconomic curtailment of generation, or undesirable load management practices such as rolling blackouts.

iii See Glossary for definition.

iv Energy storage installations are specified in terms of both rated power (measured in kilowatts (kW), megawatts (MW) or GW) and the energy capacity (kilowatt-hours (kWh), megawatt-hours (MWh) or gigawatt-hours (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.

FIGURE 52. Utility-Scale Energy Storage Capacity, Selected Technologies, 2018



Note: Numbers should not be compared with prior versions of this figure to obtain year-by-year increases, as some adjustments are due to improved or revised data. The category of electro-mechanical storage has been excluded due to limited global data availability.

Source: See endnote 39 for this chapter.

Global battery storage capacity totalled just over 3 GW in early 2019.[40] This includes primarily large, grid-connected (utility-scale) installations but excludes most smaller, behind-the-meter installations.[41] Australia, China, the Republic of Korea, the United Kingdom and the United States together accounted for nearly 80% of new battery storage systems commissioned in 2018.[42] The European energy storage[i] market grew 74% in 2018, reaching 890 MW (1,140 MWh) of installed capacity by year's end.[43] The market for front-of-meter storage in Europe doubled in size and accounted for nearly 50% of new capacity (MWh) installed in 2018.[44]

The five leading markets for new battery storage together accounted for **nearly 80%** of new global capacity.

Direct coupling of batteries with VRE generation is becoming widespread in many countries. In early 2018, combined solar PV and storage projects made up more than 40% of the estimated pipeline for new utility-scale battery installations.[45] Several utility-scale projects for solar PV with energy storage were commissioned in Australia during the year, including the country's largest with 25 MW (50 MWh) of battery storage.[46] In the Republic of Korea, two facilities totalling 13 MW (40 MWh) were under construction and planned to connect to several existing solar PV plants, and in the United States around 6 GW of utility-scale batteries to be built in parallel with solar PV were under development.[47]

In addition, smaller solar PV and battery installations (less than 30 kilowatts-peak) were widespread in many established solar PV markets, including in Germany, which had more than 120,000 such systems by the end of 2018.[48] Battery storage also is being coupled with wind energy, for example in Scotland where a 1 MW (1.3 MWh) battery was connected to an offshore wind project.[49]

Utility-scale batteries are being built to indirectly enable higher VRE shares by broadly supporting greater grid flexibility and resilience. For example, a 48 MW (50 MWh) facility installed in Germany in 2018 was the largest in Europe upon commissioning.[50] By mid-2018, seven of eight utility battery projects totalling 200 MW had been completed in the United Kingdom under the Enhanced Frequency Response procurement programme managed by the national grid operator.[51] In the United States, plans to build two battery systems totalling 568 MW (2.3 GWh) were approved, and some 33 GW of utility-scale battery storage was under development nationwide by year's end.[52]

The United States also saw signs of a shift from short-term frequency response applications to longer-duration battery storage, allowing for activities such as load shifting. In 2018, the country witnessed 80% growth in installed energy storage capacity (MWh), relative to a 44% increase in battery power capacity (MW) over the same period.[53] Similarly, utility installations deployed in the third quarter of 2018 showed a 14% decline in power capacity but a 178% increase in energy storage capacity relative to the same period in 2017.[54]

Utility-scale batteries are contributing to lower overall system costs in electrical grids. The 100 MW (129 MWh) Hornsdale Power Reserve, commissioned in Australia in December 2017,

i This refers to stationary electrical, electrochemical and mechanical storage excluding pumped hydro.

had reportedly saved nearly AUD 40 million (USD 28 million) in grid costs by late 2018, through grid stabilisation and avoided power outages.[55] In 2018, Ireland's flexibility market began procuring up to 140 MW of capacity – including battery storage – for fast frequency response.[56]

Decentralised, behind-the-meter battery storage has shown strong growth in several markets. In the United States, residential storage capacity additions exceeded utility-scale additions for the first time ever during the second quarter of 2018.[57] In Europe, behind-the-meter energy storage capacity grew to an estimated 287 MW (613 MWh) during the year.[58] Australia also experienced strong growth in behind-the-meter storage in 2018.[59]

Thermal energy storage (TES) – predominantly in the form of molten salts – is widely deployed to allow for greater flexibility in the generation of concentrating solar thermal power (CSP). A record 3.8 GWh of new TES was deployed at CSP facilities in 2018, increasing the total installed global capacity nearly 30% to 16.6 GWh.[60] (→ *See CSP section in Market and Industry chapter.*) Seasonal hot water storage in pits, boreholes and aquifers is increasingly common in countries such as Denmark, while TES in industrial processes has seen long-standing applications in solid media storage (for example, in bricks and stones) and heat storage for process steam.[61]

Around

95%

of current hydrogen production is based on fossil fuels, rather than on electricity.

Hydrogen is used for both chemical energy storage and other industrial processes. Around 95% of current hydrogen production is through processes using fossil fuels, with the remainder produced predominantly via electrolysis. Renewable electrolysis of hydrogen is not yet widely deployed but is seen as an important pathway for sector integration of VRE with transport, heating and cooling.[62] (→ *See Box 1.*)

BOX 1. Renewable Fuels

Renewable fuels include a range of low-carbon fuels such as conventional and advanced biofuels[i] and renewable hydrogen. These fuels either are used directly or are combined (directly or indirectly) with carbon dioxide sources to produce fuels such as methane, methanol or hydrocarbon substitutes (referred to as electro-fuels). Renewable fuels can replace conventional fossil fuels without the need for significant redesign or modification of road vehicles, watercraft or aircraft. They also can substitute fossil fuels in heating and cooling applications in both buildings and industry.

Renewable hydrogen holds large potential as an energy storage medium for allowing the improved integration of renewables. Although hydrogen produced from natural gas is already widely used in industry, for hydrogen to enable higher penetration of renewable energy, significant work is needed to decrease the cost of electrolysed hydrogen, to grow the share of hydrogen produced through electrolysis (currently less than 5% of the total) and to boost VRE shares in the electricity used to run these processes.

Renewable hydrogen faces cost competition from more established technologies, although recent cost reductions in variable renewables may allow for competitive renewable hydrogen production in certain large-scale plants. Nevertheless, some commercial applications of renewable hydrogen are taking root: in 2018, a leading Australian gas distributor announced plans to build a hydrogen production facility based on electrolysis using VRE. Hydrogen produced at the plant will be injected into the local natural gas grid. Renewable hydrogen production also began at a geothermal power plant in the southwest of Iceland.

i See Bioenergy section in Market and Industry chapter for information on developments in biofuels.

Source: see endnote 62 for this chapter.

Energy Storage Industry

The costs of battery storage technologies continued to decline in 2018, and by one estimate the costs of utility-scale storage technologies decreased 40% during the year.[63] For lithium-ion batteries, which remain the leading battery storage technology, the cost per unit of storage (USD/kWh) dropped 80% between 2010 and 2017.[64]

Utility-scale battery costs decreased an estimated **40%** during 2018.

Global manufacturing capacity of lithium-ion batteries reached just over 130 GWh in 2018, with the bulk of production based in Asia and nearly 60% in China.[65] Several new battery factories (many of which will serve the EV industry) were opened or planned in 2018. In China, one new facility aims to produce some 60 GWh of batteries annually when it reaches full capacity in 2020.[66]

Record levels of investment flowed into battery-related research, product development and manufacturing in 2018.[67] Venture capital investments in battery start-ups increased 40% year-on-year by the end of the third quarter, and one of the largest initial public offerings in the clean energy sector in 2018 involved a Chinese battery manufacturer, Contemporary Amperex Technology.[68]

Although seasonal energy storage remained undeveloped on a commercial scale, a range of R&D activities were under way in 2018, and several pilot facilities became operational.[69] In Switzerland, a new mechanical storage demonstration plant was revealed that enables long-term storage by raising and lowering large concrete blocks with a tower crane.[70] For short-term storage technologies, new pilot projects included a 2.4 MWh steel-based thermal energy storage system in Germany designed to quickly absorb large quantities of wind and solar power during production peaks.[71]

Another focus of R&D was the management and control of networks of batteries to provide grid balancing services. In 2018, German transmission system operator TenneT approved the trial of an aggregated 1 MW battery composed of distributed residential batteries that will provide balancing services to the German grid.[72] The aim is to increase the size of this "virtual" storage unit to include 30,000 home storage systems that are installed mainly in parallel with solar power capacity.[73] Efforts also are under way to use fleets of EV batteries to help balance the grid.[74] (→ *See Electric Vehicles section in this chapter.*)

HEAT PUMPS

Heat pumps are a widely applied and mature group of technologies used for heating and cooling in buildings as well as in industrial applications. Examples include air conditioners, refrigerators and freezers, and residential, commercial and industrial water heaters.[75] The world's most common heat pumps use an electrically driven refrigeration cycle to move heat from one volume or body to another.[76] The pumps are highly efficient, typically delivering three to five units of heat for each unit of electricity consumed.[77] 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).[78]

Heat pumps provide a mechanism for coupling surplus VRE with heating and cooling end-uses that are currently dominated by fossil fuels. Through this integration, the contribution of heat pumps to power system flexibility is significant: an estimated 75% of the global potential for demand response lies in electrification of the heating and cooling of buildings.[79]

Heat pumps typically deliver 3-5 units of heat for each unit of electricity consumed, and the output is **100%** renewable when driven by renewable electricity.

Heat Pump Markets

Assessing the scale of the global heat pump market is challenging due to a lack of data and to inconsistencies among existing datasets[i]. Air-source heat pumps are estimated to comprise the bulk of the global market, followed by ground-source heat pumps.[80] As global demand for heating and cooling expands, growth in the heat pump market has been consistently strong: in 2017, it increased some 30% in value from the previous year, reaching nearly USD 12 billion amid rapidly growing sales.[81] The largest markets for heat pumps are China, Japan, the United States and Europe as a whole, where (in order of scale) France, Italy, Spain, Sweden and Norway were the leading national markets in 2018.[82]

In Europe, total installations of heat pumps reached nearly 12 million units in 2018, after several years of consistent growth.[83] More than 1.2 million new heat pumps were added, a 12% increase from 2017.[84] Installations in the region's three largest heat pump markets (France, Italy and Spain) each grew 12%, and these countries accounted for nearly half of Europe's total installed units by year's end.[85] In Norway, installations grew 34%, eclipsing 100,000 units installed, and the nascent Dutch market grew 40% during the year.[86] In the United Kingdom, sales increased some 18% in 2017 (latest data available).[87] Market penetration of heat pumps for heating and cooling applications is highest in Scandinavian countries, with heat pumps installed in 47% of houses in Norway.[88]

i 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.

Large heat pumps (in excess of 1 megawatt-thermal, MW_{th}) are being deployed, particularly for district heating and cooling applications. (→ *See Box 2.*) In 2018, the Danish government increased funding for 13 large electric heat pumps to be coupled with district heating networks; the units were scheduled to enter operation in late 2019 and are expected to integrate higher shares of renewables while providing a source of grid flexibility.[89] Plans to implement two 2.5 MW_{th} water-source heat pumps were announced in early 2019 in Scotland, where the units will extract thermal energy from the Clyde River for use in local homes and buildings.[90]

District heating and cooling networks can be a significant **source of flexibility** for power systems.

The system integration and demand response potential of heat pumps gained increased attention in 2018. Heat pumps are central to the City of London's Zero Carbon London strategy released in late 2018 and are seen as important tools for smoothing electrical demand in the city's power systems.[91]

In Australia, the local government in the Australian Capital Territory partnered with a sustainable housing development to trial a gas-free residential suburb through the coupling of heat pumps with solar PV – part of the district's plan to source 100% renewable energy by 2020.[92]

Heat Pump Industry

The heat pump industry consists of both large manufacturers – such as Carrier, Daikin, Johnson Controls, Mitsubishi, Nibe and Stiebel-Eltron – and many small and medium enterprises involved in the design, manufacture, installation and maintenance of heat pumps.[93]

Several mergers and acquisitions occurred in the industry in 2018, as heat pump companies looked to expand their product lines and to serve a wider range of domestic and industrial markets. For example, the German firm Stiebel-Eltron acquired the Swedish company Thermia Heat Pumps (previously known as Danfoss Värmepumpar AB), and the Japanese firm Daikin acquired the Australian commercial refrigeration group AHT.[94]

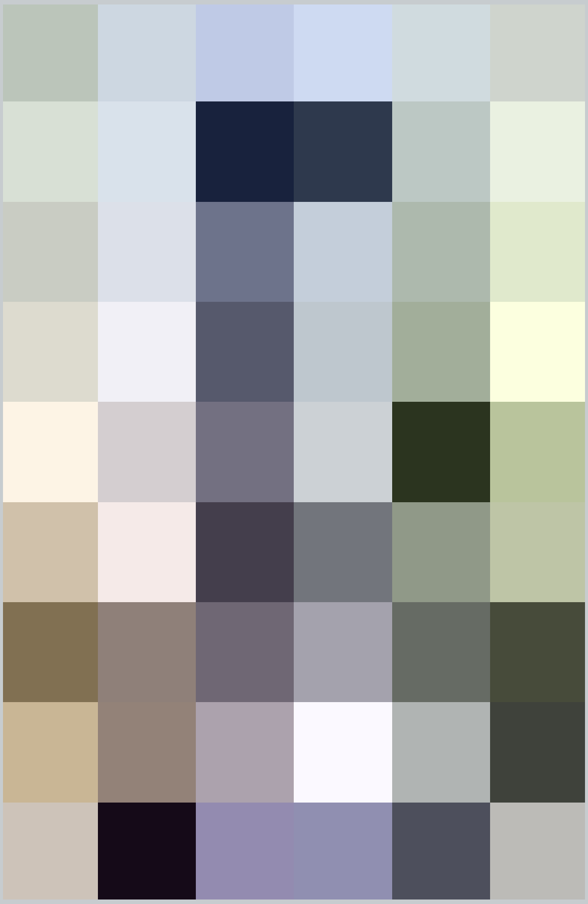
BOX 2. Renewable District Heating and Cooling

District heating and cooling (DHC) networks allow for the use of diverse sources of energy in the generation, storage and delivery of thermal energy for heating and cooling in buildings and industry. These systems can enable the widespread use of renewable thermal energy and can be effective mechanisms for providing affordable heating and cooling while also reducing reliance on fossil fuels.

DHC networks create new markets for renewable electricity through the electrification of heating and cooling end-uses, for example with heat pumps. They can be a significant source of flexibility for power systems, with large thermal reservoirs in DHC systems – such as hot water tanks – providing thermal storage capacity for the use of surplus VRE.

The extent to which existing DHC networks integrate renewable energy sources varies widely among countries. In most systems, fossil fuels remain the primary source of heating and cooling, while European countries such as Norway, Sweden, Lithuania, France and Denmark have seen shares of renewables in district heating rise above 50%.

Source: see endnote 38 for this chapter.

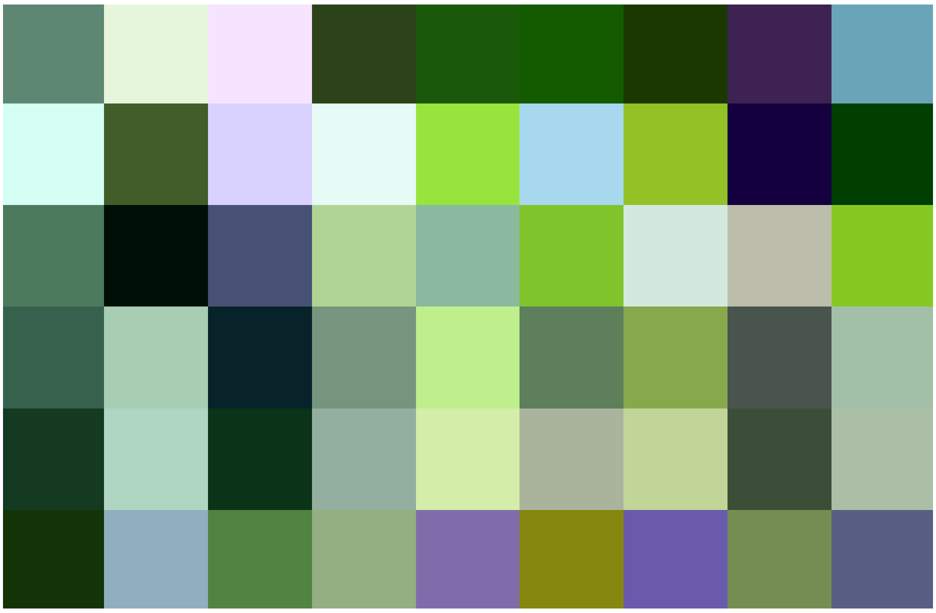


ELECTRIC VEHICLES

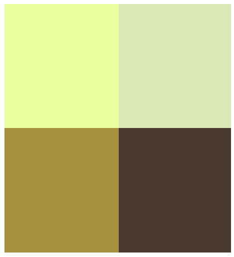
Electric vehicles[i] provide an important end-use for renewable energy by allowing for the replacement of fossil fuels in certain transport applications. As the market share of EVs grows, they also support the integration of VRE by presenting options for demand-side response, for example through vehicle-to-grid (V2G) technology. This section focuses mainly on electric road vehicles, as the largest advancements have occurred in this area in recent years.

Electric Vehicle Markets

The global stock of passenger EVs (electric cars) reached over 5.1 million units in 2018 – a 63% increase from 2017.[95] (→ *See Figure 53.*) Around 2 million new electric cars were sold during 2018, a sales increase of 68% from the previous year.[96] Nonetheless, electric cars still represented a small share of all passenger vehicles, at just over 2.1% by year's end.[97] EV markets also remain highly concentrated: as of late 2018, 40% of all EVs in use were clustered in just 20 cities that together account for 3% of the global population.[98]

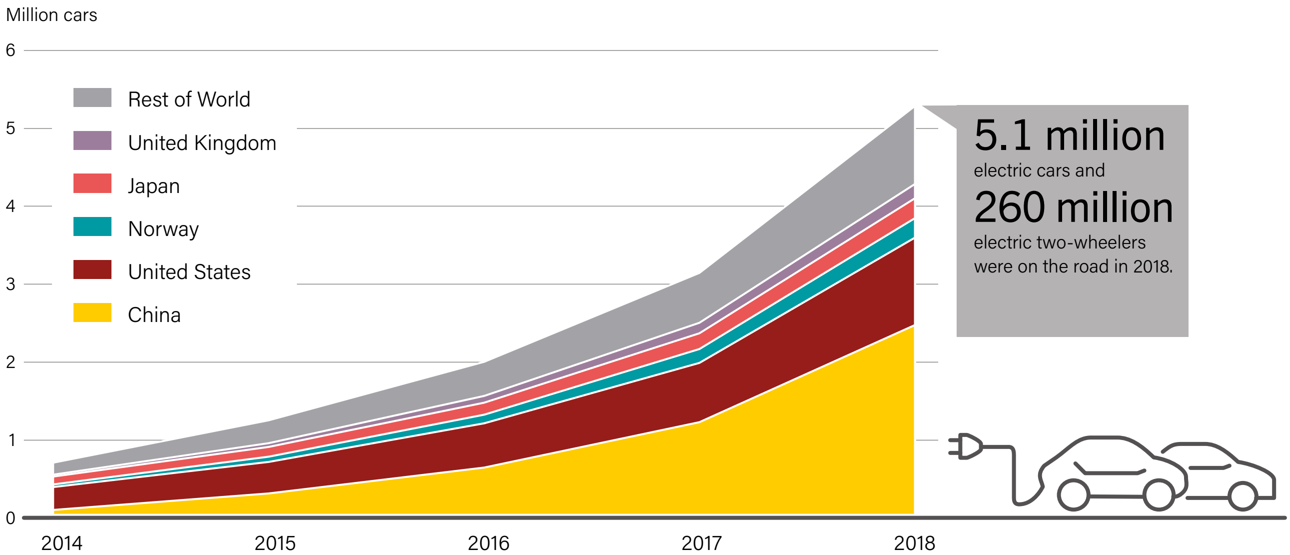


The global stock of electric cars **grew 63%** during 2018.



i Electric vehicles include any road-, rail-, sea- and air-based 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 (FCEVs). Electric road vehicles encompass battery electric vehicles (BEV), plug-in hybrids (PHEV) 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.

FIGURE 53. Electric Car Global Stock, Top 5 Countries and Rest of World, 2014-2018



Source: OECD/IEA. See endnote 95 for this chapter.

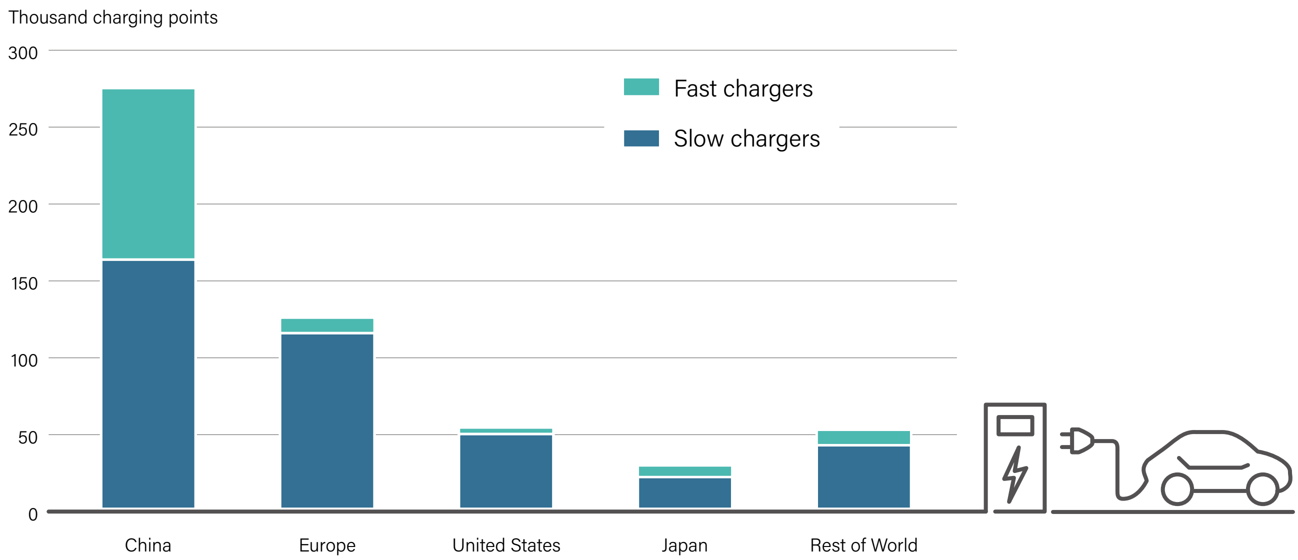
China had nearly 50% of the global EV stock by the end of 2018, followed by the United States at 22%.[99] Sales of new EVs reached nearly 1.3 million units in China, including just over 1 million passenger EVs, sales of which increased more than 80% year-on-year.[100] Norway remained the leader in the total market share of new electric cars, and around half of new cars registered in the country in 2018 were either battery electric vehicles (BEVs) (30%) or plug-in hybrid electric vehicles (PHEVs) (20%).[101] The next-largest markets were Iceland at 19%, Sweden at 8% and the Netherlands at 7%.[102]

The global stock of electric two-wheelers reached around 260 million in 2018, one-quarter of which are in China.[103] By one estimate, China's electric two-wheelers account for 80% of the avoided greenhouse gas emissions resulting from the use of EVs.[104] Some 40 million electric three-wheelers were in use by the end of 2018, virtually all in China.[105]

The stock of electric buses (both BEV and PHEV) grew more than 25% to about 460,000 in 2018, with the vast majority in China (around 421,000 units) and slightly more than 2,100 in use in Europe, Japan and the United States.[106] Electric trucks are used mainly in public and commercial fleets in urban settings. In 2018, waste companies in Brazil and China placed large orders for electric refuse trucks (200 and 500 units, respectively).[107]

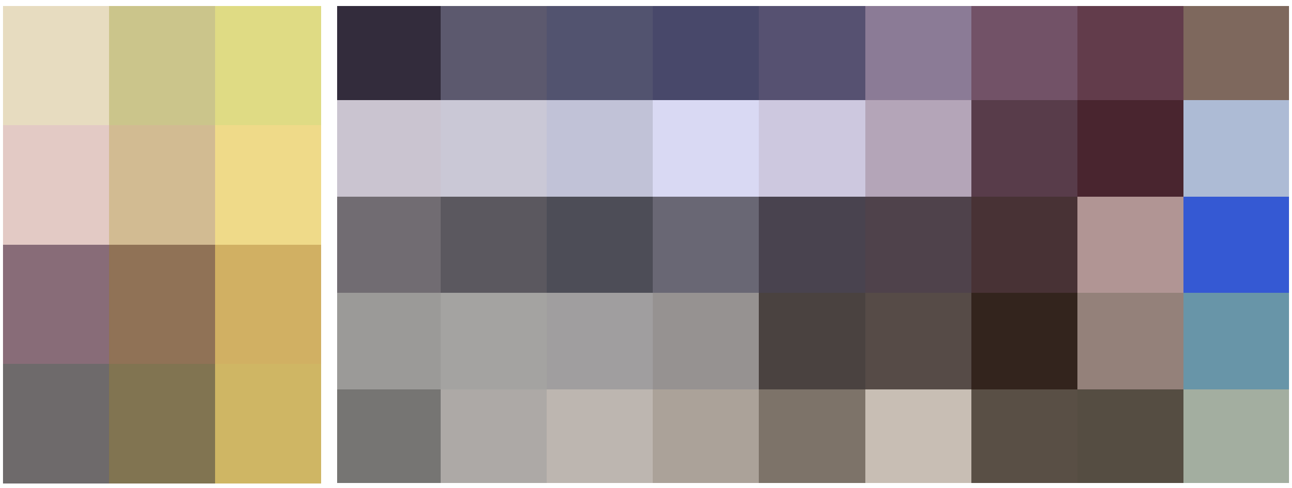
More than 100,000 public EV charging points were installed in 2018, bringing the global total to some 395,000 slow-charging units and 145,000 fast-charging units.[108] China was home to more than half (51%) of all public charging points globally by the end of 2018, followed by the United States (10%), the Netherlands (7%), Japan (6%) and France/Germany (5% each).[109] (→ *See Figure 54.*) By early 2019, the United States and Canada together had more than 5,000 fast-charging points.[110]

FIGURE 54. Public EV Charging Points by Country or Region, Fast and Slow Charging, End-2018



Note: Europe comprises the Netherlands, Germany, France, the United Kingdom, Norway, Sweden, Portugal and Finland.

Source: OECD/IEA. See endnote 109 for this chapter.



Electric Vehicle Industry

The leading manufacturers of passenger EVs in 2018 were (in order of production volume) Tesla, BYD, BAIC, SAIC, Nissan, BMW, Volkswagen, General Motors, Toyota and Mitsubishi.[111] By August 2018, some 47 plants in China were either manufacturing or planning to manufacture EVs, compared with some 39 plants in the rest of the world.[112] Chinese battery manufacturing for EVs also is scaling rapidly.[113] Established manufacturers of internal combustion engine vehicles – including VW, Daimler, Nissan, Volvo and others – have made aggressive plans to electrify their vehicles over the coming decade.[114]

In 2018, the specific use of VRE to charge EVs was piloted in a one-week US-based trial by automaker BMW and the California utility Pacific Gas and Electric (PG&E), during which participating electric cars received up to 80% of their energy from renewable resources. To increase vehicle charging during peak solar production hours, PG&E sent renewable energy production forecasts to BMW, which then used incentives and messaging to encourage EV owners to charge their cars at these times.[115]

The initiative was one of several activities in 2018 aimed at supporting power system flexibility through both the management of charging times and the implementation of bi-directional charging and discharging of EV batteries (V2G).[116] Bi-directional charging could allow fleets of EVs to act as virtual utility storage, enabling higher penetration of VRE. A number of V2G-enabled vehicles were available in 2018, and automaker Honda invested in bi-directional charging at its European R&D site.[117] The Institute of Electrical and Electronics Engineers, a global industry association, is developing technical standards for bi-directional charging systems; however, wider commercialisation of the V2G market has been slow.[118]

Considerable efforts to expand EV charging infrastructure were under way in 2018. The growth of China's EV market outpaced the deployment of EV charging points in the country during the year, highlighting the urgency of installing charging networks.[119] China's State Grid announced a goal to install some 120,000 public chargers nationwide by 2020, and private entities including German automaker VW also plan to roll out fast-charging networks in China to support EV sales.[120]

In Europe, Shell stepped into the EV industry with the installation of 80 ultra-fast, 350 kW charging points in western Europe, which can add some 150 kilometres of vehicle range in 5 minutes, or fully charge an EV battery in 10 minutes.[121] In the Netherlands, the energy storage company Leclanché is piloting the use of stationary energy storage in EV fast-charging networks, and as of early 2018 an initial 60 charging points that provide charge times of around 20 minutes had been installed.[122]

TABLE 4. Approximate Impacts of and Responses to Rising Shares of Variable Renewable Energy

Systemic impacts		**No noticeable impacts.**	Small increase in supply variability and uncertainty is **noticeable** at the system operations level. Limited impact on operations of individual power plants.	Growing supply variability and uncertainty has **significant impacts** at the system operations level. Noticeable impact on operations of some power plants.	Elevated supply variability and uncertainty has **major impacts** at the system operations level. Noticeable impact on operations of virtually all power plants.	Structural surplus of VRE generation and seasonal energy imbalances.
Response requirements		No additional measures.	Some adjustments in system operations and grid infrastructure.	Significant changes to system operations. Greater flexibility of supply and demand. Some grid reinforcement for voltage and frequency stability.	Major changes to system operations. Significant additional flexibility of supply and demand. Significant grid reinforcement for voltage and frequency stability.	Additional steps to manage supply and demand imbalances.
RESPONSES	Resource forecasting		■	■ ■	■ ■ ■	■ ■ ■
	Grid operations		■	■ ■	■ ■ ■	■ ■ ■
	Energy storage			■	■ ■	■ ■ ■
	Demand-side management			■	■ ■	■ ■ ■
	Grid reinforcement			■	■ ■	■ ■ ■
	Sector integration				■	■ ■ ■
Examples of technological and operational responses		Gathering information about grid conditions and planning – including technical standards – for future growth in VRE.	Establishing a renewable energy production forecast system. Introducing improved control technology and operating procedures for efficient scheduling and dispatch of system resources.	Managing variability through advanced forecasting, improved transmission infrastructure and a significantly more dynamic operation of a growing number of dispatchable system resources. Co-ordination across control areas with the aid of improved information and control technology, and strengthened transmission interconnections.	Improving greatly the efficiency and scope of demand response with better information and control technology. Deploying significant additional advanced storage on the grid and behind the meter for energy balancing and for voltage and frequency support.	Sector integration: electrification of heating, cooling and transport as a daily, weekly and even seasonal buffer for VRE generation. Conversion of renewable electricity into chemical forms that can be stored (e.g., hydrogen).
Countries experiencing this level of operational challenge		Republic of Korea, South Africa, Thailand	Australia, Austria, Belgium, Brazil, Chile, China, France, India, Japan, the Netherlands, New Zealand, Sweden	Costa Rica, Germany, Greece, Honduras, Italy, Nicaragua, Portugal, Spain, Sweden, the United Kingdom	Denmark, Ireland, Uruguay	

Note: This table represents generalisations. Various impacts and priorities for technological and operational responses will vary by system and will not be confined to a single path. Categorisation of example countries depends on the penetration level of VRE, as well as on the operational challenges faced by power systems to integrate VRE.

Source: see endnote 11 for this chapter.

07

Project and City:
Solar settlement in the Vauban district, Freiburg, Germany

Technology:
Solar PV, bioenergy

Freiburg, Germany

The Vauban district of Freiburg is a model of sustainable living. Every building has solar PV panels on its roof and is required to meet high efficiency standards. As a result, many houses produce more electricity than they consume, with surplus electricity being sold back to the city grid. In Freiburg, renewable energy production is encouraged through federal tax credits and financial support from the regional electric utility. Vauban's power and heat are generated by solar PV and by a highly efficient woodchip-powered combined heat and power generator connected to a district heating grid.

ENERGY EFFICIENCY

OVERVIEW

International efforts to map trajectories towards the achievement of sustainable development goals generally acknowledge the complementarity of renewable energy deployment and energy efficiency measures.[1] For example, in 2011 the United Nations' Sustainable Energy for All (SEforALL) initiative, recognising the joint role of renewables and efficiency in securing universal access to sustainable energy, set a target to double both the share of renewable energy in global final energy consumption (to 36% by 2030) and the rate of improvement in energy efficiency.[2]

Subsequently, in the second year of the United Nations Decade of Sustainable Energy for All (2014-2024), the UN General Assembly adopted the 2030 Agenda for Sustainable Development and the Agenda's 17 Sustainable Development Goals (SDGs).[3] SDG 7, on ensuring sustainable energy access, reaffirmed the earlier SEforALL objectives but replaced the 36% renewables target with a more general goal to "increase substantially the share of renewable energy in the global energy mix" by 2030.[4]

In 2018, the Intergovernmental Panel on Climate Change presented several pathways for mitigating climate change that are consistent with a relatively high probability of limiting the long-term increase in global average temperature to 1.5 degrees Celsius above pre-industrial levels.[5] Each of the outlined pathways is characterised, in part, by relative reductions in global energy demand.[6] Reducing energy demand requires advances in both energy efficiency (technology-specific) and energy conservation (behaviour-specific).[7]

Efforts have been made to disaggregate the effects of the three main determinants of total final energy demand: structural changes within economies, changes in the level of activity in each economic sector and changes in the efficiency of energy use in each sector.[8] Such analysis has indicated that, without improvements in energy efficiency, global final energy demand in 2017 would have been 12% higher than 2000 levels.[9] This translates to an average annual displacement of energy demand of below 0.7% during this period. Meanwhile, between 2005 and 2017, the share of total final energy consumption (TFEC) met by modern renewables grew at an average annual rate of 2.9%.[10]

In 2017, however, the estimated total renewable share in TFEC (modern renewables and traditional biomass combined) increased by merely 0.8%.[11] (→ *See Global Overview chapter.*) That same year, global energy demand rose an estimated 1.9% as the economy grew 3.7%, reflecting a decline in overall energy intensity[i] of 1.7% – the slowest rate of improvement since 2010.[12] The linkages between improvements in energy efficiency and growth in renewable energy are evident.[13] For example, the growth in non-thermal renewable energy improves primary energy intensity, and the improvement in end-use energy efficiency may stimulate further economic activity and, in turn, additional deployment of renewables.[14]

Government policies are instrumental in improving energy efficiency in the end-use sectors of buildings, industry and transport. For example, policies supporting energy efficiency in the European Union (EU) have been credited with advancing the share

i There is no single direct measure of economy-wide energy efficiency changes, but energy intensity has stood in as a proxy for aggregate efficiency. Energy intensity is an imperfect substitute because 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) regardless of energy efficiency changes within each economic sector.

of renewable heat in buildings to 22% in 2017, as the demand for heat in the region stabilised and dipped slightly between 2012 and 2017 (-0.3%), making the EU the only region in the world where heat demand is declining.[15]

Worldwide, policy support for energy efficiency increased substantially between 2010 and 2017.[16] However, the greatest advance was in the proliferation of national energy efficiency action plans and targets, whereas the number of specific national mandates grew more slowly.[17] City governments adopted building energy codes, minimum energy efficiency performance standards and other firm commitments, and cities continued to play a prominent role in designing and implementing policies for energy efficiency. (→ *See Feature chapter.*)

Although both renewables and efficiency are critical elements of more sustainable energy systems, policy makers may struggle with where to allocate resources most effectively: on the supply side (renewable energy) or on the demand side (energy efficiency). In the United States, the proliferation of renewable energy sources with zero variable cost, such as wind power and solar photovoltaics (PV) – as well as the low cost of natural gas – translates into lower avoided costs for energy efficiency programmes in the electricity sector, potentially diluting the cost-effectiveness of efficiency measures going forward.[18] Combined with the variability of rapidly growing solar PV and wind power, the result is greater interest among policy makers in leveraging future energy efficiency measures with advances in demand response, distributed generation and storage, and electric vehicles (EVs), in order to provide various system services that reflect location- and time-specific needs of the power grid.[19] (→ *See Systems Integration chapter.*) Nonetheless, as of 2015, incremental energy efficiency measures remained among the least-cost electricity resources in the United States.[20]

Only 34%
of global energy use falls under the reach of energy efficiency policies and mandates.

Energy efficiency policies come in the form of incentives or outright mandates, such as energy performance standards for appliances and equipment, building energy codes and vehicle fuel economy standards.[21] As of 2017, only 34% of global energy use fell under the reach of energy efficiency policies and mandates.[22] New policy coverage was attributed largely to equipment stock turnover and to new goods being covered by existing standards, rather than to the adoption of new standards.[23]

The average efficiency requirements (i.e., stringency) of energy efficiency mandates rose at a faster rate in 2017 than in 2016, but the expansion of policy coverage slowed.[24] The increase in the stringency of policy mandates was 0.5% in 2017, slightly below the 0.6% annual average since 2011, and was concentrated mostly in the transport sector on account of rising fuel economy standards.[25] (→ *See Energy Efficiency section in Policy Landscape chapter.*)

Global primary[i] energy intensity decreased more than 10% during the five-year period between 2012 and 2017, at an average annual rate of 2.2%.[26] (→ *See Figure 55.*) The total primary energy supply grew 5.9% over the same period (average annual growth of 1.2%).[27] In other words, if energy demand had moved in tandem[ii] with global economic growth (no reduction in energy intensity), primary energy demand would have risen 18% (3.4% per year).[28]

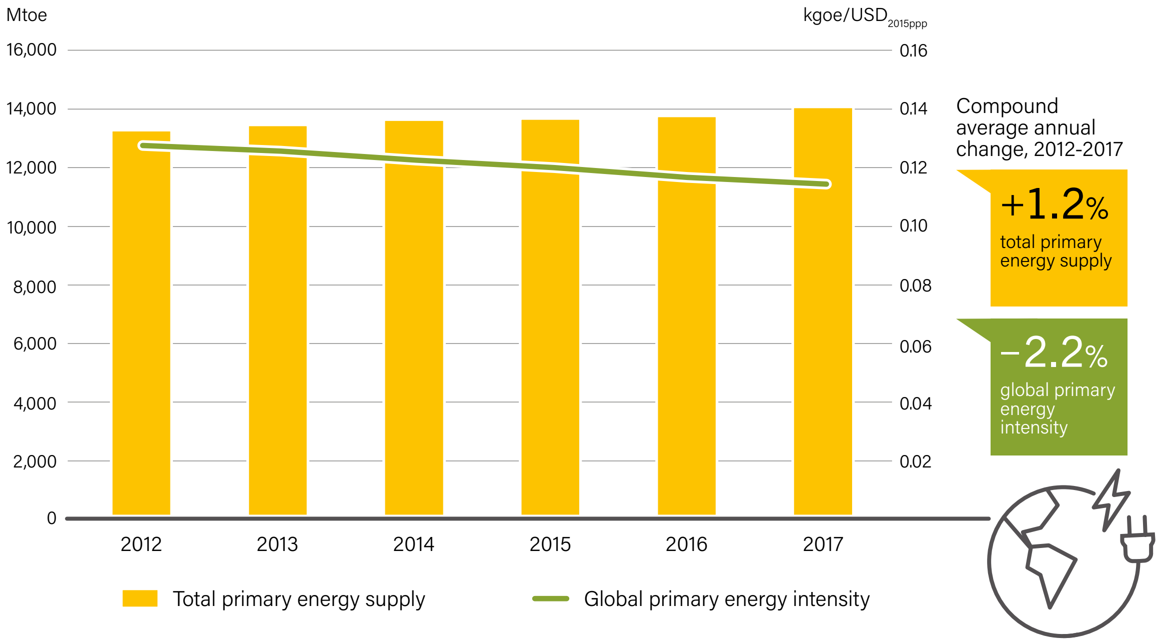
All regions of the world showed some improvement in the energy intensity of their economic activities between 2012 and 2017.[29] (→ *See Figure 56.*) Asia (led by China) had the most marked decline in energy intensity during the period – an annual average drop of 3.6% – as the share of energy-intensive industry and commerce continued to shrink relative to all other economic activity, and as manufacturing facilities became more efficient.[30] Europe improved at an average annual rate of 2%, followed by North America and Oceania (1.7%); other regions observed only marginal improvements in energy intensity (less than 1% annual average).[31]

Global primary energy intensity decreased more than
10%
between 2012 and 2017.

i The GSR discusses renewable energy mostly in the context of final energy supply, but primary energy is highly relevant in the context of energy efficiency as it pertains to the conversion and ultimate disposition of primary energy supply, including electricity generation.

ii This is only to highlight the relative scale of the effect of declining energy intensity on overall energy demand. This does not take into account unknown feed-back from higher energy intensity on economic growth. In other words, global economic growth might not have been as great over the observed period if not for the benefit of more efficient use of energy in economic activity.

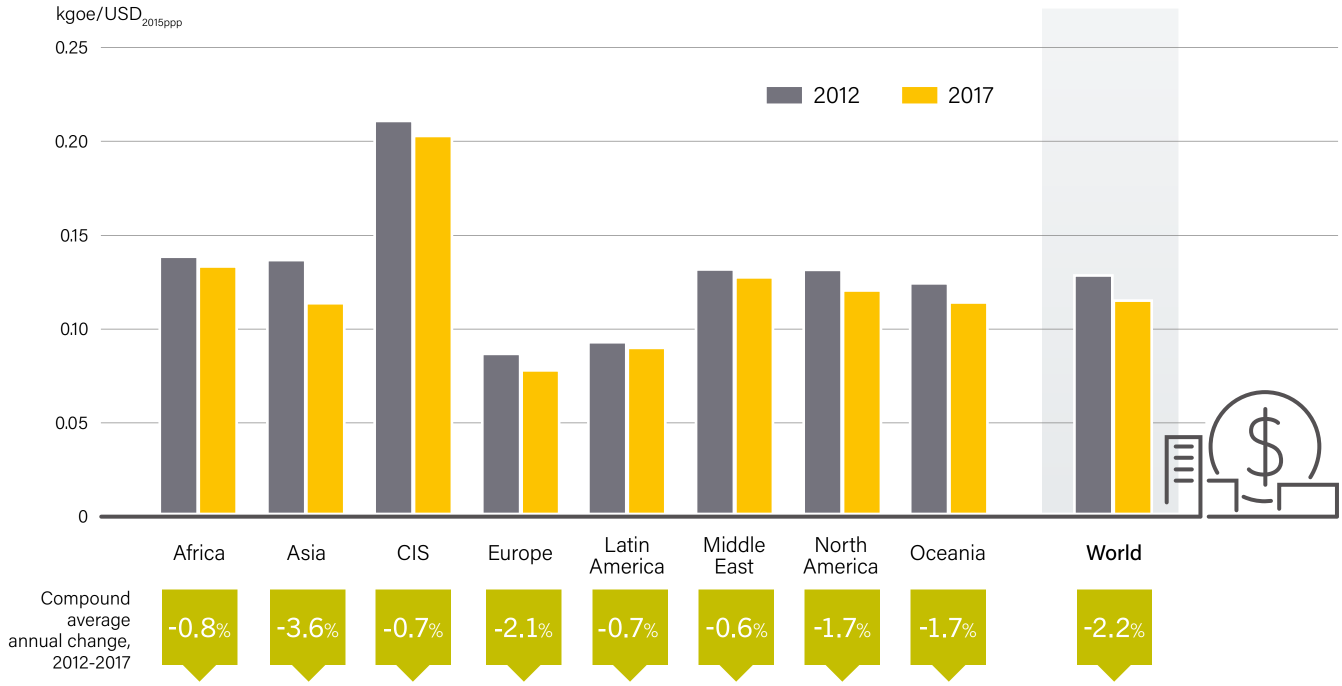
FIGURE 55. Global Primary Energy Intensity and Total Primary Energy Supply, 2012-2017



Note: Dollars are at constant purchasing power parities.
Mtoe = million tonnes of oil equivalent;
kgoe = kilograms of oil equivalent.

Source: Enerdata. See endnote 26 for this chapter.

FIGURE 56. Primary Energy Intensity of Gross Domestic Product, Selected Regions and World, 2012 and 2017



Note: Dollars are at constant purchasing power parities.
CIS = Commonwealth of Independent States.

Source: Enerdata. See endnote 29 for this chapter.

Despite the ongoing advances in energy efficiency in many economies and across various end-use sectors, total energy demand continues to rise in regions with rapid economic growth and improved access to energy. In some mature economies, however, growth in total energy demand has long since levelled off and even begun to retract. For example, as of 2017 primary energy demand in the United Kingdom was at its lowest level since 1964, and Germany's primary energy demand was more than 14% below its historical peak in 1979.[32]

Collectively, energy demand in member countries of the Organisation for Economic Co-operation and Development (OECD) reached a historical peak in 2007, which also coincided with the onset of a global economic downturn.[33] (→ *See Figure 57.*) Despite sustained economic recovery and growth since then, that peak remains unchallenged. Meanwhile, energy demand in non-OECD countries, as a whole, continues to rise. In China, the world's largest energy consumer, total annual energy demand fell slightly in 2016 – its first decline since 1997 – before reaching a new high in 2017.[34]

Advances in energy efficiency are most visible in the various end-uses of energy – such as road vehicles, appliances and lighting – and are best examined in the context of final energy use. But gains in energy efficiency also occur when primary energy sources are transformed and converted into various useful secondary forms of energy – such as the production of vehicle fuels in oil refineries and electricity generation in power plants. Those gains are examined in the context of primary energy use.

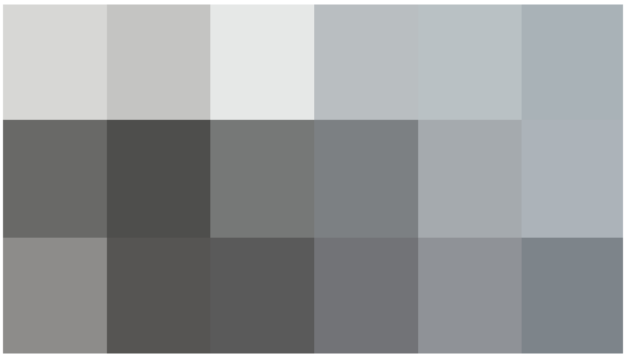
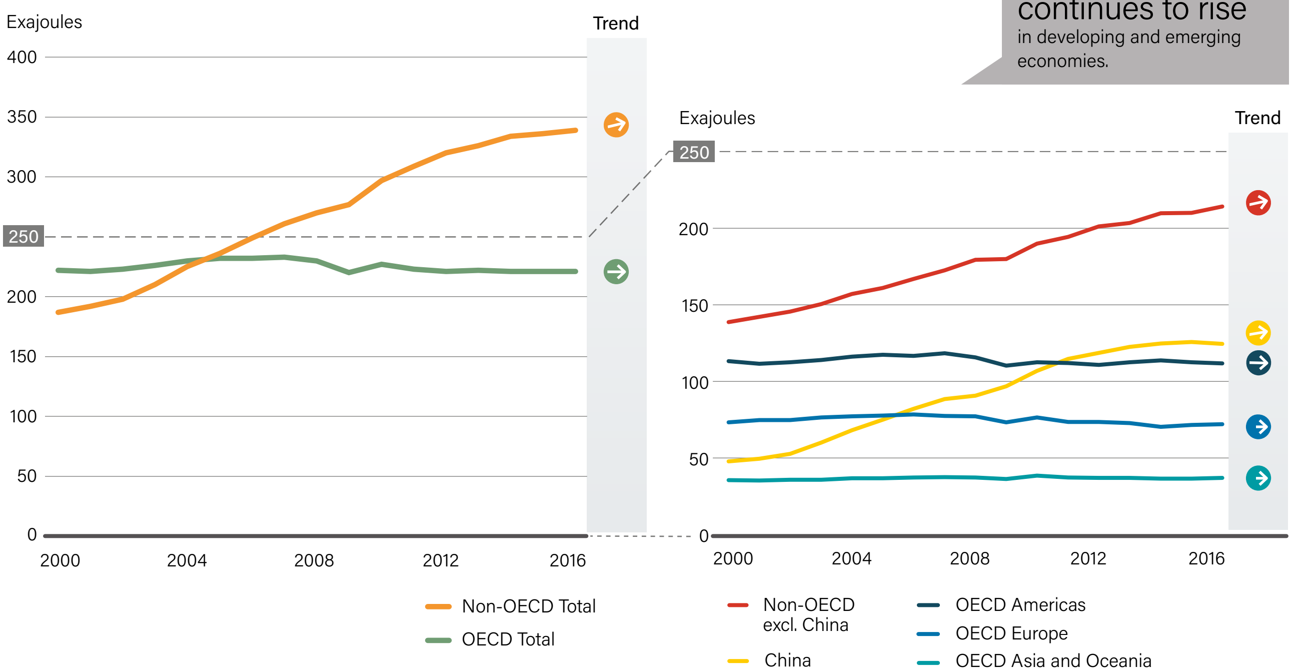


FIGURE 57. Primary Energy Demand, Selected Regions, 2000-2016

Energy demand continues to rise

in developing and emerging economies.



Note: Trend is based on a compound annual average growth rate from 2010 to 2016 for each indicated region.

Source: OECD/IEA. See endnote 33 for this chapter.

In 2016, the global total primary energy supply (TPES) was 576 exajoules (EJ).[35] Each year, more than 23% of TPES is dissipated through various transformation processes, the bulk of which is lost during electricity generation.[36] The energy industry itself accounts for another 6% of TPES through its net demand for energy[i] for purposes such as the operation of oil refineries and the mining and extraction of fossil fuels. Less than 2% of TPES goes to "non-productive" losses, which occur mainly during the transmission and distribution of electricity.[37]

What remains of TPES – amounting to 400 EJ in 2016 – is the energy available to meet various final energy uses.[38] This total final consumption of energy (TFC)[ii] includes all electricity delivered to final customers (nearly 19% of TFC), the final uses of fuels for work and heat (72%), and various non-energy uses (about 9%).[39] Broken down by sector, in 2016, the buildings sector consumed 30% of TFC, industry consumed 29%, and transport consumed 29%.[40] The remainder of TFC is consumed in other sectors – including agriculture and forestry (2.1% in 2016) – and for non-energy applications (9.1% in 2016), mainly various industrial uses such as feedstocks for petrochemical manufacturing.[41] The relative distribution of final energy demand among the three largest sectors shifted slightly between 2010 and 2016, with the shares of industry and buildings each shedding about one percentage point and the share of transport rising by more than one percentage point; the share of non-energy applications rose somewhat.[42]

ELECTRICITY GENERATION

Electricity generation is a major determinant of global primary energy efficiency. A significant portion of the world's primary energy supply (coal, natural gas, oil and biomass) is combusted in the process of generating electricity. For thermal power plants (combustion only; excluding nuclear, geothermal and concentrating solar thermal power (CSP) plants) more than half of the energy input dissipates during the transformation process.[43] The efficiency of conversion has improved only gradually: in 2016, an estimated 38.1% of the combustible energy input for electricity production[iii] in OECD countries was converted to electricity and delivered to transmission grids, up slightly from 35% in 2000.[44]

There are two main ways to improve the primary energy intensity of electricity generation. One is to improve the efficiency of thermal power plants, for example by increasing the absolute efficiency of fuel combustion, the efficiency of other plant components such as turbine-generators, and the recovery of waste heat for either thermal applications or additional electricity generation. In natural gas-fired power plants, for instance, the application of combined-cycle technology increases the conversion efficiency compared with simple-cycle technology.[45] The second main way to improve the primary energy intensity of electricity generation is by displacing thermal (combustion) generation with technologies that do not involve significant losses of primary energy during transformation – including all non-thermal renewable electricity generating technologies[iv].

The combined effect of **more-efficient** electricity generation and the growth in non-thermal **renewable** energy sources has helped to reduce global primary energy intensity.

Further efficiency gains have been accomplished post-generation – through the use of combined heat and power (CHP) production and by reducing transmission and distribution losses. Overall, the share of CHP in total electricity generation has not increased much in recent decades and actually declined slightly between 2010 and 2016 – from 16.3% to 15.7% – due in part to strong growth in non-thermal renewable electricity generation.[46] Meanwhile, improvements in grid infrastructure and management have led to reductions in global transmission and distribution losses, declining from 8.3% of gross generation on average in 2010 to 7.9% in 2016.[47]

The combined effect of more-efficient electricity generation and the growth in non-thermal renewable energy sources has helped to reduce global primary energy intensity. Between 2012 and 2017, the overall efficiency of all electricity generation (thermal and non-thermal) improved at an average annual rate of 1.1%, from 40.5% to 42.8%.[48]

i This includes energy input in blast furnaces and coke ovens.

ii Total final consumption includes energy demand in all end-use sectors, which include industry, transport, buildings and agriculture, as well as non-energy uses, such as the use of fossil fuel in production of fertiliser. It excludes international marine and aviation bunker fuels, except at the global level, where both are included in the transport sector, from OECD/IEA, *World Energy Statistics and Balances*, 2018 edition (Paris: 2018). See (Total) Final energy consumption in Glossary for differentiation between TFC and TFEC.

iii This value is based on the ratio of net electricity generation to fuel energy input at electric power plants (in OECD countries only, due to data availability) that have as their main activity the generation of electricity for sale to third parties. It excludes co-generation (combined heat and power plants) and plants that produce electricity primarily for own-use.

iv In this context, the relative conversion efficiency of non-thermal renewable energy technologies such as wind power and solar PV is irrelevant, because any potential energy not harnessed by these technologies is never part of the primary energy supply, unlike the fossil fuels that are extracted for electricity generation and other energy applications. See endnote 36.

BUILDINGS

Between 2000 and 2017, building energy demand grew

20%

while building energy intensity declined.

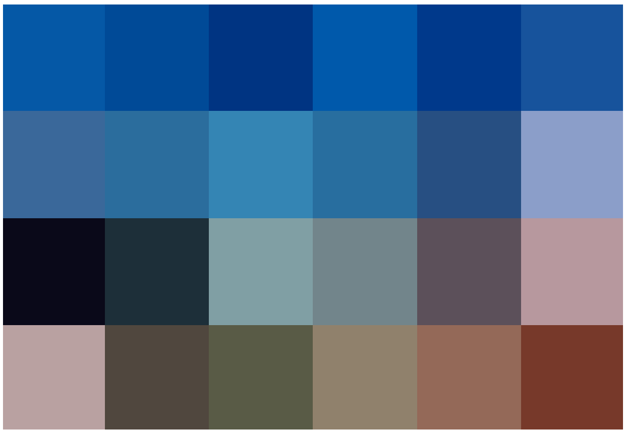
The buildings sector accounts for around 30% of TFC (including the use of traditional biomass).[49] Residential buildings consume nearly three-quarters of this energy, while the rest is used in commercial and public buildings.[50] Electricity accounts for 31% of building energy demand, and various fuels (natural gas, biomass, fuel oil, etc.) serve most of the remaining (thermal) demand.[51] Between 2000 and 2017, the energy demand of buildings worldwide increased 20%.[52]

Various factors determine the efficiency of energy use in buildings, including the building design and construction materials (for example, glazing, insulation and orientation) and the efficiency of energy-consuming (and energy-saving) devices within the building envelope (for example, heating, cooling and ventilation (HVAC) systems, lighting, appliances and other electronics). While some regions have advanced building efficiency more than others, on average, global opportunities to improve energy efficiency remain underutilised. This is due to a lack of effective policies and of affordable and accessible financing, as well as to behavioural inertia and the subsequent slow conversion to more-efficient technologies.[53]

Policies supporting energy efficiency in the buildings sector include codes (related to structures and materials) as well as minimum performance standards for HVAC systems, lighting and appliances. High-income countries generally have relatively well-developed programmes in place – covering standards, incentives, financing and access to information – whereas most developing countries have made limited progress on building energy codes and efficiency standards.[54] This is particularly salient given that the demand for new construction is greatest in developing and fast-growing economies.[55] Compliance with and enforcement of building energy codes is generally considered inadequate, particularly in middle-income countries as compared to high-income countries.[56]

The energy intensity of buildings, measured as the final energy use per unit of floor area, declined 1.6% annually on average between 2000 and 2017.[57] At the same time, the total floor area grew 3% annually on average, more than twice as fast as building energy demand.[58]

Despite energy efficiency improvements, the overall energy demand of buildings has increased. This is due primarily to the combined effect of a growing population and an increase in the total floor area occupied per person as incomes have risen.[59] Other factors that have boosted energy use in buildings include the growing use of air conditioners and other cooling equipment;



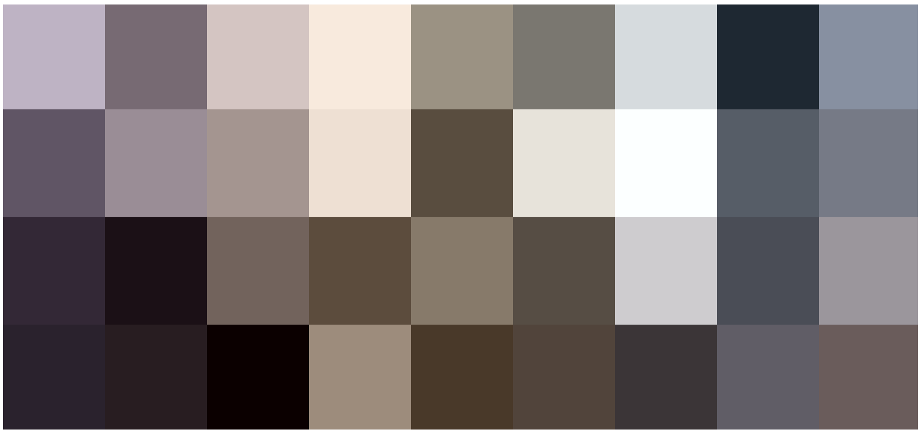
expanding ownership of appliances and electrical devices; and improved access to electricity services in developing countries.[60] Factors that have been most effective in mitigating the growth in energy demand include efficient energy systems and appliances in buildings, as well as improved building envelopes (such as glazing and insulation).[61]

In general, the energy intensity of most building end-uses has declined in recent years, with the clear exception of space cooling.[62] Global energy demand for cooling has grown more rapidly than any other end-use, more than tripling between 1990 and 2016.[63] During this period, the share of cooling in the total electricity use of buildings grew from 11% to 18.5%. Cooling already comprised nearly 10% of global electricity consumption as of 2016 and can be a significant portion of peak demand during hot periods.[64]

In China and India, energy use for space cooling doubled between 2010 and 2017, with the cooling intensity (energy use per unit of floor area) rising 71% and 42%, respectively, in these countries.[65] The increase in cooling intensity is thus mainly a consequence of the rapidly rising penetration of cooling systems, rather than a decline in the average efficiency of cooling technology. Nevertheless, most of the 135 million air conditioners installed annually (53 million in China alone) are less than half as efficient as the most advanced available technology.[66]

In addition, the lack of adequate building energy codes in many places means that the cooling load is greater than it otherwise would be for each new household that adopts air conditioning. The growth in cooling demand is already straining energy systems in some locations; however, as of 2018 only 8% of the 2.8 billion people living in the hottest parts of the world had gained access to air conditioning.[67]

Opportunities to improve energy efficiency remain underused due to a **lack of effective policies** and of affordable and accessible financing.



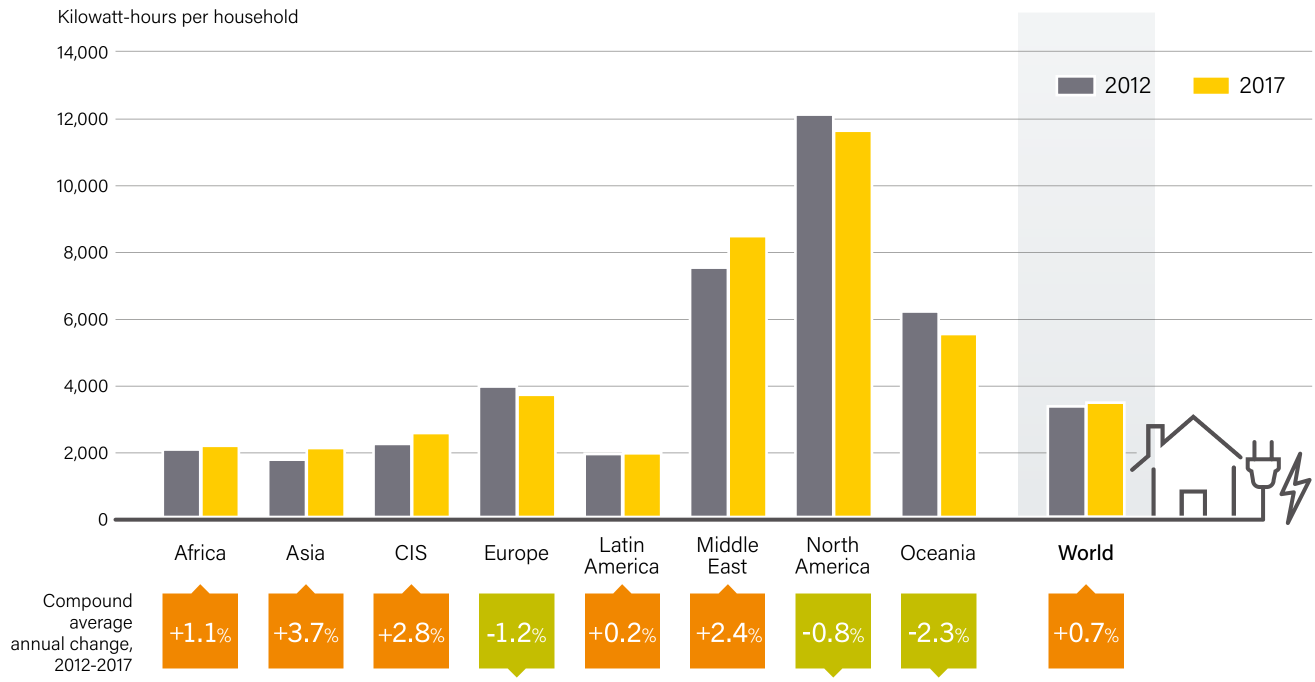
Global energy demand for cooling **more than tripled** between 1990 and 2016.

The energy intensity of space heating, meanwhile, contracted nearly 18% between 2010 and 2017.[68] Space heating contributed the highest share of energy efficiency savings in buildings during this period, followed by lighting and then space cooling, which is increasingly efficient even as its overall energy intensity has risen due to rapid demand growth.[69]

The buildings sector as a whole accounts for around 49% of world electricity consumption, with the residential sector consuming 27% and commercial and public buildings consuming 22%.[70] Between 2012 and 2017, global average electricity consumption per household grew 0.7% annually, but this growth varied widely by region.[71] (→ *See Figure 58.*) Household electricity demand rose most rapidly in Asia (average annual growth of 3.7%), followed by the Commonwealth of Independent States (2.8%) and the Middle East (2.4%).[72] Oceania showed the greatest rate of decline in household electricity demand (average annual contraction of 2.3%), followed by Europe (-1.2%) and North America (-0.8%).[73]

Some of the growth in household electricity demand (or the relatively slower decline in demand) may be associated with developments that enhance primary energy efficiency and support the deployment of renewable energy. For example, the rising use of electricity (rather than the direct use of fossil fuels such as oil and natural gas) for space heating and for transport may contribute to overall improvements in the energy efficiency of those sectors. Rising electrification also may contribute to a decline in primary energy demand and to the growth and integration of variable renewable power. (→ *See Systems Integration chapter.*)

FIGURE 58. Average Electricity Consumption per Electrified Household, Selected Regions and World, 2012 and 2017



Note: CIS = Commonwealth of Independent States.

Source: Enerdata. See endnote 71 for this chapter.

INDUSTRY

The industrial sector accounts for nearly 29% of TFC, excluding non-energy uses; when various energy feedstocks in industry are included, the share exceeds 37%.[74] The growth in industrial energy use (including feedstocks) has been gradual, averaging around 1.3% annually between 2010 and 2016.[75]

India experienced the highest average annual growth in industrial energy use (4.7%), followed by the Republic of Korea (2.7%), China (2.6%) and the Middle East (2.5%), but China accounted for two-thirds of the total net increase during this period.[76] Conversely, industrial energy use in Europe and the Americas declined during the period.[77]

Globally, the average energy intensity of the industrial sector decreased between 2012 and 2017, at an average annual rate of 2.7%.[78] (→ *See Figure 59.*) Asia's industrial energy intensity improved at a relatively higher rate – 4.1% annually on average – and both North America and Europe showed consistent annual improvements of around 2%.[79] Other regions showed mixed or relatively modest annual improvements.[80]

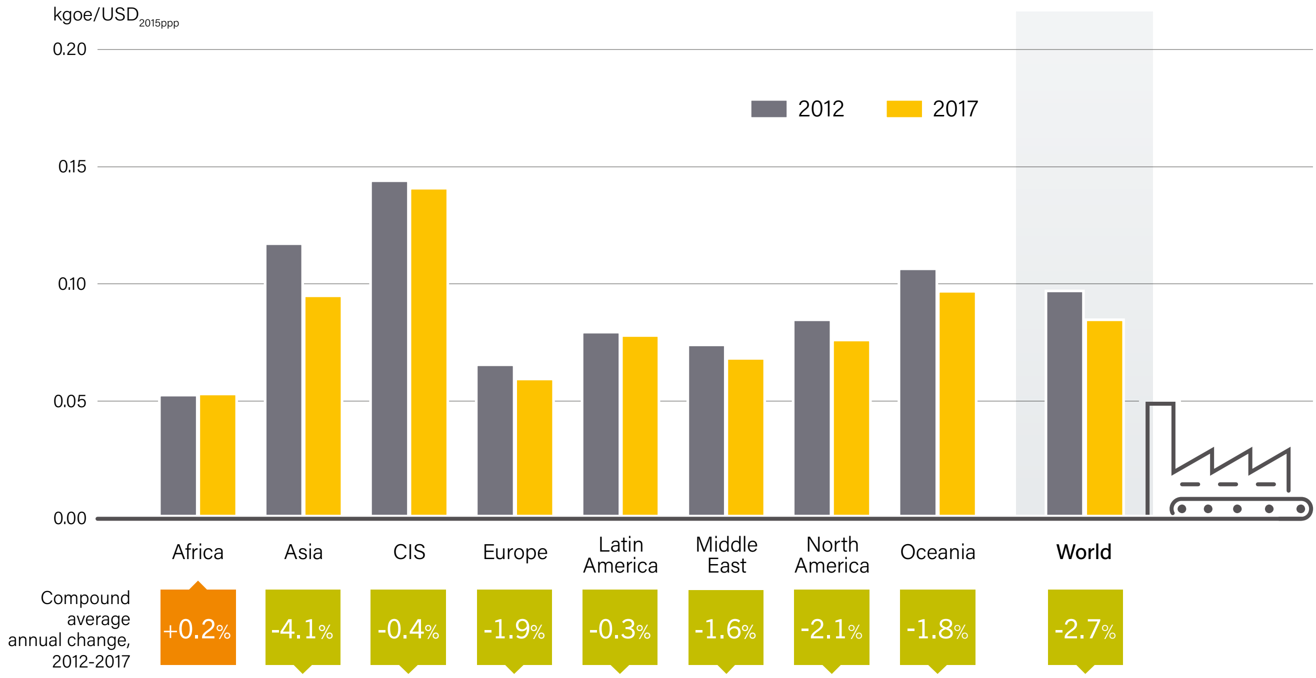
In general, advances in energy efficiency mandates and incentives in the industrial sector have exceeded policy progress in other sectors (electricity generation, buildings and transport).[81] By 2017, an estimated 60% of countries had energy efficiency measures in place for industry – well above the 26% share in 2010, and more than double the global penetration of building energy codes for efficiency.[82] However, as is true for building energy codes, adequate monitoring of compliance is lacking: only half of the energy use in industry that is covered by efficiency standards is supported with robust monitoring and enforcement.[83]

China accounted for
two-thirds
of the total net increase in global industrial energy use from 2010 to 2016.

Between 2000 and 2017, industrial activity across most major economies[i] nearly doubled, while energy demand in industry grew less than half as much, mitigated by structural changes in the economy and by energy efficiency improvements.[84] The global decline in the relative economic weight of energy-intensive industries – such as primary metals, pulp and paper, and cement – in favour of less energy-intensive manufacturing and services was responsible for just under half of the improvement in the overall energy intensity of industry.[85] More energy-efficient processes accounted for the remainder, displacing an incremental 20% of energy use (25 EJ) by the end of the 17-year period.[86] Improved cement and chemicals manufacturing facilities in China and India contributed to this increased efficiency.[87]

i These include the IEA member countries as well as Argentina, Brazil, China, India, Indonesia, the Russian Federation and South Africa.

FIGURE 59. Energy Intensity of Industry, Selected Regions and World, 2012 and 2017



Note: Dollars are at constant purchasing power parities.
CIS = Commonwealth of Independent States.

Source: Enerdata. See endnote 78 for this chapter.

In member countries of the International Energy Agency (IEA), energy demand from manufacturing – which represented more than 28% of final energy use in industry in 2016 (more than 31% when non-energy uses are included) – declined 17% between 2000 and 2016.[88] During this same period, the economic value added in manufactured goods increased nearly 23%, reducing the energy intensity of the manufacturing sector more than 32%.[89] This drop in energy intensity was driven by energy efficiency as well as by a relative decline in the most energy-intensive manufacturing sub-sectors.[90]

Meanwhile, the service industries of IEA member countries expanded their energy use 9% between 2000 and 2016; however, combined with a 31% increase in value added, the overall energy intensity of the services sector fell 17% during this period.[91] Nonetheless, including other major economies[i], the continuing decline in the overall energy intensity of industry was not enough to overcome the absolute growth in industrial activity in 2017 as the sector's energy use increased some 2%.[92]

Different industries can exhibit vastly different energy intensities. In IEA member countries, primary metals manufacturing remains the most energy-intensive industry – consuming more than 30 megajoules (MJ) per USD (in 2010 dollars at purchasing power parity, or ppp) – followed by pulp and paper, non-metallic minerals (mostly cement) and chemicals (less than 15 MJ per USD_{ppp}).[93] In IEA member countries and other major economies, the energy intensity of cement manufacturing declined by more than a third between 2000 and 2017, representing the greatest reduction in industrial energy intensity during that period.[94] The energy intensity of pulp and paper declined by just over 20%, while all other industries improved by smaller margins (for example, aluminium manufacturing by 16% and iron and steel by only 5%).[95]

TRANSPORT

Energy use in the transport sector grew an estimated 45% between 2000 and 2017 and continues to account for nearly 29% of TFC.[96] Most of the increase in energy use reflects the growing number of vehicles on the world's roads, and to a lesser extent rising air travel and shipping.[97] Renewable energy supplies only a small share of transport energy, mostly in the form of biofuels (3% of transport energy) and electricity (0.3%).[98] Road transport continues to account for the bulk of energy demand for transport – 75% in 2016 – followed by aviation (11%), marine transport (9.6%), pipeline transport (2.3%), rail (1.8%) and other forms of transport.[99]

Energy use in the transport sector grew an estimated

45%

between 2000 and 2017.

Policies supporting energy efficiency in the transport sector proliferated most rapidly in high-income countries between 2010 and 2017. In general, support for electric vehicles for passenger transport spread far more rapidly than fuel efficiency standards during this period, and, since 2016, support for EVs has become more widespread than fuel efficiency standards.[100]

The energy intensity of transport is determined by:

- growth in demand within each transport sector (transport of goods and people by air, sea and land);
- shifts between transport modes of varying energy intensity (aviation, marine, rail and road);
- changes in capacity utilisation rates (the average share of vehicle capacity occupied per journey); and
- improvements in the inherent energy efficiency of transport vehicles used.

Energy use in passenger transport grew 38% between 2000 and 2017, with an estimated two-thirds of this growth due to the rising demand for transport.[101] Improved vehicle efficiency managed to roughly offset the combined incremental effect of declining capacity utilisation (vehicle occupancy) and the growing share of larger vehicles, such as sport utility vehicles and passenger light trucks.[102] The increase in transport energy demand was concentrated in emerging economies such as Brazil, China, India and Indonesia, while growth elsewhere was generally far more modest and was tempered by gains in efficiency.

In IEA member countries, for example, energy use in passenger transport grew only 2.8% between 2000 and 2017, while overall passenger travel increased 7.1%.[103] This implies a 4% contraction in the energy intensity of passenger travel – measured as energy use per passenger-kilometre – during the period. This contraction occurred despite a decline in the average passenger car occupancy from 1.6 to 1.5 persons per vehicle and the growing popularity of larger vehicles.[104]

Energy use in freight transport increased 65% between 2000 and 2017[ii], due primarily to higher demand for freight transport but also because of an overall global shift from rail transport to roads.[105] Efficiency improvements and the use of vehicles with greater carrying capacity managed to offset the growth in demand for freight transport by a mere 1%.[106]

Unlike with passenger transport, the energy efficiency of freight transport declined in many high-income countries, as their energy use in the sector grew four times faster than demand between 2007 and 2017.[107] This increase came as capacity utilisation (load per truck) declined and despite a proportional shift in freight volume from roads to more-efficient rail transport in these countries.[108] The decline in the efficiency of freight transport is attributed in part to the fact that some European countries were badly affected by the economic crisis during the early part of the period, resulting in organisational inefficiencies.[109]

i For the countries covered, see footnote i on page 176.

ii Excluding the United States due to data anomalies, see endnote 105.

08

Heerlen, The Netherlands

Geothermal energy has been used for heating and cooling in Heerlen since 2008, when an abandoned coal mine near the city was repurposed into a source of geothermal heat. The project uses thermal energy from flooded underground mine shafts to power a large-scale district heating system. The system provides 270 homes and several large businesses in Heerlen with heating and cooling services and results in a 65% reduction in carbon dioxide emissions. The multi-purpose Centrumplan Heerlerheide complex (pictured) – which contains businesses and 194 apartments – has been connected to the mine-water network since October 2008.

Project and City:
Mijnwater BV geothermal district heating and cooling system, Heerlen, The Netherlands

Technology:
Geothermal district heating and cooling

FEATURE:
RENEWABLE ENERGY IN CITIES

By 2018, more than 55% of the world's population – 4.2 billion people – lived in cities[i], up from 46.7% (2.9 billion people) in 2000.[1] Rapid urbanisation, coupled with population growth, has led to rising energy demand at the municipal level: in 2013, cities accounted for two-thirds of global energy demand, compared with less than half (45%) in 1990.[2] Cities also are important drivers of the global economy, with a growing number of them – including London, Tokyo and New York – boasting economies larger than some G20 countries.[3] Meanwhile, cities account for around 75% of global carbon dioxide (CO_2) emissions and play a key role in addressing climate change, including limiting the rise in global average temperature to 1.5 degrees Celsius above pre-industrial levels, in line with the Paris Agreement.[4]

In part because of these concerns, cities have become leaders in renewable energy deployment. (→ *See Box 1.*) Increasingly, cities are adopting some of the world's most ambitious targets for renewables, putting them at the forefront of the rapidly expanding renewable energy movement. Renewable energy initiatives often are linked to wider city goals and urban planning efforts, driven by environmental, socio-economic, energy security and governance objectives. Cities' renewable energy deployment can be part of initiatives to transition to liveable, sustainable and low-carbon cities.[5]

City actions and policies driving renewables both supplement and complement frameworks that exist at the national and state/provincial levels. Many cities have used their direct regulatory and purchasing authority to shape renewable energy pathways within their jurisdictions. Some cities are able to accomplish more ambitious renewable energy goals than national and state/provincial bodies, as cities can tap into strengths such as their direct responsibility for providing services to residents and ensuring day-to-day quality of life, their contractual relationships with energy providers and large-scale users, and their authority to create incentives that drive lifestyle and development choices at the local level.

Cities account for around

75%

of global CO_2 emissions.

Municipal policies and mandates supporting the use of renewables in power, heating and cooling, and transport, as well as those linking renewables and energy efficiency, have gained momentum in recent years. As at the national level, most of the support for renewables at the city level has been directed towards the power sector. However, cities also have accelerated renewable energy solutions in the heating, cooling and transport sectors where overall renewable energy deployment has advanced at a far slower pace. (→ *See Global Overview chapter.*)

i In this chapter, the terms "city", "urban" and "municipal government" indicate different concepts. "City" generally refers to the larger metropolitan area and does not always specifically reference the municipal government actors. "Urban areas" generally refers to districts within metropolitan areas that are more densely populated than suburban or peri-urban communities within the same metropolitan area. "Municipal government" refers specifically to the public administration or governing body of a city.

DRIVERS FOR RENEWABLES IN CITIES

Cities are advancing renewable energy in their efforts to achieve a wide range of interlinked environmental, economic and social goals, including mitigating climate change, reducing air pollution, improving energy access and enhancing energy security.[6] Renewables have the potential to achieve all of these objectives, and most cities pursue renewable energy for more than one of these reasons.

ENVIRONMENTAL DRIVERS

Cities are vulnerable to the impacts of **climate change**. Sea-level rise and the increased frequency of extreme weather events such as floods, droughts and storms can affect city infrastructure, livelihoods and health.[7] The more than 1 billion people worldwide who live in urban slums and informal settlements are particularly vulnerable to some climate impacts, as they often live close to waterfronts and along river banks.[8] In 2017, 70% of the 96 cities that belonged to the C40 Cities network reported that they had experienced negative effects linked to climate change.[9]

Cities are using distributed renewable energy technologies to make their energy systems **more resilient** to the weather-related impacts of climate change. For example, after hurricanes Irene and Sandy hit the US east coast in 2012, locations within the New York metropolitan area began investing in renewables and microgrids to help prevent power shortages during future storms.[10] To boost resilience and meet rising energy demand, Marcus Garvey Village, a low-income housing complex in the New York borough of Brooklyn, installed a microgrid comprising a 400 kilowatt (kW) solar photovoltaic (PV) system, a 400 kW fuel cell system and a 300 kW battery storage system.[11] Boulder (Colorado, United States)implemented a solarplus-storage system that enables municipal operations to continue during power emergencies.[12] In Kamenge (Burundi), the city installed a 260 kW PV system at the Hospital University Center to provide more reliable energy.[13]

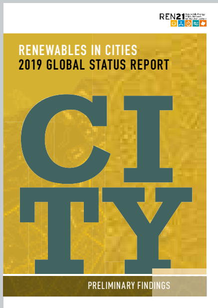
Cities are advancing renewable energy to achieve a wide range of interlinked **environmental, economic and social goals.**

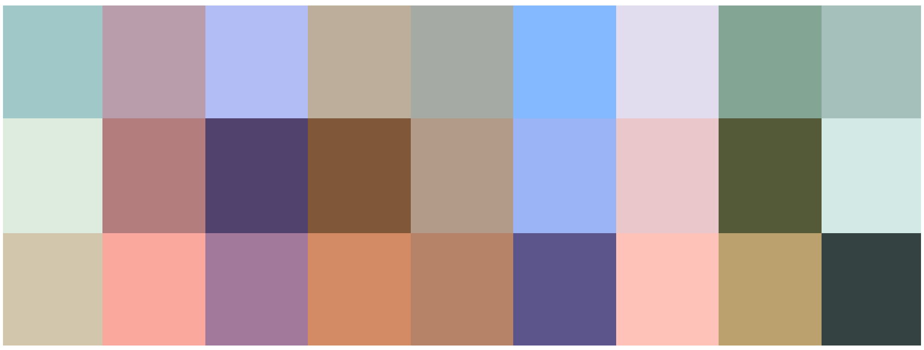
At the same time, cities are significant contributors to climate change. In 2018, one-fifth of global CO_2 emissions came from only 100 cities, and a large share of a country's emissions can be concentrated in just one or a few of its cities.[14] Thus, cities must play a key role in **reducing CO_2 emissions** and mitigating climate change, and many are doing so by scaling up renewable energy.[15]

In addition, worldwide increases in road transport, industrial activity and power generation, as well as the open burning of waste in many cities, contribute to elevated levels of urban **air pollution** and to **public health** concerns. In 2016, an estimated 91% of the global urban population was exposed to fine particulate matter (PM 2.5) levels exceeding World Health Organization (WHO) guidelines, and more than half of the urban

BOX 1. REN21 Renewables in Cities Global Status Report

As part of the annually produced *Renewables Global Status Report* (GSR), REN21 has tracked city-level action on renewable energy since the report's first edition in 2005. However, developing a comprehensive overview of city developments now necessitates a more dedicated effort, particularly as cities increasingly take action on renewables. Data on local- and city-level renewable energy policies and achievements generally are vast and decentralised, while consolidated data are limited, and available data often are outdated. To fill in some of these gaps and to showcase the many trends and developments related to renewables at the local level, REN21 is building on experience from the GSR to produce a new report series: the *Renewables in Cities Global Status Report* (REC-GSR). This chapter is based on preliminary findings of the first REC-GSR, to be released later in 2019 and available at www.ren21.net/cities.





City actions and policies on renewables both **supplement and complement** national and state/ provincial frameworks.

population was exposed to air pollution levels at least 2.5 times above the safety standard.[16] High levels of ambient (outdoor) air pollution caused an estimated 4.2 million premature deaths worldwide in 2016.[17] In many developing countries, the use of charcoal and fuelwood for heating and cooking in urban areas also contributes to poor indoor air quality. (→ *See Distributed Renewables chapter.*)

The deployment of renewables has become integral to city efforts to reduce CO_2 and other harmful emissions. In a push to improve urban air quality, Beijing (China) has been replacing local coal-fired power generation with renewable energy since 2013; in 2018, the city announced a target to achieve an 8% renewable share in its total final energy consumption by 2020.[18] Overall, the deployment of renewables in Chinese cities, along with energy efficiency measures, contributed to an estimated 12% reduction in average PM 2.5 concentrations in surveyed cities between 2017 and 2018.[19]

The deployment of **renewables** has become integral to city efforts to **reduce CO_2** and other harmful emissions.

SOCIO-ECONOMIC DRIVERS

Cities are attracted to renewable energy solutions because of the many socio-economic benefits that renewables can offer. These include the potential to create new local industries and businesses as well as associated jobs, and to meet rising energy demand. In developing and emerging economies, cities also are deploying renewables as a means to provide energy access to populations that previously were without electricity and/or clean cooking facilities.

Significant declines in renewable energy costs in recent years (→ *see Sidebar 4 in Market and Industry chapter*) have only increased interest in renewables, providing cities with opportunities to reduce and more easily control **municipal energy expenses**.[20] In 2015, the US city of Washington, D.C. installed solar panels on the roofs and parking lots of 34 government-owned facilities, driven by estimated cost savings of USD 25 million over the 20-year duration of the power purchase agreement.[21] In 2018, the city announced a broader goal of achieving 100% renewable electricity by 2032.[22]

Local renewable energy sources often provide a more stable and less expensive alternative to imported fossil fuels. Several cities in Ukraine have committed to 100% renewable energy by 2050, in part to bring down energy prices for households.[23] In the Pacific Islands, the government of Kiribati installed 548 kW of grid-connected solar systems on four buildings in South Tarawa in 2016, saving an estimated USD 290,000 annually in reduced diesel consumption and cutting greenhouse gas emissions by 765 tonnes per year.[24]

Cities in developing countries are adopting renewable energy policies and targets to advance **energy access.**

Municipal governments also have embraced local renewables as an opportunity to retain and attract local industries and businesses, thereby keeping revenue local and spurring **urban development**. The town of East Hampton (New York, United States) has set ambitious targets for 100% renewable electricity by 2020 and for 100% renewables use in heating and transport by 2030, with the aim of boosting the local economy and creating jobs.[25] Sweden's capital Stockholm has attracted companies to the city's data parks, which offer a combination of renewable power and waste heat recovery that is fed into the local district heating system.[26] Meanwhile, Freiburg (Germany) and Samsø (Denmark) are among a growing number of cities that have used their renewable energy strategies as branding tools to attract tourists, thereby stimulating the local economy.[27]

Worldwide, the number of **jobs** in renewable energy – for example, in research and development, project development, engineering, installation, and operation and maintenance – is increasing, reaching an estimated 11 million by the end of 2018. (→ *See Sidebar 1 in Global Overview chapter.*) The opportunity to create more jobs for local residents can stimulate city governments to implement policies that support renewables.[28] In China, the leading country for renewable energy jobs, many cities have experienced rapid growth in the sector: in Dezhou, in Shandong province, local policy support for solar power resulted in the presence of as many as 120 solar companies by 2010, and now solar panels are on almost every roof.[29] Fifty cities in the United States were home to more than 320,000 renewable energy jobs in 2018, led by Los Angeles, California (41,000 jobs) and New York City (21,000 jobs).[30] In the former coal mining town of Heerlen (the Netherlands), a district heating project launched in 2008, which relies on abandoned mine shafts for geothermal energy production, focuses specifically on training former coal industry workers.[31]

Increasingly, cities in the developing world are adopting renewable energy policies and targets to advance **access to modern energy services** such as electricity, space and water heating, and cooking fuel, particularly in suburban and peri-urban areas as well as in urban slums and informal settlements. For example, in 2012 the district of Kasese in western Uganda set a target for 100% electricity access by 2020 (as of 2015, only 7.6% of the district's 134,000 households had grid access) based on a transition to 100% renewables using micro-hydropower, solar PV, biomass and geothermal.[32] By 2015, tens of thousands more Kasese residents had gained access to electricity – including many off-grid – and renewables were supplying energy to an estimated 26.8% of the district.[33]

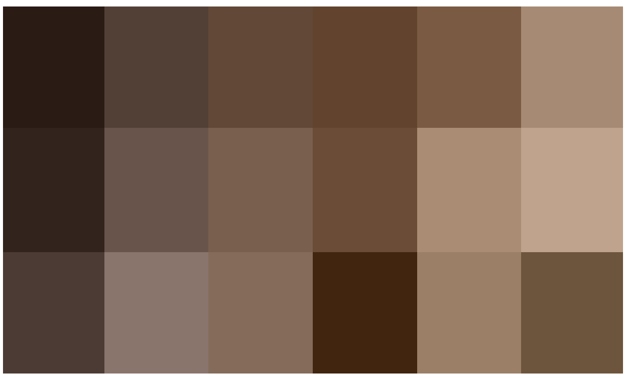
Overall, energy access in cities is expanding. In sub-Saharan Africa, nearly 76% of the urban population had access to electricity by 2016, up from only 60% in 2000.[34] Worldwide, however, more than 110 million people in cities still lacked electricity in 2018, as the overall growth in the urban population offset gains in access.[35] In many cities in the developing world (and in some industrialised countries), part of the population continues to rely on traditional biomass for cooking and heating, affecting both ambient and indoor air quality. (→ *See Distributed Renewables chapter.*)

ENERGY SECURITY AND GOVERNANCE

Cities have advanced the local production and use of renewable energy to address **energy security**. The lack of energy security, referring to the absence of reliable access to affordable energy resources, can take diverse forms and results from factors including geopolitical instability, climate change impacts, fuel shortages and price fluctuations.[36] Many cities see a transition to renewables as a way to insulate their residents and economies from the risks associated with dependence on imported fossil fuels.[37] For example, energy security was a key factor behind the Ukraine city of Zhytomyr's decision to adopt a target for 100% renewable electricity by 2050.[38]

Cities also are advancing renewables in an effort to improve the **governance** of their energy systems. In Germany, Japan and the United States, the desire for more direct citizen or municipal ownership of key energy infrastructure (also referred to as energy democracy[i]) is playing an increasing role in city action.[39] A growing number of municipalities in these countries have taken ownership of infrastructure such as district heating systems, local power grids and generation assets, often as part of efforts to increase the share of renewables in the mix.[40] For example, the municipal government of Hamburg (Germany) used the results of a 2013 local referendum to purchase the city's electricity and gas distribution grids in 2014 and the city's district heating system in 2018.[41]

At the same time, cities are using renewable energy to provide local populations with the opportunity to participate in municipal initiatives. The participation of local residents, organisations and others in renewables can take a variety of forms, including supporting the development of **community energy** projects.[42] For example, as part of its plan to generate 20% of electricity demand locally by 2050, Paris (France) is making public spaces and rooftops available to a local co-operative for the installation of solar PV plants, which also allows residents to invest in the co-op.[43]



i Energy democracy goes beyond national security of the energy supply to bringing energy resources and infrastructure under public or community ownership or control. See Gegenstrom 2012, www.gegenstromberlin.net, cited in Conrad Kunze and Sören Becker, *Energy Democracy in Europe: A Survey and Outlook* (Brussels: Rosa Luxembourg Stiftung, 2014), https://www.rosalux.eu/fileadmin/media/user_upload/energy-democracy-in-europe.pdf.

OPPORTUNITIES FOR URBAN RENEWABLE ENERGY

Building on these multiple drivers, cities are advancing renewable energy as a means to provide urban services such as electricity, heating and cooling, and transport. They also are developing cross-sectoral approaches, for example using urban waste and wastewater streams as feedstocks to produce biogas, biomethane and other renewable energy sources.[44] In many cities, there is growing recognition of the opportunities that exist in increasing the use of local renewables, driving policy makers to adopt related targets and support policies.

With cost reductions in solar PV, wind power and other technologies, cities see increasing possibilities to invest in **renewable power**. By the end of 2018, at least 100 cities worldwide were reportedly sourcing 70% or more of their electricity from renewables – including Auckland (New Zealand), Dar es Salaam (Tanzania), Nairobi (Kenya) and Seattle (United States).[45] (→ *See Figure 60.*) More than 40 cities were already entirely powered by renewables, with the majority in Latin America (30), but also elsewhere such as the US cities of Burlington (Vermont), Georgetown (Texas) and Rock Port (Missouri), as well as Reykjavik (Iceland) and Shenzhen (China).[46]

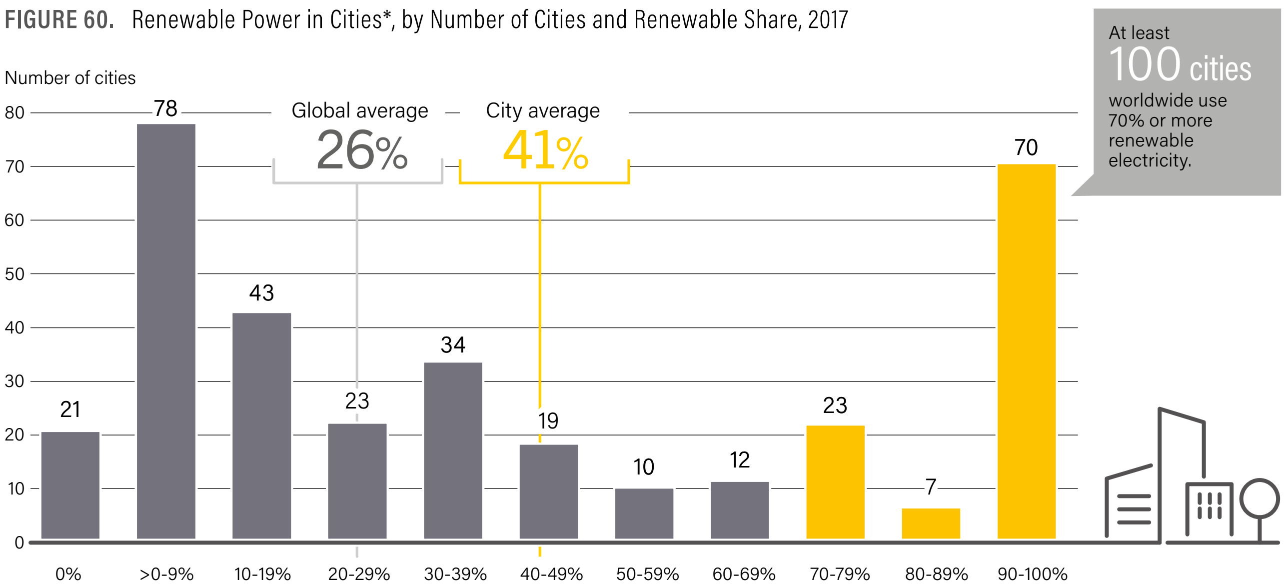
> The energy transition in the power sector is becoming increasingly attractive and **attainable for cities.**

Urban district heating and cooling networks provide an opportunity for cities to integrate renewables into the **heating and cooling** sector. Munich (Germany) uses a geothermal system and rooftop solar thermal installations to fuel the local district heating system, and in Austria more than 2,100 municipal district heating systems use local biomass to provide heat as well as revenue opportunities for local farmers.[47] In 2003, the US city of St. Paul (Minnesota) converted its district heating and cooling system from coal power to municipal wood waste, with 65 megawatts (MW) of heating capacity and 25 MW of power capacity.[48]

In the **transport** sector, renewable energy provides an opportunity to decrease fuel expenses and local emissions, particularly for public transit fleets. Stockholm has used public procurement of transport services to move towards its goal of phasing out fossil fuels in the transport sector, resulting in a mix of alternatively fuelled vehicles in the city's fleet, from biogas and biofuels to electric vehicles (EVs).[49] (→ *See Box 1 in Policy Landscape chapter.*) Although electric mobility is not a renewable technology in and of itself, it opens up the opportunity for increased penetration of renewable electricity in the transport sector. (→ *See Systems Integration chapter.*) In 2018, around 460,000 electric buses were operating in at least 300 cities worldwide.[50] More than 98% of the buses were deployed in China, but they also were present in Berlin (Germany), Moscow (Russian Federation) and Tshwane (South Africa).[51]

While the direct linking of renewable electricity and EVs remains limited, examples do exist, particularly at the city level. In 2018, Santiago (Chile) commissioned a 100 MW solar PV park to supply more than half the electricity demand of its underground rapid transit system.[52] In Melbourne (Australia), the city's entire tram system of 410 cars is transitioning to solar power, supplied by electricity from a 35 MW solar PV plant slated for completion

FIGURE 60. Renewable Power in Cities*, by Number of Cities and Renewable Share, 2017



* The figure shows shares of renewables in the electricity consumption of 340 cities that self-reported to CDP.

Note: City average is calculated based on the 340 cities shown. Categories include all values below the lower limit of adjacent category.

Source: CDP. See endnote 45 for this chapter.

in 2019.[53] In India, trains of the Delhi Metro Rail Corporation are being powered in part by off-site solar PV, while auxiliary services such as lighting and air conditioning are being powered by on-site rooftop solar.[54]

As of 2018, more than
50 cities
worldwide had set comprehensive, cross-sectoral renewable energy targets.

Commonly, municipalities are responsible for managing the large volumes of **waste and wastewater** produced at the city level, and increasingly they must face the social, economic, environmental and health impacts of this waste. As of 2017, more than 80% of the world's urban wastewater was still being discharged directly into waterways: the city of Lagos (Nigeria) alone generated 1.5 million cubic metres of wastewater every day, most of which flowed untreated into the Lagos Lagoon.[55] The world's cities also generate large volumes of solid waste – some 2 billion metric tonnes in 2016 – and production is rising.[56] When landfilled, the organic portion of municipal solid waste can release large amounts of methane, which, if not captured or used, can contribute significantly to global warming[i].[57]

By developing waste-to-energy – particularly waste-to-biogas – cities have the opportunity to provide renewable energy while improving waste management and avoiding sending waste to landfill. Because biogas is created through the anaerobic digestion of organic material, in cities it can be produced from a variety of sources, including the organic portion of municipal solid waste, restaurant waste, wastewater sludge and waste from surrounding agri-businesses. Biogas can provide heat and electricity and also can be upgraded to biomethane, a renewable substitute for natural gas that can be injected into the natural gas grid or used to fuel natural gas vehicles.[58]

As of 2018, thousands of digesters across Europe and sites in all 50 US states were producing biogas, often in or close to a city.[59] Although waste-to-biogas has been deployed mainly in Europe and North America, it is expanding elsewhere. For example, a waste-to-biogas production facility in Japan's Yabu City was expected to begin operations in 2019.[60]

Europe is home to hundreds of biomethane installations, many of them in cities, such as a plant inaugurated in Kalundborg (Denmark), and a digester facility in Beerse (Belgium).[61] Biomethane plants also are being developed rapidly in China, including sludge-to-energy systems in at least four major cities.[62] Elsewhere, buses in Karachi (Pakistan) will run on biomethane produced from cow manure.[63] (→ *See Bioenergy section in Market and Industry chapter.*)

CITY AMBITION AND TARGETS

In many cases, cities have committed to renewable energy targets that are more ambitious and comprehensive than those at the national and/or state/provincial levels. Cities increasingly are setting bold targets to support their vision for sustainable development, to establish a model for peer cities to follow, and to demonstrate municipal priorities to higher levels of government as well as to local residents and the private sector.

By the end of 2018, more than 230 cities worldwide had adopted targets for 100% renewable energy in at least one end-use sector, with the target years ranging from 2020 to 2050, while over half of these had a target for two or more sectors.[64] Meanwhile, more than 50 cities had set more-comprehensive renewable energy targets covering the power, heating and cooling, and transport sectors.[65] (→ ***See Reference Table R13.***)

Cities have adopted targets for renewable energy use in municipal operations for many reasons, including setting an example for businesses and civil society to follow and encouraging investment in renewable infrastructure. In 2018, Barcelona (Spain) met its goal of 100% renewable electricity in government operations, joining cities such as Austin (Texas, United States) and Madrid (Spain).[66] Adelaide (Australia) has committed to meeting the energy demand of all City Council buildings, including heating and cooling loads, with renewable sources by 2020.[67] Some cities – including Malmö (Sweden) and Breckenridge (Colorado, United States) – initially set targets for renewables in government operations, then extended them city-wide.[68]

Most city-wide targets focus on the power sector. By the end of 2018, more than 200 cities globally had committed to 100% renewable electricity.[69] In the United States alone, more than 100 cities and towns had set targets for 100% renewable electricity, including most recently Cincinnati (Ohio), Minneapolis (Minnesota) and Washington, D.C.[70]

Cities also are making commitments for renewable energy use in buildings. In 2018, 19 cities across five continents, representing 130 million people, pledged through C40 to ensure that all new buildings be net-zero carbon[ii] by 2030, by using energy efficiency measures coupled with renewable power, heating and cooling.[71] These signatory cities also have targets to expand their net-zero carbon goal to cover all buildings by 2050.[72] By the end of 2018, more than 110 cities and municipalities had adopted targets for 100% renewable heating and cooling.[73] For example, Munich (Germany) adopted a target in 2018 for a 100% renewable district heating network by 2040, joining cities such as Amsterdam (the Netherlands), Helsingborg (Sweden), Osnabruck (Germany) and Vienna (Austria).[74]

To achieve their renewable energy targets, cities are increasingly using their authority to set local building energy codes, including energy efficiency standards and mandates for the installation and use of solar water heaters and/or renewable power.

i Methane gas has 21 times the near-term global warming potential of CO_2 and accounted for 18% of global greenhouse gas emissions in 2017, from Jos G.J. Olivier and Jeroen A.H.W. Peters, *Trends in Global CO_2 and Total Greenhouse Gas Emissions: 2018 Report* (The Hague: PBL Netherlands Environmental Assessment Agency, 2018), https://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2018-trends-in-global-co2-and-total-greenhouse-gas-emissons-2018-report_3125.pdf.

ii A net-zero carbon building is a building that is highly energy efficient and fully powered from on-site and/or off-site renewable energy sources, from World Green Building Council, "What is Net Zero?", https://www.worldgbc.org/advancing-netzero/what-net-zero, viewed 10 May 2019.

For example, Vancouver (Canada) is putting in place codes requiring that all new buildings be zero emissions by 2030, and in 2018 Tübingen (Germany) passed legislation mandating the installation of solar PV on all new buildings.[75] Several city governments have implemented mandates specific to renewable heating and cooling. In Brazil, numerous cities have adopted solar mandates, including São Paulo, where 40% of the energy for heating water in new residential and commercial buildings must come from a solar source.[76] Municipal solar water heating mandates also exist in Barcelona (Spain), Bangalore (India), Beirut (Lebanon) and Rosario (Argentina), among others.[77]

Since the signing of the Paris Agreement, **cities have accelerated their efforts** on energy efficiency and renewables.

In the transport sector, some cities have committed to using biofuels and EVs as well as using their planning authorities to decarbonise the sector and reduce local air pollution. Targets for renewable fuels typically are part of broader strategies to promote lower-carbon transport technologies and mobility options.[i,78] By the end of 2018, more than 70 cities and municipalities had committed to using 100% renewable energy in the transport sector.[79] San Francisco (California, United States) announced renewable power targets for its transit rail system of 50% by 2025 and 100% by 2045, joining existing pledges by Oslo (Norway) to power its public transport fleet with renewables by 2020 and by Helsinki to fuel all city buses, working machines and heavy-duty vehicles with renewables by 2020.[80] In 2017, Shenzhen (China) achieved its target of 100% electric public buses.[81] Many cities also have placed restrictions on access for petrol and/or diesel-powered vehicles – including Athens, Bogota, Brussels, London and Mexico City.[82] While not directly supportive of renewable energy, these policies have the potential to increase renewable electricity use as EV deployment expands. (→ *See Sidebar 2 in Policy Landscape chapter.*)

CITY LEADERSHIP IN THE GLOBAL ENERGY TRANSITION

Climate action at the city level has both reinforced and been supported by national-level commitments to reduce greenhouse gas emissions and to take steps towards climate mitigation and adaption. For example, as part of their Nationally Determined Contributions (NDCs) submitted under the Paris Agreement, 113 national governments out of 164 made commitments as of 2016 to support the transition to low-carbon cities.[83] By contributing to wider efforts, municipal governments ensure that city voices are represented at the national and international levels, while national and state/provincial governments are able to connect more directly with communities to understand local priorities and create more effective policies.[84]

Cities also are demonstrating their willingness to partner globally, as highlighted by the commitments of city representatives at the 2015 United Nations climate talks in Paris. At the Climate Summit for Local Leaders, held in parallel to the official Paris negotiations, 440 mayors from five continents committed to collectively reducing 3.7 gigatonnes of urban greenhouse gas emissions annually by 2030.[85] Since the signing of the Paris Agreement, cities worldwide have accelerated their efforts to address climate change through energy efficiency improvements and renewable energy deployment, as well as through new partnerships. In 2017, 158 local governments, businesses, non-governmental organisations and research institutions signed the Nagano Declaration, committing to increase co-operation and accelerate the transition to 100% renewable energy cities.[86]

City-level climate commitments often exceed the current ambitions of the country-level NDCs, highlighting the importance of vertical co-operation as well as city-to-city networks to achieve greater climate goals and action.[87] For example, in response to the withdrawal of the United States from the Paris Agreement in 2017, the US Conference of Mayors – representing more than 1,400 cities nationwide – adopted a resolution in support of 100% renewables.[88] The We Are Still In coalition, including over 280 US cities and counties, alongside states, businesses, universities and other groups, similarly pledged to honour the Paris Agreement.[89]

Nationally and internationally, networks of municipal governments have expanded their scope and membership to increase their capacity, share lessons on climate and energy solutions, and inspire other cities to act. In 2018, another 1,800 signatories joined the Global Covenant of Mayors for Climate & Energy – committing to actions to address climate change, including scaling up renewable energy – bringing the total membership to over 9,200 municipalities, representing some 770 million people or nearly 10% of the global population[ii,90] Similarly, by year's end, the international network C40 had connected 96 cities (representing more than 700 million people and 25% of gross world product) to take climate action, and ICLEI – Local Governments for Sustainability had united more than 1,750 local and regional governments committed to sustainable urban development, representing more than a quarter of the global urban population.[91] In early 2019, ICLEI began collaborating with CDP to streamline the process of city climate reporting, including renewable energy, by engaging in joint reporting.[92]

i Targets for renewable energy in transport are often part of broader plans to reduce energy demand by expanding cycling, walking and public transit infrastructure.

ii Since 2017, the group has formally brought together the EU's Covenant of Mayors and the Compact of Mayors to advance the city-level transition to a low-emission, climate-resilient economy and to demonstrate the global impact of local action.

TABLE R1. Global Renewable Energy Capacity and Biofuel Production, 2018

	Added During 2018	Existing at End-2018
Power Capacity (GW)		
Bio-power	8.8	130
Geothermal power	0.5	13.3
Hydropower	20	1,132
Ocean power	0	0.5
Solar PV[1]	100	505
Concentrating solar thermal power (CSP)	0.6	5.5
Wind power	51	591
Thermal Capacity (GW_{th})		
Modern bio-heat	6	320
Geothermal direct use[2]	1.4	26
Solar collectors for water heating[3]	33	480
Transport Fuels Production (billion litres per year)		
Ethanol	7.9	112
Biodiesel (FAME)	1.4	34
Biodiesel (HVO)	0.8	7.0

[1] Solar PV data are provided in direct current (DC).
[2] Data do not include heat pumps.
[3] Data do not include air or concentrating collectors.
Note: Annual additions are net, except for the additions pertaining to solar collectors for water heating, which are gross. Numbers are rounded to the nearest GW/GW_{th}/billion litres, 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. Data reflect adjustments to year-end 2017 capacity data (particularly for bio-power and hydropower). For more precise data, see Reference Tables R14-R20, Market and Industry chapter and related endnotes.

Source: See endnote 1 for this section.

TABLE R2. Renewable Power Capacity, World and Top Regions/Countries[1], 2018

Technology	World Total	BRICS[2]	EU-28	China	United States	Germany	India	Japan	United Kingdom
		GW				GW			
Bio-power	130	44	42	17.8	16.2	8.4	10.2	4.0	7.7
Geothermal power	13.3	0.1	0.9	~0	2.5	~0	0	0.5	0
Hydropower	1,132	519	130	322	80	5.6	45	22	1.9
Ocean power	0.5	~0	0.2	0	~0	0	0	0	~0
Solar PV[3]	505	214	115	176	62	45	33[4]	56	13
Concentrating solar thermal power (CSP)	5.5	0.8	2.3	0.2	1.7	0	0.2	0	0
Wind power	591	262	179	210	96	59	35	3.7	21
Total renewable power capacity (including hydropower)	**2,378**	**1,040**	**469**	**727**	**260**	**119**	**124**	**86**	**44**
Total renewable power capacity (not including hydropower)	**1,246**	**521**	**339**	**404**	**180**	**113**	**78**	**64**	**42**
Per capita capacity (kilowatts per inhabitant, not including hydropower)	0.2	0.2	0.7	0.3	0.6	1.4	0.06	0.5	0.6

[1] Table shows the top six countries by total renewable power capacity not including hydropower; if hydropower were included, countries and rankings would differ somewhat (the top six would be China, the United States, Brazil, India, Germany and Canada).

[2] The five BRICS countries are Brazil, the Russian Federation, India, China and South Africa.

[3] Solar PV data are in direct current (DC). See Solar PV section in Market and Industry chapter and Methodological Notes for more information.

[4] Solar PV data for India are highly uncertain. See Solar PV section in Market and Industry chapter for details.

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 Targets for Share of Primary or Final Energy, 2018, and Progress, End-2016

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous target where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level. Some targets shown may be non-binding.

Country	Primary Energy		Final Energy	
	Share	Target	Share	Target
EU-28	13.3%		17.5% (2017)	→ 20% by 2020 → **32% by 2030**
Afghanistan			8.8%	→ 10% (no date given)
Albania	34.4%	→ 18% by 2020[1]	34.6% (2017)	→ 38% by 2020
Algeria			0.1%	→ 37% by 2030 → 40% by 2030
Angola		→ 7.5% by 2025	4.4%	
Armenia	12.4%	→ 21% by 2020 → 26% by 2025	6.4%	
Austria[2]	30.1%		32.6% (2017)	→ 45% by 2020
Bangladesh	24.8%		0.2%	→ 10% by 2020[1]
Belarus	5.5%		6.8%	→ 32% by 2020
Belgium	6.7%	→ 9.7% by 2020	9.1% (2017)	→ 13% by 2020
Wallonia				→ *20% by 2020*
Benin	59.6%		8.8%	→ 25% by 2025[1]
Bosnia and Herzegovina	24.9%		8.9%	→ 40% by 2020
Brazil	45.3%		47%	→ 45% by 2030
Brunei Darussalam			0.1%	→ 10% by 2035
Bulgaria	10.7%		18.7% (2017)	→ 16% by 2020
Burundi			2.6%	→ 2.1% by 2020[1]
China[3]	8.4%	→ 15% by 2020 → 20% by 2030	9.9%	
Costa Rica			35.3%	
Côte d'Ivoire	3%	→ 15% by 2020 → 20% by 2030	7.6%	
Croatia	23.3%		27.3% (2017)	→ 20% by 2020
Cuba			19.3%	
Cyprus	7.3%		9.9% (2017)	→ 13% by 2020
Czech Republic[2]	10.5%		14.9%	→ 13.5% by 2020
Denmark	30%		35.8%	→ 35% by 2020 → 100% by 2050
Djibouti		→ 17% by 2035		
Egypt	3.8%	→ 14% by 2020	4%	
Estonia	17.6%		29.2% (2017)	→ 25% by 2020
Fiji			30.1%	→ 23% by 2030
Finland	31.2%		41% (2017)	→ 38% by 2020[1] → 40% by 2025[1]
France	9.6%		16.3% (2017)	→ 23% by 2020 → 32% by 2030
Gabon	76.7%		60,1%	→ 80% by 2020
Germany[2]	12.7%		15.5% (2017)	→ 18% by 2020 → 30% by 2030 → 45% by 2040 → 60% by 2050
Ghana	42.5%		13.5%	→ Increase by 10% by 2030 (base year 2010)

TABLE R3. Renewable Energy Targets for Share of Primary or Final Energy, 2018, and Progress, End-2016 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous target where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level. Some targets shown may be non-binding.

Country	Primary Energy		Final Energy	
	Share	Target	Share	Target
Greece[2]	12.1%		15.2%	→ 20% by 2020
Grenada		→ 20% by 2020	0.7%	
Guatemala	63%		6.5%	→ 80% by 2026
Guinea			2.4%	→ 30% by 2030
Guinea-Bissau			7.8%	
Guyana			20.8%	→ 20% by 2025
Haiti			4%	
Honduras			11%	
Hungary[2]	11.5%		13.3% (2017)	→ 14.65% by 2020
Iceland	89.5%		77%	→ 64% by 2020
India			9.9%	
Indonesia	13% (2018)	→ 23% by 2025 → 31% by 2050	6.2%	
Ireland	7.9%		10.7% (2017)	→ 16% by 2020
Israel	2.4%		3.7%	→ 13% by 2025 → 17% by 2030
Italy	17.4%		18.3% (2017)	→ 17% by 2020
Jamaica	18.6%		7.5%	→ 20% by 2030
Japan	4.8%	→ 14% by 2030	6.3%	
Jordan	2.1%	→ 10% by 2020	2.8%	→ 11% by 2025
Korea, Republic of	1.7%	→ 6.1% by 2020 → 11% by 2030	2.7%	
Kosovo[4]			22.9% (2017)	→ 25% by 2020
Lao PDR	80%		23.4%	→ 30% by 2025[1]
Latvia	39.1%		39% (2017)	→ 40% by 2020
Lebanon			1.6%	→ 12% by 2020 → 15% by 2030
Liberia	5%	→ 30% by 2030	73.8%	→ 10% by 2030
Libya		→ 10% by 2020		
Lithuania	19.6%	→ 20% by 2025	25.8% (2017)	→ 23% by 2020 → **80% by 2050**
Luxembourg	5.6%		6.4% (2017)	→ 11% by 2020
Macedonia, FYR	15.7%		19.7% (2017)	→ 28% by 2020
Madagascar			38.6%	→ 54% by 2020[1]
Malawi		→ 7% by 2020	47.3%	
Mali		→ 15% by 2020	4.3%	
Malta	3.2%		7.2% (2017)	→ 10% by 2020
Mauritania		→ 20% by 2020	1.1%	
Moldova	10.3%	→ 20% by 2020	14.3%	→ 17% by 2020
Mongolia	3.2%	→ 20-25% by 2020	1.4%	
Montenegro	30.6%		40% (2017)	→ 33% by 2020
Nepal	84.1%	→ 10% by 2030[1]	6.4%	
Netherlands[2]	4.9%		6.6% (2017)	→ 14% by 2020
Niger	74.7%	→ 10% by 2020[1]		
Norway	49.2%		57.8%	→ 67.5% by 2020

TABLE R3. Renewable Energy Targets for Share of Primary or Final Energy, 2018, and Progress, End-2016 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous target where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level. Some targets shown may be non-binding.

Country	Primary Energy		Final Energy	
	Share	Target	Share	Target
Palau		→ 20% by 2020		
Palestine, State of			4.4%	→ 25% by 2020
Panama	21.1%	→ 30% by 2050	16.4%	
Peru			14%	→ 15% by 2030
Poland	8.5%	→ 12% by 2020	10.9% (2017)	→ 15% by 2020
Portugal	24.3%		28.1% (2017)	→ 31% by 2020 → 47% by 2030
Romania	18.7%		24.5% (2017)	→ 24% by 2020
Rwanda			8.2%	
Samoa		→ 20% by 2030	4.8%	
Serbia	13.1%		20.6% (2017)	→ 27% by 2020
Slovak Republic	9.7%		11.5% (2017)	→ 14% by 2020
Slovenia	16.8%		21.5% (2017)	→ 25% by 2020
Spain[2]	14.3%		17.5% (2017)	→ 20% by 2020
Sudan		→ 20% by 2020	24.7%	
Sweden[2]			54.5%	→ 49% by 2020
Switzerland		→ 24% by 2020		
Syria	0.4%	→ 4.3% by 2030		
Tajikistan	37%		44.6%	→ 50% by 2020
Tanzania	22.3%	→ 24% by 2020	19.8%	
Thailand	19.2%		14.4%	→ 25% by 2021 → 40% by 2035
Togo	78.9%		12.7%	→ 4% (no date given)[1]
Tonga			0.8%	
Ukraine	3%	→ 18% by 2030	1.9%	→ 11% by 2020 → 25% by 2035
United Arab Emirates				→ 24% by 2021
United Kingdom	8.2%		10.2%	→ 15% by 2020
Vanuatu				→ 65% by 2020
Vietnam	27.6%	→ 5% by 2020 → 8% by 2025 → 11% by 2050	13.3%	

[1] Targets may exclude large-scale hydropower and/or traditional biomass. "Large-scale hydropower" is defined as more than 10 MW of installed capacity, but the definition varies by country.

[2] 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 here. The government of the Netherlands has reduced its more ambitious target to the level set in the EU Directive.

[3] The Chinese target is for share of "non-fossil" energy. All targets include nuclear power.

[4] 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 Tables R4-R8). Some targets shown may be non-binding.

Source: See endnote 3 for this section

TABLE R4. Renewable Heating and Cooling Targets, 2018, and Progress, End-2017

Note: Text in **bold** indicates new/revised in 2018.

Country	Progress 2017	Target
EU-28	19.5%	**1.3% annual increase in the share of renewable heat through 2030**
Albania	24.9%	
Austria	32%	33% by 2020
Belgium	8.1%	11.9% by 2020
Bhutan		Solar thermal: 3 MW equivalent by 2025
Bulgaria	30%	24% by 2020
China	462.9 million m^2 (2016)	Solar thermal: 800 million m^2 by 2020
Croatia	36.6%	19.6% by 2020
Cyprus	24.5%	23.5% by 2020
Czech Republic	19.7%	14.1% by 2020
Denmark	46.6%	39.8% by 2020
		100% by 2050
Estonia	51.6%	38% by 2020
Finland	54.8%	47% by 2020
France	21.4%	38% by 2030
Germany	13.4%	14% by 2020
Greece	26.6%	20% by 2020
Hungary	19.6%	18.9% by 2020
India	6.7 GW_{th} (2016)	Solar water heating: 14 GW_{th} (20 million m^2) by 2022
Ireland	6.8%	15% by 2020
Italy	20%	17.1% by 2020
	6,320 ktoe	Bioenergy: 5,670 ktoe for heating and cooling by 2020
	207 ktoe (2016)	Geothermal: 300 ktoe for heating and cooling by 2020
	231.3 ktoe (2016)	Solar water and space heating: 1,586 ktoe by 2020
Jordan	882 MW_{th} (2015)	Solar water heating: systems for 30% of households by 2020
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[1]	50.5%	45.65% by 2020
Latvia	54.6%	53.4% by 2020
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	46.5%	39% by 2020
		90% by 2030
Luxembourg	8.1%	8.5% renewables in gross final consumption in heating and cooling by 2020
Macedonia, FYR	36.4%	11% by 2020
Malawi		Solar water heating: produce 2,000 solar water heaters; increase total installed to 20,000 by 2030
Malta	19.8%	6.2% by 2020
Mexico	3.4 million m^2	Solar water heating: install 18.2 million m^2 of collectors by 2027
Moldova		27% by 2020

■ TABLE R4. Renewable Heating and Cooling Targets, 2018, and Progress, End-2017 (continued)

Country	Progress 2016	Target
Montenegro	67.5%	38.2% by 2020
Morocco	316 MW_{th} (2015)	Solar water heating: 1.2 GW_{th} (1.7 million m^2) by 2020
Mozambique	1 MW_{th} (2015)	Solar water and space heating: 100,000 systems installed in rural areas (no date)
Netherlands	5.9%	8.7% by 2020
Poland	14.5%	17% by 2020
Portugal	34.4%	38% by 2030 69-72% by 2050
Romania	26.6%	22% by 2020
Serbia	24.4%	30% by 2020
Sierra Leone		Solar water heating: 2% penetration in hotels, guest houses and restaurants by 2020; 5% by 2030
		Solar water heating: 1% penetration in the residential sector by 2030
Slovak Republic	9.8%	14.6% by 2020
Slovenia	33.2%	30.8% by 2020
Spain	17.5%	17.3% by 2020
Sweden	69%	62.1% by 2020
Thailand	6,573 ktoe for heating (2015)	Bioenergy: 8,200 ktoe by 2022
	495 ktoe for heating (2015)	Biogas: 1,000 ktoe by 2022
	88 ktoe for heating (2015)	Organic MSW[2]: 35 ktoe by 2022
	11.3 ktoe (2016)	Solar water heating: 300,000 systems in operation and 100 ktoe by 2022
Ukraine		12.4% by 2020
United Kingdom	7.5%	12% by 2020

[1] Kosovo is not a member of the United Nations.

[2] 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 refer to share of renewable heating and cooling in total energy supply unless otherwise noted. Blank cells indicate that no data are available. 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 for the country. As calculation of heating and cooling shares is not standardised across countries, the table presents a variety of targets for the purpose of general comparison. ktoe = kilotonnes of oil equivalent

Source: See endnote 4 for this section.

TABLE R5. Renewable Transport Targets, 2018, and Progress, End-2017

Note: Text in **bold** indicates new/revised in 2018 and text in italics indicates policies adopted at the state/provincial level.

Country	Progress	Target
EU-28	7.6%	→ 10% by 2020 → **14% by 2030**
Albania		→ 10% by 2020
Austria	9.7%	→ 11.4% by 2020
Belgium	6.6%	→ 10% by 2020
Wallonia		→ 10.14% by 2020
Bulgaria	7.2%	→ 11% by 2020
Croatia	1.2%	→ 10% by 2020
Cyprus	2.6%	→ 10% by 2020
Czech Republic	6.6%	→ 10.8% by 2020
Denmark	6.8%	→ 10% by 2020
		→ 100% by 2050
Estonia	0.4%	→ 10% by 2020
Finland	18.8%	→ 30% biofuel blending and 40% renewable transport fuel use by 2030
France	9.1%	→ 15% by 2020
Germany	7%	→ 10% by 2020
Greece	4%	→ 10.1% by 2020
Hungary	6.8%	→ 10% by 2020
Iceland	7.2%	→ 10% by 2020
Ireland	7.4%	→ 10% by 2020
Italy	6.5%	→ 10.1% (2,899 ktoe) by 2020
Latvia	2.5%	→ 10% by 2020
Liberia		→ 5% palm oil blends in transport fuel by 2030
Lithuania	3.6%	→ 10% by 2020
Luxembourg	6.4%	→ 10% by 2020
Macedonia, FYR	0.1%	→ 2% by 2020

Country	Progress	Target
Malta	6.8%	→ 10.7% by 2020
Moldova		→ 20% by 2020
Montenegro	1%	→ 10.2% by 2020
Netherlands	5.9%	→ 10% by 2020
Norway	19.7%	→ 20% by 2020
Poland	4.2%	→ 20% by 2020
Portugal	7.9%	→ 20% by 2030
		→ 100% by 2050 (excluding aviation and shipping)
Qatar		→ 10% by 2020
Romania	6.6%	→ 10% by 2020
Serbia	1.2%	→ 10% by 2020
Slovak Republic	7%	→ 10% by 2020
Slovenia	2.7%	→ 10.5% by 2020
Spain	5.9%	→ 10% by 2020
Sri Lanka		→ 20% from biofuels by 2020
Sweden	38.6%	→ Vehicle fleet independent from fossil fuels by 2030
Thailand		→ 9 million litres per day ethanol consumption by 2022
		→ 6 million litres per day biodiesel consumption by 2022
		→ 25 million litres per day advanced biofuels production by 2022
Ukraine		→ 10% by 2020
United Kingdom	5.1%	→ 10.3% by 2020
Vietnam		→ 5% of transport petroleum energy demand replaced by 2025

Note: Targets refer to share of renewable transport in total energy supply unless otherwise noted. Blank cells indicate that no data are available. 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. ktoe = kilotonnes of oil equivalent

Source: See endnote 5 for this section

TABLE R6. Renewable Power Targets for Share of Electricity Generation, 2018, and Progress, End-2017

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Progress	Target
EU-28	30.7%	
Afghanistan[1]	86.1%	→ 100% by 2050
Algeria	0.32%	→ 27% by 2030
Antigua and Barbuda		→ 10% by 2020 → 15% by 2030
Argentina	2%	→ 12% by 2019 → 16% by 2021 → 18% by 2023 → 20% by 2025
Armenia	12%	→ 40% by 2025
Aruba		→ 100% by 2020
Australia	72.2%	→ 23% by 2020
Australian Capital Territory		→ *100% by 2025*
Northern Territory		→ *50% by 2030*
Queensland		→ *50% by 2030*
Victoria		→ *40% by 2025*
Austria	72.2%	→ 70.6% by 2020
Azerbaijan		→ 20% by 2020
Bahamas, The		→ 15% by 2020 → 30% by 2030
Bahrain		→ 5% by 2030
Bangladesh[1]		→ 10% by 2020 → 100% by 2050
Barbados[1]		→ 65% by 2030 → 100% by 2050
Belgium	17.2%	→ 20.9% by 2020
Belize	91%	→ 85% by 2030
Benin		→ 50% by 2025 (off-grid and rural)
Bhutan[1]		→ 100% by 2050
Bolivia		→ 79% by 2030
Brazil[2]		→ 23% by 2030
Brunei Darussalam		→ 10% by 2035
Bulgaria	19.2%	→ 20.6% by 2020
Burkina Faso[1]		→ 50% by 2025 → 100% by 2050
Cabo Verde	25%	→ 100% by 2025
Cambodia[1]		→ 100% by 2025
Cameroon		→ 25% by 2035
Canada[3]	66% (2016)	→ No national target
Alberta		→ *30% by 2030*
British Columbia		→ *93% (no date given)*
New Brunswick		→ *40% by 2020*
Nova Scotia		→ *40% by 2020*
Saskatchewan		→ *50% by 2030*
Chile	18%	→ 20% by 2025
China	26.4%	→ **35% by 2030**
Chinese Taipei	4.5%	→ 9% by 2020 → 20% by 2025
Colombia[1]		→ 100% by 2050
Comoros[1]		→ 43% by 2030 → 100% by 2050
Congo, Democratic Republic of the[1]		→ 100% by 2050
Congo, Republic of the		→ 85% by 2025
Costa Rica	98.6%	→ 100% by 2030
Côte d'Ivoire		→ 42% by 2020
Croatia	46.4%	→ 39% by 2020
Cuba	4%	→ 24% by 2030
Cyprus	8.9%	→ 16% by 2020
Czech Republic	13.7%	→ 14.3% by 2020
Denmark[4]	60.4%	→ 50% by 2020 → 100% by 2050
Djibouti		→ 100% by 2020
Dominica		→ 100% (no date)
Dominican Republic[1]	12%	→ 25% by 2025 → 100% by 2050
Egypt		→ 20% by 2021/2022 → 42% by 2035
Eritrea		→ 70% by 2030
Estonia	17%	→ 17.6% by 2020
Ethiopia[1]		→ 100% by 2050
Fiji		→ 100% by 2030
Finland	35.2%	→ 33% by 2020
France	19.9%	→ 40% by 2030
Gabon		→ 70% by 2020 → 80% by 2025
Gambia[1]		→ 35% by 2020 → 100% by 2050
Germany	34.4%	→ 40-45% by 2025 → **65% by 2030** → 80% by 2050
Ghana[1]		→ 10% by 2020 → 100% by 2050
Greece	24.5%	→ 40% by 2020
Grenada[1]		→ 100% by 2050
Guatemala[1]	59%	→ 80% by 2030 → 100% by 2050
Guyana		→ 90% (no date)
Haiti[1]		→ 47% by 2030 → 100% by 2050
Honduras[1]	75%	→ 60% by 2022 → 80% by 2038 → 100% by 2050
Hungary	7.5%	→ 10.9% by 2020
India[5]	7.8%	→ 40% by 2030
Indonesia		→ 26% by 2025
Iraq		→ 10% by 2030
Ireland	30.1%	→ 42.5% by 2020
Israel	2%	→ 10% by 2020 → 17% by 2030
Italy	34.1%	→ 26% by 2020
Jamaica		→ **50% by 2030**
Japan		→ 22-24% by 2030
Kazakhstan		→ 3% by 2020 → 50% by 2030
Kenya[1]		→ 100% by 2050
Kiribati[1]		→ 3% by 2020 → 100% by 2050
Korea, Republic of		→ 6% by 2019 → 7% by 2020 → 20% by 2030

TABLE R6. Renewable Power Targets for Share of Electricity Generation, 2018, and Progress, End-2017 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Progress	Target
Kuwait		→ 10% (no date)
Latvia	54.4%	→ 60% by 2020
Lebanon[1]		→ 12% by 2020 → 100% by 2050
Lesotho		→ 35% by 2020 (off-grid and rural)
Liberia		→ 30% by 2021
Libya		→ 7% by 2020 → 10% by 2025
Lithuania	18.3%	→ 21% by 2020 → 45% by 2030
Luxembourg	8.1%	→ 11.8% by 2020
Macedonia, FYR	24.8%	→ 24.7% by 2020
Madagascar[1]		→ 85% by 2030 → 100% by 2050
Malawi[1]		→ 100% by 2050
Malaysia		→ 9% by 2020 → **20% by 2030**
Maldives[1]		→ 100% by 2050
Mali[6]		→ 25% by 2033
Malta	6.6%	→ 3.8% by 2020
Marshall Islands[1]		→ 20% by 2020 → 100% by 2050
Mauritius		→ 35% by 2025
Mexico		→ 25% by 2018 → 30% by 2021 → 35% by 2024
Micronesia, Federated States of		→ 10% in urban centres and 50% in rural areas by 2020
Moldova		→ 10% by 2020
Mongolia[1]		→ 20% by 2020 → 30% by 2030 → 100% by 2050
Montenegro	50.1%	→ 51.4% by 2020
Morocco		→ 52% by 2030 → 100% by 2050
Namibia		→ 70% by 2030
Nepal[1]		→ 100% by 2050
Netherlands	13.8%	→ 37% by 2020
New Zealand		→ 90% by 2025
Cook Islands		→ *100% by 2020*
Niue		→ *100% by 2020*
Tokelau		→ *100% (no date)*
Nicaragua	50%	→ 90% by 2027
Niger[1]		→ 100% by 2050
Nigeria[7]		→ 10% by 2020
Palau[1]		→ 100% by 2050
Palestine, State of[1]		→ 10% by 2020 → 100% by 2050
Papua New Guinea		→ 100% by 2030
Paraguay		→ 60% increase from 2014 to 2030
Peru		→ 15% by 2030
Philippines[1]		→ 40% by 2020 → 100% by 2050
Poland	13.1%	→ 19.3% by 2020
Portugal	53.7%	→ 60% by 2020 → 80% by 2030 → 100% by 2050
Qatar		→ 2% by 2020 → 20% by 2030
Romania	41.6%	→ 43% by 2020
Russian Federation[8]		→ 4.5% by 2020
Altai Republic		→ *80% by 2020*
Rwanda[1]		→ 100% by 2050
Samoa		→ 100% by 2030
São Tomé and Príncipe		→ 47% (no date)
Senegal[1]		→ 100% by 2050
Serbia	28.7%	→ 37% by 2020
Seychelles		→ 5% by 2020 → 15% by 2030
Sierra Leone		→ 33% by 2020 → 36% by 2030
Singapore		→ 8% (no date)
Slovak Republic	21.3%	→ 24% by 2020
Slovenia	32.4%	→ 39.3% by 2020
Solomon Islands		→ 100% by 2030
South Africa		→ 9% by 2030
South Sudan[1]		→ 100% by 2050
Spain	36.3%	→ 39% by 2020
Sri Lanka[1]		→ 20% by 2020 → 100% by 2050
St. Lucia[1]		→ 35% by 2020 → 100% by 2050
St. Vincent and the Grenadines		→ 60% by 2020
Sudan[1]		→ 20% by 2030 → 100% by 2050
Sweden	65.9%	→ **100% by 2040**
Tajikistan		→ 10% (no date)
Tanzania[1]		→ 100% by 2050
Thailand[9]		→ 20% by 2036
Timor-Leste[1]		→ 50% by 2020 → 100% by 2050
Togo		→ 15% by 2020
Tonga		→ 50% by 2020
Trinidad and Tobago		→ 5% of peak demand (or 60 MW) by 2020
Tunisia[1]		→ 30% by 2030 → 100% by 2050
Turkey	35.1%	→ 30% by 2023
Tuvalu		→ 100% by 2020
Ukraine		→ 11% by 2020 → 20% by 2030 → 25% by 2035

TABLE R6. Renewable Power Targets for Share of Electricity Generation, 2018, and Progress, End-2017 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Progress	Target
United Arab Emirates		→ No national target
Abu Dhabi		→ *7% by 2020*
Dubai		→ *7% by 2020* → *15% by 2030*
United Kingdom	28.1%	→ No national target
Scotland		→ *100% by 2020*
United States[10]	18%	→ No national target
Arizona		→ *15% by 2025*
California		→ *33% by 2020* → *50% by 2030* → **100% by 2045**
Colorado		→ *30% by 2020*[11]
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*
Maryland		→ *25% by 2020*
Massachusetts		→ *15% by 2020 and an additional 1% each year thereafter*
Michigan		→ *15% by 2021*
Minnesota		→ *26.5% by 2025 (IOUs)*[11] → *31.5% by 2020 (Xcel)*
Missouri		→ *15% by 2021*[11]
Nevada		→ *25% by 2025*

Country	Progress	Target
New Hampshire		→ *24.8% by 2025*
New Jersey		→ *20.38% by 2020 and 4.1% solar by 2027* → **50% by 2030**
New Mexico		→ *20% by 2020 (IOUs)*[11] → *10% by 2020 (co-ops)*[12]
New York		→ *50% by 2030*
North Carolina		→ *12.5% by 2021*
Ohio		→ *12.5% by 2026*
Oregon		→ *50% by 2040*
Pennsylvania		→ *18% by 2021*
Rhode Island		→ *38.5% by 2035*
Vermont		→ *Increasing by 4% every three years until reaching 75% by 2032*
Washington		→ *15% by 2020*
District of Columbia		→ **100% by 2032**
Puerto Rico		→ *20% by 2035*
U.S. Virgin Islands		→ *30% by 2025*
Uzbekistan	12.6%	→ 19.7% by 2025
Vanuatu		→ 65% by 2020 → 100% by 2030
Vietnam[1]		→ 7% by 2020 → 10% by 2030 → 100% by 2050
Yemen[1]		→ 15% by 2025 → 100% by 2050

[1] 100% by 2050 target established by the Climate Vulnerable Forum.
[2] Brazil's target excludes all hydropower.
[3] Canada's share excludes all hydropower.
[4] In March 2012, Denmark set a target of 50% electricity consumption supplied by wind power by 2020.
[5] India does not classify hydropower installations larger than 25 MW as renewable energy sources, so hydro >25 MW is excluded from national shares and targets. De facto sub-national targets have been set through existing renewable portfolio standard (RPS) policies.
[6] Mali's target excludes large-scale hydropower.
[7] Nigeria's target excludes hydropower plants >30 MW.
[8] The Russian Federation's targets exclude hydropower plants >25 MW.
[9] Thailand does not classify hydropower installations larger than 6 MW as renewable energy sources, so hydro >6 MW is excluded from national shares and targets.
[10] The United States does not have a renewable electricity target at the national level. De facto state-level targets have been set through existing RPS policies.
[11] RPS mandate is for investor-owned utilities (IOUs), which are utilities operating under private control rather than government or co-operative operation.
[12] RPS mandate is for co-operative utilities.

Note: Unless otherwise noted, all targets and corresponding shares represent all renewables including hydropower. Blank cells indicate that no data are available. 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. 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, R4, R5, R6, R9, R10, R14). 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 endnote 6 for this section.

TABLE R7. Renewable Power Targets for Technology-Specific Share of Electricity Generation, 2018

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level. Some targets shown may be non-binding.

Country	Technology	Target
Denmark	Wind power	50% by 2020
Egypt	Wind power	12% by 2020
Eritrea	Wind power	50% (no date)
Guinea	Solar power	6% of generation by 2025
	Wind power	2% of generation 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[1]		
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% through 2021-22*
Japan	Bio-power	3.7-4.6% by 2030
	Geothermal power	1-1.1% 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

[1] India has established state-specific solar power purchase obligations.

Note: Unless otherwise noted, all targets and corresponding shares represent all renewables, including hydropower. A number of states/provinces and local jurisdictions have additional targets not listed here. Some countries shown have other types of targets (Tables R3-R6 and R8). See Policy Landscape chapter and Table R13 for more information about sub-national and municipal-level targets, and see Tables R21 and R23 for information on electricity access. Existing shares are indicative and may need adjusting if more accurate national statistical data are published.

Source: See endnote 7 for this section.

TABLE R8. Renewable Power Targets for Specific Amount of Installed Capacity or Generation, 2018

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Algeria	Electricity	22 GW by 2030
	Bio-power from waste-to-energy	1 GW by 2030
	Geothermal power	15 MW by 2030
	Solar PV	13.5 GW by 2030
	CSP	2 GW by 2030
	Wind power	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
Azerbaijan	Electricity	1 GW by 2020
Bahrain	**Electricity**	**700 MW by 2030**
Bangladesh	Hydropower	4 MW by 2021
	Biomass power	7 MW by 2021
	Biogas power	7 MW by 2021
	Waste-to-energy	40 MW by 2021
	Solar power	1,676 MW by 2021
	Wind power	1,370 MW by 2021
Belarus	Electricity generation	2.6 billion kWh renewable production 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 added 2015-2025
Bosnia and Herzegovina	Hydropower	120 MW by 2030
	Solar PV	4 MW by 2030
	Wind power	175 MW by 2030
Brazil	Bio-power	13.7 GW by 2021
	Hydropower (small-scale)	7.8 GW by 2021
	Wind power	19.5 GW by 2021
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 renewable technologies, including:*
	Hydropower	*9.3 GW by 2025*
	Solar PV	*40 MW by 2025*
	Wind power	*5 GW by 2025*

TABLE R8. Renewable Power Targets for Specific Amount of Installed Capacity or Generation, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Canada (continued)		
Prince Edward Island	*Wind power*	*30 MW increase by 2030 (base year 2011)*
China	Electricity	680 GW non-fossil fuel generation capacity by 2020
	Hydropower	340 GW by 2020
	Biomass power	15 GW by 2020
	Solar power	105 GW solar PV by 2020; 5 GW CSP 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; 3-5.5 GW by 2025
Croatia	Hydropower	1,655 MW by 2020
Cuba	Electricity	2.1 GW biomass, wind, solar and hydropower capacity by 2030
Egypt	Hydropower	2.8 GW by 2020
	Solar PV	220 MW by 2020; 700 MW by 2027
	CSP	1.1 GW by 2020; 2.8 GW by 2030
	Wind power	7.2 GW by 2020
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	Ocean power	380 MW by 2020
	Hydropower	0.1-2 GW by 2023
	Solar power	18.2-20.2 GW by 2023 [8 GW by 2020] **45 GW by 2030**
	Wind power (offshore)	5.2 GW by 2030
	Wind power (onshore)	21.8-26 GW by 2023
Germany	Biomass	100 MW added per year
	Solar PV	2.5 GW added per year
	Wind power (onshore)	Tendering of 2.8 GW per year through 2019, 2.9 GW per year after 2019
	Wind power (offshore)	6.5 GW added by 2020
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)
India	Electricity	175 GW by 2022
	Bio-power	10 GW by 2022
	Hydropower (small-scale)[1]	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

TABLE R8. Renewable Power Targets for Specific Amount of Installed Capacity or Generation, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
India (continued)		
Andhra Pradesh	*Electricity*	*18 GW added by 2020-2021*
Delhi	*Solar PV*	*5,000 MW added between 2015 and 2020*
	Solar power	*1 GW by 2020; 2 GW by 2025*
Jharkhand	*Solar PV*	*2,650 MW by 2019-2020*
Indonesia	Geothermal power	12.6 GW by 2025
	Hydropower	2 GW by 2025, including 0.43 GW micro-hydropower
	Pumped storage[2]	3 GW by 2025
	Solar power	5 GW by 2020
	Wind power	100 MW by 2025
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
	Solar power	1 GW by 2020
	Wind power	1.2 GW by 2020
Kazakhstan	Bio-power	15.05 MW at 3 bioelectric stations by 2020
	Hydropower	539 MW at 41 hydroelectric power stations by 2020
	Solar power	713.5 MW at 28 solar electric plants by 2020
	Wind power	1,787 MW at 34 wind power 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 renewable 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	1.5 GW by 2019; 16,619 GWh per year by 2030
	Wind power (offshore)	2.5 GW by 2019
Kosovo[3]	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	344 MW by 2020; 844 MW by 2025
	CSP	125 MW by 2020; 375 MW by 2025
	Wind power	600 MW by 2020; 1 GW by 2025

TABLE R8. Renewable Power Targets for Specific Amount of Installed Capacity or Generation, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Macedonia, FYR	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 hydropower); 11.2 TWh per year, or 10% of national supply (no date given)
	Solar power	1 GW added by 2020
Morocco	Hydropower	2 GW by 2020
	Solar PV and CSP	2 GW by 2020
	Wind power	2 GW by 2020
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 installed (no date)
Myanmar	Renewable power	27% of total installed power capacity by 2030
Nigeria	Bio-power	400 MW by 2025
	Hydropower (small-scale)[4]	2 GW by 2025
	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
Portugal	Electricity	15.8 GW by 2020; 31.1 GW by 2030
	Bio-power from solid biomass	769 MW by 2020
	Bio-power from biogas	59 MW by 2020
	Geothermal power	29 MW by 2020
	Hydropower (small-scale)	400 MW by 2020
	Ocean power (wave)	6 MW by 2020
	Solar PV	670 MW by 2020; 7.8-9.3 GW by 2030
	Concentrated solar photovoltaics (CPV)	50 MW by 2020; 0.3 GW by 2030
	Wind power	5.3 GW onshore by 2020 and 8.5-8.9 GW by 2030; 27 MW offshore by 2020 and 0.3 GW by 2030

TABLE R8. Renewable Power Targets for Specific Amount of Installed Capacity or Generation, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
Russian Federation[5]	Electricity	5.5 GW by 2024, of which:
	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	9.5 GW by 2023; 54 GW by 2040
	Geothermal, bio-power (waste-to-energy)[6], wind power	13 GW combined by 2040
	Solar power	41 GW by 2040 (25 GW CSP, 16 GW solar PV)
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	20-40 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 generation capacity installed 2010-2030
Sudan	Bio-power from solid biomass	54 MW by 2031
	Bio-power from biogas	68 MW by 2031
	Hydropower	63 MW by 2031
	Solar PV	667 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
	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[6]	400 MW by 2021
	Geothermal power	1 MW by 2021
	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 given)
Tunisia	Electricity	4.6 GW (40% of capacity) by 2030
	Bio-power from solid biomass	300 MW by 2030
	Solar power	10 GW by 2030
	Wind power	16 GW by 2030

■ TABLE R8. Renewable Power Targets for Specific Amount of Installed Capacity or Generation, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Technology	Target
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*[7]
Massachusetts	***Wind power (offshore)***	***1.6 GW by 2027, additional 1.6 GW by 2035***
New York	*Energy storage*	*1.5 GW of energy storage by 2025* *3 GW of energy storage by 2030*
Texas	*Electricity*	*5,880 MW*
Uzbekistan	Solar PV	157.7 MW by 2019; 382.5 MW by 2020; 601.9 MW by 2021; 1.24 GW by 2025
	Wind power	102 MW by 2021; 302 MW by 2025
Venezuela	Electricity	613 MW added 2013-2019, including:
	Wind power	500 MW added 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	Bio-power	6 MW by 2025
	Geothermal power	160 MW by 2025
	Solar PV	5.5 MW off-grid by 2025
	CSP	100 MW by 2025
	Wind power	400 MW by 2025

[1] 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.

[2] 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, in particular for variable renewable resources.

[3] Kosovo is not a member of the United Nations.

[4] Nigeria's target excludes hydropower plants >30 MW.

[5] The Russian Federation's targets exclude hydropower plants >25 MW.

[6] 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. Uganda utilises predominantly organic waste.

[7] Investor-owned utilities (IOUs) are those operating under private control rather than government or co-operative operation.

Note: All capacity targets are for cumulative capacity unless otherwise noted. Targets are rounded to the nearest tenth decimal. Renewable energy targets are not standardised across countries; therefore, the table presents a variety of targets for the purpose of general comparison. Countries on this list may also have primary/final energy, electricity, heating/cooling or transport targets (see Tables R3-R7).

Source: See endnote 8 for this section.

TABLE R9. Renewable Heating and Cooling Policies, 2018

Note: Text in **bold** indicates new/revised in 2018.

Country	Investment Subsidy	Rebates	Loans/Grants	Tax Credits	Feed-in Tariff
Armenia[1]			R/C		
Austria	C		**R**		
Bulgaria			R		
Chile				R	
Croatia			**P**		
Czech Republic	R				
Denmark			I		
France	R/I/C/P			R	
Georgia[1]			R/C		
Germany	R/C/P				
Hungary			R		
India	R/I/C/P	I			
Ireland			C		
Italy		R/C/P		R/C/I	
Korea, Republic of	R				
Lebanon			R		
Macedonia, FYR	R				
Malta		R			
Mauritius			R		
Netherlands				C/I	R/I/C/P
Norway	C/P	R			
Poland	P[2]		R		
Romania			R/I/C/P		
Slovak Republic	R				
Slovenia	**C/P**		R		
Spain	R/P/C		R/C		
Tunisia	R/C		R/C		
Ukraine			R		
United Kingdom			**R/C/P**		R/C/P
United States (California)	R/I/C/P				
Uruguay	R		R		

R Residential
I Industrial
C Commercial
P Public facilities

[1] Incentives provided by the European Bank for Reconstruction and Development under the Caucusus Energy Efficiency Program II.

[2] Subsidies applicable to municipalites with over 10,000 inhabitants.

Source: See endnote 9 for this section.

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, 2018

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Biofuel Blend Mandates				Other Renewable Transport Mandates
	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	
EU				1% advanced biofuels and biogas by 2025; **3.5% by 2030**	
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	
Belgium	6% [4%]	8.5% [4%]			
Brazil	**10%**	27%			
Bulgaria	6%	8%			
Canada	2%	5%			
Alberta	*2%*	*5%*			
British Columbia	*4%*	*5%*			
Manitoba	*2%*	*9%*			
Ontario	*4%*	*5%*			
Saskatchewan	*2%*	*8%*			
China[1]		10%			
Chinese Taipei	1%				
Colombia	10%	**10%** [8%]			
Costa Rica	20%	7%			
Croatia	5.75%	0.97%	6.92%		0.1% second-generation biofuels
Czech Republic	6%	4.1%			
Denmark			5.75%	0.9% advanced biofuels from waste materials by 2020	
Ecuador	5%	10%			
Ethiopia		10%			
Finland			15%		
France	7.7%	7.5%			
Germany				0.05% advanced biofuels by 2020; 0.5% by 2025	6.5% cap on conventional biofuels
Greece			7%		
Guatemala		5%			
Hungary	4.9%	4.9%			
India	20%	10%			
Indonesia	20%	3%			**Expanded B20 blending mandate from the road transport sector to cover fuel use for railroads**

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Biofuel Blend Mandates				Other Renewable Transport Mandates
	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	
Ireland			8.7%	**B10 beginning in 2019**	
Italy			7%	**0.9% advanced biofuels by 2020; 1.85% by 2022** [0.6% advanced biofuels by 2018; 1% by 2022]	6.7% cap on conventional biofuels by 2022
Jamaica		10%			
Korea, Republic of	3%				
Malawi		10%			
Malaysia	10%	10%			
Mexico[2]		10% [5.8%]			
Mozambique		15%		E20 from 2021	
Netherlands			**8.5%**	**1% advanced biofuels by 2020**	5% cap on conventional biofuels by 2020
New Zealand	7%				Maximum methanol blend of 3%
Norway	4%			**E20 by 2020**	**0.5% renewable fuels in aviation by 2020**
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	
Portugal			9%		
Romania	6.5%	8%		10% by 2020	
Slovak Republic			**5.8%**		
Slovenia			7.5%		100% of heavy-duty trucks to run on biodiesel by 2030
South Africa	5%	2%			
Spain			6%		
Sudan		5%			
Sweden					Fossil fuel-independent vehicle fleet by 2030
Thailand	7%	5%			4.1 billion litres of ethanol and 5.1 billion litres of biodiesel by 2036
Turkey		2%			
Ukraine		7%			

TABLE R10. Renewable Transport Mandates at the National/State/Provincial Levels, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

Country	Biofuel Blend Mandates				Other Renewable Transport Mandates
	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Unspecified/ Overall Blend Mandate	Biofuel Mandate by Future Year	
United Kingdom			9.6%	0.2% advanced biofuels by 2020; 2.8% by 2032	**4% cap on crop-based fuels decreasing to 2% in 2032; 12.4% renewable fuels in road and non-road mobile machinery transport by 2032** [6%]
United States					Renewable Fuel Standard (RFS) of 2018: 73 billion litres total renewable fuels, including 1.1 billion litres cellulosic biofuel, 7.9 billion litres biomass-based diesel, 16.2 billion litres advanced biofuel[3]
Hawaii, Missouri and Montana		*10%*			
Louisiana	*2%*	*2%*			
Massachusetts	*5%*				
Minnesota	*10%*	***20%*** *[10%]*			
New Mexico	*5%*				
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[3]*
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%]			

[1] E10 mandate extended to cover 15 regions.

[2] Mexico's E10 maximum blend was subsequently halted in response to several court cases challenging the increase.

[3] Original target(s) set in gallons and converted to litres for consistency.

Note: 'E' refers to ethanol and 'B' refers to biodiesel. Blank cells indicate that data are not available. This table lists only renewable transport mandates; transport and biofuel targets can be found in Table R5.

Source: See endnote 10 for this section.

TABLE R11. Feed-in Electricity Policies, Cumulative Number of Countries/States/Provinces and 2018 Revisions

Note: Text in **bold** indicates new/revised in 2018, and text with a ~~strikethrough~~ indicates discontinuation and text in *italics* indicates policies adopted at the state/provincial level.

Year	Cumulative #[1]	Countries/States/Provinces Added That Year
1978	1	~~United States~~[2]
1988	2	Portugal
1990	3	Germany
1991	4	**Switzerland**
1992	5	Italy
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**; 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; Macedonia FYR; Moldova; Mongolia; South Australia (Australia)
2008	70	Iran; Kenya; 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	94	Ghana; Montenegro; Netherlands; Syria; **Vietnam**; Nova Scotia (Canada)[3]; Rhode Island (United States)
2012	99	Jordan; Nigeria; State of Palestine; Rwanda; Uganda
2013	101	Kazakhstan; Pakistan
2014	104	Egypt; Vanuatu; Virgin Islands (United States)
2015	104	[None identified]
2016	104	Czech Republic (reinstated)
2017	107	Zambia; Vietnam; Massachusetts (United States)
2018	107	[None identified]
Total Existing[4]	**111**	

2018 FIT Policy Adjustments	
Australia – New South Wales	*Solar PV FIT rates reduced 44%*
Canada – Ontario	*End of FIT*
China	End of wind FIT Utility-scale solar PV FIT reduced; 10 GW cap introduced for distributed solar PV FIT
Japan	Final full year for 2009 residential solar PV FIT; residential FIT rate cuts postponed to September 2019
Serbia	FIT extended by one year until 31 December 2019
Switzerland	Geothermal FIT increased from USD 0.48 per kWh to USD 0.54 per kWh
United Kingdom	Discontinuing FIT for new household solar PV installations by April 2019
Vietnam	Wind power FIT increased from VND 1,809 (USD 0.078) per kWh to VND 1,928 (USD 0.085) per kWh for onshore wind and VND 2,223 (USD 0.098) per kWh for offshore wind

1 "Cumulative number" refers to number of jurisdictions that had enacted feed-in policies as of the given year.

2 The US PURPA policy (1978) is an early version of the FIT, which has since evolved.

3 Nova Scotia's community feed-in tariff (COMFIT) was removed in 2015, the same year the province's Developmental Tidal Feed-in Tariff Program was introduced.

4 "Total existing" excludes 10 countries, states and provinces that are known to have subsequently discontinued policies (Brazil, Republic of Korea, Mauritius, Norway, Ontario (Canada), South Africa, Spain, Sweden, the United States and Uruguay and adds 9 countries (Andorra, Honduras, Maldives, Panama, Peru, Poland, the Russian Federation, Senegal and Tajikistan) and five Indian states (Bihar, Himachal Pradesh, Jammu and Kashmir, Jharkhand and Orissa) that are believed to have FITs but with an unknown year of enactment.

Source: See endnote 11 for this section

■ TABLE R12. Renewable Power Tenders Held at the National/State/Provincial Levels, 2018

Country	Technology	Description
Afghanistan	Solar PV	2 GW announced
Albania	Solar PV	100 MW awarded
Algeria	Solar PV	150 MW offered
Argentina	Renewable energy	400 MW offered
Armenia	Solar PV	55 MW awarded
Bahrain	Solar PV	100 MW awarded
Bangladesh	Solar PV	100 MW offered
Benin	Solar PV	25 MW offered
Brazil	Technology-neutral	1,191.9 MW wind, 424.76 hydropower and 8.5 MW biomass awarded
Chinese Taipei	Offshore wind	3.8 GW awarded
Denmark	Renewable energy	540 MW offered; 165 MW onshore wind, 104 MW solar PV awarded
Egypt	Solar PV	626 MW offered
Eswatini	Solar PV	10 MW offered
Ethiopia	Solar PV	250 MW offered
Finland	Renewable energy	1.4 TWh offered
France	Onshore wind	118 MW awarded
	Renewable energy	200 MW solar PV awarded
Germany	Renewable energy	200 MW solar PV awarded
	Solar PV	623 MW awarded
	Onshore wind	2,324 MW awarded
	Offshore wind	3,100 MW offered
Greece	Solar PV and wind	106.4 MW awarded (53.48 MW for projects up to 1 MW; 52.92 MW for projects larger than 1 MW)
	Wind	159.65 MW awarded
India	Wind	2.3 GW awarded
	Wind and solar (hybrid project)	160 MW offered
	Solar PV	22 GW offered
Japan	Solar PV	447 MW offered, 197 MW awarded
Jordan	Solar PV	200 MW offered
Kazakhstan	Renewable energy	1 GW offered
	Wind	400 MW awarded
Kuwait	Solar PV	1.5 GW offered
Lebanon	Solar PV + storage	300 MW offered
Madagascar	Solar PV + storage	25 MW offered
Malawi	Solar PV	40 MW offered
Malta	Solar PV	50 MW offered
Montenegro	Solar PV	100 MW awarded
Niger	Solar-diesel hybrid	22 MW offered
Oman	Solar PV	500 MW offered
Palestine, State of	Solar PV	35 MW offered
Poland	Wind and solar	Undisclosed capacity; wind won auction
	Biomass	Undisclosed capacity
Qatar	Solar PV	500 MW offered
Russian Federation	Wind power	823 MW awarded
Saudi Arabia	Solar PV	300 MW awarded
Senegal	Solar PV	60 MW awarded
Seychelles	Floating solar PV	4 MW offered
Singapore	Solar PV (rooftop)	50 MW awarded
South Africa	Renewable energy	2.3 GW of PPAs signed under REIPPP[1]
Sri Lanka	Solar PV	90 MW offered
Tanzania	Solar PV	150 MW offered
Tonga	Solar PV	6 MW offered[2]
Tunisia	Solar PV	500 MW announced
Turkey	Offshore wind	1.2 GW offered
	Solar PV	5 solar parks offered[3]
Zambia	Solar PV	100 MW offered

TABLE R12. Renewable Power Tenders Held at the National/State/Provincial Levels, 2018 (continued)

State/Provincial Renewable Energy Auctions Held in 2018

Country	State/Province	Technology	Description
Australia	Victoria	Renewable energy	Three solar PV (combined capacity of 256.4 MW) and three wind (combined capacity of 673.5 MW) awarded
Canada	Alberta	Wind	Two tenders in 2018: first awarded 362.9 MW, second awarded 499.8 MW
	Saskatchewan	Wind	200 MW awarded
India	Andhra Pradesh	Solar PV	4 MW offered
		Wind	750 MW offered
	Assam	Solar PV	70 MW offered
	Bihar	Solar PV	40 MW offered
	Karnataka	Solar PV	1.2 GW offered
	Maharashtra	Floating solar PV	1 GW offered
		Wind	2 GW offered
	Odisha	Solar PV	200 MW offered
	Tamil Nadu	Wind	500 MW offered
	Uttar Pradesh	Floating solar PV	100 MW offered
		Solar PV	1 GW offered[4]
United States	Rhode Island	Renewable energy	400 MW offered

[1] REIPP = South Africa's Renewable Energy Independent Power Procurement Programme.
[2] Awarded in March 2019.
[3] Another tender for 1 GW solar PV was announced in October 2018 but cancelled in January 2019.
[4] 100 MW awarded in April 2019.

Note: This table provides an overview of identified renewable energy tenders in 2018 and likely does not constitute a comprehensive picture of all capacity offered through tenders during the year.

Source: See endnote 12 for this section.

TABLE R13. Renewable Energy Targets, Selected City and Local Examples, 2018

Note: Text in **bold** indicates new/revised in 2018.

Targets for 100% of Total Energy or Electricity from Renewables

City	Target date for 100% total energy	Target date for 100% electricity
Atlanta, Georgia, United States		**2050**
Australian Capital Territory, Australia		2020
Berkeley, California, United States	**2050**	
Byron Shire County, Australia	2025	
Cincinnati, Ohio, United States		2035
City of Vancouver, Canada	2050	
Cleveland, Ohio, United States		**2050**
Coffs Harbour, Australia		2030
Copenhagen, Denmark	2050	
Denver, Colorado, United States		**2030**
Durban, South Africa		**2050**
Frankfurt, Germany	2050	
Frederikshavn, Denmark	2030	
Fukushima, Japan		**2040**
Fukushima Prefecture, Japan	2040	
Groningen, The Netherlands		2035
Hamburg, Germany	2050	
Inje County, Republic of Korea		2045
Jeju Self Governing Province, Republic of Korea		2030
Kasese, Uganda		**2020**
Lismore, Australia		**2023**
Madison, Wisconsin, United States		2050
Malmö, Sweden	2030	
Minneapolis, Minnesota, United States		2030
Munich, Germany		2025
Nederland, Colorado, United States		2025
Nevada City, California, United States	2050	2030
Orlando, Florida, United States		2050
Osnabrück, Germany		2030
Oxford County, Canada	2050	
Paris, France		**2050**
Park City, Utah, United States		2032
Pittsburgh, Pennsylania, United States		2035
Portland, Oregon, United States	2050	2035
Rochester, Minnesota, United States		2031
Salt Lake City, Utah, United States		2032
San Diego, California, United States		2035
San Francisco, California, United States		2030
San Jose, California, United States		2022

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TABLE R13. Renewable Energy Targets, Selected City and Local Examples, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018.

Targets for 100% of Total Energy or Electricity from Renewables

City	Target date for 100% total energy	Target date for 100% electricity
Skellefteå, Sweden		2020
Sønderborg, Denmark	2029	
St. Louis, Missouri, United States		2035
St. Petersburg, Florida, United States		2030
Stockholm, Sweden	2040	2035
Sumba Island, Indonesia		**2025**
Uralla, Australia	2020-2025	
Växjö, Sweden	2030	
Yokohama, Japan	**2050**	

Targets for Renewable Share of Total Energy, All Consumers

A Coruna, Spain	→ 20% by 2020
Amurrio, Spain	→ 20% by 2020
Ancona, Italy	→ 20% by 2020
Antwerp, Belgium	→ 13% by 2020
Areatza, Spain	→ 20% by 2020
Austin, Texas, United States	→ 65% by 2027
Balmaseda, Spain	→ 29% by 2020
Baltimore, Maryland, United States	→ 15% of city-wide energy demand with renewable sources by 2020 through the development of solar, wind, and combined heat and power generation sites
Barcelona, Spain	→ 10% by 2024
Belo Horizonte, Brazil	→ 79.3% by 2030
Berlin, Germany	→ 17.8% by 2020
Bucaramanga, Colombia	→ 30% by 2025
Calgary, Alberta, Canada	→ 30% by 2030
Cape Town, South Africa	→ 10% by 2020 through large- and small-scale wind and solar generation projects, solar water heaters, and biogas power generation at landfill and wastewater facilities
City of Sydney, Australia	→ 50% of electricity, heating and cooling by 2030 (does not include transport)
Nagano Prefecture, Japan	→ 70% by 2050
Paris, France	→ 25% by 2020
Skellefteå, Sweden	→ Net exporter of biomass, hydropower or wind energy by 2020

TABLE R13. Renewable Energy Targets, Selected City and Local Examples, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018.

Targets for Renewable Share of Electricity, All Consumers	
Adelaide, Australia	→ 50% by 2025
Amsterdam, The Netherlands	→ 25% by 2025; 50% by 2040
Arlington, Virginia, United States	→ 15% by 2050
Atlanta, Georgia, United States	→ 5% by 2020
Austin, Texas, United States	→ 55% by 2025
Auckland, New Zealand	→ **90% by 2040**
Boulder, Colorado, United States	→ 20% by 2020
Canberra, Australian Capital Territory, Australia	→ 90% by 2020
Cape Town, South Africa	→ 20% by 2020
Durban, South Africa	→ **40% by 2030**
Île de la Réunion, France	→ **50% by 2020**
Nagano Prefecture, Japan	→ 10% by 2020; 20% by 2030; 30% by 2050
Nelson Mandela Bay Metropolitan Municipality, South Africa	→ 10% by 2020
Taipei City, Chinese Taipei	→ 12% by 2020
Tokyo, Japan	→ 30% by 2030
Wellington, New Zealand	→ 78-90% by 2020

Targets for Renewable Electric Capacity or Generation	
Adelaide, Australia	→ 2 MW solar PV on residential and commercial buildings by 2020
Amsterdam, The Netherlands	→ 75,000 MW renewable energy capacity by 2020
Atlanta, Georgia, United States	→ Triple renewable energy capacity by 2020 by leasing city land for large-scale solar energy development projects
Bologna, Italy	→ 20 MW renewable electricity capacity by 2020; 10 MW solar PV electricity capacity by 2020
Boston, Massachusetts, United States	→ 25 MW solar electricity capacity by 2020
Esklistuna, Sweden	→ 48 GWh wind power and 9.5 GWh solar PV by 2020
Gothenburg, Sweden	→ 500 GWh renewable electricity by 2030
Los Angeles, California, United States	→ 1.3 GW solar PV by 2020
New York, New York, United States	→ 1 GW solar power and 100 MWh energy storage by 2020
San Francisco, California, United States	→ 100% of peak demand (950 MW) by 2020

TABLE R13. Renewable Energy Targets, Selected City and Local Examples, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018.

Targets for Renewable Share of City/Local Government Operations	
Amurrio, Spain	→ 20% by 2020
Ancona, Italy	→ 20% by 2020
Antwerp, Belgium	→ 13% by 2020
Areatza, Spain	→ 20% by 2020
Balmaseda, Spain	→ 29% by 2020
Beaverton, Oregon, United States	→ 75% by 2020
Belo Horizonte, Brazil	→ 30% of electricity from solar PV by 2030
Besancon, France	→ 23% by 2020
Boulder, Colorado, United States	→ 60% by 2050
Breckenridge, Colorado, United States	→ 100% by 2025
Bucaramanga, Colombia	→ 30% by 2025
Calgary, Alberta, Canada	→ 100% of government operations by 2025
City of Sydney, Australia	→ 100% of electricity in buildings; 20% for street lamps
Cockburn, Australia	→ 20% of final energy in city buildings by 2020
Fayetteville, Arkansas, United States	→ 100% clean energy for all government operations by 2030
Geneva, Switzerland	→ 100% renewable energy for public buildings by 2050
Ghent, Belgium	→ 50% of final energy by 2020
Hepburn Shire, Australia	→ 100% of final energy in public buildings; 8% of electricity for public lighting
Kristianstad, Sweden	→ 100% of final energy by 2020
Malmö, Sweden	→ 100% of final energy by 2020
Minneapolis, Minnesota, United States	→ 100% renewable energy for municipal facilities and operations by 2022
Orlando, Florida, United States	→ 100% renewable electricity for municipal operations by 2030
Portland, Oregon, United States	→ 100% of final energy by 2030
Salt Lake City, Utah, United States	→ 50% renewable electricity for municipal operations by 2020

TABLE R13. Renewable Energy Targets, Selected City and Local Examples, 2018 (continued)

Note: Text in **bold** indicates new/revised in 2018.

Heat-Related Mandates and Targets	
Amsterdam, The Netherlands	→ District heating for at least 200,000 houses by 2040 (using biogas, woody biomass and waste heat)
Chandigarh, India	→ Mandatory use of solar water heating in industry, hotels, hospitals, prisons, canteens, housing complexes, and government and residential buildings (as of 2013)
Copenhagen, Denmark	→ **Combined heat and power plants to be 100% biomass powered by 2025**
Helsingborg, Sweden	→ 100% renewable energy district heating (community-scale) by 2035
Loures, Portugal	→ Solar thermal systems mandated as of 2013 in all sports facilities and schools that have good sun exposure
Munich, Germany	→ 100% district heating from renewable sources by 2040; 80% reduction of heat demand by 2058 (base 2009) through passive solar design (includes heat, process heat and water heating)
New York, New York, United States	→ Biofuel blend in heating oil equivalent to 10% by 2025 and 20% by 2034
Oslo, Norway	→ Phase out fossil fuels and transition to electric heating in homes and offices by 2020
Osnabrück, Germany	→ 100% renewable heat by 2050
Täby, Sweden	→ 100% renewable heat in local government operations by 2020
Vienna, Austria	→ 50% of total heat demand with solar thermal energy by 2050
Wilhelmsburg, Germany	→ **100% renewable heat by 2050**

Transport-Related Mandates and Targets	
Athens, Greece	→ Ban petrol- and diesel-powered cars and vans by 2025
Carinthia, Austria	→ **100% renewable transport by 2035**
Gävle Municipality, Sweden	→ **Transport free from fossil fuels by 2030**
Madrid, Spain	→ Ban petrol- and diesel-powered cars and vans by 2025
Mexico City, Mexico	→ Ban petrol- and diesel-powered cars and vans by 2025
Paris, France	→ Ban petrol- and diesel-powered cars and vans by 2025
Rome, Italy	→ Ban diesel vehicles from city centre by 2024
San Francisco, California, United States	→ 50% renewable power by 2025 and 100% renewable power by 2045 for Bay Area Rapid Transit rail system
Jeju Province, Republic of Korea	→ **100% renewable transport by 2030**

Note: This table provides a sample of local renewable energy commitments worldwide. It does not aim to present a comprehensive list of all municipal renewable energy goals. For example, in Germany more than 150 municipalities have a target to achieve 100% renewables in their energy system, and in the United States at least 102 cities have targets for 100% renewable electricity. For more comprehensive information on cities, see REN21, *Renewables in Cities 2019 Global Status Report* (Paris: forthcoming, 2019), www.ren21.net/cities.

Source: See endnote 13 for this section.

TABLE R14. Biofuels Global Production, Top 15 Countries and EU-28, 2018

Country	Ethanol	Biodiesel (FAME)	Biodiesel (HVO)	Change Relative to 2017
	Billion litres			
United States	60.9	6.9	2.2	1.9
Brazil	33.0	5.4		5.5
China	4.1	1.0		1.0
Germany	1.0	3.5		0.1
Indonesia	0.1	4.0		0.9
Argentina	1.2	2.8		-0.4
France	0.9	2.2		-0.3
Thailand	1.5	1.6		0.4
Canada	1.9	0.4		0.1
Netherlands	0.3	0.7	1.1	-0.1
Spain	0.5	2.0	0.5	0.4
India	1.4	0.2		0.6
Italy	–	1.4		0.6
Poland	0.2	1.0		0.1
United Kingdom	0.5	0.5		-0.1
EU-28	**4.4**	**4.4**	**3.5**	**-0.8**
World Total	**111.9**	**34.3**	**7.0**	**9.0**

Source: See endnote 14 for this section.

TABLE R15. Geothermal Power Global Capacity and Additions, Top 10 Countries, 2018

Country	Added 2018	Total End-2018
	MW	GW
Top Countries by Additions		
Turkey	219	1.28
Indonesia	140	1.95
United States	58	2.54
Iceland	45	0.75
New Zealand	25	1.03
Croatia	18	0.02
Philippines	12	1.93
Kenya	11	0.68
Top Countries by Total Capacity		
United States	58	2.54
Indonesia	140	1.95
Philippines	12	1.93
Turkey	219	1.28
New Zealand	25	1.03
Mexico	–	0.92
Italy	–	0.76
Iceland	45	0.75
Kenya	11	0.68
Japan	–	0.53
World Total	**527**	**13.3**

Note: Capacity additions are rounded to the nearest 1 MW, and totals are rounded to the nearest 0.01 GW. Rounding is to account for uncertainties and inconsistencies in available data. For more information and statistics, see Geothermal section in Market and Industry chapter and related endnotes.

Source: See endnote 15 for this section.

TABLE R16. Hydropower Global Capacity and Additions, Top 10 Countries, 2018

Country	Added 2018	Total End-2018
	GW	
Top Countries by Additions		
China	7.0	322
Brazil	3.8	104
Pakistan	2.5	9.8
Turkey	1.1	28
Angola	0.7	3.1
Tajikistan	0.6	5.8
Ecuador	0.6	5.1
India	0.5	45
Norway	0.4	31
Canada	0.4	81
Top Countries by Total Capacity		
China	7.0	322
Brazil	3.8	104
Canada	0.4	81
United States	0.1	80
Russian Federation	0.1	47
India	0.5	45
Norway	0.4	31
Turkey	1.1	28
Japan	–	22
France	~0	19
World Total	**20**	**1,132**

Note: Capacity additions are rounded to the nearest 0.1 GW, and totals are rounded to the nearest 1 GW. Rounding is to account for uncertainties and inconsistencies in available data. Capacity amounts of less than 10 MW are designated by "~0". For more information and statistics, see Hydropower section in Market and Industry chapter and related endnotes.

Source: See endnote 16 for this section.

TABLE R17. Solar PV Global Capacity and Additions, Top 10 Countries, 2018

	Total End-2017	Added 2018	Total End-2018
		GW	
Top Countries by Additions			
China	131.1	45	176.1
India[1]	22.1	10.8	32.9
United States	51.8	10.6	62.4
Japan	49.5	6.5	56
Australia	7.2	3.8	11.1
Germany	42.3	3	45.3
Mexico	0.7	2.7	3.4
Republic of Korea	5.9	2	7.9
Turkey	3.4	1.6	5.1
Netherlands	2.9	1.4	4.3
Top Countries by Total Capacity			
China	131.1	45	176.1
United States	51.8	10.6	62.4
Japan	49.5	6.5	56
Germany	42.3	3	45.3
India	22.1	10.8	32.9
Italy	19.7	0.4	20.1
United Kingdom	12.7	0.3	13
Australia	7.2	3.8	11.1
France	8.1	0.9	9
Republic of Korea	5.9	2	7.9
World Total	**405**	**100**	**505**

[1] For India, data are highly uncertain, and estimates from various sources range from well below to well above the numbers in this table. (See Solar PV section in Market and Industry chapter and related endnotes for more details.)

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 Spain were converted from official data reported in alternating current (AC) into DC by the 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 17 for this section.

TABLE R18. Concentrating Solar Thermal Power (CSP) Global Capacity and Additions, 2018

Country	Total End-2017	Added 2018	Total End-2018
		MW	
Spain	2,304	–	2,304
United States	1,738	–	1,738
South Africa	300	100	400
Morocco	166	200	366
India	225	–	225
China	20	200	220
United Arab Emirates	100	–	100
Saudi Arabia	–	50	50
Algeria	20	–	20
Egypt	20	–	20
Iran	17	–	17
World Total	**4,910**	**550**	**5,460**

Note: Table includes all countries with operating commercial CSP capacity at end-2018. 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 18 for this section.

TABLE R19. Solar Water Heating Collectors and Total Capacity End-2017 and Newly Installed Capacity 2018, Top 20 Countries

	Total End-2017			Gross Additions 2018		
	GW$_{th}$			MW$_{th}$		
Country	**Glazed**	**Unglazed**	**Total**	**Glazed**	**Unglazed**	**Total**
China	334.5	–	334.5	24,801	–	24,801
Turkey	16.3	–	16.3	1,316	–	1,316
India	7.7	–	7.7	1,247	–	1,247
Brazil	6.7	3.8	10.4	436	439	875
United States	2.1	15.6	17.8	112	511	623
Australia	2.5	3.9	6.4	128	280	408
Germany	13.4	0.4	13.7	401	–	401
Israel	3.3	–	3.3	291	1	291
Mexico	1.8	0.9	2.7	200	84	284
Greece	3.2	–	3.2	230	–	230
Poland	1.6	–	1.6	217	–	217
Spain	2.8	0.1	2.9	141	3	144
Italy	3.2	–	3.2	125	–	125
South Africa	0.6	0.8	1.4	48	46	94
Austria	3.4	0.3	3.6	69	–	69
Denmark	1.1	–	1.1	50	–	50
Switzerland	1.0	0.1	1.2	44	4	48
Tunisia	0.7	–	0.7	41	–	41
Cyprus	0.5	1.5	2.0	40	–	40
France	1.8	0.1	1.9	39	–	39
Total Top 20 Countries	408.2	27.6	435.8	29,978	1,367	31,345
World Total	**444**	**29**	**472**	**31,834**	**1,463**	**33,297**

Note: Countries are ranked according to newly installed glazed collector capacity in 2018. Data are for glazed and unglazed water collectors excluding air collectors, which added 1,697,233 m² to the year-end world total for 2017, and excluding concentrating collectors with 439,977 m² additional aperture area in 2017. End-2017 data for individual countries, Total Top 20 Countries and World Total are rounded to the nearest 0.1 GW$_{th}$; additions for individual countries, Total Top 20 Countries and World Total 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 2017 is the most recent one for which firm global data on total capacity in operation are available. However, 480 GW$_{th}$ of solar thermal capacity (water and non-concentrating collectors only) was estimated to be in operation worldwide by end-2018. For 2017 details and source information, see Solar Thermal section in Market and Industry chapter and related endnotes.

Source: See endnote 19 for this section.

TABLE R20. Wind Power Global Capacity and Additions, Top 10 Countries, 2018

Country	Total End-2017	Added 2018	Total End-2018
		GW	
Top Countries by Additions			
China[1]	163.4/188.4	20.6/21.1	184.3/210
United States	89.0	7.6	96.5
Germany[2]	56.2	3.1	59.3
India	32.9	2.2	35.1
Brazil	12.8	1.9	14.7
United Kingdom	19.1	1.9	21
France	13.8	1.6	15.3
Mexico	4.0	0.9	5.0
Sweden	6.7	0.7	7.4
Canada	12.2	0.6	12.8
Top Countries by Total Capacity			
China[1]	163.4/188.4	20.6/21.1	184.3/210
United States	89	7.6	96.5
Germany[2]	56.2	3.1	59.3
India	32.9	2.2	35.1
Spain	23.1	0.4	23.5
United Kingdom	19.1	1.9	21
France	13.8	1.6	15.3
Brazil	12.8	1.9	14.7
Canada	12.2	0.6	12.8
Italy	9.5	0.5	10
World Total	**540**	**51**	**591**

[1] 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.)

[2] For Germany, some capacity was decommissioned in 2018; number in table reflects net additions. (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, and 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. 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 20 for this section.

TABLE R21. Electricity Access by Region and Country, 2017 and Targets

World/Region/Country	Electrification Rate in 2017	People Without Access to Electricity in 2017	Target
	Share of population with access	Millions	Share of population with access
World[1]	**87%**	**992**	
All Developing Countries	**83%**	**992**	
Africa	**52%**	**601**	
North Africa	**100%**	**<1**	
Sub-Saharan Africa	**43%**	**602**	
Developing Asia	**91%**	**351**	
Central and South America	**96%**	**20**	
Middle East	**92%**	**18**	
Africa			
Algeria	99%	<1	
Angola	43%	19	→ 100% by 2030
Benin	30%	8	→ 95% by 2025 (urban) → 65% by 2025 (rural)
Botswana	57%	<1	→ 100% by 2030
Burkina Faso	18%	16	→ 100 by 2025
Burundi	10%	10	→ 25% by 2025
Cabo Verde	96%	<1	→ 100% by 2020
Cameroon	62%	9	
Central African Republic	3%	5	→ 50% by 2030
Chad	8%	14	
Comoros	69%	<1	
Congo	60%	2	
Côte d'Ivoire	60%	10	→ 100% by 2025
Democratic Republic of the Congo	15%	69	→ 60% by 2025
Djibouti	42%	<1	→ 100% by 2035
Egypt	99.8%	<1	
Equatorial Guinea	80%	<1	
Eritrea	44%	3	
Eswatini	84%	<1	→ 85% by 2020 → 100% by 2025
Ethiopia	45%	58	→ 100% by 2030
Gabon	91%	<1	
Gambia	45%	1	→ 100% by 2030
Ghana	84%	5	→ 100% by 2020
Guinea	17%	11	→ 100% by 2030
Guinea-Bissau	10%	2	→ 80% by 2030
Kenya	73%	13	→ 100% by 2022
Lesotho	34%	1	→ 40% by 2020
Liberia	10%	4	→ 100% by 2030
Libya	99.8%	<1	
Madagascar	23%	20	
Malawi	11%	17	→ 30% by 2020
Mali	38%	11	→ 87% by 2030
Mauritania	30%	3	

TABLE R21. Electricity Access by Region and Country, 2017 and Targets (continued)

World/Region/Country	Electrification Rate in 2017	People Without Access to Electricity in 2017	Target
	Share of population with access	Millions	Share of population with access
Africa (continued)			
Mauritius	100%	0	
Morocco	99%	<1	
Mozambique	28%	21	→ 100% by 2025
Namibia	56%	1	
Niger	12%	19	→ 65% by 2030
Nigeria	60%	77	→ 75% by 2020 → 90% by 2030
Rwanda	43%	7	→ 100% by 2030
São Tomé and Príncipe	68%	<1	
Senegal	65%	6	→ 100% by 2025
Seychelles	99%	<1	
Sierra Leone	20%	6	→ 100% by 2025
Somalia	17%	12	
South Africa	84%	9	→ 100% by 2019
South Sudan	1%	12	
Sudan	45%	22	
Tanzania	33%	39	→ 75% by 2030
Togo	36%	5	→ 82% by 2030
Tunisia	100%	0	
Uganda	20%	34	→ 98% by 2030
Zambia	33%	12	→ 66% by 2030
Zimbabwe	34%	11	→ 66% by 2030 → 90% by 2030 (urban) → 51% by 2030 (rural)
Developing Asia			
Bangladesh	80%	33	→ 100% by 2021
Brunei	99.9%	<1	
Cambodia	61%	6	→ 70% by 2030 (rural)
China	100%	0	
India	87%	168	→ 100% by 2019
Indonesia	95%	23	
Korea, Democratic People's Republic	26%	19	
Lao PDR	94%	<1	
Malaysia	98%	<1	
Mongolia	91%	<1	
Myanmar	56%	24	→ 87% by 2030
Nepal	91%	3	
Pakistan	74%	52	
Philippines	90%	11	
Singapore	100%	0	
Sri Lanka	100%	0	
Thailand	100%	0	
Vietnam	99%	1	

■ TABLE R21. Electricity Access by Region and Country, 2017 and Targets (continued)

World/Region/Country	Electrification Rate in 2017	People Without Access to Electricity in 2017	Target
	Share of population with access	Millions	Share of population with access
Central and South America			
Argentina	98.8%	<1	
Barbados[2]	100%	0	
Bolivia	88%	1	→ 100% by 2025 (rural)
Brazil	99.7%	<1	
Chile[1]	100%	0	
Colombia	97%	1	
Costa Rica	99.3%	<1	
Cuba	99.6%	<1	
Dominican Republic	97%	<1	
Ecuador	97%	<1	→ 98.9% by 2022 (urban) → 96.3% by 2022 (rural)
El Salvador	96%	<1	
Guatemala	92%	1	
Haiti	30%	8	→ 50% by 2020
Honduras	75%	2	
Jamaica	98%	<1	
Mexico[2]	100%	0	
Nicaragua	90%	<1	
Panama	92%	<1	
Paraguay	99%	<1	
Peru	95%	2	
Suriname[2]	87%	0.1	
Trinidad and Tobago	99%	<1	
Uruguay	98.8%	<1	
Venezuela	98.9%	<1	
Middle East			
Bahrain	100%	0	
Iran	99%	<1	
Iraq	98%	<1	
Jordan	100%	0	
Kuwait	100%	0	
Lebanon	100%	0	
Oman	98.7%	<1	
Qatar	99.9%	<1	
Saudi Arabia	99.4%	<1	
Syria	92%	1.4	
United Arab Emirates	100%	0	
Yemen	47%	15	
Oceania			
Federated States of Micronesia[2]	75%	<1	→ 90% by 2020 (rural)[3]

[1] Includes countries in the OECD and economies in transition.
[2] Based on 2016 data.
[3] 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).

Disclaimer: The tracking of data related to energy access and distributed renewable energy systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

Source: See endnote 21 for this section.

TABLE R22. Population Without Access to Clean Cooking, 2017

World/Region/Country	Population without access to clean cooking in 2017	Population	Target
	Share of population	Millions	Share of population with access to clean cooking
World[1]	**36%**	**2,677**	
All Developing Countries	**46%**	**2,677**	
Africa	**71%**	**895**	
North Africa	**<1%**	**1.1**	
Sub-Saharan Africa	**84%**	**893**	
Developing Asia	**44%**	**1,715**	
Central and South America	**11%**	**56**	
Middle East	**5%**	**11**	
Africa			
Algeria	<1%	<1	
Angola	49%	15	→ 100% by 2030
Benin	>95%	11	
Botswana	42%	<1	
Burkina Faso	87%	17	→ 100% by 2030 (urban) → 65% by 2030 (rural)
Burundi	>95%	10	
Cabo Verde	20%	<1	→ 100% by 2020
Cameroon	74%	17	
Central African Republic	>95%	5	
Chad	94%	14	
Comoros	92%	<1	
Congo	75%	4	
Côte d'Ivoire	76%	18	
Democratic Republic of the Congo	>95%	79	
Djibouti	94%	<1	
Egypt	<1%	<1	
Equatorial Guinea	76%	<1	
Eritrea	90%	5	
Eswatini	46%	<1	→ 100% by 2030
Ethiopia	93%	98	→ 100% by 2025
Gabon	14%	<1	
Gambia	90%	2	→ 100% by 2030
Ghana	71%	20	→ 100% by 2030
Guinea	>95%	12	→ 50% by 2025
Guinea-Bissau	>95%	2	→ 75% by 2030
Kenya	85%	42	→ 100% by 2022
Lesotho	62%	1.4	
Liberia	>95%	5	→ 100% by 2030
Libya	<1%	<1	
Madagascar	>95%	25	
Malawi	>95%	18	
Mali	>95%	18	→ 100% by 2030
Mauritania	49%		
Mauritius	2%	<1	

TABLE R22. Population Without Access to Clean Cooking, 2017 (continued)

World/Region/Country	Population without access to clean cooking in 2017	Population	Target
	Share of population	Millions	Share of population with access to clean cooking
Africa (continued)			
Morocco	1.5%	<1	
Mozambique	94%	28	
Namibia	54%	1.4	
Niger	>95%	21	→ 100% by 2030 (urban) → 60% by 2030 (rural)
Nigeria	93%	178	
Rwanda	>95%	12	→ 100% by 2030
São Tomé and Príncipe	>95%	<1	
Senegal	72%	11	
Seychelles	2%	<1	
Sierra Leone	>95%	7	
Somalia	94%	14	
South Africa	15%	9	
South Sudan	>95%	12	
Sudan	64%	26	
Tanzania	95%	54	→ 75% by 2030
Togo	90%	7	→ 80% by 2030
Tunisia	3%	<1	
Uganda	94%	40	→ 99% by 2030
Zambia	83%	14	
Zimbabwe	70%	12	
Developing Asia			
Bangladesh	80%	132	
Brunei	<1%	<1	
Cambodia	81%	13	
China	30%	409	
India	53%	703	
Indonesia	30%	79	
Korea DPR	47%	12	
Lao PDR	92%	6	
Malaysia	<1%	<1	
Mongolia	59%	2	
Myanmar	77%	41	
Nepal	71%	21	
Pakistan	66%	130	
Philippines	61%	64	
Singapore	<1%	<1	
Sri Lanka	71%	15	
Thailand	20%	14	
Vietnam	39%	37	

TABLE R22. Population Without Access to Clean Cooking, 2017 (continued)

World/Region/Country	Population without access to clean cooking in 2017	Population	Target
	Share of population	Millions	Share of population with access to clean cooking
Central and South America			
Argentina	<1%	<1	
Bolivia	16%	2	
Brazil	4%	9	
Chile[2]	7%	1.3	
Colombia	9%	4	
Costa Rica	5%	<1	
Cuba	<1%	<1	
Dominican Republic	13%	1	
Ecuador	6%	<1	
El Salvador	10%	<1	
Guatemala	51%	9	
Haiti	94%	10	
Honduras	52%	5	
Jamaica	13%	0.3	
Mexico[2]	15%	19.1	
Nicaragua	52%	5	
Panama	13%	<1	
Paraguay	32%	2	
Peru	22%	7	
Trinidad and Tobago	<1%	<1	
Uruguay	1%	<1	
Venezuela	1%	<1	
Middle East			
Bahrain	<1%	<1	
Iran	<1%	<1	
Iraq	2%	<1	
Jordan	<1%	<1	
Kuwait	<1%	<1	
Lebanon	<1%	<1	
Oman	<1%	<1	
Saudi Arabia	<1%	<1	
Qatar	<1%	<1	
United Arab Emirates	<1%	<1	
Yemen	39%	11	

[1] Includes countries in the OECD and economies in transition.
[2] Based on 2016 data.

Disclaimer: The tracking of data related to energy access and distributed renewable energy systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

Source: See endnote 22 for this section.

TABLE R23. Programmes Furthering Energy Access: Selected Examples

Name	Brief Description	Web Address
Ashden Awards	An annual awards event that uncovers and rewards the most exciting sustainable energy pioneers in the UK and the developing world who are leading the way to a thriving low-carbon future. The winners' solutions get support through events, publicity, research and engagement in policy consultations.	https://www.ashden.org
Asian Development Bank – Energy for All Initiative	An initiative that strengthens the ADB's investments in energy access by offering a suite of services to sustainable energy companies, depending on their level of maturity. The aim is to build a dynamic ecosystem where technology innovation and application flow seamlessly across borders in Asia.	https://energyforall.asia
CleanStart	A programme developed by the UN Capital Development Fund and UN Development to help poor households and micro-entrepreneurs access micro-financing for low-cost clean energy. By 2020, CleanStart aims to invest USD 26 million in six countries in Asia and Africa to set 500,000 people on a clean energy pathway, thereby affecting the lives of more than 2.5 million people.	https://www.uncdf.org/cleanstart
Efficiency for Access Coalition R&D Fund	A fund that invests in research and development projects that help to accelerate the availability, affordability, efficiency and performance of a range of Low Energy Inclusive Appliances that are particularly suited to developing country contexts and that promote social inclusion.	https://efficiencyforaccess.org/grants
Electrification Financing Initiative (ElectriFI)	A flexible financial facility funded by the European Commission and managed by the Association of European Development Finance Institutions. ElectriFI aims to support investments that increase and/or improve access to modern, affordable and sustainable energy services.	http://electrifi.eu
Energising Development (EnDev)	A multilateral initiative supported by the governments of Germany, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom. EnDev operates in 25 countries in Africa, Asia and Latin America with the aim of facilitating sustainable access to modern energy services.	http://endev.info
Energy Access Booster	A call for projects, launched in 2018, that supports entrepreneurs in the field of energy access in Africa. Winners receive support in areas such the identification of relevant and sustainable economic models, customer acquisition and retention, pilot project development, production organisation, building adapted distribution models, scale-up to the national or international level and financing.	http://energyaccessbooster.com
Energy Access Venture Fund	A fund that invests in small and medium enterprises that are active in electricity generation and distribution and electricity-related services in sub-Saharan Africa. The fund focuses on off-grid rural electrification, in particular solar home systems, micro-grid infrastructure, and other small/micro-scale renewable energy and hybrid technologies.	http://www.eavafrica.com

TABLE R23. Programmes Furthering Energy Access: Selected Examples (continued)

Name	Brief Description	Web Address
Energy & Environment Partnership (EEP) Southern and East Africa	A challenge fund that promotes renewable energy, energy efficiency and clean technology investments in Southern and East Africa. EEP supports projects that aim to provide sustainable energy services to the poor and to combat climate change. The EEP Programme is jointly funded by the Ministry of Foreign Affairs of Finland, the Austrian Development Agency and the UK Department for International Development.	http://eepafrica.org
EU-Africa Infrastructure Trust Fund (ITF)	A fund that combines grants and loans from the EU and its Member States and banks to support local infrastructure projects, notably in electricity generation. Since 2007, the ITF has allocated more than EUR 50 million (USD 57.2 million) to projects focusing on energy access.	http://www.eu-africa-infrastructure-tf.net/about/index.htm
GET.invest	A European programme that aims to mobilise investment in decentralised renewable energy projects. GET.invest supports private sector business and project developers, financiers and regulators in building sustainable energy markets. It was launched in early 2019, building on its predecessor, the Africa-EU Renewable Energy Cooperation Programme (RECP).	https://www.get-invest.eu
Global LEAP Awards	An international competition to identify and promote the world's best off-grid appliances, accelerating market development and innovation. The Global LEAP Awards have held annual competitions for technologies such as televisions, refrigerators, LED lighting, fans and solar water pumps.	https://globalleapawards.org
Green Climate Fund (GCF)	A fund established in 2010 by 194 countries party to the UN Framework Convention on Climate Change that aims to mobilise funding at scale to invest in low-emission and climate-resilient development in developing countries. The fund aims to mobilise USD 100 billion annually by 2020.	https://www.greenclimate.fund
Green Mini-grids Helpdesk	An online "help desk", co-ordinated by the AfDB, designed to help mini-grid developers and policy makers find practical information on mini-grids quickly. This includes market reports, links to industry stakeholders, instruction guides, business forms and templates, financial models and much more. The website was developed by Energy 4 Impact and INENSUS for the SEforALL Africa Hub.	http://greenminigrid.se4all-africa.org
IRENA – Abu Dhabi Fund for Development (ADFD) Facility	A partnership between IRENA and the ADFD to provide and facilitate finance for renewable energy projects in developing countries. The ADFD committed USD 350 million in concessional loans, over seven annual funding cycles, to renewable energy projects recommended by IRENA.	http://adfd.irena.org
Lighting Africa	An IFC and World Bank programme to accelerate the development of sustainable markets for affordable, modern off-grid lighting solutions for low-income households and micro-enterprises across Africa.	http://www.lightingafrica.org
Lighting Asia	An IFC market transformation programme aimed at increasing access to clean, affordable energy in Asia by promoting modern off-grid lighting products, systems and mini-grid connections. The programme works with the private sector to remove market entry barriers, provide market intelligence, foster business-to-business linkages and raise consumer awareness on modern lighting options.	http://www.lightingasia.org

TABLE R23. Programmes Furthering Energy Access: Selected Examples (continued)

Name	Brief Description	Web Address
Mobile for Development (M4D) Utilities – Innovation Fund	A fund supported by the UK government and the Scaling Off-Grid Energy Grand Challenge for Development that aims to test and scale the use of mobile to improve or increase access to energy, water and sanitation services. The fund was launched in June 2013 and, as of early 2019, had completed two phases of funding and closed its third and final round of applications.	https://www.gsma.com/mobilefordevelopment/m4dutilities/innovation-fund-2
Moving Energy Initiative (MEI)	The first international partnership working to aggregate the emerging findings and to act as a knowledge hub for best practices in humanitarian energy provision. The MEI shares insightful and policy-relevant research, encourages learning from innovative on-the-ground projects and invests in partner organisations that provide sustainable solutions.	https://mei.chathamhouse.org
Power Africa's Beyond the Grid Initiative	An initiative launched in 2014 focused on unlocking investment and growth for off-grid and small-scale energy solutions on the African continent. Beyond the Grid has partnered with more than 40 investors and practitioners that have committed to investing over USD 1 billion in off-grid and small-scale energy. The goal is to provide energy access to 1 million people.	https://www.usaid.gov/powerafrica/beyondthegrid
Renewable Energy and Energy Efficiency Partnership (REEEP)	A partnership that develops innovative, efficient financing mechanisms to advance market readiness for clean energy services in low- and middle-income countries. REEEP designs and implements tailor-made financing mechanisms, using targeted injections of public funding to build dynamic, sustainable markets and to ultimately make clean energy and energy efficiency technology accessible and affordable to all.	http://www.reeep.org
Renewable Energy, Energy and Resource Efficiency Promotion in International Cooperation (REPIC)	A joint initiative of several Swiss government agencies aimed at the promotion of renewable energy, energy and resource efficiency in international co-operation. The REPIC platform's specific objectives, activities and expected results include promotion and implementation of projects, networking, information and communication, co-ordination and quality assurance. REPIC's financial contributions are intended primarily as complementary measures for the quality assurance of proposals, for the reduction of project transaction costs in the international context and as seed funding for larger projects.	http://www.repic.ch
Scaling Up Renewable Energy Program in Low Income Countries (SREP)	The USD 720 million SREP is empowering transformation in the world's poorest countries by demonstrating the economic, social and environmental viability of renewable energy. SREP is one of the biggest global funders of mini-grids, with over USD 200 million for projects in 14 countries.	https://www.climateinvestmentfunds.org/topics/energy-access
SIDS Lighthouses	A framework for action to support Small Island Developing States (SIDS) in the transformation from a predominantly fossil-based to a renewables-based and resilient energy system. The initiative addresses all elements of the energy transition, from policy and market frameworks to technology options and capacity building. Lighthouses brings together 36 SIDS as well as 22 other partners, including regional and international organisations, development agencies, private companies, research institutes and non-profit organisations.	https://islands.irena.org

TABLE R23. Programmes Furthering Energy Access: Selected Examples (continued)

Name	Brief Description	Web Address
Sustainable Energy Fund for Africa (SEFA)	A multi-donor trust fund administered by the ADB with a total budget of USD 95 million supporting small and medium-scale clean energy and energy efficiency projects in Africa through grants for technical assistance and capacity building, investment capital and guidance.	http://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/sustainable-energy-fund-for-africa
Transforming Energy Access (TEA)	A programme leading the development of innovative technologies, business models, partnerships and skills that will accelerate access to affordable clean energy services for households and enterprises in developing countries. A programme of the UK Department for International Development, TEA is designed to have a transformative impact on the deployment of renewable energy solutions in developing countries to support progress in clean energy access. Up to GBP 69 million (USD 76.5 million) will be invested over five years.	https://www.carbontrust.com/tea
USADF Off-grid Energy Challenge	A challenge led by the US African Development Foundation (USADF) to develop, scale up or extend the use of proven technologies for off-grid energy to reach communities not served by existing power grids. Through the Challenge, USADF and its partners – including All On, GE and Power Africa – support energy entrepreneurs in nine countries across the continent. As of early 2019, USADF had funded more than 75 African energy entrepreneurs, with a total investment of USD 7 million in off-grid energy solutions.	https://www.usadf.gov/off-grid
USAID Development Innovation Ventures (DIV)	An open competition supporting breakthrough solutions to the world's most intractable development challenges – interventions that could change millions of lives at a fraction of the usual cost.	https://www.usaid.gov/div

TABLE R24. International Networks Furthering Energy Access: Selected Examples

Name	Brief Description	Web Address
ACCESS Coalition	A coalition of national and international civil society organisations (CSOs) that aims to strengthen the efforts of CSOs working to deliver universal energy access. The coalition advocates at the national and regional levels for transparent and inclusive multi-stakeholder participation at all stages of energy processes.	https://access-coalition.org
Africa Minigrid Developers Association (AMDA)	An association representing the mini-grid development industry that works to alleviate the problem of energy access through the use of sustainable and environmentally friendly renewable energy mini-grids. AMDA is active in Kenya and Tanzania through advocacy, promotion and co-ordination.	http://africamda.org
African Renewable Energy Alliance (AREA)	A global multi-stakeholder platform to exchange information and consult about policies, technologies and financial mechanisms for the accelerated uptake of renewable energy in Africa.	http://www.area-net.org http://area-network.ning.com
ALER	A non-profit association with the mission of promoting renewable energy in Portuguese-speaking countries. ALER facilitates business opportunities by supporting the private sector and attracting financing and investment, by liaising with national and international authorities to create a favourable regulatory framework, and by co-ordinating all stakeholders, acting as a co-operation platform and the common voice of renewable energy in Portuguese-speaking countries.	http://www.aler-renovaveis.org
Alliance for Rural Electrification (ARE)	An international business association that represents the decentralised energy sector and works towards the integration of renewables into rural electrification markets in developing and emerging countries. ARE has more than 150 members along the entire value chain of off-grid technologies.	http://www.ruralelec.org
Clean Cooking Alliance	An alliance that works with a global network of partners to build an inclusive industry that makes clean cooking accessible to families around the world. Established in 2010, the Alliance supports the development, sale, distribution and consistent use of clean cooking solutions that transform lives by improving health, protecting the climate and environment, and helping families save time and money.	http://cleancookingalliance.org
Climate Technology Centre and Network (CTCN)	An international centre that promotes the accelerated transfer of environmentally sound technologies for low-carbon and climate-resilient development at the request of developing countries. CTCN provides technology solutions, capacity building and advice on policy, legal and regulatory frameworks tailored to the needs of individual countries.	https://www.ctc-n.org
Climate Technology Initiative Private Financing Advisory Network (CTI PFAN)	A multilateral, public-private partnership initiated by CTI in co-operation with the UNFCCC Expert Group on Technology Transfer. PFAN operates to bridge the gap between investments and clean energy businesses. It is designed to be an "open source" network to fit seamlessly with existing global and regional initiatives and to be inclusive of all stakeholders with an interest in clean energy financing.	http://www.cti-pfan.net

TABLE R24. International Networks Furthering Energy Access: Selected Examples (continued)

Name	Brief Description	Web Address
Consultative Group to Assist the Poor (CGAP)	A global partnership of 37 leading organisations, housed at the World Bank, that seeks to advance financial inclusion. CGAP develops innovative solutions through practical research and active engagement with financial service providers, policy makers and funders to enable approaches at scale.	http://www.cgap.org
Efficiency for Access Coalition	A coalition that promotes energy efficiency as a potent catalyst in global clean energy access efforts. Coalition programmes aim to scale up markets and reduce prices for super-efficient, off- and weak-grid appropriate products, to support technological innovation and to improve sector co-ordination. Coalition members have programmes and initiatives spanning 3 continents, 44 countries and 19 key technologies.	https://efficiencyforaccess.org
ENERGIA International	An international network of more than 22 organisations working in Africa and Asia that are focused on gender issues, women's empowerment and sustainable energy.	http://www.energia.org
Energy Access Practitioner Network	A global network of more than 2,500 members in over 170 countries representing small, medium and large clean energy enterprises; civil society; government and academia. The Practitioner Network was established in 2011 to catalyse the delivery of modern energy services, particularly decentralised solutions for rural electrification.	http://www.energyaccess.org
Energy for All Partnership	A regional platform for co-operation, knowledge, technical exchange and key project development. It brings together key stakeholders from the private sector, financial institutions, governments, and bilateral, multilateral and non-governmental development partners. Led by the ADB, the Partnership aims to provide access to safe, clean and affordable modern energy to 200 million households in the Asia-Pacific region by 2020.	https://energyforall.asia/energy_for_all_partnership
Global Off-Grid Lighting Association (GOGLA)	An independent, not-for-profit industry association that represents more than 140 members as the voice of the off-grid solar energy industry and promotes the solutions they offer. GOGLA's mission is to help its members build sustainable markets, delivering quality, affordable products and services to as many households, businesses and communities as possible across the developing world.	https://www.gogla.org
Hydro Power Empowerment Network (HPNET)	A diverse set of international, national and local actors committed to collectively promoting and advancing pico (<5 kW), micro (<100 kW) and mini (<1,000 kW) hydro in South and Southeast Asia. HPNET's aim is to catalyse micro hydro practitioners for the advancement and advocacy of resilient micro hydropower, towards equitable and sustainable development of rural communities in South and Southeast Asia.	http://www.hpnet.org
International Network for Sustainable Energy (INFORSE)	A network of 140 NGOs operating in 60 countries that was established as part of the Rio Convention. INFORSE is dedicated to promoting sustainable energy and social development and is funded by a mix of national governments, multilateral institutions and CSOs. It focuses on four areas: raising awareness about sustainable energy use; promoting institutional reform among national governments; building local and national capacity on energy-related issues; and supporting research and development..	http://www.inforse.org

TABLE R24. International Networks Furthering Energy Access: Selected Examples (continued)

Name	Brief Description	Web Address
International Solar Alliance (ISA)	A coalition of solar resource-rich countries conceived to address their special energy needs and to provide a platform to collaborate on addressing the identified gaps through a common, agreed approach. A common goal of the Alliance is to increase the use of solar energy in meeting energy needs of prospective ISA member countries in a safe, convenient, affordable, equitable and sustainable manner.	http://www.isolaralliance.org
Power for All	A global coalition of 200 private and public organisations campaigning to deliver universal energy access before 2030 through the power of decentralised, renewable electricity. Power for All is committed to delivering access to energy for the 85% of the 1.1 billion people without reliable power that live in rural areas within 10 years.	http://www.powerforall.org
RedBioLAC	A multinational network of institutions involved in research and dissemination of anaerobic bio-digestion and the treatment and management of organic waste in Latin America and the Caribbean. The RedBioLAC has become a lively platform for knowledge exchange, development and dissemination. This is achieved via diverse methods and activities, specifically through the annual conference, annual magazine, e-learning, online library and forum.	http://www.wisions.net/pages/redbiolac
Scaling Off-grid Energy	A platform for leading donors and investors to develop Africa's off-grid energy sector and to co-ordinate investments to connect more households and businesses to electricity, faster. Founded jointly by USAID, the UK Department for International Development and the Shell Foundation, Scaling Off-Grid Energy aims to incentivise technological innovation, fund early-stage companies and support critical elements of the off-grid ecosystem.	https://www.scalingoffgrid.org
Wind Empowerment	An association for the development of locally manufactured small wind turbines for sustainable rural electrification. The association represents dozens of member organisations, consisting of wind turbine manufacturers, NGOs, universities, social enterprises, co-operatives and training centres, as well as over 1,000 individual participants across the world.	http://windempowerment.org

TABLE R25. Global Trends in Renewable Energy Investment, 2008-2018

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Billion USD										
New Investment by Stage											
Technology Research											
Government R&D	2.8	5.4	4.9	4.8	4.7	5.2	4.5	4.4	5.1	5.1	5.5
Corporate R&D	3.3	3.3	3.8	4.3	4.1	4.0	4.3	4.1	4.3	6.7	7.5
Development/Commercialisation											
Venture capital	3.3	1.6	2.6	2.6	2.4	0.8	1.0	1.4	0.8	0.7	0.2
Manufacturing											
Public markets	10.5	11.7	10.6	9.9	3.8	9.8	14.9	12.0	6.2	5.6	6.0
Private equity expansion capital	6.7	3.0	5.3	2.4	1.6	1.3	1.7	1.8	1.7	0.7	1.8
Projects											
Asset finance	132.8	112.3	152.4	190.8	166.5	171.3	226.9	269.2	247.5	267.8	236.5
(re-invested equity)	-4.4	-3.7	-1.8	-2.1	-2.9	-1.2	-3.6	-6.7	-4.4	-2.9	-4.8
Small-scale distributed capacity	22.2	34.7	60.9	75.1	70.0	40.4	37.1	32.4	32.7	42.4	36.3
Total New Investment	**177.2**	**168.2**	**238.7**	**287.7**	**250.2**	**231.6**	**286.9**	**318.5**	**293.8**	**326.3**	**288.9**
New Investment by Technology											
Solar power	60.4	63.3	101.7	158.6	141.8	121.3	147.4	176.0	145.4	180.2	139.7
Wind power	73.6	73.3	98.6	86.5	77.8	82.9	110.8	122.0	126.3	130.9	134.1
Biomass and waste-to-energy	16.1	13.4	17.0	20.4	15.4	13.7	12.9	10.2	13.0	5.7	8.7
Biofuels	17.6	9.4	10.1	10.4	7.3	5.1	5.3	3.6	2.1	3.2	3.0
Geothermal	1.7	2.5	2.8	3.9	1.5	2.7	2.9	2.5	2.7	2.4	2.2
Hydropower <50 MW	7.6	6.0	8.2	7.7	6.1	5.7	7.1	4.0	4.1	3.6	0.9
Ocean power	0.2	0.3	0.3	0.3	0.3	0.2	0.4	0.2	0.2	0.2	0.2
Total New Investment	**177.2**	**168.2**	**238.7**	**287.7**	**250.2**	**231.6**	**286.9**	**318.5**	**293.8**	**326.3**	**288.9**

Note: Excludes large hydro-electric projects of more than 50 MW.

Source: See endnote 25 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 2019 report is the 14th 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 2018 data[i] for national and global capacity, output, growth and investment portrayed 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 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-use by technology, combined with global average losses, is as follows: solar PV, ocean power and wind power (8.2%); hydropower (10.1%); 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*, 2018 edition (Paris: 2018).

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 2016, from IEA, *World Energy Statistics and Balances*, 2018 edition (Paris: 2018).

NOTES ON RENEWABLE ENERGY IN TOTAL FINAL ENERGY CONSUMPTION, BY SECTOR

GSR 2019 presents an illustration (Figure 4) of the share of renewable energy in total final energy consumption (TFEC) by sector in 2016. The share of TFEC consumed in each sector is portrayed: Heating and Cooling (51%), Transport (32%) and Power (17%). There are three important points about this figure and about how the GSR treats sectoral TFEC in general:

1. Definition of Heating and Cooling

In the GSR, the term "Heating and Cooling" refers to applications of thermal energy including space and water heating, space

i For information on renewable energy data and related challenges, see Sidebar 4 in GSR 2015 and Sidebar 1 in GSR 2014.

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

2. Sectoral Shares of TFEC

In Figure 4, each sectoral share of TFEC portrays the energy demand for all end-uses within the sector. The shares of TFEC allocated to Heating and Cooling and to Transport also account for the electricity consumed in these sectors – that is, electricity for heating and cooling, and electricity for transport. These amounts have been reallocated from final demand in the Power sector. Therefore, the share of TFEC allocated to the Power 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 intended to strengthen the accuracy of the representation.

3. Shares of Non-renewable Electricity

Figure 4 illustrates the share of non-renewable electricity in Heating and Cooling 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 2016, all electricity for heating and cooling met 7.1% of final energy demand in the sector (1.8% 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 earlier in this 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 2009-2018. For details on the situation in China and on the reasoning for capacity data used in this GSR, see endnote 25 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, HVO data 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 for specific sources.*)

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) 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 2018 have ratios in the range of 1.1 to 1.5[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 (e.g., Canada, Chile, India, Japan, Spain and the United States) report official capacity data on the basis of output in AC; these capacity data were converted to DC output by data providers (see relevant endnotes) for the sake of consistency. Global renewable power capacity totals in this report include solar PV data in DC; as with all statistics in this report, they should be considered as indicative of global capacity and trends rather than as exact statistics.

7. Concentrating Solar Thermal Power (CSP) Data

Global CSP data are based on commercial facilities only. Demonstration or pilot facilities and facilities of 5 MW or less are excluded. Discrepancies between REN21 data and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals. The GSR aims to report net CSP capacities for specific CSP plants that are included. In certain cases, it may not be possible to verify if the reported capacity of a given CSP plant is net or gross capacity. In these cases net capacity is assumed.

8. Solar Thermal Heat Data

Starting with GSR 2014, the GSR includes all solar thermal collectors that use water as the heat transfer medium (or heat carrier) in global capacity data and the ranking of top countries. Previous GSRs focused primarily on glazed water collectors (both flat plate and evacuated tube); the GSR now also includes unglazed water collectors, which are used predominantly for swimming pool heating. For the first time in this year´s GSR, data for concentrating collectors are available. These include new installations overall as well as in key markets. Data for solar air collectors (solar thermal collectors that use air as the heat carrier) are far more uncertain, and these collectors play a minor role in the market overall. Both collector types – air and concentrating collectors – are included where specified.

OTHER NOTES

Editorial content of this report closed by 3 June 2019 for technology data, and by 15 May 2019 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 2018 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: International Energy Agency (IEA) Photovoltaic Power Systems Programme (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; IEA PVPS, *Trends in Photovoltaic Applications 2018: Survey Report of Selected IEA Countries Between 1992 and 2017* (Paris: 2018), p. 8; Gaëtan Masson, Becquerel Institute and IEA PVPS, personal communication with REN21, May 2017; Dave Renné, International Solar Energy Society, personal communication with REN21, March 2017; Michael Schmela, SolarPower Europe, personal communication with REN21, 11 May 2019.

ii IEA PVPS, *Trends in Photovoltaic Applications 2018*, p. 8, and IEA PVPS, *2019 Snapshot of Global PV Markets*, p. 8.

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 transformed into biomethane through a process known as scrubbing that removes 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.

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 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.)

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.

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 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 substations (at varying stepped-down voltages) and distributes electricity to customers.

Drop-in biofuels. Liquid biofuels that are functionally equivalent to liquid fossil fuels and are fully compatible with existing fossil fuel infrastructure.

Electric vehicle (EV) (also called electric drive vehicle). A vehicle that uses one or more electric motors for propulsion. A battery electric vehicle is a type of EV that uses chemical energy stored in rechargeable battery packs. A plug-in hybrid EV can be recharged by an external source of electric power. Fuel cell vehicles are EVs that use pure hydrogen (or gaseous hydrocarbons before reformation) as the energy storage medium.

Energiewende. German term that means "transformation of the energy system". It refers to the move away from nuclear and fossil fuels towards an energy system based primarily on energy efficiency improvements and renewable energy.

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.

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 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. 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.

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 (PAYG). 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.

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.

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 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); as well as 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 (SHS). 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.

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 substations, 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. 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.

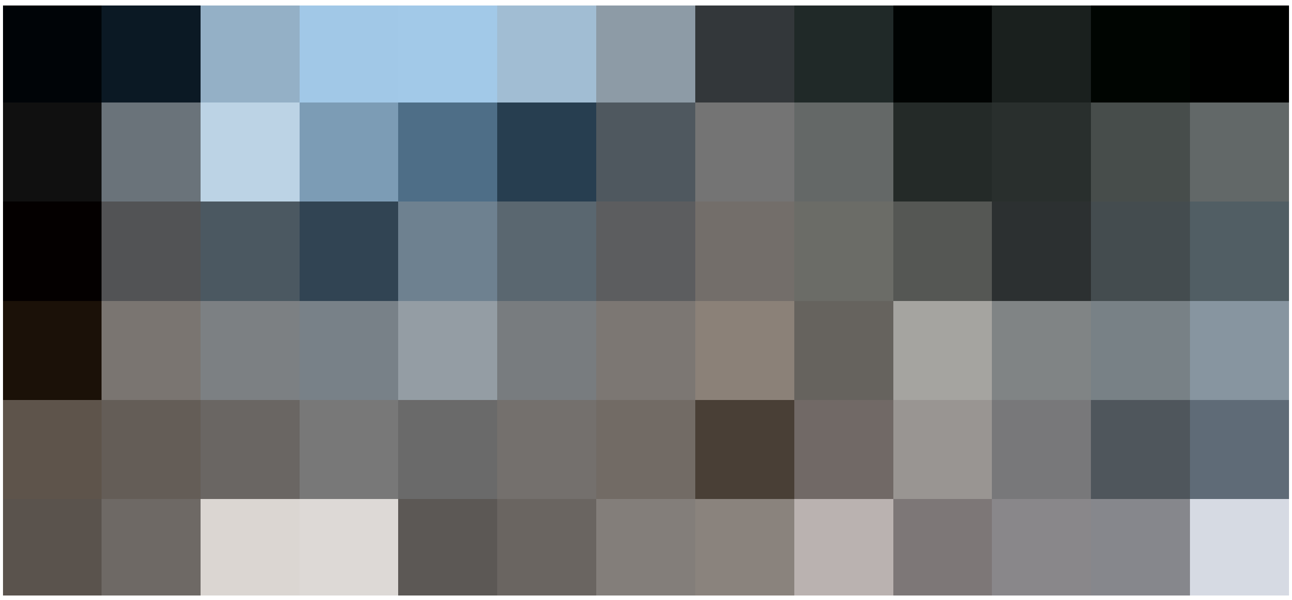
Virtual power plant (VPP). A network of decentralised, independently owned and operated power generating units combined with flexible demand units and possibly also with storage facilities. A central control station monitors operation, forecasts demand and supply, and dispatches the networked units as 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) 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.

Yield company (yieldco). Renewable energy yieldcos are publicly traded financial vehicles created when power companies spin off their renewable power assets into separate, high-yielding entities. They are formed to reduce risk and volatility, and to increase capital and dividends. Shares are backed by completed renewable energy projects with long-term power purchase agreements in place to deliver dividends to investors. They attract new types of investors who prefer low-risk and dividend-like yields, and those who wish to invest specifically in renewable energy projects. The capital raised is used to pay off debt or to finance new projects at lower rates than those available through tax equity finance.



LIST OF ABBREVIATIONS

AC	Alternating current
AfDB	African Development Bank
AUD	Australian dollar
BNEF	BloombergNEF
BRICS	Brazil, Russian Federation, India, China and South Africa
CDM	Clean Development Mechanism
CHP	Combined heat and power
CNY	Chinese yuan
CO_2	Carbon dioxide
COP24	Conference of the Parties, 24th meeting
CSP	Concentrating solar thermal power
DC	Direct current
DFI	Development finance institution
DHC	District heating and cooling
DOE	US Department of Energy
DREA	Distributed renewables for energy access
EC	European Commission
EJ	Exajoule
EMEC	European Marine Energy Centre
EPA	US Environmental Protection Agency
ESCO	Energy Service Company
ETS	Emissions Trading System
EU	European Union (specifically the EU-28)
EV	Electric vehicle
FAME	Fatty acid methyl ester
FIT	Feed-in tariff
G20	Group of Twenty
GDP	Gross domestic product
GSR	Global Status Report
GW/GWh	Gigawatt/gigawatt-hour
GW_{th}	Gigawatt-thermal
HEFA	Hydrotreated esters and fatty acids
HVO	Hydrotreated vegetable oil
ICE	Internal combusion engine
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
INDC	Intended Nationally Determined Contribution
INR	Indian rupee
IOU	Investor-owned utility
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
IRENA	International Renewable Energy Agency
IT	Information technology
ktoe	Kilotonnes of oil equivalent
kW/kWh	Kilowatt/kilowatt-hour
kW_{th}	Kilowatt-thermal
LCOE	Levelised cost of energy (or electricity)
LPG	Liquefied petroleum gas
m^2	Square metre
m^3	Cubic metre
MJ	Megajoule
MSW	Municipal solid waste
Mtoe	Million tonnes of oil equivalent
MW/MWh	Megawatt/megawatt-hour
MW_{th}	Megawatt-thermal
NDC	Nationally Determined Contribution
O&M	Operations and maintenance
OECD	Organisation for Economic Co-operation and Development
P2G	Power-to-gas
PAYG	Pay-as-you-go
PERC	Passivated Emitter Rear Cell
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
PPA	Power purchase agreement
PPP	Purchasing power parity
PTO	Power take-off device
PV	Photovoltaic/photovoltaics
R&D	Research and development
REC	Renewable electricity certificate
RED	EU Renewable Energy Directive
RFS	US Renewable Fuel Standard
RPS	Renewable portfolio standard
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SHIP	Solar heat for industrial processes
SHS	Solar home system
TES	Thermal energy storage
TFC	Total final consumption
TFEC	Total final energy consumption
TW/TWh	Terawatt/terawatt-hour
UAE	United Arab Emirates
UN	United Nations
UNEP	United Nations Environment
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
V2G	Vehicle-to-grid
VAT	Value-added tax
VC/PE	Venture capital and private equity
VRE	Variable renewable energy
W/Wh	Watt/watt-hour

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55 All values derived from OECD/IEA, op. cit. note 51. Consumption of traditional biomass based on the combined values for solid biomass and charcoal consumption in the residential sector of non-OECD countries. Consumption of renewable electricity is based on the share of renewables in global gross electricity generation, adjusted by technology-specific estimates of industry own-use, analogous to the methodology applied for Figure 1. Industry own-use includes the difference between gross and net generation at thermal power plants (the difference lies in the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants), and other uses such as electricity use in coal mining and fossil fuel refining. Consumption of produced heat from renewable sources (from heat plants) is based on the renewable share of heat production in heat plants.

56 Ibid.

57 **Figure 2** based on Ibid.

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59 Total capacity from Ibid. Data on non-renewable capacity provided by International Renewable Energy Agency (IRENA), personal communication with REN21, April 2019.

60 **Figure 3** based on Ibid. In 2015, 2016, 2017 and 2018, renewable energy demonstrated shares of net installed power capacity of 59%, 58%, 63% and 64%, respectively.

61 **Figure 4** based on OECD/IEA, op. cit. note 51; renewable electricity for heat from OECD/IEA, personal communication with REN21, 28 April 2019. In 2016, all electricity for heating and cooling met 7.1% of final energy demand in the sector (1.8% 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). See Methodological Notes for details.

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137 Allen et al., op. cit. note 43, p. 27.

138 Broader concerns for policy makers in the transport sector include environmental and health impacts (e.g., congestion, pollution, road safety) and transport security. In developing countries and rural areas, equitable access to transport is also a major concern. IRENA, OECD/IEA and REN21, op. cit. note 64, p. 23; GIZ Sustainable Urban Transport Project, "Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I)", https://www.sutp.org/files/contents/documents/resources/E_Fact-Sheets-and-Policy-Briefs/SUTP_GIZ_FS_Avoid-Shift-Improve_EN.pdf.

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capacity in 2018, see Reference Table R1, technology sections in Market and Industry chapter and related endnotes.

184 Total capacity based on Ibid., on data provided throughout this report and on data from past GSRs. See Market and Industry chapter, Reference Table R1 and related endnotes for sources and details.

185 Solar PV from OECD/IEA PVPS, *Snapshot of Global Photovoltaic Markets 2019*, op. cit. note 183, p. 5. Capacity provided is in direct current (DC). See Solar PV section in Market and Industry chapter for details.

186 Additions of solar PV (100 GW), wind power (51 GW) and hydropower (20 GW), with a total of 181 GW added. See note 183 in this chapter, and Market and Industry chapter and related endnotes, for sources.

187 Total capacity based on data provided throughout this report. See Market and Industry chapter, Reference Table R1 and related endnotes for details and sources.

188 Based on year-end capacities reported throughout this GSR. See Reference Table R1 for details and sources.

189 Ibid.

190 **Figure 7** based on renewable power capacity reported throughout this GSR and on non-renewable power capacity from sources in note 59. By the end of 2018, 7,110 GW of total power capacity had been installed, comprising 2,378 GW (33.4%) of renewable and 4,732 GW (65.6%) of non-renewable power capacity.

191 Share of generation based on the following: total global electricity generation in 2018 estimated at 26,698 TWh, based on 25,679 TWh in 2017 from OECD/IEA, op. cit. note 42, p. 528, and on estimated 3.97% growth in global electricity generation in 2018. Growth rate in 2018 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 2017): United States (+3.6% net generation), EU (+0.0%), Russian Federation (+1.6%), India (+1.0%), China (+7.7%), Canada (-1.2%) and Brazil (+1.4%). Generation data for 2017 and 2018 by country or region from the following: EIA, *Electric Power Monthly with Data for December 2018* (Washington, DC: February 2019), Table 1.1, https://www.eia.gov/electricity/monthly/archive/february2019.pdf; EC, Eurostat database, http://ec.europa.eu/eurostat, viewed April 2019; Ministry of Energy of the Russian Federation, "Statistics", https://minenergo.gov.ru/en/activity/statistic, Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly generation report", http://www.cea.nic.in/monthlyarchive.html, viewed April 2019; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2018 national economic and social development", press release (Beijing: 28 February 2019), http://www.stats.gov.cn/english/PressRelease/201902/t20190228_1651335.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 18 April 2019; 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 2019. **Hydropower** generation in 2018 of 4,210 TWh from IHA, personal communications with REN21, April and May 2019. **CSP** estimated at 10.94 TWh, based on preliminary data for Spain (4,309 GWh) from Red Eléctrica de España (REE), *The Spanish Electricity System – Preliminary Report 2018* (Madrid: 5 February 2019), with estimated data as of 16 January 2019, p. 16, https://www.ree.es/sites/default/files/11_PUBLICACIONES/Documentos/InformesSistemaElectrico/2019/Avance_ISE_2018_en.pdf; US generation (3,376 GWh) from EIA, op. cit. this note, Table 1.1.A, and projected global generation in 2018 for rest of world (3,251 GWh) from OECD/IEA, Renewables 2018 Databook, op. cit. note 54. **Solar PV** worldwide production potential of 640 TWh, from Gaëtan Masson and Alice Detollenaere, Becquerel Institute and IEA PVPS, personal communication with REN21, 23 April 2019. 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 2018. **Wind power** estimated wind generation of 1,471 TWh, based on wind power capacity at end-2018 from the following sources: **Costa Rica, Dominican Republic, Guatemala, Iran, Israel, Jamaica, New Zealand, Panama** and **Peru** from IRENA, Renewable Energy Capacity Statistics Database, https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Statistics-Time-Series, viewed April 2019; **Europe** (including **Russian Federation**) from WindEurope, *Wind Energy in Europe in 2018* (Brussels: 2019), p. 10, https://windeurope.org/about-wind/statistics/european/wind-energy-in-europe-in-2018/; **Honduras** from Empresa Nacional de Energía Eléctrica (ENEE), *Boletín de Datos Estadistíco Diciembre 2018* (Tegucigalpa: undated), p. 2, http://www.enee.hn/planificacion/2019/Boletin%20Estadistico%20Diciembre2018.pdf; **Nicaragua** from Instituto Nicaragüense de Energía (INE), "Capacidad Instalada Sistema Eléctrico Nacional", p. 1 https://www.ine.gob.ni/DGE/estadisticas/2018/Capacidad_Instalada_2_2018_actMar19.pdf; **Turkey** from Turkish Wind Energy Association, *Türkiye Rüzgar Enerjisi Istatistik Raporu 2019* (Ankara: 2019), p. 5, http://www.tureb.com.tr/files/bilgi_bankasi/turkiye_res_durumu/istatistik_raporu_ocak_2019.pdf; **United States** from American Wind Energy Association (AWEA), "Consumer demand drives record year for wind energy purchases", press release (Washington, DC: 30 January 2019), https://www.awea.org/resources/news/2019/consumer-demand-drives-record-year-for-wind-energy); **Uruguay** from Uruguay Ministry of Industry, Energy and Mining (MIEM), "Renewable Energy Market Data – Renewable Energy Source", provided by MIEM, personal communications with REN21, March 2019; **remaining countries and regions** from GWEC, op. cit. note 183, p. 29; generation estimated with selected weighted average capacity factors by region, and for both onshore and offshore wind power, from the following sources: Asia from Feng Zhao, GWEC, personal communication with REN21, 14 May 2019; **Brazil** from ONS, *Boletim Mensal de Geração Eólica Março 2019* (Brasilia: 2019), p. 31, http://ons.org.br/AcervoDigitalDocumentosEPublicacoes/Boletim_Eolica_mar%C3%A7o_%202019.pdf; Europe from WindEurope, op. cit. this note, p. 19; remaining countries and regions from IRENA, personal communications with REN21, April 2019 (see Table 3 in this report). **Geothermal power** generation of 89.3 TWh from OECD/IEA, Renewables 2018 Databook, op. cit. note 54; **Ocean energy** generation of 1.1 TWh from idem; **Bio-electricity** generation of 581 TWh from note 34 in Bioenergy section of Market and Industry chapter.

192 **Figure 8** based on all sources in Ibid.

193 Numbers of countries exceeding 1 GW and 10 GW from data for over 75 countries based on the world's top countries for cumulative capacity of hydro, wind, solar PV, bio-power, CSP, geothermal and ocean power. See Market and Industry chapter and related endnotes for more details. More than 90 concluded by complementing collected data from 75 countries with remaining countries from IRENA, *Capacity and Generation Statistics 2019* (Abu Dhabi: 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf. **Hydropower** national data mainly from IHA, personal communications with REN21, April-May 2019; except China National Energy Agency (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; EIA, op. cit. note 191, Tables 6.2.B and 6.3; AGEE-Stat, op. cit. note 183. **Wind** national data mainly from GWEC, op. cit. note 183, except AWEA, op. cit. note 191; AGEE-Stat, op. cit. note 183; China at around 210 GW from Chinese Wind Energy Agency, see note 23 in Wind Power section of Market and Industry chapter for details; European countries from WindEurope, op. cit. note 191. **Solar PV** national data collected in direct current and mainly from OECD/IEA PVPS, *Snapshot of Global Photovoltaic Markets 2019*, op. cit. note 183, and complemented from Detollenaere, op. cit. note 191; except India with 32.9 GW from various sources, see note 34 in Solar PV section in Market and Industry chapter for details. Bio-power mainly from OECD/IEA, *Renewables 2018*, op. cit. note 54; except from bio-power national sources in note 178. **Geothermal** mainly from idem, except United States from EIA, op. cit. note 191, Table 6.2.B; Germany from BMWi, op. cit. note 183; Japan capacity from IEA Geothermal, *2018 Annual Report* (Paris: February 2019), http://iea-gia.org/publications-2/annual-reports/ and no capacity added in 2018; Turkey from note 1 in Geothermal section in Market and Industry chapter; **CSP** capacity limited to 10 countries, see CSP section in Market and Industry chapter and Reference Table R18. **Ocean power** capacity negligible worldwide and has no effect on capacity rankings or whether or not a certain country exceeded 1 GW or 10 GW of capacity. Wherever national data are unavailable from previously referenced sources, gaps are filled from IRENA, op. cit. this note.

194 Ibid.

195 Ranking for top countries for non-hydropower capacity based on Ibid. and on various sources throughout Market and Industry

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BACK

POLICY LANDSCAPE

1 This section is intended to be only indicative of the overall landscape of policy activity and is not a definitive reference. Generally, listed policies are those that have been enacted by legislative bodies. Some of the listed policies may not yet be implemented, or are awaiting detailed implementing regulations. It is difficult to capture every policy change, so some policies may be unintentionally omitted or incorrectly listed. This report does not cover policies and activities related to technology transfer, capacity building, carbon finance and Clean Development Mechanism projects, nor does it attempt to provide a comprehensive list of broader framework and strategic policies – all of which are still important to renewable energy progress. For the most part, this report also does not cover policies that are still under discussion or formulation, except to highlight overall trends. Information on policies comes from a wide variety of sources, including the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) Global Renewable Energy Policies and Measures Database, the US Database of State Incentives for Renewables & Efficiency (DSIRE), press reports, submissions from REN21 regional- and country-specific contributors and a wide range of unpublished data. **Table 2** and **Figures 12 through 17** are based on numerous sources cited throughout this section.

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BIOENERGY

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5 Based on analysis summarised in **Figure 18**; see Ibid.

6 See analysis and references in sections that follow.

7 While such uses of bioenergy are concentrated in developing and emerging economies, in more-developed countries large quantities of wood are used to heat homes in inefficient and often polluting devices such as open grates, contributing to local air pollution problems. However, under the statistical conventions that define traditional biomass as that used for heating in non-OECD countries, such fuel use is classified as being "modern".

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14 Each EU member state is obligated under the Renewable Energy Directive to develop renewable energy to meet a mandatory national target for 2020 for the share of renewables in final energy consumption. To achieve this, each country has prepared a National Renewable Energy Action Plan that includes measures to promote renewable heat, leading to growing efforts to encourage renewable heating, which comes primarily from biomass.

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16 Based on analysis of data in Ibid., pp. 199-201.

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18 Based on analysis summarised in Figure 18, op. cit. note 4.

19 This concentration is due to climatic reasons, as building heating requirements are limited in more southern countries and bioenergy so far plays a very limited role in providing cooling. Also, note that by definition use of biomass for residential heating outside the OECD is classified as "traditional use of biomass" and so is not counted within the statistics as "modern use of biomass".

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27 Ibid., p. 149.

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31 Bioelectricity generation data based on analysis of national data from the following sources: EIA, op. cit. note 30; BMWi, op. cit. note 29; UK Department for Business, Energy & Industrial Strategy, op. cit. note 29, updated 14 March 2019; other countries based on forecast 2018 capacity figures from OECD/IEA, *Renewables 2018*, op. cit. note 3, datafiles.

32 **Figure 19** based on analysis conducted using historical data from REN21 for years to 2015, and the results of analysis carried out for this report on the national data referenced above.

33 Bioelectricity generation data based on analysis of national data from the following sources: EIA, op. cit. note 30; BMWi, op. cit. note 29; UK Department for Business, Energy & Industrial Strategy, op. cit. note 29, updated 14 March 2019; China from CEC, op. cit. note 29, and from China Energy Portal, op. cit. note 29; other countries based on forecast 2018 capacity figures from OECD/IEA, *Renewables 2018*, op. cit. note 3, datafiles.

34 Bioelectricity generation data based on analysis of national data from the following sources: EIA, op. cit. note 30; BMWi, op. cit. note 29; UK Department for Business, Energy & Industrial Strategy, op. cit. note 29, updated 14 March 2019; China from CEC, op. cit. note 29, and from China Energy Portal, op. cit. note 29; other countries based on forecast 2018 capacity figures from OECD/IEA, *Renewables 2018*, op. cit. note 3, datafiles.

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41 Ibid.

42 Government of India, MNRE, op. cit. note 29; OECD/IEA, *Renewables 2018*, op. cit. note 3, datafiles.

43 OECD/IEA, *Renewables 2018*, op. cit. note 3, datafiles.

44 Ibid.

45 Based on EIA, op. cit. note 30.

46 Ibid.

47 Gas Technologies Institute, *Low Carbon Renewable Natural Gas from Wood Wastes* (Des Plaines, IL: February 2019), p. 7, https://www.gti.energy/wp-content/uploads/2019/02/Low-Carbon-Renewable-Natural-Gas-RNG-from-Wood-Wastes-Final-Report-Feb2019.pdf.

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50 Ibid.

51 Difference.net, "Difference between corn and maize", http://www.differencebetween.net/object/comparisons-of-food-items/difference-between-corn-and-maize/, viewed 13 May 2019.

52 Ethanol is produced principally from sugar- and starch-containing materials including maize, sugar cane, wheat and cassava. After pretreatment and fermentation, the ethanol is separated by distillation. Most biodiesel is made by chemically treating vegetable oils and fats (including palm, soy and canola oils, and some animal fats) to produce FAME biodiesel. Ethanol and biodiesel are collectively referred to as "conventional biofuels". While FAME fuels can be used in diesel engines, their properties depend on their origin and differ from those of fossil-based diesel, so they are usually used as a blend with fossil diesel products. An alternative is to take the oils and treat them with hydrogen to produce a hydrocarbon product that then can be refined to produce fuels with properties equivalent to those of a range of fuels derived from fossil fuels such as diesel or jet fuel. These fuels are described as HVO/HEFA and sometimes as renewable diesel. (See, for example, Aviation Initiative for Renewable Fuels in Germany, "Hydro-processed esters and fatty acids (HEFA)", http://www.aireg.de/en/production/hydro-processed-esters-and-fatty-acids-hefa.html.) In addition, a range of other biofuels are produced at a much smaller scale, including ethanol from cellulosic feedstocks, pyrolysis oils, etc. See Liquid Fuels Industry section of this chapter for further details and references. Based on biofuels data in OECD/IEA, op. cit. note 49, supplemented by national data as referenced elsewhere in this section. Volumes of fuel converted to energy content using conversion factors from US Department of Energy, "Alternative Fuels Data Centre", https://www.afdc.energy.gov/, viewed 4 April 2018. Lower caloric value for ethanol 76,330 Btu/US gallon (21.27 MJ/litre) and for biodiesel 119,550 Btu/US gallon (3.32 MJ/litre). Caloric value for HVO 34.4 MJ/litre (Neste, *Neste Renewable Diesel Handbook* (Espoo, Finland: 2016), p. 15, https://www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf). **Figure 20** based on biofuels data in OECD/IEA, op. cit. note 49, supplemented by national data as referenced elsewhere in this section.

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GEOTHERMAL POWER AND HEAT

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15 Schmela, op. cit. note 1; Masson, op. cit. note 13. For an example of a large-scale plant without subsidies, commissioned in 2018 (but not yet grid-connected), see BayWa, "BayWa sells 175 MW solar park 'Don Rodrigo' to MEAG", press release (Munich: 28 December 2018), https://www.baywa-re.com/en/news/details/baywa-sells-175-mw-solar-park-don-rodrigo-to-meag/.

16 IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1; SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 12; and from data and sources provided throughout this section.

17 China's share of 2018 additions based on data from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1; share of 2017 additions based on data from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 1, p. 83. China's share of deployment in 2018 was 49%, from SPV Market Research, *The Solar Flare*, no. 2 (San Francisco, CA: April 2019), p. 8.

18 Americas based on data from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1.

19 Top countries and share of top five, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1, p. 8, and based on data and sources provided throughout this section. Figure of 84% in 2017 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.

20 Figure for 2018 from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1, p. 7. Figure for 2017 from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 1, p. 13. The market level to be among the top 10 for annual additions was 675 MW in 2015 and 683 MW in 2016, from IEA PVPS, idem.

21 Based on data from Becquerel Institute, op. cit. note 1, on IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1, p. 8, and on data and sources provided throughout this section. **Figure 26** based on historical global and country-specific data from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 1, and on country-specific data and sources provided throughout this section for China, Germany, India, Japan and the United States. India data for 2008-2016 from the following: for 2008 and 2009 from European Photovoltaic Industry Association (EPIA), *Global Market Outlook for Photovoltaics Until 2015* (Brussels: 2011), p. 10, https://www.solarserver.de/fileadmin/user_upload/PDF/epia_market_outlook_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), http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2012_-_FINAL_4.pdf; data for 2013 from IEA-PVPS, *PVPS Report – Snapshot of Global PV 1992-2013: Preliminary Trends Information from the IEA PVPS Programme* (Paris: March 2014), http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2013_-_final_3.pdf; data for 2014 from Bridge to India, May 2015, provided by Sinead Orlandi, Becquerel Institute, personal communication with REN21, 11 May 2015; data for 2015 from IEA PVPS, *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), http://www.iea-pvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf; data for 2016 from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements)", data as on 31 December 2016, https://mnre.gov.in/achievements, viewed 19 January 2017.

22 First time since 2014 from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 11; figure of 45 GW includes unsubsidised capacity additions on top of official data for subsidised capacity, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1. China added 44.26 GW, including 23.3 GW centralised and 20.96 GW distributed, from China's National Energy Administration (NEA), "Photovoltaic power generation statistics for 2018", 19 March 2019, http://www.nea.gov.cn/2019-03/19/c_137907428.htm (using Google Translate); added 44,730 MW of grid-connected capacity (although 200 MW of this might be concentrating solar thermal power (CSP) capacity), from 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/; added 44.4 GW (down from 52.8 GW in 2017), from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 5; added a net of 44,216 MW for a total of 175,018 MW, based on data from IRENA, op. cit. note 1, p. 24.

23 Down more than 15% based on 53,068 MW installed in 2017, from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 1, p. 83, and about 45 GW installed in 2018, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1. Installations were down 16.6% from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 55; and down approximately 17%, from Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co (AECEA), personal communication with REN21, 8 April 2019, and down 21% from NEA, cited in Saumy Prateek, "China installs better than expected 44 GW of solar capacity in CY 2018", Mercom India, 5 February 2019, https://mercomindia.com/china-installs-44-gw-solar-capacity-cy-2018/. Larger than expected from Masson, op. cit. note 13; China from "China considers how to support solar beyond subsidies", Power Technology, 28 March 2019, https://www.power-technology.com/comment/china-solar-pv/, and from Vincent Shaw, "China installed 43.6 GW of solar late year – despite 5/31 New Policy", pv magazine, 17 January 2019, https://www.pv-magazine.com/2019/01/17/china-installed-42-6-gw-of-solar-last-year-despite-5-31-new-policy/. **Figure 27** 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 R17).

24 Figure of 176.1 GW includes unsubsidised capacity on top of official statistics, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1. China's cumulative year-end capacity was 174 GW, 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); year-end capacity was 174.46 GW, from NEA, op. cit. note 22; year-end capacity was 174,630 MW, from CEC, cited in China Energy Portal, op. cit. note 22. Sandra Enkhardt, "China may raise 2020 solar target to more than 200 GW", pv magazine, 5 November 2018, https://www.pv-magazine.com/2018/11/05/china-may-raise-2020-solar-target-to-over-200-gw/; Liu Bin, "China's solar industry is at a crossroads", Eco Business, 15 August 2018, https://www.eco-business.com/news/chinas-solar-industry-is-at-a-crossroads/.

25 Vincent Shaw, "China releases new provisions for PV development in 2018", pv magazine, 1 June 2018, https://www.pv-magazine.com/2018/06/01/china-releases-new-provisions-for-pv-development-in-2018/; Petra Hannen, "China shakes PV world", pv magazine, 5 June 2018, https://www.pv-magazine.com/2018/06/05/china-shakes-pv-world/; Emma Foehringer Merchant, "China's bombshell solar policy shift could cut expected capacity by 20 gigawatts", Greentech Media, 6 June 2018, https://www.greentechmedia.com/articles/read/chinas-bombshell-solar-policy-could-cut-capacity-20-gigawatts.

26 Ibid., all references.

27 FIT payment and deficits from Mark Osborne, "GCL New Energy receives US$142.5 million in China tariff back payments", PV Tech, 1 November 2018, https://www.pv-tech.org/news/gcl-new-energy-receives-us142.5-million-in-china-tariff-back-payments, and from Muyu Xu and David Stanway, "China launches subsidy-free solar, wind power after project costs fall", *Reuters*, 10 January 2019, https://www.reuters.com/article/us-china-energy-renewables/china-launches-subsidy-free-solar-wind-power-after-project-costs-fall-idUSKCN1P30ZQ; uncontrolled growth, Top Runner bids and additional information on Top Runner programme from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 11, 55, and from Schmela, op. cit. note 1. The FIT payment backlog reached about USD 17.5 billion at the end of 2017, from Osborne, op. cit. this note. The deficit in the fund was CNY 150 billion or USD 23.4 billion at the end of 2017, from Hill, op. cit. note 1. Outstanding payments for the FIT were in the range of EUR 7.5-8 billion, from Frank Haugwitz, AECEA, personal communication with REN21, 8 March 2019.

28 NEA, cited in Prateek, op. cit. note 23; Bin, op. cit. note 24.

29 SolarPower Europe, *Global Market Outlook for Solar Power 2018-2022*, op. cit. note 3, p. 49; Masson, op. cit. note 13.

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32 China NEA, "2018 added solar PV capacities", op. cit. note 24.

33 Share of generation in 2018 (2.6%) from NEA, op. cit. note 22; and 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 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).

34 Based on official estimates (in AC) with a multiplier of 1.3 for conversion to DC, from IEA PVPS and Becquerel Institute, personal communication with REN21, 3 June 2019. Also based on the following data and sources for India: annual demand of just over 9 GW_{DC} in 2018 and cumulative end-2018 total demand (sum of annual demand over the period 2000-2018) of nearly 28.1 GW_{DC}, from Paula Mints, SPV Market Research, personal communication with REN21, 20 May 2019; added 8,321 MW_{AC} in 2018 for a year-end operating total of 28,855 MW_{AC} from Jyoti Gulia, Bridge to India, personal communication with REN21, 21 May 2019; added 9.2 GW for a total of 26,869 MW (based on official data, in AC), from IRENA, *Renewable Capacity Statistics 2019*, op. cit. note 1; added 8.3 GW for a total of 27.9 GW, from Sampath Krishna, "India installs 8.3 GW of solar in 2018", Mercom India, 27 February 2019, https://mercomindia.com/india-installs-8-3-gw-solar-2018/; and year-end grid-connected capacity of 25 GW_{AC} from Government of India MNRE, cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2019) (utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-01.pdf. Mercom India data were confirmed to be in AC by Saumy Prateek, Mercom India, personal communication with REN21, 16 May 2019. For conversion from AC to DC, Bridge to India provided the following multipliers: 1.25 for utility-scale until 2017; 1.15 for rooftop solar until 2017; 1.4 for utility-scale in 2018; and 1.20 for rooftop solar in 2018, from Vinay Rustagi, Bridge to India, personal communication with REN21, 21 May 2019. Conversion rate also informed by IRENA, "Conversion factors for net capacity and generation", table based on T. Huld and A. M. Gracia Amillo, "Estimating PV module performance over large geographical regions: The role of irradiance, air temperature, wind speed and solar spectrum", *Energies*, vol. 8 (2015), pp. 5159-5181, provided by Adrian Whiteman, IRENA Statistics, personal communication with REN21, 28 May 2019. Also, note that market demand and installations are not necessarily the same; in 2017, for example, India's demand was 9.4 GW_{DC} and annual installations for the year totalled 9.6 GW_{DC}, from Mints, op. cit. this note.

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in 2017 to 8,321 MW_{AC} in 2018, from Gulia, op. cit. note 34; and installations were down 6.5% relative to 2017 based on 11,590 MW installed in 2017 and on 10,840 MW installed in 2018 (all in DC), from IEA PVPS and Becquerel Institute, op. cit. note 34. Decline also from SPV Market Research, op. cit. note 3, p. 26.

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37 Decline of 27% (to USD 8.2 billion) from BNEF Desktop database; other information from Prateek, op. cit. note 35. Note that India's investment in the solar sector was down 15% in 2018, from idem.

38 Second year running from Saumy Prateek, "Infographic: India installed 1 MW of solar every hour in the first half of 2018", Mercom India, 25 September 2018, https://mercomindia.com/infograph-india-1mw-solar-every-hour-1h-2018/; more than half (50.7%) for first time from Krishna, op. cit. note 34.

39 Preeti Verma Lal, "India will miss 100 GW solar target according to Wood Mackenzie", pv magazine, 8 February 2019, https://www.pv-magazine.com/2019/02/08/india-will-miss-100-gw-solar-target-according-to-wood-mackenzie/; SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 59.

40 About two-thirds based on figure of 66%, from Krishna, op. cit. note 34. The growth rate was even higher (73%), from Singhvi, op. cit. note 36. About 0.8 GW_{DC} was added in 2017, for a total of 1.7 GW_{DC}, from Becquerel Institute, personal communication with REN21, 29 March 2018.

41 About 1,655 MW_{AC} was added in 2018 for a total of 3,260 MW_{AC}, from Krishna, op. cit. note 34; 1,592 MW_{AC} was added for a total of 3,855 MW_{AC}, from Gulia, op. cit. note 34; and year-end total of 1.35 GW grid-connected rooftop capacity (believed to be in AC), from MNRE, cited in Anu Ghambhani, "India: 25 GW total PV capacity end of 2018. With over 5 GW solar power installed in Karnataka, India's cumulative grid interactive solar power capacity till December 2018 reached 25.21 GW: MNRE", *TaiyangNews*, 27 January 2019, http://taiyangnews.info/markets/india-25-gw-total-pv-capacity-end-of-2018/. Another source estimates that total rooftop capacity reached 3,399 MW by the end of September 2018, from Lal, op. cit. note 39. See also Sushma U.N., "India has quietly downscaled its rooftop solar power target", Quartz India, 23 January 2018, https://qz.com/india/1180435/india-has-quietly-downscaled-its-rooftop-solar-power-target/.

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49 The first three auctions resulted in only about 500 MW of assigned capacity versus a government target of 1-1.5 GW, from Maisch, op. cit. note 48; Bellini, op. cit. note 48. See also Beetz, op. cit. note 48.

50 Noriaki Yamashita, *Lessons Learned from Local Conflicts on Solar PV Projects in Order to Promote Community-based PV Projects* (Tokyo: Kagaku, Iwanami Shoten Publishers, 2018). Information provided by Hironao Matsubara, ISEP, Tokyo, personal communication with REN21, 14 April 2019. A survey published by ISEP in October 2018, based on newspaper articles, found 68 cases of local conflicts regarding solar PV plants that were confirmed as of August 2018. The main causes of these conflicts are concerns about landscapes, disaster prevention, preservation of the living environment, and nature conservation, from idem.

51 Japan Ministry of Environment, draft report on environmental assessment of solar PV facilities and other energy facilities (2018), https://www.env.go.jp/press/files/jp/110764.pdf (in Japanese), with information provided by Matsubara, op. cit. note 50, 14 April 2019.

52 Matsubara, op. cit. note 47.

53 Ibid. As of early 2019, tariffs for rooftop systems larger than 10 kW were around JPY 14 (USD 0.127) per kWh, which was below the price of electricity from the grid for industry, from idem.

54 Matsubara, op. cit. note 50. See also Shota Furuya, "Solar sharing for the future generation — the story of Iitate Electric Power in Fukushima", The Beam, 8 May 2018, https://medium.com/thebeammagazine/solar-sharing-for-the-future-generation-the-story-of-iitate-electric-power-in-fukushima-c28efd5d7e41.

55 Shares of national generation in 2018 and 2017 from ISEP, "Domestic natural energy power ratio in 2018 (calendar year)", op. cit. note 10, and based on data of Japan's major TSOs; 2018 share also from ISEP, "Status and Trends of Renewable Energies in Japan", op. cit. note 10, p. 7. Share of solar PV generation in Kyushu from ISEP, "Domestic natural energy power ratio in 2018 (calendar year)", op. cit. note 10, and provided by Matsubara, op. cit. note 47.

56 A total of eight curtailments were carried out in late 2018, with curtailment reaching as high as about 14% on one day, from ISEP, "Domestic natural energy power ratio in 2018 (calendar year)", op. cit. note 10; causes from Matsubara, op. cit. note 47. In 2018, Kyushu Electric Power saw the share of variable renewables in its electricity mix reach 19.9% and the share of nuclear power from four plants (about 4 GW) reached 25.5%. Because the nuclear plants cannot adjust their output, the utility curbed renewable output on eight occasions in late 2018. The situation worsened in 2019, with 17 instances of solar PV curtailment in March and instances almost every day in April, all from ISEP, "Domestic natural energy power ratio in 2018 (calendar year)", op. cit. note 10, and provided by Matsubara, op. cit. note 47. See also Romain Zissler, "Renewable energy curtailment in Japan – room for improvement", Renewable Energy Institute, 9 April 2019, https://www.renewable-ei.org/en/activities/column/REupdate/20190409.php, and Osamu Tsukimori, "Update 1: Japan's Kyushu Electric may restrict renewable energy supplies after nuclear ramp-up", *Reuters*, 29 August 2018, https://www.reuters.com/article/japan-nuclear-renewables-restrictions/update-1-japans-kyushu-electric-may-restrict-renewable-energy-supplies-after-nuclear-ramp-up-idUSL3N1VK2J8.

57 The Republic of Korea added 2,027.6 MW for a total of 7,900 MW, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1, and added more than 2 GW (2,027 MW) for the first time, to end 2018 with 7.7 GW, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 12, 15, 69.

58 SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 70.

59 Turkey added 1,642 MW for a total of 5,069 MW, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1; Turkey added 1,642 MW for a total of 5,063 MW, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 71; target of 5 GW from SHURA Energy Transition Center, *On the Way to Efficiently Supplying More than Half of Turkey's Electricity from Renewables: Opportunities to Strengthen the YEKA Auction Model for Enhancing the Regulatory Framework of Turkey's Power System Transformation* (Istanbul: Sabanci Universitesi, 2018), p. 29, https://www.shura.org.tr/wp-content/uploads/2019/01/SHURA_Opportunities-to-strengthen-the-YEKA-auction-model-for-enhancing-the-regulatory-framework-of-Turkeys-power-system.pdf. Turkey's capacity was predominantly made up of small-scale (≤1 MW) systems, from idem. However, systems up to 1 MW do not need to be licensed and are clustered together to make larger projects, from Schmela, op. cit. note 1.

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61 Chinese Taipei added 971 MW, up from 523 MW in 2017, and market drivers from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 12; added over 1 GW in 2018 from EnergyTrend, cited in Tsvetomira Tsanova, "To-the-point: Taiwan reaches 1 GW solar installs in 2018", Renewables Now, 10 April 2019, https://renewablesnow.com/news/to-the-point-taiwan-reaches-1-gw-solar-installs-in-2018-650228/; added 0.7 GW from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1. Additions in Pakistan and Malaysia from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1.

62 Tom Kenning, "Bangladesh tenders 200MW of solar PV", PV Tech, 18 July 2018, https://www.pv-tech.org/news/bangladesh-tenders-200mw-of-solar-pv; Tom Kenning, "Kazakhstan awards 170MW of solar in first auction", PV Tech, 19 October 2018, https://www.pv-tech.org/news/kazakhstan-awards-170mw-of-solar-in-first-auction; Emiliano Bellini, "Kazakhstan tenders 290 MW of solar", pv magazine, 9 March 2018, https://www.pv-magazine.com/2018/03/09/kazahkstan-tenders-290-mw-of-solar/; Kelvin Ross, "Solar deals could mark renewables shifts in Philippines", Renewable Energy World, 3 September 2018, https://www.renewableenergyworld.com/articles/2018/09/solar-deals-could-mark-renewables-shift-in-philippines.html; Emiliano Bellini, "Philippine utility Meralco receives Southeast Asia's lowest solar bid", pv magazine, 13 August 2018, https://www.pv-magazine.com/2018/08/13/philippine-utility-meralco-receives-southeast-asias-lowest-solar-bid/.

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66 Wood Mackenzie Power & Renewables and SEIA, cited in SEIA, op. cit. note 64. Texas added 996 MW and North Carolina added 907 MW, from idem. Geographic shift also from Christian Roselund and John Weaver, "2018 solar power year in review (part 2)", pv magazine USA, 21 December 2018, https://pv-magazine-usa.com/2018/12/21/2018-solar-power-year-in-review-part-2/.

67 Wood Mackenzie Power & Renewables and SEIA, cited in SEIA, op. cit. note 64.

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71 Figures of 153 MW and 21%, from Wood Mackenzie Power & Renewables and SEIA, cited in SEIA, op. cit. note 64. Figures of 2.8 GW, 1 GW and more than in all previous years combined from Business Renewables Center, Rocky Mountain Institute, cited in Christian Roselund, "United States: 2.8 GW of corporate solar deals in 2018", pv magazine, 20 December 2018, https://www.pv-magazine.com/2018/12/20/united-states-2-8-gw-of-corporate-solar-deals-in-2018.

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77 Based on data from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1. **Figure 28** based on ibid. and on country-specific data and sources provided throughout this section (or see endnote for Reference Table 17).

78 Data for 2018 from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1; additions in 2017 from IEA PVPS, *Trends 2018 in Photovoltaic Applications*, op. cit. note 1, p. 83. Mexico added 2.8 GW, up from 285 MW in 2017, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 12.

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80 Becquerel Institute, op. cit. note 1; IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1.

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84 ABSOLAR, cited in Bellini, "Distributed solar tops 500 MW in Brazil", op. cit. note 83; net metering and state incentives also from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 77. See also Emiliano Bellini, "Solar distributed generation set for another record year in Brazil", pv magazine, 7 May 2019, https://www.pv-magazine.com/2019/05/07/solar-distributed-generation-set-for-another-record-year-in-brazil.

85 Brazil added 1,145.7 MW for a year-end total of 2,295 MW, based on data from ABSOLAR, based on data from ANEEL, cited in "Brazil to surpass 3,000 megawatts of PV in 2019", op. cit. note 83; added around 1.2 GW, with nearly one-third in distributed systems, for a year-end total of about 2.3 GW, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 12, 77; and added 1.4 GW for a year-end total approaching 2.6 GW, from Johan Lindahl, Becquerel Institute, personal communication with REN21, 10 May 2019. See also Bellini, "Brazil's PV capacity exceeds 2.5 GW", op. cit. note 83; José Rojo Martin, "ABSOLAR: Brazilian PV ready to go with new auction timetable", PV Tech, 13 March 2019, https://www.pv-tech.org/news/absolar-brazilian-pv-ready-to-go-with-new-auction-timetable.

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87 Ibid.

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89 IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1.

90 Belarus and Russian Federation from SolarPower Europe, *Global Market Outlook for Solar Power 2018-2022*, op. cit. note 3, p. 73; Ukraine from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1.

91 Added more than 0.7 GW for a total of 1.6 GW, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1, p. 5. Ukraine's additions more than tripled relative to 2017, to 803 MW, motivated by a FIT for large-scale projects and a net metering scheme for systems up to 30 kW; energy security was an important driver of incentives for large-scale and residential solar PV systems, all from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 12, 83, 86. Ukraine's year-end total was 2,004 MW, from idem, p. 86; however, capacity reached only 948 MW by the end of June 2018 according to Sergij Savchuk, Head of the State Department of Energy Efficiency and Energy Saving, cited in Emiliano Bellini, "Solar set to cross 1 GW milestone in Ukraine", pv magazine, 2 July 2018, https://www.pv-magazine.com/2018/07/02/solar-set-to-cross-1-gw-milestone-in-ukraine/.

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Trends in Photovoltaic Applications 2018, op. cit. note 1, p. 10; added 8.2 GW to the grid, an increase of 37% over 2017, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 12, 79.

93 SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 12, 79.

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101 SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 79.

102 Bundesverband Solarwirtschaft e.V., op. cit. note 100.

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106 Steady growth since 2014 from Dutch New Energy Research, *Dutch Solar Trend Report 2019* (Heerhugowaard, The Netherlands: 2019), p. 24, https://www.solarsolutions.nl/en/solar-trendrapport/; the Netherlands added 1.4 GW from Lindahl, op. cit. note 85, and added 1.4 GW from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 75; and year-end capacity was 4,300 MW, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1. Note that an estimated 1,330 MWp was added (up from a record 853 MWp in 2017), bringing total capacity to 4,244 GWp at the end of 2018, from Dutch New Energy Research, op. cit. this note, pp. 9, 18, 23; and the Netherlands added 1.4 GW in 2018, compared to 0.77 GW installed during 2017, from SolarPower Europe, op. cit. note 60.

107 Residential rooftops from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, p. 75; utility-scale from Daan Witkop, Dutch New Energy, personal communication with REN21, 11 April 2019, and from Dutch New Energy Research, op. cit. note 106.

108 France added 862 MW for a total of 8,968 MW, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1; and added 873 MW (and 4% decline relative to 2017) for a total of 8,920 MW, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 80, 86.

109 IEA PVPS, 2019 *Snapshot of Global PV Markets*, op. cit. note 1, p. 5. Italy added 435 MW for a total of 20,117 MW, and Spain added 374 MW for a total of 5,619 MW, from Becquerel Institute, op. cit. note 1, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 1. Data from Becquerel Institute for Spain were based on additions of 287.87 MW grid-connected and 86.42 MW of off-grid capacity, for a total of 374.29 MW added in 2018, from Unión Española Fotovoltaica (UNEF). Hungary installed over 400 MW in 2018, and Italy closed out the year with 19.9 GW, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 1, pp. 15, 83. Hungary had a record year (410 MW added for total of around 700 MW), driven by a FIT and net metering, from Ádám Szolnoki, Hungarian Photovoltaic Industry Association, cited in Emiliano Bellini, "Hungary deployed more than 400 MW of solar in 2018", pv magazine, 10 April 2019, https://www.pv-magazine.com/2019/04/10/hungary-deployed-more-than-400-mw-of-solar-in-2018/.

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WIND POWER

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15 EU share and six member states from WindEurope, op. cit. note 7, p. 17; Denmark's share of consumption from Bjarke Lund Larsen, "2018 satte record i solenergi", Dansk Energi, updated 8 January 2019, https://www.danskenergi.dk/nyheder/2018-satte-rekord-solenergi (using Google Translate). In addition to Denmark, the European countries ranked from highest to lowest share of annual electricity demand met by wind power were Ireland (28%), Portugal (24%), Germany (21%), Spain (19%) and the United Kingdom (whose share increased the most of all countries in Europe, from 13.5% to 18%), all from WindEurope, op. cit. note 7, p. 17. Denmark's share of production (48%) based on net wind power generation of 13,899 GWh during all of 2018, and total net generation from all sources of 28,940 GWh in 2018, from Danish Energy Agency, "Månedlig elstatistik. Hele landet", in Monthly Energy Statistics, "Electricity Supply", January 2019 version, https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics, viewed 27 March 2019.

16 Based on nine countries in Europe as well as Costa Rica, Nicaragua and Uruguay, all from sources provided in this note. Most of these countries are in Europe, a sign of a mature wind market, from Ohlenforst, op. cit. note 7. Nine countries in Europe (Denmark, Ireland, Portugal, Germany, Spain, United Kingdom, Sweden, Romania and Austria) from WindEurope, op. cit. note 7, pp. 8, 17. Note that Greece, Lithuania and the Netherlands were at 9%, from idem. **Portugal** had a 23% share, from Portuguese power utility Redes Energeticas Nacionais (REN), cited in Lucas Morais, "Renewables account for 52% of Portugal's consumption in 2018", Renewables Now, 4 January 2019, https://renewablesnow.com/news/renewables-account-for-52-of-portugals-consumption-in-2018-638471/. The **United Kingdom** met 17% of its power needs with wind energy, from Susanna Twidale, "Britain targets a third of electricity from offshore wind by 2030", *Reuters*, 6 March 2019, https://www.reuters.com/article/us-britain-windfarm/britain-targets-a-third-of-electricityfrom-offshore-wind-by-2030-idUSKCN1QO00K, and 17.1%, with 9.1% from onshore wind capacity and 8% from offshore, from Rob Norris, "New annual wind energy record shows wind power taking central role in UK's modern energy system", renewableUK, 28 March 2019, https://www.renewableuk.com/news/444033/New-annual-wind-energy-record-shows-wind-power-taking-central-role-in-UKs-modern-energy-system.htm. **Costa Rica** met nearly 16% (15.84%) of gross electricity production with wind energy in 2018, from Centro Nacional de Control de Energía, Instituto Costarricense de Electricidad, *Generación y Demanda Informe Annual, 2018* (San José: 2019), p. 2, https://apps.grupoice.com/CenceWeb/CenceDescargaArchivos.jsf?init=true&categoria=3&codigoTipoArchivo=3008, and 11.5% in 2017, from Instituto Costarricense de Electricidad, *Generación y Demanda Informe Annual Centro Nacional de Control de Energía, 2017* (San José: March 2018), p. 2, https://appcenter.grupoice.com/CenceWeb/CenceDescargaArchivos.jsf?init=true&categoria=3&codigoTipoArchivo=3008. **Uruguay**

from Ministerio de Industria, Energía y Minería (MIEM), "Generación de electricidad por fuente (GWh)", personal communication with REN21, 21 March 2019. **Nicaragua** generated 18.6% of net generation with wind energy in 2018, from Instituto Nicaragüense de Energía (INE), Ente Regulador, "Generación neta de energia electrica sistema eléctrico nacional año 2018", https://www.ine.gob.ni/DGE/estadisticas/2018/generacion_neta_2018_actfeb19.pdf, viewed 14 April 2019, and 15.1% in 2017, from INE, Ente Regulador, "Generación neta sistema eléctrico nacional año 2017", http://www.ine.gob.ni/DGE/estadisticas/2017/generacion_neta_2017_actmar18.pdf, viewed 12 April 2018.

17 Uruguay data for 2014 based on historical data from MIEM, "Generación bruta de energía eléctrica por planta", http://www.dne.gub.uy/publicaciones-y-estadisticas/planificacion-y-balance/estadisticas?p_p_auth=LJ2wf27A&p_p_id=101&p_p_lifecycle=0&p_p_state=maximized&_101_struts_action=%2Fasset_publisher%2Fview_content&_101_assetEntryId=39886&_101_type=document&redirect=%2F-%2Fseries-estadisticas-de-energia-electrica-, viewed 1 April 2018; data for 2017 (26.3%) and 2018 from MIEM, op. cit. note 16.

18 Share of 5.5% based on the following: estimated wind generation of 1,471 TWh, based on wind power capacity at end-2018 from the following sources: Costa Rica, Dominican Republic, Guatemala, Iran, Israel, Jamaica, New Zealand, Panama and Peru from IRENA, *Renewable Energy Capacity Statistics Database*, https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Statistics-Time-Series, viewed April 2019; **Europe** (including the **Russian Federation**) from WindEurope, op. cit. note 7, p. 10; **Honduras** from Empresa Nacional de Energía Eléctrica (ENEE), *Boletín de Datos Estadistíco Diciembre 2018* (Tegucigalpa: undated), p. 2, http://www.enee.hn/planificacion/2019/Boletin%20Estadistico%20Diciembre2018.pdf; **Nicaragua** from INE, "Capacidad Instalada Sistema Eléctrico Nacional", p. 1, https://www.ine.gob.ni/DGE/estadisticas/2018/Capacidad_Instalada_2_2018_actMar19.pdf; **Turkey** from Turkish Wind Energy Association (TWEA), *Türkiye Rüzgar Enerjisi Istatistik Raporu 2019* (Ankara: 2019), p. 5, http://www.tureb.com.tr/files/bilgi_bankasi/turkiye_res_durumu/istatistik_raporu_ocak_2019.pdf; **United States** from AWEA, "Consumer demand drives record year for wind energy purchases", press release (Washington, DC: 30 January 2019), https://www.awea.org/resources/news/2019/consumer-demand-drives-record-year-for-wind-energy); **Uruguay** from MIEM, "Renewable Energy Market Data – Renewable Energy Source", provided by MIEM, personal communications with REN21, March 2019; remaining countries and regions from GWEC, op. cit. note 1, p. 29. Generation estimated with selected weighted average capacity factors by region, and for both onshore and offshore wind power, from the following sources: **Asia** from Feng Zhao, GWEC, personal communication with REN21, 14 May 2019; **Brazil** from Operador Nacional do Sistema Eléctrico (ONS), *Boletim Mensal de Geração Eólica Março 2019* (Brasilia: 2019), p. 31, http://ons.org.br/AcervoDigitalDocumentosEPublicacoes/Boletim_Eolica_mar%C3%A7o_%202019.pdf; **Europe** from WindEurope, op. cit. note 7, p. 19; remaining countries and regions from IRENA, personal communications with REN21, April 2019. Total global electricity generation in 2018 estimated at 26,698 TWh, based on 25,679 TWh in 2017 from OECD/IEA, *World Energy Outlook 2018* (Paris: 2018), p. 528, https://www.iea.org/weo2018/, and on estimated 3.97% growth in global electricity generation in 2018. Growth rate in 2018 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 2017): United States (+3.6% net generation), EU (+0.0%), Russian Federation (+1.6%), India (+1.0%), China (+7.7%), Canada (-1.2%) and Brazil (+1.4%). Generation data for 2017 and 2018 by country or region from the following: US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2018* (Washington, DC: February 2019), Table 1.1, https://www.eia.gov/electricity/monthly/archive/february2019.pdf; European Commission, Eurostat database, http://ec.europa.eu/eurostat, viewed April 2019; Ministry of Energy of the Russian Federation, "Statistics", https://minenergo.gov.ru/en/activity/statistic; Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly generation report", http://www.cea.nic.in/monthlyarchive.html, viewed April 2019; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2018 national economic and social development", press release (Beijing: 28 February 2019), http://www.stats.gov.cn/english/PressRelease/201902/t20190228_1651335.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 18 April 2019; ONS, "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed April 2019. Wind energy generated an estimated 5% of global electricity in 2018, from OECD/IEA, *Global Energy & CO2 Status Report: The Latest Trends in Energy and Emissions in 2018* (Paris: 2018), data tables, https://www.iea.org/geco/data/, viewed 28 April 2018; wind energy generated enough electricity in 2018 to meet close to 6% of global electricity demand, from WWEA, op. cit. note 1; there was enough capacity in place at the end of 2018 to generate about 1,182 TWh (a conservative assumption of an average load factor of 23%), which is about 4.7% of global electricity output, calculated on a 25,000 TWh base, from EurObserv'ER, *Wind Energy Barometer* (Paris: March 2019), p. 3, https://www.eurobserv-er.org.

19 Figure of 48% in 2017 based on data from GWEC, *Global Wind Report – Annual Market Update 2017*, op. cit. note 4, p. 17; figure of 52% and total in 2018 based on data from GWEC, op. cit. note 1.

20 Shares based on data from GWEC, op. cit. note 1. 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.

21 Based on data from GWEC, "51.3 GW of global wind capacity installed in 2018", op. cit. note 3, and GWEC, op. cit. note 1, p. 29.

22 Based on data from GWEC, op. cit. note 1, p. 29, from WindEurope, op. cit. note 7, p. 10, and from GWEC, *Global Wind Report – Annual Market Update 2017*, op. cit. note 4. **Figure 36** based on country-specific data and sources provided throughout this section (or see endnote for Reference Table R20).

23 Based on newly installed capacity in 2018 of 21,143 MW for cumulative total of about 210 GW, and 1,655 MW offshore capacity added for total of 4,445 GW, all from China Renewable Energy Society Wind Energy Committee, the China Agricultural Machinery Industry Association Wind Power Branch and the National Renewable Energy Center, "2018 China Wind Power Lifting Capacity Statistics Briefing", cited in CWEA, "This year, the downward adjustment of wind power pricing will become a trend. There are two options for cutting old and new", 25 April 2019, http://www.cwea.org.cn/news_lastest_detail.html?id=242 (using Google Translate), and CWEA, "Wind power has achieved remarkable results in 2018. The installed capacity of offshore wind power is obviously increasing", 25 April 2019, http://www.cwea.org.cn/news_lastest_detail.html?id=243 (using Google Translate); increase of 7.5% based on additions of 19,660 MW in 2017, from CWEA, "2017 China wind power lifting capacity statistics presentation", 3 April 2018 (using Google Translate), provided by Liming Qiao, GWEC, personal communication with REN21, 2 May 2018. Data published by CWEA are issued jointly by members of the Wind Energy Professional Committee of the Chinese Association of Renewable Energy, the Wind Machinery Branch of the China Agricultural Machinery Industry Association and the National Renewable Energy Center, and include all capacity that has been fully installed (but is not necessarily grid-connected) as reported by companies involved in project construction, per Qiao, op. cit. this note.

24 China Renewable Energy Society Wind Energy Committee, the China Agricultural Machinery Industry Association Wind Power Branch and the National Renewable Energy Center, "2018 China Wind Power Lifting Capacity Statistics Briefing", cited in CWEA, op. cit. note 23; CWEA, "Wind power has achieved remarkable results in 2018", op. cit. note 23. China added 25.9 GW in 2018 for total of 221 GW, from WWEA, op. cit. note 1, and China added a net of 20.3 GW for a total of 184.7 GW, based on data from IRENA, op. cit. note 1, p. 14.

25 China National Energy Administration (NEA), "Introduction to the operation of renewable energy grid connection in 2018", 28 January 2019, http://www.nea.gov.cn/2019-01/28/c_137780519.htm (using Google Translate); NEA, cited in China Electricity Council (CEC), "Wind power grid connection operation in 2018", 29 January 2019, http://www.cec.org.cn/yaowenkuaidi/2019-01-29/188549.html (using Google Translate). Differences in statistics result at least in part from differences in what is counted and when. Most of the capacity added in 2018 was feeding the grid by year's end. The difference in

statistics among Chinese organisations and agencies is because they count different things: installed capacity refers to capacity that is constructed and usually has wires carrying electricity from the turbines to a substation; capacity qualifies as grid-connected (i.e., included in CEC statistics) once certification is granted and operators begin receiving the FIT premium payment, which can take weeks or even months. It is no longer the case that thousands of turbines stand idle awaiting connection in China because projects must be permitted in order to start construction; however, 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, from Steve Sawyer, GWEC, personal communication with REN21, 20 April 2018. 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 Qiao, op. cit. note 23.

26 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).

27 Top provinces based on data from 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/.

28 Curtailment situation improved from NEA, op. cit. note 26; direct trade and transmission lines from, for example, Liu Yuanyuan, "China's Xinjiang region cuts wind and solar curtailment rate by almost 30 percent", Renewable Energy World, 27 December 2017, https://www.renewableenergyworld.com/articles/2017/12/china-s-xinjiang-region-cuts-wind-and-solar-curtailment-rate-by-almost-30-percent.html, and from GWEC, *Global Wind Report – Annual Market Update 2017*, op. cit. note 4, p. 40; limitations from Liu Yuanyuan, "China's wind industry installs more than 20 GW of capacity in 2018 and curtailment decreases", Renewable Energy World, 5 February 2019, https://www.renewableenergyworld.com/articles/2019/02/chinas-wind-industry-installs-more-than-20-gw-of-capacity-in-2018-and-curtailment-decreases.html.

29 National curtailment data for 2018 from NEA, op. cit. note 26, and from NEA, "Introduction to the operation of renewable energy grid connection in 2018", op. cit. note 25; national curtailment data for 2017 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 49.7 TWh, from NEA and CEC, provided by Shi 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).

30 In Xinjiang, the curtailment rate fell more than 5 percentage points relative to 2017, to 23%; Gansu's declined more than 14 percentage points, to 19%; Inner Mongolia's also fell more than 14 percentage points, to 10%, all from NEA, op. cit. note 26.

31 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.

32 Figures of 20% and 366 TWh from NEA, op. cit. note 26, and from NEA, "Introduction to the operation of renewable energy grid connection in 2018", op. cit. note 25; 5.2% in 2018 from China Energy Portal, op. cit. note 27, 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); 4.8% in 2017 from China National Energy Board, cited in NEA, "Wind grid operation in 2017", op. cit. note 29. Wind generation in 2017 was 305.7 TWh, from China National Energy Board, cited in NEA, "Wind grid operation in 2017", op. cit. note 29. This was up from 241 TWh and 4% of generation in 2016, from NEA, "Wind power grid operation in 2016", op. cit. note 29; and 186.3 TWh and 3.3% in 2015, from China National Energy Board, cited by NEA, "2015 wind power industry development", 2 February 2016, www.nea.gov.cn/2016-02/02/c_135066586.htm (using Google Translate).

33 Nearly 50% based on 4,148 MW added in 2017 and 2,191 MW in 2018, from GWEC, op. cit. note 1; FTI Consulting, *Global Wind Market Update – Demand & Supply 2017, Part Two – Demand Side Analysis* (London: April 2018), p. 20, https://fti-intelligenceresearch.com/gwmu2017-demand-side-analysis/. 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.

34 Added 2,191 MW for a total of 35,129 MW, from GWEC, op. cit. note 1; added 2,290 MW for a total of 35,138 MW based on data from Government of India, Ministry of Power, CEA, *All India Installed Capacity, Monthly Report January 2019* (New Delhi: 2019), Table: "All India installed capacity (in MW) of power stations (as on 31.01.2019) (utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-01.pdf, and from Government of India, Ministry of Power, CEA, *All India Installed Capacity, Monthly Report January 2018* (New Delhi: 2018), Table: "All India installed capacity (in MW) of power stations (as on 31.01.2018) (utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2018/installed_capacity-01.pdf.

35 Figure of 9.2 GW represents capacity that was bid out and under implementation as of December 2018, from Indian Ministry of New and Renewable Energy (MNRE), provided by Manoj Singh, India Power Corporation Limited, personal communication with REN21, 6 April 2019. Figure was 9.8 GW based on awardee auctions, from Ohlenforst, op. cit. note 7. As of March 2019, about half of the more than 1 GW capacity awarded in first auctions, in 2017, were incomplete five months after their commissioning deadline, from Anindya Upadhyay, "Indian wind farm developers face troubling delays in getting projects built", Renewable Energy World, 1 March 2019, https://www.renewableenergyworld.com/articles/2019/03/indian-wind-farm-developers-face-troubling-delays-in-getting-projects-built.html.

36 Turkey installed 497 MW for total of 7,369 MW, from TWEA, op. cit. note 18, p. 5; WindEurope, op. cit. note 7, p. 10.

37 GWEC, op. cit. note 1.

38 Ibid. Vietnam and Chinese Taipei also added small amounts of capacity in 2018, from idem, and Indonesia added 75 MW for a total of the same amount, from idem, p. 45. Another source shows that Thailand added 130 MW to an existing 648 MW for a year-end total approaching 800 MW, and that Vietnam added 92 MW for a total of 289 MW, from Windpower Intelligence, cited in David Weston, "The 7 best performing wind markets in 2018", Windpower Monthly, 7 January 2019, https://www.windpowermonthly.com/article/1522140/7-best-performing-wind-markets-2018.

39 Added 10,111 MW gross capacity, made up of 7,450 MW onshore and 2,661 MW offshore, and a net of 9,690 MW, for a total of 178,826 MW (including 160,332 MW onshore and 18,495 MW offshore), all from WindEurope, op. cit. note 7, pp. 7, 10, 19. The EU had gross additions of 10,051 MW, less 345 MW of decommissioned capacity, for net additions of 9,706 MW, bringing the cumulative total to 178,950 MW, from EurObserv'ER, op. cit. note 18, p. 5.

40 Decline of 35% based on gross additions of 15,638 MW in 2017, and rush to install, all from WindEurope, *Wind in Power 2017: Annual Combined Onshore and Offshore Wind Statistics* (Brussels: February 2018), pp. 7, 9, 11, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf.

41 Based on data and information from WindEurope, op. cit. note 40, from GWEC, op. cit. note 1, p. 25, and from WindEurope, op. cit. note 7.

42 WindEurope, op. cit. note 7, p. 8; data for 2017 from WindEurope, op. cit. note 40, pp. 7, 9, 15.

43 Based on data from European Network of Transmission System Operators for Electricity (ENTSO-E) Transparency Platform, cited in WindEurope, op. cit. note 7, pp. 8, 17-19. EU wind power capacity generated 362 TWh in 2018, and total EU electricity consumption in 2018 was 2,645 TWh, from idem. That 2018 was less windy relative to 2017 was reflected in lower capacity factors for wind power, both onshore (22%) and offshore (36%), from WindEurope, op. cit. note 7, p. 18. Wind energy's share of generation was 12% in 2012, from WindEurope, Brussels, personal communication with REN21, 29 March 2018.

44 Based on data from ENTSO-E Transparency Platform, cited in WindEurope, op. cit. note 7, pp. 8, 17-19. Wind power output was an estimated 379.3 TWh, a 4.7% rise over 2017, enough to account for 11.4% of the EU's total electricity output, from EurObserv'ER,

op. cit. note 18, p. 7.

45 Based on data from WindEurope, op. cit. note 7, p. 10.

46 Ibid., p. 10.

47 Germany added 3,371 GW gross (including gross additions of 2,402 MW onshore and 969 MW offshore) and 3,122 MW net (accounting for decommissioning of 249 MW), for a year-end total of 59,311 MW, from WindEurope, op. cit. note 7, p. 10. WindEurope reports net capacity connected to the grid by 31 December of each year, from WindEurope, personal communication with REN21, 30 April 2018. Data from other sources vary considerably due to differences in methodology. For example, end-2017 total of 55,719 MW and end-2018 total of 58,982 MW (net difference of 3,263 MW, including 2,273 MW onshore and 990 MW offshore), from Bundesministerium für Wirtschaft und Energie (BMWi), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik* (AGEE-Stat) (Stand: Februar 2019) (Berlin: 2019), p. 7, https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2018.pdf; additions of 2,402 MW onshore and 1,312 MW offshore, and end-2018 total of 59,560 MW (53,180 MW onshore and 6,380 MW offshore), from GWEC, op. cit. note 1, p. 29; net additions of 3,123 MW (2,154 MW onshore and 969 MW offshore) and end-2018 total of 59,313 MW (52,931 MW onshore and 6,382 MW offshore), from Deutsche WindGuard, *Status of Land-based Wind Energy Development in Germany, Year 2018* (Varel: 2019), p. 3, https://www.windguard.com/year-2018.html, and from Deutsche WindGuard, *Status of Offshore Wind Energy Development in Germany, Year 2018* (Varel: 2019), p. 3, https://www.windguard.com/year-2018.html; end-2017 total of 56,190 MW and end-2018 total of 59,313 MW (for net additions of 3,123 MW), from WWEA, op. cit. note 1; and 3,374 MW added (185 MW decommissioned) for a year-end total of 58,908 MW, from EurObserv'ER, op. cit. note 18, p. 7.

48 Almost half based on down 49%, from WindEurope, op. cit. note 7, p. 8; down 51.9% based on year-end data for 2016, 2017 and 2018, from BMWi, op. cit. note 47, p. 7; down 48% from EurObserv'ER, op. cit. note 18, p. 7; period of rapid expansion (2013-2017) from VDMA (Mechanical Engineering Industry Association) and Bundesverband WindEnergie e.V. (BWE), cited in Vera Eckert, "German onshore wind industry warns of sharp drop in new turbines", *Reuters*, 29 January 2019, https://www.reuters.com/article/us-germany-wind-onshore/german-onshore-windindustry-warns-of-sharp-drop-in-new-turbines-idUSKCN1PN1J1.

49 VDMA and BWE, cited in Eckert, op. cit. note 48; Jason Deign, "Europe on the cusp of a 'corporate PPA revolution'", Greentech Media, 4 September 2019, https://www.greentechmedia.com/articles/read/windeurope-europe-on-verge-of-corporate-ppa-revolution; Ivan Komusanac, WindEurope, Brussels, personal communication with REN21, 13 April 2019; EurObserv'ER, op. cit. note 18, p. 8.

50 Generation increase based on total gross electricity production from wind energy onshore and offshore in 2017 (105,693 GWh) and in 2018 (111,590 GWh), and share of total gross electricity consumption (15.4% onshore and 3.2% offshore), from BMWi, op. cit. note 47, pp. 6, 44. Wind produced 111 TWh (on and offshore), or 20.4% of total German power output, from Fraunhofer Institute, cited in Vera Eckert, "Renewables overtake coal as Germany's main energy source", *Reuters*, 3 January 2019, https://uk.reuters.com/article/us-germany-power-renewables/renewables-overtakecoal-as-germanys-main-energy-source-idUKKCN1OX0U2. Wind accounted for 13.3% of total net generation, based on Germany's total net generation of 541.88 TWh and net wind power generation of 111.46 TWh, from Fraunhofer Institute for Solar Energy Systems, "Energy charts – annual electricity generation in Germany in 2017", https://www.energy-charts.de/energy.htm?source=all-sources&period=annual&year=2018, updated 13 March 2019.

51 Based on 4,270 MW added in 2017, from WindEurope, op. cit. note 40, pp. 9, 11, and on 1,901 MW added in 2018, of which 589 MW was onshore and 1,312 MW was offshore, for a total of 20,970 MW, from WindEurope, op. cit. note 7, p. 10. Added 1,957 MW (net increase of 731 MW onshore and 1,226 MW offshore) for a total of 21,743 MW, based on data from UK Department for Business, Energy & Industrial Strategy, "Energy Trends: Renewables, Section 6, Renewable electricity capacity and generation", Table 6.1 "Renewable electricity capacity and generation", https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, viewed 8 May 2019. The year 2017 saw a peak in onshore installations due to the pending transition away from the Renewables Obligation to a need for new wind installations to rely on PPAs and other merchant options, from WindEurope, op. cit. note 7, p. 12. The UK added 2.9 GW for a total of 20.7 GW, from WWEA, op. cit. note 1.

52 Wind energy's share of generation was 17.1%, with 9.1% from onshore wind capacity and 8% from offshore, from Norris, op. cit. note 16.

53 Ibid.; Adam Vaughan, "Wind power overtakes nuclear for the first time in UK across a quarter", *The Guardian* (UK), 16 May 2018, https://www.theguardian.com/environment/2018/may/16/wind-power-overtakes-nuclear-for-first-time-in-uk-across-a-quarter. In 2017, the United Kingdom's National Grid paid GBP 100 million for curtailment, and payments were down by two-thirds as of May, from idem. See also Joshua S. Hill, "British wind power sets new generation record", CleanTechnica, 4 December 2018, https://cleantechnica.com/2018/12/04/british-wind-power-sets-new-generation-record/.

54 France added 1,565 MW gross (1,552 net based on 13 MW decommissioned) for a total of 15,309 MW; Sweden added 717 MW (decommissioned 3 MW), including 3 MW offshore, for a total of 7,407 MW; Belgium added 513 MW, of which 309 MW was offshore, for a total of 3,360 MW, all from WindEurope, op. cit. note 7, p. 10. France added 1,558 MW for a total of 15,108 MW, from Réseau de transport d'électricité (RTE), *Bilan Électrique 2018* (Paris: 2019), p. 26, https://www.rte-france.com/sites/default/files/be_pdf_2018v3.pdf, added 1.5 GW for a total of 15.1 GW, from French energy ministry, cited in "France added 1.5 GW of wind power capacity in 2018", *Reuters*, 28 February 2019, https://www.reuters.com/article/france-renewables-idUSL5N20N3CV, and added 1.5 GW for a total of 15.3 GW from WWEA, op. cit. note 1.

55 Spain added 397 MW in 2018 for a total of 23,494 MW, from WindEurope, op. cit. note 7, p. 10; Spain added 1,110 MW in 2012, but 175 MW in 2013 and below 100 MW for each of the years 2014-2017, from "AEE presentó en WindEurope los datos de la eólica en España", REVE, 3 April 2019, https://www.evwind.com/?s=%2Fespana-incremento-la-potencia-eolica-en-392-mw-en-2018.

56 Norway added 480 MW for a total of 1,675 MW, and Serbia added 356 MW for a total of 374 MW, from WindEurope, op. cit. note 7, p. 10.

57 WindEurope, op. cit. note 7, p. 10; see also Maja Zuvela, "First wind farm operational in coal-reliant Bosnia", *Reuters*, 14 March 2018, https://uk.reuters.com/article/us-bosnia-energy-windfarm/firstwind-farm-operational-in-coal-reliant-bosnia-idUKKCN1GQ1OB.

58 First commercial wind farm from Steve Sawyer, GWEC, personal communication with REN21, 27 June 2018; "Russia's first commercial-scale wind farm has been commissioned", REVE, 15 January 2018, https://www.evwind.es/2018/01/15/russias-first-commercial-scale-wind-farm-has-been-commissioned/62378; Fortum, "Fortum adds 35 MW of wind power to the Russian power market", press release (Espoo, Finland: 12 January 2018), https://www3.fortum.com/media/2018/01/fortum-adds-35-mw-wind-power-russian-power-market. The project was the first to result from a Russian tender in 2014, from FTI Consulting, op. cit. note 33, p. 17; Russian tender from GWEC, *Global Wind Report – Annual Market Update 2017*, op. cit. note 4, p. 12; first firm orders from WindEurope, *Wind Energy in Europe: National Policy and Regulatory Developments January 2019* (Brussels: January 2019), p. 40.

59 Capacity awarded through government tenders and auctions based on data from WindEurope, op. cit. note 7, p. 21. In addition, results of the Finnish auction from December 2018 were published in early 2019, with 505 MW of onshore wind awarded feed-in premium, from Komusanac, op. cit. note 49. Corporate wind deals from WindEurope, "Corporate wind energy PPAs are booming", press release (Brussels: 29 January 2019), https://windeurope.org/newsroom/press-releases/corporate-wind-energy-ppas-are-booming/. The 1.5 GW of new corporate contracts in 2018 included deals in Sweden and Norway by aluminium manufacturers Norsk Hydro and Alcoa, in Germany and Poland by Mercedes-Benz, and PPAs signed by pharmaceutical companies; by early 2019, companies across Europe had signed 5 GW of wind power PPAs, from idem. Norway, a European leader in corporate PPAs, contracted 821 MW of capacity (all wind power) in 2018, from WindEurope, op. cit. note 58, p. 39. Norsk Hydro signed a 29-year wind power contract in mid-year for a new project in Sweden, believed to be the world's longest-term corporate wind PPA, from "Aluminium giant signs world's longest wind contracts; UK targets 2 GW offshore installs per year", New Energy Update, 25 July 2018, http://newenergyupdate.com/wind-energy-update/aluminium-giant-signs-worlds-longest-wind-contract-uk-targets-2-gw-offshore. Note that in the EU specifically, under the Renewable

Energy Directive, member states are instructed to identify and remove administrative barriers to corporate PPAs for wind and solar power, from Deign, op. cit. note 49.

60 Regional share of new capacity from GWEC, "Americas install 11.9GW wind capacity in 2018 – increase by 12%", press release (Brussels: 5 February 2019), https://gwec.net/americas-install-11-9gw-wind-capacity-in-2018-increase-by-12/; US share based on data from AWEA, op. cit. note 18, and from GWEC, *Global Wind Report – Annual Market Update 2017*, op. cit. note 4.

61 Second place based on data and sources throughout this section; 7,588 MW added and share installed in fourth quarter based on installations noted for full year and fourth quarter additions of 5,944 MW, all from AWEA, op. cit. note 18; 8% increase from AWEA, cited in Veselina Petrova, "US adds 7.6 GW of fresh wind in 2018", Renewables Now, 31 January 2019, https://renewablesnow.com/news/us-adds-76-gw-of-fresh-wind-in-2018-641247/. Of the fourth quarter additions, 909 MW was partial repowerings, from idem.

62 Based on 96,488 MW of capacity in operation across 41 states, and another 16,521 MW under construction, from AWEA, op. cit. note 18. The United States added 7.6 GW for total of 96 GW, from WWEA, op. cit. note 1.

63 Texas ended 2018 with 24,899 MW of wind power capacity, from AWEA, cited in Petrova, op. cit. note 61; South Dakota from AWEA, op. cit. note 18.

64 "United States: Windpower Monthly Rating 4/5", Windpower Monthly, https://www.windpowermonthly.com/united-states, viewed 12 March 2019.

65 US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), *2017 Wind Technologies Market Report* (Washington, DC: 2018), p. 11, https://emp.lbl.gov/sites/default/files/2017_wind_technologies_market_report.pdf.

66 Utilities signed contracts for 4,304 MW, and non-utility customers signed contracts for 4,203 MW, from AWEA, op. cit. note 18.

67 See, for example: Greg Alvarez, "2018 highlights: Six trends shaping the future of wind power", AWEA blog, 10 January 2019, https://www.aweablog.org/2018-highlights-six-trends-shaping-future-wind-power/; Erin 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; Rye 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; Greg Alvarez, "A huge record in the Southwest Power Pool", AWEA blog, 22 March 2018, http://www.aweablog.org/huge-new-record-southwest-power-pool/.

68 States include Kansas (36.4%), Iowa (33.8%), Oklahoma (31.7%), North Dakota (25.8%), South Dakota (24.4%) and Maine (21.1%), with another six states (Colorado, Minnesota, Nebraska, New Mexico, Texas and Vermont) in which wind supplied over 10%, and 6.6% of US total, all based on data for utility-scale facilities net generation during 2018 from EIA, op. cit. note 18, Tables 1.14.B and 1.3.B.

69 The region added 3,789 MW of capacity, based on data from GWEC, op. cit. note 1; percentage increase from GWEC, "Americas install 11.9GW wind capacity in 2018", op. cit. note 60.

70 Based on data from GWEC, op. cit. note 1, p. 29.

71 Ibid.

72 Brazil added 1,939 MW for a total of 14,707 MW, from GWEC, op. cit. note 1, p. 29; Brazil ended the year with 14.71 GW of wind power capacity, from Associação Brasileira de Energia Eólica (ABEEólica), *Números ABEEólica* (January 2019), p. 2, http://abeeolica.org.br/wp-content/uploads/2019/02/N%C3%BAmeros-ABEE%C3%B3lica-01.2019.pdf.

73 Data for 2018 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; data for 2017 from ABEEólica, "CCEE: geração eólica cresce 26,5% em 2017", 19 February 2018, http://www.abeeolica.org.br/noticias/ccee-geracao-eolica-cresce-265-em-2017/ (using Google Translate); data for 2017 and 2016 (5.9%) also from ONS, op. cit. note 18, viewed March 2018.

74 Mexico added 929 MW, from GWEC, "51.3 GW of global wind capacity installed in 2018", op. cit. note 3; total of 4,935 MW from GWEC, op. cit. note 1, p. 29.

75 Argentina added 494 MW for a total of 722 MW, and Chile added 207 MW for a total of 1,747 MW, from GWEC, op. cit. note 1, p. 29; Argentina added about 412 MW to increase its total from 228 MW at the end of 2017 to 640 MW at the end of 2018, from Windpower Intelligence, cited in Weston, op. cit. note 38.

76 GWEC, "Americas install 11.9 GW wind capacity in 2018", op. cit. note 60; GWEC, op. cit. note 1, p. 36. Other countries in the region that have held auctions and tenders include Belize, Uruguay and El Salvador, from Ohlenforst, op. cit. note 7.

77 Canada added 566 MW, from Canadian Wind Energy Association (CanWEA), "Installed capacity", https://canwea.ca/wind-energy/installed-capacity/, as of December 2018, viewed 11 March 2019; this is up almost 63% over the 348 MW added in 2017, from CanWEA, "Powering Canada's Future, December 2018", https://canwea.ca/wp-content/uploads/2019/02/powering-canadas-future-web.pdf, viewed 28 April 2019; tenth place based on data and sources throughout this section.

78 Largest source based on data from Statistics Canada, cited in CanWEA, "Powering Canada's Future", op. cit. note 77; 12,816 MW in operation at end-2018 and 6% both from CanWEA, "Installed capacity", op. cit. note 77.

79 Top provinces for operating capacity are Ontario (with 40% of Canada's installed capacity, or 5,076 MW); Québec (30%; 3,882 MW) and Alberta (nearly 12%; 1,483 MW); top provinces for share of electricity demand generated from wind energy are Prince Edward Island (28%), Nova Scotia (12%) and Ontario (8%), with estimates based on year-end capacity, all from CanWEA, "Installed capacity", op. cit. note 77.

80 GWEC, op. cit. note 1.

81 Australia added more than 0.5 GW for a total of 5.4 GW, from GWEC, op. cit. note 1. Australia commissioned 866.5 MW for total of 5,678.7 MW, from Clean Energy Council, op. cit. note 9, pp. 72-76.

82 Clean Energy Council, op. cit. note 9, pp. 72-76.

83 Sonali 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 idem.

84 Clean Energy Council, op. cit. note 9, pp. 72-76.

85 Based on data from GWEC, op. cit. note 1.

86 GWEC, "Africa and Middle East installed 962MW new wind capacity in 2018 – over 300MW more than in 2017", 11 February 2019, https://gwec.net/africa-and-middle-east-installed-962mw-new-wind-capacity-in-2018-over-300mw-more-than-in-2017/.

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88 LTWP, "#LTWP is going from strength to strength in 2019. Approx 140,000 MWh of clean energy was injected into Kenya's national grid in Jan's 31 days & then over 137,000 MWh in just 28 days in Feb -recording an average capacity factor of 80%, one of the highest in the world! #WindPower", Twitter, 11 March 2019, https://twitter.com/hashtag/LTWP?src=hash, provided by Sawyer, op. cit. note 10; see also "Sub-Saharan Africa's largest wind farm connected to grid", Development Channel, 13 March 2019, http://www.developmentchannel.org/2019/03/13/sub-saharan-africas-largest-wind-farm-connected-to-grid/.

89 Iran and Jordan from GWEC, op. cit. note 1; Saudi Arabia from Sawyer, op. cit. note 58.

90 "EDF and Masdar build first Saudi Arabian wind farm", Renewable Energy World, 14 January 2019, www.renewableenergyworld.com/articles/2019/01/edf-and-masdar-build-first-saudi-arabian-wind-farm.html. The project is the 400 MW Dumat al Jandal wind farm.

91 Based on data from GWEC, op. cit. note 1.

92 Number of countries and other data based on GWEC, op. cit. note 1. A total of 4,496 GW was added in 2018, raising cumulative capacity from 18,658 MW (end 2017) to 23,140 MW at the end of 2018, from idem.

93 GWEC, op. cit. note 1, p. 24.

94 Based on newly installed offshore capacity of 1,655 MW for a total of 4,445 GW, from China Renewable Energy Society Wind Energy Committee, the China Agricultural Machinery Industry Association Wind Power Branch and the National Renewable Energy Center, "2018 China Wind Power Lifting Capacity Statistics Briefing", op. cit. note 23, cited in CWEA; CWEA, "Wind power has achieved remarkable results in 2018", op. cit. note 23.

95 National target from GWEC, *Global Wind Report – Annual Market Update 2017*, op. cit. note 4, p. 58.

96 Provincial targets from GWEC, "Latest update on China offshore wind", 2018, http://gwec.net/latest-update-on-china-offshore-wind/, and from Feng Zhao, GWEC, personal communication with REN21, 17 April 2019.

97 GWEC, op. cit. note 1.

98 Europe added a gross capacity of 2,660 MW (2,649 MW net), down about 16% from 2017 additions, for a cumulative total of 18,499 MW offshore; about 70% of Europe's offshore capacity is in the North Sea; the rest is in the Irish Sea (16%), the Baltic Sea (12%) and the Atlantic Ocean (2%), all from WindEurope, *Offshore Wind in Europe: Key Trends and Statistics 2018* (Brussels: February 2019), pp. 7, 8, 9, 11, 18, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2018.pdf. Europe added an estimated net of 2,668.8 MW offshore in 2018, compared with 3,200.6 MW in 2017, from EurObserv'ER, op. cit. note 18, p. 5, and added 2,661 MW for a total of 18,278 MW, from GWEC, op. cit. note 1. The North Sea benefits from a good wind resource and shallow water conditions, from Stiesdal, "The potential of offshore windpower is enormous", https://www.stiesdal.com/offshore-windpower/, viewed 13 March 2019.

99 The United Kingdom commissioned 1,312 MW, followed by Germany (969 MW), Belgium (309 MW), Denmark (61 MW), Spain (5 MW), Sweden (3 MW) and France (2 MW), for a cumulative total of 18,499 MW offshore, from WindEurope, op. cit. note 98, pp. 7, 8, 9, 11.

100 "Spain gets its first offshore wind turbine", Offshore Wind, 21 June 2018, https://www.offshorewind.biz/2018/06/21/spain-gets-its-first-offshore-wind-turbine/; three floating turbines from WindEurope, op. cit. note 98, p. 14; see also WindEurope, op. cit. note 58, pp. 9, 39.

101 WindEurope, op. cit. note 98, pp. 8, 9, 34-35. Much of the additional investment was in capacity under construction; it takes 2-3 years to complete an offshore project once the final investment decision is made, from Komusanac, op. cit. note 49.

102 Total of 17 includes Germany, Spain, the United Kingdom, France, Sweden, Denmark, the Netherlands, Ireland, Belgium, Norway and Finland in Europe; China, Japan, Chinese Taipei, the Republic of Korea and Vietnam in Asia; and the United States, all based on data from GWEC, op. cit. note 1. European countries with demonstration projects only were France (including the Floatgen floating demonstrator), Norway (2.3 MW Hywind project) and Spain, and all other European countries with offshore wind power capacity had demonstration projects, from Lizet Ramirez, WindEurope, Brussels, personal communication with REN21, 16 April 2019.

103 The United Kingdom had 7,963 MW from GWEC, op. cit. note 1, and 8,183 MW, from WindEurope, op. cit. note 98, p. 12; Germany had 6,380 MW, Denmark 1,329 MW and Belgium 1,186 MW, all from idem, p. 12; and China ended the year with 4,445 MW, from China Renewable Energy Society Wind Energy Committee, the China Agricultural Machinery Industry Association Wind Power Branch and the National Renewable Energy Center, "2018 China Wind Power Lifting Capacity Statistics Briefing", op. cit. note 23, and from CWEA, "Wind power has achieved remarkable results in 2018", op. cit. note 23. Note that Denmark added 437 MW in 2018 for a year-end total of 1,700.8 MW, from Danish Energy Agency, cited in EurObserv'ER, op. cit. note 18, p. 6.

104 Based on data from GWEC, op. cit. note 1. **Figure 37** based on data from the following: GWEC, *Global Wind Report – Annual Market Update 2015* (Brussels: April 2016), pp. 50-51, http://www.gwec.net/wp-content/uploads/vip/GWEC-Global-Wind-2015-Report_April-2016_19_04.pdf; GWEC, *Global Wind Report – Annual Market Update 2016* (Brussels: April 2017), p. 58, http://www.gwec.net/strong-outlook-for-wind-power/; GWEC, *Global Wind Report – Annual Market Update 2017*, op. cit. note 4, p. 55; GWEC, op. cit. note 1, pp. 29, 33; Shi Pengfei, CWEA, personal communication with REN21, April 2010 and March 2017; FTI Consulting, *Global Wind Market Update – Demand & Supply 2016, Part Two – Demand Side Analysis* (London: March 2017), p. 60; WindEurope, *The European Offshore Wind Industry – Key Trends and Statistics 2016* (Brussels: January 2017), p. 17, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2016.pdf; WindEurope, *Offshore Wind in Europe – Key Trends and Statistics 2017* (Brussels: February 2018), p. 6, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2017.pdf; AWEA, "First US offshore wind farm unlocks vast new ocean energy resource", press release (Block Island, RI: 12 December 2016), https://www.awea.org/resources/news/2016/first-us-offshore-wind-farm-unlocks-vast-new-ocean.

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115 Ibid.

116 Ibid., p. v. However, per unit sales of units <1 kW increased during the year, from idem.

117 Total global capacity was an estimated 1.1 GW at end-2017, from Ibid., p. 9; approximately 1 million turbines and more than 1 GW in operation based on data as of end-2016, from WWEA, personal communications with REN21, April-May 2018.

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3 **Table R3** from the following sources: Renewable Energy Policy Network for the 21st Century (REN21) database; submissions by report contributors; various industry reports; share of final energy from World Bank, "Renewable energy consumption (% of total final energy consumption)", https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS, viewed 15 May 2019; Eurostat "Share of energy from renewable sources", http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_ren&lang=en, viewed 12 February 2019; IEA et al., *Tracking SDG7: The Energy Progress Report*, Data Annex (Washington, DC: World Bank, 2018), https://trackingsdg7.esmap.org/; share of primary energy from OECD, "Renewable energy", https://data.oecd.org/energy/renewable-energy.htm, viewed 16 May 2018; share of primary energy for **Côte d'Ivoire** and **Liberia** from BloombergNEF (BNEF), Climatescope 2017, "Results for all regions", http://global-climatescope.org/en/results/, viewed 17 May 2018; share of primary energy for **Canada** from Natural Resources Canada, "Renewable energy facts", https://www.nrcan.gc.ca/energy/facts/renewable-energy/20069, updated 12 September 2018; share of primary energy for **Colombia** from OECD, op. cit. this note, viewed 15 May 2019; primary share and target for **Indonesia** from Amanda Siddharta, "Indonesia struggles to meet renewable energy target", VOA News, 29 November 2018, https://www.voanews.com/a/indonesia-struggles-to-meet-renewable-energy-target/4679578.html; primary share for **Lao PDR** from Open Development Laos, "Energy", 8 October 2018, https://laos.opendevelopmentmekong.net/topics/energy/; primary share for **California** from EIA, "U.S. energy facts explained: Consumption & production", https://www.eia.gov/energyexplained/?page=us_energy_home, updated 16 May 2018; share and target of final energy for **Brunei Darussalam** from Angaindrankumar Gnanasagaran, "Brunei's shift towards renewables", The Asean Post, 6 May 2018, https://theaseanpost.com/article/bruneis-shift-towards-renewables; target for **Angola** from Ministry of Energy and Water, Angola Energy 2025, "New renewables strategy", http://www.angolaenergia2025.com/en/conteudo/new-renewables-strategy, viewed 15 May 2019; target for **Denmark** from IRENA, *Towards 100% Renewable Energy: Status, Trends and Lessons Learned* (Abu Dhabi: 2019), https://coalition.irena.org/-/media/Files/IRENA/Coalition-for-Action/IRENA_Coalition_100percentRE_2019.pdf; target for **Lithuania** from Vesilina Petrova, "Lithuania pursuing energy independence through renewables-based strategy", Renewables Now, 25 June 2018, https://renewablesnow.com/news/lithuania-pursuing-energy-independence-through-renewables-based-strategy-617518/; target for **Mauritania** from Regional Center for Renewable Energy and Energy Efficiency (RCREEE), "Mauritania", http://www.rcreee.org/content/mauritania, viewed 15 May 2019; target for **Panama** from BNEF, Climatescope 2017, "Panama Renewable Energy Target", http://global-climatescope.org/policies/4990, viewed 17 May 2019; target for **Peru** from Lucas Morais, "Wind, solar bring 4% of Peru's power in H1 2018",

Renewables Now, 24 August 2018, https://renewablesnow.com/news/wind-solar-bring-4-of-perus-power-in-h1-2018-624528/; target for **Sweden** from Government Offices of Sweden, "Government making broad investments in energy", 21 September 2017, https://www.government.se/press-releases/2017/09/government-making-broad-investments-in-energy/.

4 **Table R4** from the following sources: REN21 database compiled from all available policy references plus submissions from report contributors. European Union (EU) targets and shares from Eurostat, SHARES (Renewables) database, 2018, http://ec.europa.eu/eurostat/web/energy/data/shares, viewed 21 April 2019. Targets for the **EU-28** and Energy Community countries were set in each country's National Renewable Energy Action Plan (NREAP), from European Commission, "National renewable energy action plans 2020", https://ec.europa.eu/energy/en/topics/renewable-energy/national-renewable-energy-action-plans-2020, viewed 1 June 2019. Certain NREAP targets have been revised subsequently. Other targets from the following: **Austria** from Eurosolar, "National Energy Action Plan of Austria", https://www.eurosolar.de/en/index.php/sections-eurosolar/austria-eurosolar-sections/780-national-energy-action-plan-of-austria, viewed 16 May 2019; **Denmark** from IRENA, op. cit. note 3; **Lithuania** from Veselina Petrova, "Lithuania pursuing energy independence through renewables-based strategy", Renewables Now, 25 June 2018, https://renewablesnow.com/news/lithuania-pursuing-energy-independence-through-renewables-based-strategy-617518/.

5 **Table R5** from the following sources: REN21 database; submissions by report contributors; various industry reports; Eurostat, SHARES (Renewables) database, 2016, http://ec.europa.eu/eurostat/web/energy/data/shares, viewed 21 April 2019.

6 **Table R6** from the following sources: REN21 database; submissions by report contributors; various industry reports; Eurostat, op. cit. note 4. Targets for the **EU-28** were set in each country's NREAP; see note 4. Certain NREAP targets have been revised subsequently. Other targets from the following: **Argentina** from Mariyana Yaneva, Plamena Tisheva and Tsvetomira Tsanova, "2018 Argentina Renewable Energy Report 2018", Renewables Now, May 2018, http://minaaysp.cba.gov.ar/wp-content/uploads/2018/06/AIRECweek-2018-The-Argentina-Report.pdf; **Belize** from IRENA, "Clean Energy Corridor of Central America", Regional Meeting presentation, Panama, 23 May 2018, https://www.irena.org/-/media/Files/IRENA/Agency/Events/2018/May/Belize-presentation---accelerating-renewables-in-the-regional-market---23-May.pdf; **Cabo Verde** from Ministry of Environmental, Housing and Land Planning and the Ministry of Foreign Affairs, "Intended Nationally Determined Contribution of Cabo Verde", https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/Cabo%20Verde/1/Cabo_Verde_INDC_.pdf, viewed 18 May 2019; **China** from Bloomberg News Editors, "China sets new renewables target of 35 percent by 2030", Renewable Energy World, 26 September 2018, https://www.renewableenergyworld.com/articles/2018/09/china-sets-new-renewables-target-of-35-percent-by-2030.html; **Jamaica** from Office of the Prime Minister, "Jamaica to increase renewables target to 50% – PM Holness", Jamaican Information Service, 17 October 2018, https://jis.gov.jm/jamaica-to-increase-renewables-target-to-50-pm-holness/; **Lithuania** from Petrova, op. cit. note 4; **Malaysia** from Neily Syafiqah Eusoff, "Malaysia sets new goal of 20% clean energy generation by 2030", The Edge Markets, 18 September 2018, https://www.theedgemarkets.com/article/malaysia-sets-new-goal-18-clean-energy-generation-2030; **Sweden** from IRENA, op. cit. note 3; **Thailand** from Royal Thai Embassy, Washington, D.C., "Clean and green: government aims for 50% renewable energy", http://thaiembdc.org/2018/08/20/clean-and-green-government-aims-for-50-renewable-energy, viewed 12 December 2018; **California** from David Roberts, "California just adopted its boldest energy target yet: 100% clean electricity", Vox, 10 September 2018, https://www.vox.com/energy-and-environment/2018/8/31/17799094/california-100-percent-clean-energy-target-brown-de-leon; **New Jersey** from Jabir Mohamed, "New Jersey bill to close SREC program, increase solar RPS", Renewable Energy World, 29 August 2018, https://www.renewableenergyworld.com/ugc/articles/2018/08/29/new-jersey-bill-to-close-srec-program-increase-solar-rps.html; **District of Columbia** from Kelsey Misbrener, "Washington, D.C., sets 100% renewable energy target by 2032", Solar Power World, 19 December 2018, https://www.solarpowerworldonline.com/2018/12/washington-dc-100-percent-renewable-energy-by-2032/.

7 **Table R7** from the following sources: REN21 database; submissions by report contributors; various industry reports; EurObserv'ER. Targets for the EU-28 were set in each country's NREAP; see note 4. Certain NREAP targets have been revised subsequently. **Myanmar** target from Zaw Min Naing, "Renewable Energy Market Developments in Myanmar – Opportunities for Investments", presentation, Bangkok, Republic of the Union of Myanmar, Ministry of Education, 9 June 2017, http://www.entechpollutec-asia.com/Portals/0/conference/EEPO/1.%20Presentation%20EPPO%20Myanmar%20(MR216-217%20Afternoon%20Sec).pdf; **United Kingdom** target from Susanna Twidale, "Britain targets a third of electricity from offshore wind by 2030", *Reuters*, 6 March 2019, https://www.reuters.com/article/us-britain-windfarm/britain-targets-a-third-of-electricity-from-offshore-wind-by-2030-idUSKCN1QO00K.

8 **Table R8** from the following sources: REN21 database; submissions by report contributors; various industry reports. Other targets from the following: Emiliano Bellini, "Bahrain issues tender for solar IPP project at landfill site", pv magazine, 13 March 2018, https://www.pv-magazine.com/2018/03/13/bahrain-issues-tender-for-solar-ipp-project-at-landfill-site/; **Croatia** and **Kosovo** from Hydropower Balkans, Balkan Hydropower Overview, conference document, Podgorica, Montenegro, November 2017, https://www.hydropower.org/sites/default/files/Facts_Hydro_Balkans_en_NOV11.pdf; **France** from Mariyana Yaneva, "France locks renewables target for 70-76 GW by 2023", Renewables Now, 31 October 2016, https://renewablesnow.com/news/france-locks-renewables-target-for-70-76-gw-by-2023-545098/; **Massachusetts** from Offshore WIND, "Massachusetts opens door to additional 1.6 GW of offshore wind", 1 August 2018, https://www.offshorewind.biz/2018/08/01/massachusetts-opens-door-to-additional-1-6gw-of-offshore-wind/.

9 **Table R9** from the following sources: Ottmar Edenhofer et al., "Summary for Policymakers", in *Intergovernmental Panel on Climate Change Special Report on Renewable Energy Sources and Climate Change Mitigation* (Cambridge, UK: Cambridge University Press, 2011), https://www.ipcc.ch/site/assets/uploads/2018/03/Summary-for-Policymakers-1.pdf; IRENA, *Renewable Energy Benefits: Understanding the Socio-Economics* (Abu Dhabi: 2017), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_Understanding_Socio_Economics_2017.pdf; OECD/IEA, *Contribution of Renewables to Energy Security* (Paris: 2007), https://www.iea.org/publications/freepublications/publication/so_contribution.pdf; Alan Sherrard, "SEAI publishes terms and conditions draft for Irish renewable heat scheme", Bioenergy International, 10 August 2018, https://bioenergyinternational.com/policy/seai-publishes-terms-and-conditions-draft-for-irish-renewable-heat-scheme; **Netherlands** from IEA Policies & Measures Database, "Feed-in Premium Programme SDE + (Stimulering Duurzame Energie +)", https://www.iea.org/policiesandmeasures/pams/netherlands/name-24872-en.php, updated 19 July 2018; **United Kingdom** from "New UK heat networks investment project scheme to launch in the autumn", Bioenergy International, 11 April 2018, https://bioenergyinternational.com/policy/new-uk-heat-networks-investment-project-scheme-to-launch-in-the-autumn, and from IEA Policies & Measures Database, "Renewable Heat Incentive (RHI) for domestic and non-domestic generators", https://www.iea.org/policiesandmeasures/pams/unitedkingdom/name-24966-en.php, updated 29 July 2015.

10 **Table R10** from the following sources: all available policy references, including the IEA/IRENA online Global Renewable Energy Policies and Measures database, published sources as given in the endnotes for the Policy Landscape chapter of this report, and submissions from report contributors; Jim Lane, "Biofuels mandates around the world: 2019", Biofuels Digest, 1 January 2019, https://www.biofuelsdigest.com/bdigest/2019/01/01/biofuels-mandates-around-the-world-2019/; US Department of Agriculture, Foreign Agricultural Service, Global Agricultural Information Network, *EU-28: Biofuels Annual* (Washington, DC: 10 July 2019), https://www.fas.usda.gov/data/eu-28-biofuels-annual-0; OECD and United Nations Food and Agriculture Organization, *Agricultural Outlook 2018-2027* (Paris and Rome: 2018), p. 193, http://www.agri-outlook.org/commodities/Agricultural-Outlook-2018-Biofuels.pdf; Partnership on Sustainable Low Carbon Transport (SLoCaT), *E-Mobility Trends and Targets*, 29 November 2018, http://slocat.net/sites/default/files/e-mobility_overview.pdf. Other mandates from the following: **EU** from European Parliament, "Energy: new target of 32% from

renewables by 2030 agreed by MEPs and ministers", press release (Brussels: 14 June 2018), http://www.europarl.europa.eu/news/en/press-room/20180614IPR05810/energy-new-target-of-32-from-renewables-by-2030-agreed-by-meps-and-ministers; **Queensland** from Queensland Government, "Queensland biofuels mandates", https://www.business.qld.gov.au/industries/manufacturing-retail/retail-wholesale/selling-fuel-qld/qld-biofuels-mandates, updated 1 July 2018; **Colombia** from "Colombia increases ethanol blend mandate to 10%", Bioenergy International, 28 March 2018, https://bioenergyinternational.com/policy/colombia-increases-ethanol-blend-mandate-10; **Denmark, Germany, Italy, Netherlands, Sweden** and **United Kingdom** from International Council on Clean Transportation, "Advanced Biofuel Policies in Select EU Member States: 2018 Update" (November 2018), https://www.theicct.org/sites/default/files/publications/Advanced_biofuel_policy_eu_update_20181130.pdf; **Republic of Korea** from Jin-Suk Lee, Korea Institute of Energy Research, "Country Report: Korea", presentation, IEA Bioenergy Task 39 Beijing Meeting, 7-9 April 2018, http://task39.sites.olt.ubc.ca/files/2018/04/Korea_Presentation-file.pdf; **Norway** from "Norway to introduce 0.5% sustainable aviation fuel quota from 2020", Bioenergy International, 5 October 2018, https://bioenergyinternational.com/policy/norway-to-introduce-0-5-sustainable-aviation-fuel-quota-from-2020.

11 **Table R11** from the following sources: All available policy references, including the IEA/IRENA online Global Renewable Energy Policies and Measures database, published sources as given in the endnotes for the Policy Landscape chapter of this report, and submissions from report contributors. FIT policy adjustments from the following: **Australia** from Mike, "New South Wales solar feed-in tariff to drop by 44%", Saving with Solar, 4 July 2018, https://www.savingwithsolar.com.au/new-south-wales-solar-feed-in-tariff-to-drop-by-44/; **China** from Nitin Kabeer, "China ends wind feed-in tariffs and opts for auctions", Mercom India, 3 July 2018, https://mercomindia.com/china-ends-wind-feed-in-tariffs/, and from Jill Baker, "Solar leader China is slashing its subsidies on solar power – what you need to know", *Forbes*, 18 June 2018, https://www.forbes.com/sites/jillbaker/2018/06/18/solar-leader-china-is-slashing-its-subsidies-on-solar-power-what-you-need-to-know/; **Japan** from Andy Colthorpe, "End of 2009 feed-in tariff brings new era for Japan's solar homes", Energy Storage News, 5 December 2018, https://www.energy-storage.news/news/end-of-2009-feed-in-tariff-brings-new-era-for-japans-solar-homes, and from Emiliano Bellini, "Japan postpones FIT cuts by six months for projects over 2 MW", pv magazine, 6 December 2018, https://www.pv-magazine.com/2018/12/06/japan-postpones-fit-cuts-by-six-months-for-projects-over-2-mw/; **Ontario** from Government of Ontario, "Ontario scraps the Green Energy Act", 7 December 2018, https://news.ontario.ca/mndmf/en/2018/12/ontario-scraps-the-green-energy-act.html; **Serbia** from Vladimir Spasić, "Serbia pushes back introduction of renewables auctions by a year, extends existing support decree", Balkan Green Energy News, 27 November 2018, https://balkangreenenergynews.com/serbia-pushes-back-introduction-of-renewables-auctions-by-a-year-extends-existing-support-decree/; **Switzerland** from Alexander Richter, "Switzerland announces higher feed-in-tariffs for geothermal power generation", ThinkGeoEnergy, 17 August 2018, http://www.thinkgeoenergy.com/switzerland-announces-higher-feed-in-tariffs-for-geothermal-power-generation/; **United Kingdom** from Diana A. N., "UK government confirms plans to end feed-in tariff payments for new solar installations", pvbuzz, 20 December 2018, https://pvbuzz.com/end-feed-in-tariff-payments/; **Vietnam** from Koushan Das, "Vietnam increases feed-in tariffs for wind projects", Vietnam Briefing, 2 November 2018, https://www.vietnam-briefing.com/news/vietnam-increases-feed-in-tariffs-for-wind-projects.html/.

12 **Table R12** from the following sources: All available policy references, including the IEA/IRENA online Global Renewable Energy Policies and Measures database; OECD/IEA, *Renewable Energy Policy Update*, No. 18 (19 February 2018), https://www.iea.org/media/pams/REDRenewablePolicyUpdateNo1820180219_web.pdf; published sources as given in the endnotes for the Policy Landscape chapter of this report, and submissions from report contributors. Full sources can be found in the REN21 GSR 2019 Data Pack.

13 **Table R13** from the following sources: REN21 database, compiled from all available policy references, including published sources as given in the endnotes for the Policy Landscape chapter of this report, and submissions from report contributors. Sources for new additions can be found in the REN21 GSR 2019 Data Pack. For more comprehensive information on cities, see REN21, *Renewables in Cities 2019 Global Status Report* (Paris: forthcoming 2019), www.ren21.net/cities.

14 **Table R14** from the following sources: **Ethanol** from EIA, op. cit. note 1, Table 10.3, and from Brazil Agencia Nacional do Petroleo, Gas Natural e Biocombustiveis (ANP), "Dados estatísticos", http://www.anp.gov.br/dados-estatisticos, viewed 19 March 2019. **Biodiesel** from EIA, op. cit. note 1, and from ANP, op. cit. this note; Argentine Ministry of Energy and Mines, "Estadisticas de biodiesel y bioethanol", http://datos.minem.gob.ar/dataset/estadisticas-de-biodiesel-y-bioetanol, viewed 11 April 2019. Spain ethanol and biodiesel production from Comisión Nacional de los Mercados y la Competencia (CNMC), "Estadística de biocarburantes", https://www.cnmc.es/estadistica/estadistica-de-biocarburantes, viewed 8 June 2019. Other ethanol and biodiesel data based on biofuels data in OECD/IEA, *Oil 2019*, op. cit. note 1; HVO production is estimated based on a review of the production of the major producers.

15 **Table R15** from the following sources: data for **Italy, Japan, Mexico** and **New Zealand** from IEA Geothermal, *2018 Draft Annual Report* (Taupo, New Zealand: February 2019), http://iea-gia.org/publications-2/annual-reports/; IEA Geothermal, *Geothermal Power Statistics 2017* (Taupo, New Zealand: February 2019), http://iea-gia.org/publications-2/working-group-publications/; **Croatia** from Turboden, "Turboden completed the commissioning of the 17.5 MWe Velika Ciglena Geothermal Plant", press release (Brescia, Italy: 11 December 2018), https://www.turboden.com/upload/blocchi/X12219allegato1-2X_5269_Turboden_Velika_Ciglena_ENG.pdf; **Iceland** from Orkustofnun, *Energy Statistics in Iceland 2017* (Reykjavik: 2018), http://os.is/gogn/os-onnur-rit/Orkutolur-2017-enska.pdf; capacity of 753 MW based on capacity at end-2017 of 708 MW, with addition of 45 MW in 2018 from National Power Company of Iceland (Landsvirkjun), "Þeistareykjastöð komin í fullan rekstur", 18 April 2018, https://www.landsvirkjun.is/fyrirtaekid/fjolmidlatorg/frettir/frett/theistareykjastod-komin-i-fullan-rekstur/; **Indonesia** capacity at end-2018 from Indonesian Ministry of Energy and Mineral Resources (ESDM), "Pemerintah Tetap Komit, Pemanfaatan EBT Capai 23% Pada Tahun 2025", press release (Jakarta: 9 January 2019), https://www.esdm.go.id/en/media-center/news-archives/pemerintah-tetap-komit-pemanfaatan-ebt-capai-23-pada-tahun-2025; capacity of 1.81 GW at end-2017 from ESDM, "Capaian Sub Sektor Ketenagalistrikan Dan EBTKE Tahun 2017 Dan Outlook 2018", press release (Jakarta: 10 January 2018), https://www.esdm.go.id/en/media-center/news-archives/capaian-sub-sektor-ketenagalistrikan-dan-ebtke-tahun-2017-dan-outlook-2018; **Philippines** installed capacity of 1,916 MW as of 2017, from Philippines Department of Energy, Electrical Power Industry Management Bureau, *2017 Power Demand and Supply Highlights* (Taguig City, The Philippines: 2018), https://www.doe.gov.ph/sites/default/files/pdf/electric_power/2017-power-demand-and-supply-highlights-as-of-10122018.pdf; capacity additions of 12 MW in 2018 from Lenie Lectura, "Maibarara Geothermal puts power plant online", BusinessMirror, 12 March 2018, https://businessmirror.com.ph/maibarara-geothermal-puts-power-plant-online; "Maibarara-2 geothermal facility adds 12 MW to Luzon Grid", Power Philippines News, 12 March 2018, https://powerphilippines.com/maibarara-2-geothermal-facility-adds-12-mw-luzon-grid/; **Turkey** capacity of 1,063.7 MW and 40 plants at end-2017, and 43 plants and 1,199 MW of capacity as of September 2018, from Turkish Electricity Transmission Company (TEİAŞ), http://www.teias.gov.tr, viewed March 2019; capacity of 1,238 MW for 2018 from IRENA, *Renewable Capacity Statistics 2019* (Abu Dhabi: 2019), https://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019; United States net generating capacity from EIA, *Electric Power Monthly with Data for December 2018* (Washington, DC: February 2019), Table 6.2.B, https://www.eia.gov/electricity/monthly/archive/february2019.pdf. Capacity data for other countries from IRENA, op. cit. this note; additional capacity data by country from REN21, *Renewables Global Status Report 2018* (Paris: 2018), http://www.ren21.net/gsr_2018_full_report_en. See Geothermal section in Market and Industry chapter and related endnotes for additional statistics and details.

16 **Table R16** from the following sources: Global capacity estimates based on IHA, op. cit. note 2. At end-2018, total installed capacity was 1,292 GW, less 160 GW of pumped storage. Additional country data from the following sources: **China** total capacity including pumped storage of 352.26 GW, capacity additions of 8.54 GW,

utilisation and investment from China National Energy Agency (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); pumped storage capacity of 30.2 GW as of January 2019 from CEC, "China's pumped storage capacity has jumped to the top in the world", 9 January 2019, http://www.cec.org.cn/xinwenpingxi/2019-01-09/188013.html (using Google Translate); generation of 1,234.2 TWh and annual growth of 3% from National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2018 national economic and social development", press release (Beijing: 28 February 2019), http://www.stats.gov.cn/english/PressRelease/201902/t20190228_1651335.html. Total capacity including pumped storage of 352.3 GW, pumped storage capacity of 30 GW and hydropower capacity of 322.3 GW; capacity additions (excluding pumped storage) of 7.0 GW; and pumped storage additions of 1.5 GW from IHA, op. cit. note 2. **Brazil** capacity additions in 2018 of 3,800 MW (3,609 MW large-scale hydro, 182 MW small-scale hydro and 9 MW very small-scale hydro), from National Agency for Electrical Energy (ANEEL), "Acompanhamento da Expansão da Oferta de Geração de Energia Elétrica", http://www.aneel.gov.br/acompanhamento-da-expansao-da-oferta-de-geracao-de-energia-eletrica, updated 15 May 2019; total installed capacity at end-2018 from ANEEL, "Informações gerenciais", report for the 4th quarter of 2018, December 2018, http://www.aneel.gov.br/informacoes-gerenciais; total large-scale hydro capacity is listed as 98,287 MW at end-2018, small-scale hydro as 5,157 MW, and very small-scale (less than 5 MW) hydro as 695 MW, for a total of 104,139 MW. **United States** capacity from EIA, op. cit. note 15. **Canada** data for 2017 only from Statistics Canada, "Table 25-10-0022-01 Installed plants, annual generating capacity by type of electricity generation", https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002201, viewed February 2019. **Russian Federation** capacity and generation from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2018* (Moscow: 31 January 2019), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2019/ups_rep2018.pdf. **India** installed capacity in 2018 (units larger than 25 MW) of 40,614 MW (plus 4,786 MW of pumped storage), from Government of India, Ministry of Power, Central Electricity Authority (CEA), "Hydro reports", December 2018, http://www.cea.nic.in/monthlyarchive.html; installed small-scale (<25 MW) hydro capacity of 4,517 MW, installed capacity expansion in 2018 of 535 MW, and generation for plants larger than 25 MW (131 TWh) based on idem, "Installed capacity" and "Generation reports", viewed March 2019; output from hydro plants smaller than 25 MW (8.6 TWh) from idem, "Renewable energy generation report", viewed March 2019. **Norway** generation from Statistics Norway, "Elektrisitet", https://www.ssb.no/statbank/list/elektrisitet, viewed March 2019; capacity from Norwegian Water Resources and Energy Directorate (NVE), "Ny kraftproduksjon", https://www.nve.no/energiforsyning/energiforsyningsdata/ny-kraftproduksjon/?ref=mainmenu, viewed March 2019 (using Google Translate).

17 **Table R17** from the following sources: unless noted otherwise, data for end-2017 from IEA PVPS, op. cit. note 2, pp. 8, 9, 82, from Becquerel Institute, op. cit. note 2, and from SolarPower Europe, *Global Market Outlook for Solar Power 2018-2022* (Brussels: 2018), http://www.solarpowereurope.org/global-market-outlook-2018-2022/; data for 2018 from IEA PVPS, *2019 Snapshot of Global PV Markets* (Paris: April 2019), pp. 5-7, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_T1_35_Snapshot2019-Report.pdf, from Becquerel Institute, op. cit. note 2, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023* (Brussels: May 2019), p. 5, http://www.solarpowereurope.org/wp-content/uploads/2019/05/SolarPower-Europe-Global-Market-Outlook-2019-2023.pdf, and from 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, Spain 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 listed as follows: **China** additions in 2018 from Becquerel Institute, op. cit. note 2, 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), and from CEC, cited in "2018 electricity & other energy statistics", 25 January 2019, https://chinaenergyportal.org/en/2018-electricity-other-energy-statistics/; total capacity in 2018 from Becquerel Institute, op. cit. note 2, 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), 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), and from CEC, cited in "2018 electricity & other energy statistics", op. cit. this note. **India** total end-2017, additions and total in 2018 from IEA PVPS, op. cit. note 2 and from Becquerel Institute, personal communication with REN21, 3 June 2019. Also based on data from Paula Mints, SPV Market Research, personal communication with REN21, 20 May 2019, from Jyoti Gulia, Bridge to India, personal communication with REN21, 21 May 2019, from Government of India, MNRE, cited in Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2019) (utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-01.pdf, from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, pp. 11, 15, 59, and from Sampath Krishna, "India installs 8.3 GW of solar in 2018", Mercom India, 27 February 2019, https://mercomindia.com/india-installs-8-3-gw-solar-2018/. **United States** total at end-2017, additions and total in 2018 based on data from Wood Mackenzie Power & Renewables and Solar Energy Industries Association (SEIA), *U.S. Solar Market Insight Report 2018*, cited in SEIA, "Solar Market Insight Report 2018 Year in Review", press release (Washington, DC: 13 March 2019), https://www.seia.org/research-resources/solar-market-insight-report-2018-year-review, and from IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note. **Japan** from Becquerel Institute, op. cit. note 2; Hironao Matsubara, Institute for Sustainable Energy Policies (ISEP), Tokyo, personal communication with REN21, 23 April 2019. **Australia** total at end-2017, additions and total in 2018 from Australian PV Institute, "Australian PV market since April 2001", Table "Australian PV installations since April 2001: Total capacity (kW)", http://pv-map.apvi.org.au/analyses, viewed 19 April 2019, from Clean Energy Regulator REC-Registry, extrapolated by Green Energy Markets, cited in Smart Energy Council, "Smashing solar PV records", 18 January 2019, https://www.smartenergy.org.au/news/smashing-solar-pv-records, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. this note. **Germany** from the following: BMWi, *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) (Stand: Februar 2019)* (Berlin: 2019), p. 7, https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2018.pdf; SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, pp. 12, 15, 65; IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note; Bundesverband Solarwirtschaft e.V., "Statistische Zahlen der deutschen: Solarstrombranche (Photovoltaik)", March 2019, https://www.solarwirtschaft.de/fileadmin/user_upload/bsw_faktenblatt_pv_2019_3.pdf. **Mexico** total at end-2017 from IEA PVPS, op. cit. note 2; additions and total in 2018 from Becquerel Institute, op. cit. note 2, from IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note, and from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, p. 12. **Republic of Korea** total at end-2017 from IEA PVPS, op. cit. note 2, p. 82; additions and total in 2018 from Becquerel Institute, op. cit. note 2, from IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note, and from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, pp. 12, 15, 69. **Turkey** total at end-2017 from IEA PVPS, op. cit. note 2, p. 82; additions and total in 2018 from Becquerel Institute, op. cit. note 2, from IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note, and from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, p. 71. **Netherlands** total at end-2017 from IEA PVPS, op. cit. note 2, p. 82; additions and total in 2018 from Becquerel Institute, op. cit. note 2, from IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note, from Dutch New Energy Research, *Dutch Solar Trend Report 2019* (Heerhugowaard, The Netherlands: 2019), p. 24, https://www.solarsolutions.nl/en/solar-trendrapport/, and from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, p. 75. **Italy** total at end-2017 from IEA PVPS, op. cit. note 2, p. 82; additions and total in 2018 from Becquerel Institute, op. cit. note 2, and from IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note. **United**

Kingdom total at end-2017 from IEA PVPS, op. cit. note 2, p. 82; additions and total in 2018 from UK Department for Business, Energy & Industrial Strategy, "Solar photovoltaics deployment in the UK", February 2019, Table 1, "Solar photovoltaics deployment by capacity", https://www.gov.uk/government/statistics/solar-photovoltaics-deployment, viewed 31 March 2019, from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. this note, p. 5, and from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, pp. 81, 86. **France** total at end-2017 from IEA PVPS, op. cit. note 2, p. 82; additions and total in 2018 from IEA PVPS, *2019 Snapshot of Global Photovoltaic Markets*, op. cit. this note, p. 7, and from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. this note, pp. 80, 86. See Solar PV section in Market and Industry chapter and related endnotes for additional statistics and details.

18 **Table R18** based on the following sources: New Energy Update, "CSP today global tracker", http://tracker.newenergyupdate.com/tracker/projects, viewed on numerous dates leading up to 9 May 2019; US National Renewable Energy Laboratory (NREL), "Concentrating solar power projects", https://solarpaces.nrel.gov, with the page and its subpages viewed on numerous dates leading up to 9 May 2019 (some subpages are referenced individually throughout this text of the CSP section); and references cited in the CSP section of REN21, op. cit. note 15, pp. 100-102, 210. In some cases, information from the above sources was verified against additional country-specific sources, as cited in other endnotes for the CSP section. Global CSP data are based on commercial facilities only; demonstration and pilot facilities are excluded. 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. Global CSP data are based on commercial facilities only; demonstration or pilot facilities are excluded.

19 **Table R19** from the following sources: cumulative solar thermal capacity in operation nationally and globally at end-2017 from Monika Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communications with REN21, March-May 2019; Werner Weiss and Monika Spörk-Dür, *Solar Heat Worldwide. Global Market Development and Trends in 2018/Detailed Market Figures 2017* (Gleisdorf, Austria: IEA Solar Heating and Cooling Programme (SHC), 2019). Gross national additions from the following associations and experts: David Ferrari, Sustainability Victoria, Melbourne, Australia; Werner Weiss, AEE INTEC, Vienna, Austria; José Vitor Mamede, 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; Marco Tepper, BSW Solar, Berlin, Germany; Edwige Porcheyre, Enerplan, France; 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; David Stickelberger, Swissolar, Zurich, Switzerland; Abdelkader Baccouche, ANME, Tunis, Tunisia; Turkey from Kutay Ülke, Bural Heating, Kayseri, Turkey and from Krystyna Dawson, BSRIA, Berkshire, United Kingdom; 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 2019. Data for China and World Total assume systems have a 10-year operational lifetime in China; national data for all other countries reflect a 25-year lifetime, with the exceptions of Turkey (14 years, 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.

20 **Table R20** from the following sources: unless noted otherwise, data are from GWEC, op. cit. note 2, and from WindEurope, op. cit. note 2, pp. 7-10. **China** official totals based on data from NEA, "Introduction to the operation of renewable energy grid connection in 2018", http://www.nea.gov.cn/2019-01/28/c_137780519.htm (using Google Translate), and from NEA, cited in CEC, "Wind power grid connection operation in 2018", 29 January 2019, http://www.cec.org.cn/yaowenkuaidi/2019-01-29/188549.html (using Google Translate). Unofficial data for end-2017 from China Wind Energy Association (CWEA), "2017 China wind power lifting capacity statistics presentation", 3 April 2018 (using Google Translate), provided by Liming Qiao, GWEC, personal communication with REN21, 2 May 2018; 2018 additions and total from China Renewable Energy Society Wind Energy Committee, the China Agricultural Machinery Industry Association Wind Power Branch and the National Renewable Energy Center, "2018 China Wind Power Lifting Capacity Statistics Briefing", cited in CWEA, "This year, the downward adjustment of wind power pricing will become a trend. There are two options for cutting old and new", 25 April 2019, http://www.cwea.org.cn/news_lastest_detail.html?id=242 (using Google Translate), and from CWEA, "Wind power has achieved remarkable results in 2018. The installed capacity of offshore wind power is obviously increasing", 25 April 2019, http://www.cwea.org.cn/news_lastest_detail.html?id=243 (using Google Translate). **United States** total at end-2017 from American Wind Energy Association (AWEA), *AWEA U.S. Wind Industry Annual Market Report Year Ending 2017* (Washington, DC: April 2018), https://www.awea.org/resources/publications-and-reports/market-reports/2017-u-s-wind-industry-market-reports; additions and total in 2018 from AWEA, "Consumer demand drives record year for wind energy purchases", press release (Washington, DC: 30 January 2019), https://www.awea.org/resources/news/2019/consumer-demand-drives-record-year-for-wind-energy. **Germany** from the following: WindEurope, op. cit. note 2, p. 10; Deutsche WindGuard, *Status of Land-based Wind Energy Development in Germany, Year 2018* (Varel: 2019), p. 3, https://www.windguard.com/year-2018.html; Deutsche WindGuard, *Status of Offshore Wind Energy Development in Germany, Year 2018* (Varel: 2019), p. 3, https://www.windguard.com/year-2018.html; BMWi, op cit. note 17. **India** from GWEC, op. cit. note 2; also based on data from Government of India, Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2019) (utilities)", op. cit. note 17, and from Government of India, Ministry of Power, CEA, "All India installed capacity (in MW) of power stations (as on 31.01.2018) (utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2018/installed_capacity-01.pdf. **Brazil** total at end-2017 from GWEC, op. cit. note 2, p. 29; additions and total in 2018 from Associação Brasileira de Energia Eólica (ABEEólica), *Números ABEEólica* (January 2019), p. 2, http://abeeolica.org.br/wp-content/uploads/2019/02/N%C3%BAmeros-ABEE%C3%B3lica-01.2019.pdf, and from GWEC, op. cit. note 2, p. 29. **United Kingdom** from WindEurope, op. cit. note 2, also based on data from UK Department for Business, Energy & Industrial Strategy, "Energy Trends: Renewables, Section 6, Renewable electricity capacity and generation", Table 6.1 Renewable electricity capacity and generation, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, viewed 8 May 2019. **France** from WindEurope, op. cit. note 2; also based on data from Réseau de transport d'électricité (RTE), *Bilan Électrique 2018* (Paris: 2019), p. 26, https://www.rte-france.com/sites/default/files/be_pdf_2018v3.pdf. **Mexico** from GWEC, op. cit. note 2, p. 29. **Sweden**, **Spain** and **Italy** from WindEurope, op. cit. note 2. **Canada** end-2017 from Canadian Wind Energy Association (CanWEA), "Installed capacity", https://canwea.ca/wind-energy/installed-capacity/, viewed 31 January 2018; additions and total in 2018 from CanWEA, "Installed capacity", https://canwea.ca/wind-energy/installed-capacity/, as of December 2018, viewed 11 March 2019. See Wind Power section in Market and Industry chapter and related endnotes for additional statistics and details.

21 **Table R21** from the following sources: IEA, "Sustainable Development Goal 7: Access to electricity", https://www.iea.org/sdg/electricity/, viewed 1 March 2019; Sustainable Energy for All (SEforALL), "SEforALL in Africa: Country data", https://www.se4all-africa.org/se4all-in-africa/country-data/, viewed 1 March 2019; World Bank, "Access to electricity (% of population)", https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS, viewed 1 March 2019; Joe 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.

22 **Table R22** from the following sources: IEA, "Sustainable Development Goal 7: Access to clean cooking", https://www.iea.org/sdg/cooking/, viewed 1 March 2019; SEforALL, op. cit. note 21; Chile and Mexico from World Bank, "Access to clean fuels and technologies for cooking (% of population)", https://data.worldbank.org/indicator/EG.CFT.ACCS.ZS.

23 **Table R23** from submissions by report contributors and from various institutional reports and websites.

24 **Table R24** from Ibid.

25 **Table R25** from BNEF Desktop database, personal communication with REN21, 27 May 2019.

RENEWABLES GLOBAL STATUS REPORT 2019

ISBN 978-3-9818911-7-1

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