REN21 Renewable Energy Policy Network for the 21st Century

RENEWABLES 2018
GLOBAL STATUS REPORT

A comprehensive annual overview of the state of renewable energy.

2018

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REN21 COMMUNITY

REN21 is a multi-stakeholder network that is built on an international community of over 900 experts from governments, inter-governmental organisations, industry associations, non-governmental organisations, 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, among other things, to produce its annual flagship publication, the *Renewables Global Status Report (GSR)*. The report is a truly collaborative effort where the contributors and peer reviewers work alongside an international authoring team and the REN21 Secretariat.

REN21 COMMUNITY INVOLVEMENT IN GSR:

60% new experts in the community every year

40% have been involved at least twice

Over **900** experts internationally

400 experts actively involved in 2018 edition

RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY

REN21 is the global renewable energy policy multi-stakeholder network that connects a wide range of key actors. REN21's goal is to facilitate knowledge exchange, policy development and joint action towards a rapid global transition to renewable energy.

REN21 brings together governments, non-governmental organisations, research and academic institutions, international organisations and industry to learn from one another and build on successes that advance renewable energy. To assist policy decision-making, REN21 provides high-quality information, catalyses discussion and debate, and supports the development of thematic networks.

Bridging and building the energy future.

www.ren21.net

REN21 facilitates the collection of comprehensive and timely information on renewable energy. This information reflects diverse viewpoints from both private and public sector actors, serving to dispel myths about renewable energy and to catalyse policy change. It does this through six product lines:

REN21 PRODUCTS

Global Status Report: yearly publication since 2005

RENEWABLES GLOBAL STATUS REPORT (GSR)

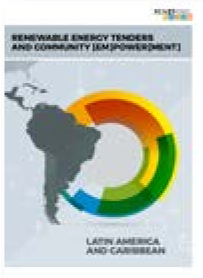
First released in 2005, REN21's *Renewables Global Status Report* (GSR) has grown to become a truly collaborative effort, drawing on an international network of over 900 authors, contributors and reviewers. Today it is the most frequently referenced report on renewable energy market, industry and policy trends.

	2004	2005	2006	2007	2008	2009	2010	2011	2012
REN21 publications:		First GSR published				Chinese Renewable Energy Status Report	Indian Renewable Energy Status Report Renewables Interactive Map	Global Status Report on Local Renewable Energy Policies	
REN21 events:	Renewables 2004, Bonn	BIREC, Beijing International Renewable Energy Conference			WIREC, Washington International Renewable Energy Conference		DIREC, Delhi International Renewable Energy Conference		

REN21 Renewable Energy Policy Network for the 21st Century

Regional Status Reports

Global Futures Reports



Thematic Reports

REN21 Renewables Academy

REN21 Renewables Academy

International Renewable Energy Conferences

REGIONAL STATUS REPORTS

These reports detail the renewable energy developments of a particular region; their production also supports regional data collection processes and informed decision making.

GLOBAL FUTURES REPORTS (GFR)

REN21 produces reports that illustrate the credible possibilities for the future of renewables within particular thematic areas.

THEMATIC REPORTS

Each report covers a specific topic related to renewable energy in detail. Examples of reports covered in this series include the *Mini-grid Policy Toolkit, Renewable Energy Tenders and Community [Em]power[ment]* and *Renewables Energy Policies in a Time of Transition.*

RENEWABLES ACADEMY

The REN21 Renewables Academy provides an opportunity for lively exchange among the growing community of REN21 contributors. It offers a venue to brainstorm on future-orientated policy solutions and allows participants to actively contribute on issues central to a renewable energy transition.

INTERNATIONAL RENEWABLE ENERGY CONFERENCES (IREC)

The International Renewable Energy Conference (IREC) is a high-level political conference series. Dedicated exclusively to the renewable energy sector, the biennial IREC is hosted by a national government and convened by REN21.

2013

Global Futures Report

MENA Renewable Energy Status Report

ADIREC, Abu Dhabi International Renewable Energy Conference

2014

Mini-grid Policy Toolkit

ECOWAS Renewable Energy and Energy Efficiency Status Report

First REN21 Renewables Academy, Bonn

2015

SADC and UNECE Renewable Energy and Energy Efficiency Status Reports

Renewables Interactive Map revamp

SAIREC, South Africa International Renewable Energy Conference

2016

EAC Renewable Energy and Energy Efficiency Status Report

First GSR Microsite

2017

100% Renewables Global Futures Report

UNECE Renewable Energy Status Report

Renewable Energy Tenders and Community [Em]Power[ment]

MEXIREC, Mexico International Renewable Energy Conference

2018

Renewable Energy Policies in a Time of Transition

SADC Renewable Energy and Energy Efficiency Status Report

Second REN21 Renewables Academy, Bonn

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SUSTAINABLE ENERGY FOR ALL

REN21's *Renewables Global Status Report* series contributes to the objectives of the UN Secretary-General's Sustainable Energy for All by providing the latest data on: the development and uptake of renewable energy; the evolution of distributed renewables for energy access; and energy efficiency's contribution to achieving sustainable energy access for all. REN21 is a recognised partner of SEforALL.

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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, was released in April 2018 and is available for download at www.fs-unep-centre.org.

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FOREWORD

Renewable power accounted for 70% of net additions to global power generating capacity in 2017, but global energy-related carbon dioxide emissions rose 1.4% in 2017, after three years of holding steady. The increase in carbon emissions was the result of robust global economic growth (of 3.7%), lower fossil fuel prices and weaker energy efficiency efforts.

This year's *Renewables 2018 Global Status Report* (GSR) reveals two realities: one in which a revolution in the power sector is driving rapid change towards a renewable energy future, and another in which the overall transition is not advancing with the speed needed. While momentum in the power sector is positive, it will not on its own deliver the emissions reductions demanded by the Paris climate agreement or the aspirations of Sustainable Development Goal 7. The heating, cooling and transport sectors, which together account for about 80% of global total final energy demand, are lagging behind.

But the news is not all bad. Renewable power generation capacity saw its largest annual increase ever with an estimated 178 gigawatts added globally. New solar photovoltaic generating capacity alone was greater than additions in coal, natural gas and nuclear power combined.

And while China, Europe and the United States accounted for nearly 75% of the global investment in renewable power and fuels, 2017 saw significant investment in developing country markets. When measured per unit of gross domestic product, the Marshall Islands, Rwanda, the Solomon Islands, Guinea-Bissau and many other developing countries are investing as much as or more in renewables than developed and emerging economies. These positive developments need to be scaled up for a global energy transition.

Corporate sourcing of renewable power is also on the rise. Initially many companies saw the adoption of renewable energy solutions mainly as an act of corporate social responsibility. Significant reductions in renewable energy costs, however, as well as maturing market and policy environments, have made renewables cost-competitive and attractive sources of energy in their own right. As this year's report shows, corporate renewable energy sourcing has moved beyond the United States and Europe and is now found in countries such as Burkina Faso, Chile, China, Egypt, Ghana, India, Japan, Mexico, Namibia and Thailand.

Better reporting is needed to reflect the myriad developments happening at the small scale and in end-use sectors. Grassroots efforts, decentralised solutions, innovation, start-ups, off-grid applications, solar thermal and other activities are not visible when reporting at the global level, yet collectively they make a significant contribution. These developments offer opportunities for scaling up and furthering the transition in the energy system. Collecting data and tracking the evolution of small-scale solutions as well as how renewables are being used in key sectors such as transport and agriculture must be a new priority.

Building on the data, and in an attempt to present an increasingly complex picture in the renewables sector, REN21 has created *Advancing the Global Renewable Energy Transition: Highlights of the REN21 Renewables 2018 Global Status Report in Perspective*. Like its 2017 predecessor, this document presents the overarching trends and developments from 2018 so that policy makers and others can more easily understand the significance of the latest renewable energy developments. Attention is paid to the uneven distribution of renewables at both the sector and regional levels. The document complements the *Renewables 2018 Global Status Report*.

In closing, I would like to thank all those who have contributed to the successful production of this year's report. At its heart is a multi-stakeholder network of more than 900 experts who give their time and expertise. They are complemented by the research direction and lead authoring team Janet L. Sawin, Jay Rutovitz and Freyr Sverrisson, the section authors, GSR Project Manager Hannah E. Murdock and the dedicated team at the REN21 Secretariat, under the leadership of Executive Secretary Rana Adib and her predecessor, Christine Lins.

Arthouros Zervos

Chair, REN21

ES

EXECUTIVE SUMMARY

Bouwdokken Windpark, Zeeland, The Netherlands

AkzoNobel, DSM, Google and Philips formed a unique partnership to jointly sign two power purchase agreements (PPAs) in 2016 to create two wind power projects – Krammer and Bouwdokken – in Zeeland, the Netherlands. Together, these two wind parks have a total capacity exceeding 140 MW, enough to power some 128,800 EU households. The consortium represents a potentially replicable model for multiple renewable energy buyers to aggregate their electricity demand under a single PPA deal.

EXECUTIVE SUMMARY

01 GLOBAL OVERVIEW

Positive developments show that the renewable energy transition is possible, but advances so far are uneven across sectors.

The year 2017 was another record-breaking one for renewable energy, characterised by the largest ever increase in renewable power capacity, falling costs, increases in investment and advances in enabling technologies. Many developments during the year impacted the deployment of renewable energy, including the lowest-ever bids for renewable power in tenders throughout the world, a significant increase in attention to electrification of transport, increasing digitalisation, jurisdictions pledging to become coal-free, new policies and partnerships on carbon pricing, and new initiatives and goals set by groups of governments at all levels.

Increasingly, sub-national governments are becoming leaders in renewable energy and energy efficiency initiatives. At the same time, many developing and emerging countries are expanding their deployment of and investment in renewables and related infrastructure. The private sector is also increasingly playing a role in driving the deployment of renewable energy through its procurement and investment decisions.

As of 2016, renewable energy accounted for an estimated 18.2% of global total final energy consumption, with modern renewables representing 10.4%. The number of countries with renewable energy targets and support policies increased again in 2017, and several jurisdictions made their existing targets more ambitious.

Strong growth continued in the renewable power sector, while other renewable sectors grew very slowly. Solar photovoltaic (PV) capacity installations were remarkable – nearly double those of wind power (in second place) – adding more net capacity than coal, natural gas and nuclear power combined.

In the transport sector, the use of biofuels is still held back by sustainability debates, policy uncertainty and slow technological progress in advanced fuels, such as for aviation. Similarly, renewable heating and cooling[i] continues to lag behind. Both sectors receive much less attention from policy makers than does renewable power generation. However, lack of policy attention does not reflect relative importance, as heating and cooling account for 48% of final energy use, transport for 32% and electricity for 20%.

The interconnection of power, heating and cooling, and transport in order to integrate higher shares of renewable energy gained increased attention during the year, in particular the electrification of both heating and transport.

i "Heating and cooling" in this report refers to thermal applications including climate control/space heating, heat for industrial use, cooking, agricultural drying, etc.

HEATING AND COOLING

There is slow progress in renewable energy uptake in heating and cooling.

Modern renewable energy supplied approximately 10.3% of total global energy consumption for heat in 2015. Another 16.4% was supplied by traditional biomass, predominantly for cooking and heating in the developing world. While additional bio-heat, geothermal direct use and solar thermal capacities were added, growth was very slow.

Energy demand for cooling is growing rapidly, and access to cooling is an issue for health and well-being. Renewables currently play a small role in providing cooling services, although there is considerable potential.

TRANSPORT

Renewable energy progress in the transport sector remains slow. Biofuels provide most of the current renewable energy contribution, although electrification is gaining attention.

The renewable energy share of transport continues to be low (3.1%), with more than 90% provided by liquid biofuels.

Electrification of the transport sector expanded in 2017 – with electric vehicles (EVs) exceeding 1% of global light vehicle sales – and a number of countries announced plans to phase out sales of petrol and diesel vehicles. There are signs that the shipping and aviation sectors also may become open to electrification. Further electrification of the transport sector has the potential to create a new market for renewable energy and to facilitate the integration of higher shares of variable renewable energy, provided that the policy and market settings are suitable.

POWER

The electricity transition is well under way, due mostly to increases in installed capacity and in the cost-competitiveness of solar PV and wind power.

Renewable power generating capacity saw its largest annual increase ever in 2017, raising total capacity by almost 9% over 2016. Overall, renewables accounted for an estimated 70% of net additions to global power capacity in 2017, due in large part to continued improvements in the cost-competitiveness of solar PV and wind power.

Solar PV led the way, accounting for nearly 55% of newly installed renewable power capacity in 2017. More solar PV capacity was added than the net additions of fossil fuels and nuclear power combined. Wind (29%) and hydropower (11%) accounted for most of the remaining capacity additions. Several countries are successfully integrating increasingly larger shares of variable renewable power into electricity systems.

Renewable-based stand-alone and off-grid single home or mini-grid systems represented about 6% of new electricity connections worldwide between 2012 and 2016.

More solar PV capacity
was added in 2017 than the net additions of coal, gas and nuclear combined

RENEWABLE ENERGY INDICATORS 2017

		2016	2017
INVESTMENT			
New investment (annual) in renewable power and fuels [1]	billion USD	274	**279.8**
POWER			
Renewable power capacity (including hydro)	GW	2,017	**2,195**
Renewable power capacity (not including hydro)	GW	922	**1,081**
Hydropower capacity [2]	GW	1,095	**1,114**
Bio-power capacity	GW	114	**122**
Bio-power generation (annual)	TWh	501	**555**
Geothermal power capacity	GW	12.1	**12.8**
Solar PV capacity [3]	GW	303	**402**
Concentrating solar thermal power (CSP) capacity	GW	4.8	**4.9**
Wind power capacity	GW	487	**539**
Ocean energy capacity	GW	0.5	**0.5**
HEAT			
Solar hot water capacity [4]	GW_{th}	456	**472**
TRANSPORT			
Ethanol production (annual)	billion litres	103	**106**
FAME biodiesel production (annual)	billion litres	31	**31**
HVO production (annual)	billion litres	5.9	**6.5**
POLICIES [5]			
Countries with national/state/provincial renewable energy targets	#	176	**179**
Countries with 100% renewable electricity targets	#	57	**57**
Countries with 100% renewable heating and cooling targets	#	1	**1**
Countries with 100% renewable transport targets	#	1	**1**
Countries with 100% renewable energy in primary or final energy targets	#	1	**1**
States/provinces/countries with heat obligations/mandates	#	21	**22**
States/provinces/countries with biofuel mandates [6]	#	68	**70**
States/provinces/countries with feed-in policies	#	110	**113**
States/provinces/countries with RPS/quota policies	#	33	**33**
Countries with tendering (held in 2017)	#	34	**29**
Countries with tendering (cumulative) [7]	#	73	**84**

[1] Investment data are from Bloomberg New Energy Finance 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 energy 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 in this report for more information.

[4] Solar hot water capacity data include water collectors only. The number for 2017 is a preliminary estimate.

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

[6] Biofuel policies include policies listed both under the biofuel obligation/mandate column in Table 2 (Renewable Energy Support Policies) and in Table R7 (Renewable Transport Mandates at the National/State/Provincial Levels, End-2017.)

[7] Data for tendering reflect all countries that have held tenders at any time up through the year of focus.

Note: All values are rounded to whole numbers except for numbers <15 and investment, which are rounded to one decimal point. Where totals do not add up, the difference is due to rounding.

FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil.

02 POLICY LANDSCAPE

Renewable energy policies and targets remain focused on the power sector, with support for heating and cooling and transport still lagging.

Renewable energy continues to attract the attention of policy makers worldwide. Renewable technologies for power generation, heating and cooling, and transport are considered key tools for advancing multiple policy objectives, including boosting national energy security and economic growth, creating jobs, developing new industries, reducing emissions and local pollution, and providing affordable and reliable energy for all citizens.

Many historical policy trends remained unchanged in 2017. The growth of renewable energy around the world continues to be spurred by a combination of targeted public policy and advances in energy technologies. Direct policy support for renewable energy once again focused primarily on power generation, with support for renewable technologies lagging in the heating and cooling and transport sectors.

Policies coupling the thermal (heating and cooling), transport and power sectors – and policies increasing the linkages between renewable energy and energy efficiency – continue to emerge slowly. New cross-sectoral integrated policies were introduced in 2017 in several countries, including Indonesia and Switzerland. Renewable energy and energy efficiency also are being advanced in some cases by climate change policies, including under commitments to achieve net-zero emissions or through specific mechanisms such as carbon taxes, the elimination of fossil fuel subsidies, and emissions trading schemes. In 2017, China launched the world's largest emissions trading scheme, with the first phase of the new cap-and-trade programme focusing on the country's power sector.

Targets remain one of the primary means for policy makers to express their commitment to renewable energy deployment. Targets are enacted for economy-wide energy development as well as for specific sectors. As of year-end 2017, targets for the renewable share of primary and final energy were in place in 87 countries, while sector-specific targets for renewable power were in place in 146 countries, for renewable heating and cooling in 48 countries, and for renewable transport in 42 countries.

POLICIES FOR HEATING AND COOLING

Policies aligning renewables and energy efficiency are common in the buildings sector, but not in industry.

The buildings and industry sectors often see alignment between policies for renewable energy and energy efficiency, with such measures routinely aimed at both increasing renewable energy supply and reducing energy demand. Often these policies encourage the use of renewable energy in heating and cooling. By the end of 2017, at least 145 countries had enacted energy efficiency policies, and at least 157 countries had enacted energy efficiency targets. Mandatory and voluntary energy codes for buildings, one of the most common policy tools to promote renewables and energy efficiency in the buildings sector, exist in more than 60 countries worldwide. By comparison, specific mechanisms to increase renewable energy use for industrial processes are not commonplace, although countries including Mexico and Tunisia launched new support mechanisms during 2017.

57 countries
have 100% renewable electricity targets

POLICIES FOR TRANSPORT

Cities lead in "greening" public transport fleets, but policy attention is lacking for rail, aviation and shipping.

Policies to promote renewable energy and energy efficiency in the transport sector continued to focus primarily on road transport, promoting biofuels, electric mobility and fuel-efficiency. Rail, aviation and shipping have drawn comparably less policy attention. However, many cities are expanding policy coverage, taking steps to integrate renewable solutions into public transport fleets, including city rail systems.

POLICIES FOR ELECTRICITY

Use of tendering continues to spread, yet feed-in policies remain vital in support schemes for renewables.

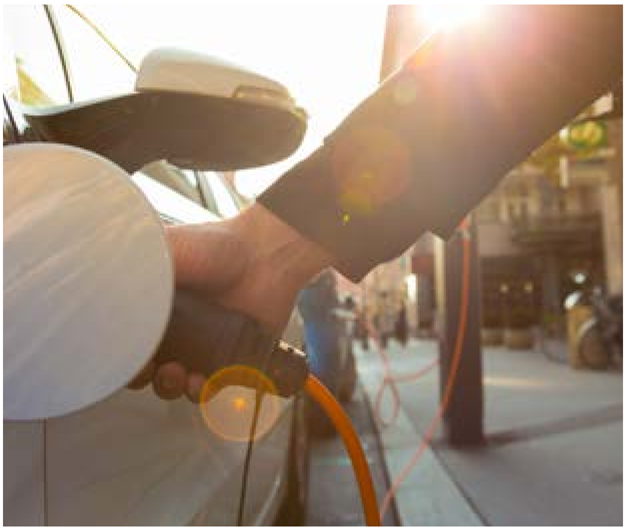
As renewable power technologies and markets have matured, policy makers have grappled with new challenges related to integrating renewable electricity into power systems. Many countries are moving away from some of the policy mechanisms that served as the foundational elements of numerous renewable energy support programmes. Developed countries have followed the lead of emerging economies such as Brazil and South Africa by continuing to replace feed-in policies with renewable energy tenders. More than 29 countries held renewable energy tenders in 2017.

Feed-in policies remain a vital component of many national support schemes for renewables, often for promoting the development of small-scale renewable energy systems. Two countries adopted new feed-in policies in 2017 (Zambia and Vietnam), increasing the number of countries with such policies in place to 113, while rates set under many existing policies were revised. New net metering policies also were enacted in six countries in 2017, primarily to promote rooftop solar PV.

RENEWABLES INTEGRATION, SECTOR COUPLING AND SYSTEM-WIDE ENERGY TRANSFORMATION POLICIES

New cross-sectoral integrated policies are emerging to support integration of variable renewables.

Many policy makers and regulators are leading in efforts to address the need for increased flexibility in electricity grids. Their challenge is to modify policies, standards, and market and regulatory frameworks to effectively harness the benefits that can be derived from variable renewable energy, while ensuring system reliability and security of supply. Policies that promote grid services, such as synthetic inertia and voltage regulation, as well as enabling technologies such as energy storage, are increasingly playing a role in the advancement of energy systems. Similarly, some policy makers are starting to take a systems view, introducing cross-sectoral policies that advance the coupling of electricity, transport, and heating and cooling to provide economy-wide benefits.



03 MARKET AND INDUSTRY TRENDS

BIOENERGY

Modern use of bioenergy for heating is growing slowly due to a lack of policy attention and to low fossil fuel prices.

Bioenergy is the largest renewable contributor to global final energy demand, providing nearly 13% of the total. The traditional use of biomass in developing countries (for cooking and heating) accounts for almost 8% of this, and modern use for the other 5%. Modern bioenergy provides about 4% of heat demand in buildings and 6% in industry, as well as some 2% of global electricity generation and 3% of transport needs.

Growth in modern use of bioenergy for heating has been relatively slow in recent years (below 2% annually) due to a lack of policy attention and to low fossil fuel prices. The electricity sector has seen more rapid growth, with generation from biomass increasing 11% in 2017. China overtook the United States as the largest producer of bioelectricity during the year.

Production of biofuels for transport increased 2.5% in 2017. The United States and Brazil remained the world's largest producers of ethanol and biodiesel. The production and use of new transport fuels such as hydrotreated vegetable oil (HVO) have grown significantly over the last five years, and in 2017 HVO accounted for about 6% of total biofuel production by energy content. Progress also is being made in developing the technologies needed to produce advanced biofuels for aviation use, for example.

GEOTHERMAL POWER AND HEAT

Technology innovation is addressing sector-specific challenges in the geothermal industry.

An estimated 0.7 gigawatts (GW) of new geothermal power capacity came online in 2017, bringing the global total to around 12.8 GW. Indonesia and Turkey accounted for three-fourths of new capacity; installations also came online in Chile, Iceland, Honduras, Mexico, the United States, Japan, Portugal and Hungary.

Geothermal direct use (direct thermal extraction for heating and cooling) increased by an estimated 1.4 gigawatts-thermal (GW_{th}) of capacity to an estimated global total of 25 GW_{th}. Space heating continued to be one of the largest and fastest growing sectors, with several new projects feeding into district heat systems in Europe and China, in particular.

The geothermal industry remained constrained by various sector-specific challenges, such as long project lead-times and high resource risk, but technology innovation to address such challenges continued during 2017. The industry is focused on advancing technologies to reduce development risk and to cost-effectively tap geothermal resources in more locations, as well as to reduce the potential environmental consequences.

HYDROPOWER

Hydropower industry prioritises sustainability, modernisation and digitalisation of facilities.

Global additions to hydropower capacity in 2017 were an estimated 19 GW, bringing total capacity to approximately 1,114 GW. While significant, this is the smallest annual increment seen over the last five years. China remained the perennial leader in commissioning new hydropower capacity, accounting for nearly 40% of new installations in 2017, and was followed by Brazil, India, Angola and Turkey. Other countries that added significant capacity included Iran, Vietnam, the Russian Federation and Sudan.

Pumped storage is the dominant source of large-scale energy storage, accounting for an estimated 96% of global energy storage capacity. Global pumped storage capacity rose by more than 3 GW in 2017, for an estimated year-end total of 153 GW.

Among the priorities of the hydropower industry in 2017 were continued advances towards more sustainable development of hydropower resources, increased climate change resilience, and ongoing modernisation efforts and digitalisation of existing and new facilities.

OCEAN ENERGY

Industry's optimism and development efforts bring ocean energy closer to commercialisation.

Of the approximately 529 megawatts (MW) of operating ocean energy capacity at the end of 2017, more than 90% was represented by two tidal barrage facilities. Ocean energy technologies deployed in open waters (excluding tidal barrage) had a good year, as tidal stream and wave energy saw new capacity come online, much of it in the waters of Scotland.

Optimism prevailed in the industry in 2017, particularly in Europe, where some technologies advanced enough to be on the brink of commercialisation. The industry started constructing its first manufacturing plants, promising greater production scale and cost reductions. Government support of ocean energy, through direct funding and through research and infrastructure support, remains a critical element in ongoing development.

SOLAR PHOTOVOLTAICS (PV)

New solar PV installations surpassed net additions of fossil fuels and nuclear power combined.

Solar PV was the top source of new power generating capacity in 2017, due largely to strong growth in China, with more solar PV installed globally than the net additions of fossil fuels and nuclear power combined. Global capacity increased nearly one-third, to approximately 402 GW_{dc}.

Although solar PV capacity is concentrated in a short list of countries, by year's end every continent had installed at least 1 GW of capacity, and at least 29 countries had 1 GW or more. Solar PV is playing an increasingly important role in electricity generation, accounting for over 10% of generation in Honduras in 2017 and for significant shares in Italy, Greece, Germany and Japan.

Globally, market expansion is due largely to the increasing competitiveness of solar PV, combined with growing demand for electricity in developing countries and rising awareness of the technology's potential to alleviate pollution, reduce carbon dioxide emissions and provide energy access. Nevertheless, most global demand continues to be driven largely by government policy.

The year 2017 saw record-low auction prices driven by intense competition, thinning margins for manufacturers and developers alike, and continued consolidation in the industry. The drive to increase efficiencies and reduce energy costs has pushed innovations in manufacturing and product performance. Even as falling prices have challenged many existing solar PV companies, low and predictable energy prices offered by solar PV, along with expanding markets, are luring new participants to the industry, including oil and gas companies.

CONCENTRATING SOLAR THERMAL POWER

CSP plants with thermal energy storage emerge as a viable competitor to fossil fuel thermal power plants.

Global concentrating solar thermal power (CSP) capacity reached 4.9 GW in 2017, with South Africa being the only country to bring new CSP capacity online (100 MW). However, at year's end about 2 GW of new plants was under construction; China (300 MW being built) and Morocco (350 MW) were particularly active. An estimated 13 gigawatt-hours of thermal energy storage (TES) was operational, and most new plants are incorporating TES.

Spain remained the global leader in existing CSP capacity – followed by the United States – with Spanish CSP plants achieving record electricity generation in 2017. The year also saw record low CSP tariffs being bid and/or awarded in competitive tenders in Australia, Chile and the United Arab Emirates, where a 700 MW CSP tender was awarded. CSP with TES emerged as a viable competitor to fossil fuel thermal power plants. Price reductions were driven by competition as well as by technology cost reductions aided by ongoing research and development activity in the sector.

SOLAR THERMAL HEATING AND COOLING

Solar heat for industrial processes had a record year, and use in district energy systems advanced.

An estimated 35 GWth of new solar thermal capacity was commissioned in 2017, increasing total global capacity 4% to around 472 GW_{th}[i]. China again led for new installations, followed by Turkey, India, Brazil and the United States.

Driven by government support, solar district heating advanced in an increasing number of countries, with the first large-scale installations coming online in Australia, France, the Kyrgyz Republic and Serbia. By year's end, an estimated 296 large-scale solar thermal systems were connected to heating networks.

The year also saw records for new solar heat for industrial processes (SHIP) installations, driven by economic competitiveness, a strong supply chain and policies to reduce air pollution. At least 110 such systems (totalling 135 MW_{th}) started operation globally, raising the world total by 21%. Concentrating collector technologies played an increasing role in providing space heating and industrial heat, with Oman, China, Italy, India and Mexico being the largest markets.

For the first time since the peak years of 2011-2012, new manufacturing capacity was constructed for flat plate and concentrating collectors. To make up for continued declines in their home markets, several European manufacturers increased their export volumes, supplying new emerging markets in North Africa, the Middle East and Latin America.

WIND POWER

Prices fell rapidly for both onshore and offshore wind power, and the offshore sector had its best year yet.

The year 2017 brought tumbling bid prices for both onshore and offshore wind power capacity in auctions around the world. Bid prices were down due to technology innovation and scale, expectations of continued technology advances, reduced financing costs due to lower perceived risk, and fierce competition in the industry. Electric utilities and large oil and gas companies continued to move further into the industry.

Wind power had its third strongest year ever, with more than 52 GW added (about 4% less than in 2016) for a total of 539 GW. China saw installations decline for the second year running, while Europe and India had record years.

In some of the largest wind power markets, strong growth was driven by looming regulatory changes; elsewhere, wind energy's cost-competitiveness and its potential environmental and developmental benefits drove deployment. Rapidly falling prices for wind power have made it the least-cost option for new power capacity in a large and growing number of countries.

The offshore wind sector had its best year yet, as total capacity increased 30%. China's offshore market started to take off in 2017, and the world's first commercial floating project was commissioned in Scotland. The sizes of turbines and projects continued to increase, and several manufacturers announced plans to produce machines of 10 MW and larger.

At least 13 countries – including Costa Rica, Nicaragua and Uruguay, and several countries in Europe – met 10% or more of their electricity consumption with wind power during 2017.

i Total does not include solar concentrator technologies used for space and water heating and for industrial process heat.

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

Distributed renewables for energy access (DREA) systems are increasingly being considered as a solution to achieve energy access goals.

Approximately 1.06 billion people (about 14% of the global population) live without electricity, and about 2.8 billion people (38% of the global population) are without clean cooking facilities. The vast majority of people without access to both electricity and clean cooking are in sub-Saharan Africa and developing Asia, and most of them live in rural regions.

DREA systems are increasingly being considered as a solution to achieve energy access goals through the deployment of off-grid solar systems and renewable-based mini-grids, and through the distribution of clean cook stoves. Off-grid solar systems, and in particular those commercialised through the pay-as-you-go (PAYG) business model, were the most significant technology in the sector, providing electricity access to more than 360 million people worldwide. In 2017, although the sales of off-grid solar systems decreased in the two main regional markets of East Africa and South Asia, markets in Central Africa, East Asia and the Pacific were growing rapidly. An increasing number of private mini-grid developers are actively testing a range of business models and helping to move the mini-grids sector to maturity. In India alone, an estimated 206 mini-grid systems were installed during 2016-2017.

Investment continued to flow to PAYG companies – with an estimated USD 263 million raised in 2017 – although investment in off-grid solar companies as a whole decreased 10% from 2016 to 2017. Investment in clean cook stove companies fell in 2016 to its lowest level since 2012 (USD 18.1 million), highlighting the need for more effort to raise funds in the sector.

A growing trend in 2017 was the establishment of partnerships between multinationals, local businesses and/or governments to deploy DREA systems to meet energy access targets. The year also saw an increasing number of national governments enhancing the enabling environment to advance DREA. Similarly, development finance institutions continued to support the sector through various programmes and initiatives.

05 INVESTMENT FLOWS

Global investment in renewables increased even as costs continued to fall, and developing and emerging countries extended their lead over developed countries.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) exceeded USD 200 billion annually for the eighth year running. The investment total of USD 279.8 billion[i] was up 2% over 2016, despite further cost reductions for wind and solar power technologies. Including investments in hydropower projects larger than 50 MW, total new investment in renewable power and fuels was at least USD 310 billion in 2017.

Dollar investment in new renewable power capacity (including all hydropower) was three times the investment in fossil fuel generating capacity, and more than double the investment in fossil fuel and nuclear power generation combined.

Investment in renewable energy continued to focus on solar power, particularly solar PV, which increased its lead over wind power in 2017. Asset finance of utility-scale[ii] projects, such as wind farms and solar parks, dominated investment during the year at USD 216.1 billion. Small-scale solar PV installations (less than 1 MW) saw an investment increase of 15%, to USD 49.4 billion.

Developing and emerging economies overtook developed countries in renewable energy investment for the first time in 2015 and extended their lead in 2017, accounting for a record 63% of the global total, due largely to China. Investment in developing and emerging countries increased 20% to USD 177 billion, while that of developed countries fell 19% to USD 103 billion. China accounted for a record 45% of global investment in renewables (excluding hydropower larger than 50 MW), up from 35% in 2016, followed by Europe (15%), the United States (14%) and Asia-Oceania (excluding China and India; 11%). Smaller shares were seen in the Americas (excluding Brazil and the United States, 5%), India (4%), the Middle East and Africa (4%) and Brazil (2%).

Investment in PAYG companies was an estimated USD 263 million in 2017

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

ii "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 5 COUNTRIES 2017

Annual Investment / Net Capacity Additions / Production in 2017

	1	2	3	4	5
Investment in renewable power and fuels (not including hydro over 50 MW)	**China**	United States	Japan	India	Germany
Investment in renewable power and fuels per unit GDP[1]	**Marshall Islands**	Rwanda	Solomon Islands	Guinea-Bissau	Serbia
Geothermal power capacity	**Indonesia**	Turkey	Chile	Iceland	Honduras
Hydropower capacity	**China**	Brazil	India	Angola	Turkey
Solar PV capacity	**China**	United States	India	Japan	Turkey
Concentrating solar thermal power (CSP) capacity[2]	**South Africa**	-	-	-	-
Wind power capacity	**China**	United States	Germany	United Kingdom	India
Solar water heating capacity	**China**	Turkey	India	Brazil	United States
Biodiesel production	**United States**	Brazil	Germany	Argentina	Indonesia
Ethanol production	**United States**	Brazil	China	Canada	Thailand

Total Capacity or Generation as of End-2017

	1	2	3	4	5
POWER					
Renewable power capacity (including hydropower)	**China**	United States	Brazil	Germany	India
Renewable power capacity (not including hydropower)	**China**	United States	Germany	India	Japan
Renewable power capacity *per capita* (not including hydro)[3]	**Iceland**	Denmark	Germany/Sweden		Finland
Bio-power generation	**China**	United States	Brazil	Germany	Japan
Bio-power capacity	**United States**	Brazil	China	India	Germany
Geothermal power capacity	**United States**	Philippines	Indonesia	Turkey	New Zealand
Hydropower capacity[4]	**China**	Brazil	Canada	United States	Russian Federation
Hydropower generation[4]	**China**	Brazil	Canada	United States	Russian Federation
Solar PV capacity	**China**	United States	Japan	Germany	Italy
Solar PV capacity *per capita*	**Germany**	Japan	Belgium	Italy	Australia
Concentrating solar thermal power (CSP)	**Spain**	United States	South Africa	India	Morocco
Wind power capacity	**China**	United States	Germany	India	Spain
Wind power capacity *per capita*	**Denmark**	Ireland	Sweden	Germany	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 capacity[6]	**China**	Turkey	Iceland	Japan	Hungary

[1] Countries considered include only those covered by Bloomberg New Energy Finance (BNEF); GDP (at purchasers' prices) data for 2016 from World Bank. BNEF data include the following: 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 (small-scale capacity) estimated separately; all ocean energy projects; and 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] Only one country brought CSP capacity online in 2017, which is why no countries are listed in places 2, 3, 4 and 5.

[3] Per capita renewable power capacity (not including hydropower) ranking based on data gathered from various sources for more than 70 countries and on 2016 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 2016 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 2017.

[6] Not including heat pumps.

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

06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

Energy systems are adapting to rising shares of renewable energy.

With rising penetration of renewable energy – whether variable renewable energy (VRE; wind and solar power), thermal energy or gaseous and liquid fuels – there are challenges to integrating it into existing energy systems. The penetration of modern renewable energy is highest in the electricity sector, where many countries already are successfully integrating high shares of VRE. At least 10 countries generated 15% or more of their electricity with solar PV and wind power in 2017, and many had far higher short-term shares.

Power systems are adjusting to better accommodate rising shares of VRE by increasing system flexibility. Utilities and system operators also are adjusting their operations, adding energy storage and digitising systems to help integrate VRE. At the same time, renewables are evolving to improve the ease of integration, and state-of-the-art solar PV and wind energy generators can provide a variety of relevant system services to stabilise the power grid.

Several technologies – including energy storage, heat pumps and electric vehicles – have evolved in parallel with renewable energy and are now helping to integrate VRE into the electricity sector and to facilitate the coupling of renewable power with the thermal and transport sectors.

Energy storage, mainly in the form of pumped storage, has been used for decades to support grid reliability, increase infrastructure resilience and for other purposes; increasingly, it is being used in conjunction with renewable energy technologies. During 2017, at least 3.5 GW of utility-scale storage capacity was commissioned. Residential and commercial electricity storage capacity also grew rapidly in some countries, particularly in combination with solar PV. The year saw continued technology advances and cost reductions, the diversification of renewable energy and other companies into the storage industry, and increasing linkages with VRE.

Heat pump markets continued to expand, driven by policies to mitigate air pollution (particularly in China) and to advance opportunities to use renewable electricity for heating and cooling (particularly in Europe). Heat pumps have the potential to help balance the electrical system by shifting loads and reducing VRE curtailment, using (surplus) solar and wind power to meet heating and cooling demand. Manufacturers continued to pursue acquisitions to gain access to new markets and know-how, and to increase their market share.

Electrification of the transport sector gained increasing attention in 2017, and could enable greater integration of renewable electricity. Global sales of electric passenger cars increased 58% over 2016, and more than 3 million of them were traveling the world's roads by year's end. The passenger car market remained a small share (1.3%) of total passenger vehicle sales and was eclipsed by two- and three-wheeled EVs. Use of electric buses also increased, with an estimated 386,000 in service (mostly in China). In several countries, utilities are playing a significant role in expanding EV charging points and, along with vehicle manufacturers and others, continue working to advance the synergies between EVs and VRE.

Global sales of electric passenger cars increased

58 %

over 2016

07 ENERGY EFFICIENCY

The importance of energy efficiency is increasingly recognised internationally, while global energy intensity continues to fall.

Dialogue at the international level has begun to recognise the importance of integrating energy efficiency and renewable energy. International organisations, global campaigns and a host of other actors are increasingly raising awareness and encouraging policy makers to consider the two in concert. As a result, policies have emerged in recent years that attempt to link renewables and energy efficiency.

In 2016, global gross domestic product (GDP) grew 3%, whereas energy demand increased only 1.1%. However, countries outside of the Organisation for Economic Co-operation and Development (OECD) continue to see increasing energy use alongside growing GDP, while OECD countries, as a whole, do not.

The decline in energy demand per unit of economic output has been made possible by a combination of supply- and demand-side focused policies and mechanisms as well as structural changes. These include: the expansion, strengthening and long-lasting impact of energy efficiency standards for appliances, buildings and industries; improved fuel efficiency standards and, more recently, the growing deployment of EVs – especially when supplied by renewable energy sources; fuel switching to less carbon-intensive alternatives, including renewables; and structural changes in industry, including a transition towards less energy-intensive and more service-oriented industries.

08 FEATURE: CORPORATE SOURCING OF RENEWABLE ENERGY

Corporate sourcing of renewable energy continued to increase and spread to new regions.

Corporations began sourcing renewable energy in the mid-2000s to meet their own environmental and social objectives and to address the growing demand for corporate sustainability from investors and consumers. More recently, renewables have become attractive energy sources in their own right, providing cost-competitive energy, long-term price stability and security of supply, among other benefits.

US and European markets account for the bulk of corporate renewable energy sourcing, but the practice is spreading, with growth in countries such as Burkina Faso, Chile, China, Egypt, Ghana, India, Japan, Mexico, Namibia and Thailand.

In 2017, corporations sourced renewable electricity in more than 70 countries through corporate power purchase agreements (PPAs), utility green procurement programmes and unbundled renewable electricity certificates (RECs) or guarantees of origin (GOs). In addition, corporations in a large number of countries worldwide have invested directly in renewable energy systems for their own consumption.

Unbundled RECs or GOs remain the most popular approach to corporate sourcing. As other cost-competitive options have become available, however, many large corporations have begun considering sourcing options that allow them to play a more active role in adding new renewable capacity to the grid.

The information technology sector continues to purchase by far the largest amounts of renewable energy, mainly through wind energy PPAs. Heavy industry, which has a tradition of owning energy-generating assets or holding bilateral contracts with generators, also has increased its sourcing of renewables in recent years.

The options available for corporations to source renewable energy depend greatly on the markets and policy frameworks in which they operate, as well as on the nature of their operations and internal capacity. In response to rising corporate interest in renewable energy sourcing, several initiatives have been established to recognise and further support the development and pursuit of ambitious renewable energy goals through various sourcing options.

The importance of **integrating** energy efficiency and renewable energy is increasingly recognised

01

Electric vehicle of Deutsche Post DHL

By the end of 2017, Deutsche Post DHL had 5,000 StreetScooter electric vehicles operating entirely on renewable electricity for the company's urban postal delivery service. According to DHL, the EVs' maintenance and wear costs are 60-80% below those for similar conventional vehicles, and the use of renewable electricity reduces the company's CO_2 emissions by 16,000 tonnes annually, contributing to DHL's commitment to achieve net-zero emissions by 2050.

GLOBAL OVERVIEW

The year 2017 was another record-breaking one for renewable energy, characterised by the largest ever increase in renewable power capacity as well as by falling costs, increases in investment and advances in enabling technologies. Many developments during the year affected the deployment of renewable energy, including the lowest ever bids for solar and wind power in tenders in several countries around the world, increasing digitalisation, heightened attention to electrification of transport, a number of jurisdictions pledging to become coal-free, new policies and partnerships on carbon pricing, and new initiatives and goals set by governments at all levels.

Several renewable energy technologies – such as hydropower, bioenergy and geothermal power and heat – have long been established as mainstream and cost-competitive sources of energy. Solar PV and wind power are joining them: both are now competitive with new fossil fuel capacity in an increasing number of locations, and they are coming closer to being competitive with existing fossil fuel and nuclear power generation.[1]

Growth in renewable energy deployment and output continued in 2017, particularly in the power sector, thanks to several factors, including: increasing access to finance; concerns about energy security, the environment and human health; growing demand for energy in developing and emerging economies; the need for access to electricity and clean cooking facilities; and dedicated policy initiatives and ambitious targets.

Increasingly, sub-national governments are becoming leaders in renewable energy and energy efficiency initiatives, and national governments in some countries are pulling back from leadership roles.[2] Many developing and emerging economies are increasing their deployment of and investment in renewable energy technologies and related infrastructure and are becoming renewable energy leaders.[3] Renewable energy investment in many developing countries continued to be as high or even higher than that in developed countries when viewed on a per gross domestic product (GDP) basis.[4] (→ *See Top 5 Countries table.*)

2017 was another
record-breaking year
for renewable energy

Many high-profile announcements and partnerships in 2017 could have important impacts on the renewable energy sector. These include:

- In the context of the United Nations Sustainable Development Goals (SDGs), 2017 saw the creation of Sustainability Mobility for All (SUM4ALL), a new strategic global alliance that aims to implement the SDGs in the transport sector, including reducing the sector's environmental footprint to combat climate change and pollution.[5]
- Sustainable Energy for All (SEforALL) and the Kigali Cooling Efficiency Program launched the Cooling for All initiative aimed at identifying the challenges and opportunities of expanding access to affordable, sustainable cooling solutions through the intersection of the Paris Climate Agreement, the SDGs and the Montreal Protocol's Kigali Amendment.[6]
- China launched the world's largest emissions trading scheme, and a coalition of national and sub-national governments launched the Carbon Pricing in the Americas co-operative framework.[7]
- In November 2017, a group of 27 national, provincial, state and city governments launched the Powering Past Coal Alliance, committing to phasing out coal power by 2030; by early 2018, membership had surpassed 60.[8]
- Twenty-five C40 member cities around the world established goals to reach net-zero emissions by 2050, with a focus on improving energy efficiency and increasing the use of renewable energy in urban buildings.[9]
- The European Commission, the Global Covenant of Mayors and R20–Regions of Climate Action created a joint venture to support sub-national authorities in Africa in identifying, structuring and developing bankable low-carbon and climate-resilient infrastructure projects, with a focus on energy access and renewable energy projects.[10]
- A multi-stakeholder group launched the Transport Decarbonisation Alliance, with national governments from Costa Rica, France, the Netherlands and Portugal, as well as the Paris Process on Mobility and Climate, alongside cities, regions, and private companies committed to ambitious action on transport and climate change.[11]
- The global Electric Vehicles Initiative launched the EV30@30 Campaign, setting a collective goal of a 30% market share for electric vehicles (EVs) among all passenger cars, light commercial vehicles, buses and trucks by 2030, a target that can help open up opportunities for greater use of renewable energy in the transport sector.[12]

While these developments are promising, renewables and the broader energy sector face several challenges. Strong global economic growth led to an estimated 2.1% increase in energy demand in 2017 – more than twice the average increase over the previous five years.[13] Energy-related carbon dioxide (CO_2) emissions rose – by an estimated 1.4% – in 2017 for the first time in four years.[14] In some instances, jurisdictions moving away from coal have switched to natural gas rather than to renewables.[15]

+5.4%

is the average growth rate of modern renewables over the past decade

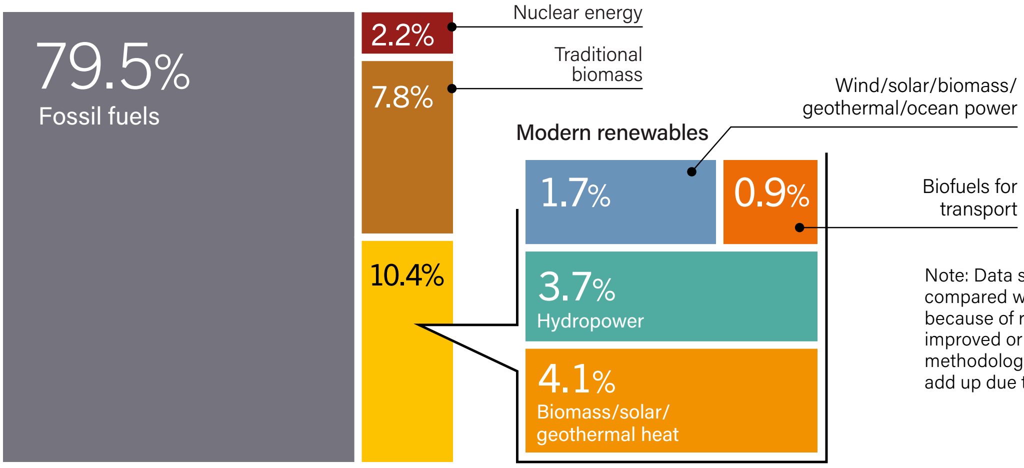
Although renewables continue to gain ground globally, progress is uneven across sectors and regions. In many developing countries, particularly in sub-Saharan Africa, energy access rates remain low, but rates are improving steadily in Asia. Approximately 1.06 billion people worldwide lived without electricity in 2016 (latest data available[i]), while about 2.8 billion people lack access to clean cooking facilities.[16] Despite rapid expansion of renewable energy capacity and output, particularly of solar photovoltaic (PV) and wind power, fossil fuels continue to make up the overwhelming majority of global total final energy consumption (TFEC).[17]

As of 2016, modern renewables (not including traditional use of biomass) accounted for approximately 10.4% of TFEC, a slight increase compared to 2015.[18] *(→ See Figure 1.)* The greatest portion of the modern renewable share was renewable electricity (accounting for 5.4% of TFEC), most of which was generated by hydropower (3.7%).[19] It was followed by renewable thermal energy (an estimated 4.1% of TFEC) and transport biofuels (about 0.9%).[20] Traditional use of biomass, primarily for cooking and heating in developing countries, accounted for an additional 7.8%.[21] Combined renewable energy accounted for an estimated 18.2% of TFEC.[22]

The overall share of renewable energy in TFEC has increased only modestly in recent years, despite tremendous growth in some renewable sectors.[23] *(→ See Figure 2.)* A primary reason for this modest rise is the continued growth in overall energy demand (except for a decline in 2009 following the global economic recession), which counteracts the strong forward momentum of modern renewable energy technologies.[24] In addition, the traditional use of biomass has grown slowly on a global basis and has even declined in some countries. Although this is a positive development, it is slowing the growth of the total global renewable energy share.

i Throughout this chapter, where data are provided for a year prior to 2017, they reflect the latest data available at the time of writing.

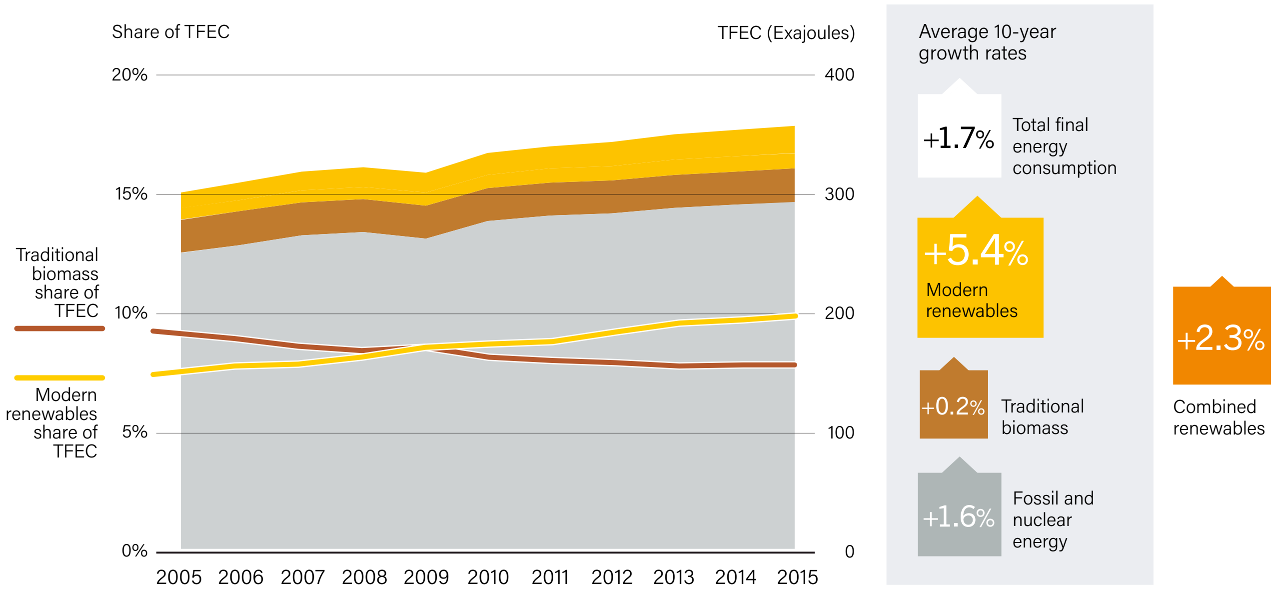
FIGURE 1. Estimated Renewable Share of Total Final Energy Consumption, 2016



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: See endnote 18 for this chapter.

FIGURE 2. Growth in Global Renewable Energy Compared to Total Final Energy Consumption, 2005-2015



Note: Combined renewables = both modern renewables and traditional biomass.

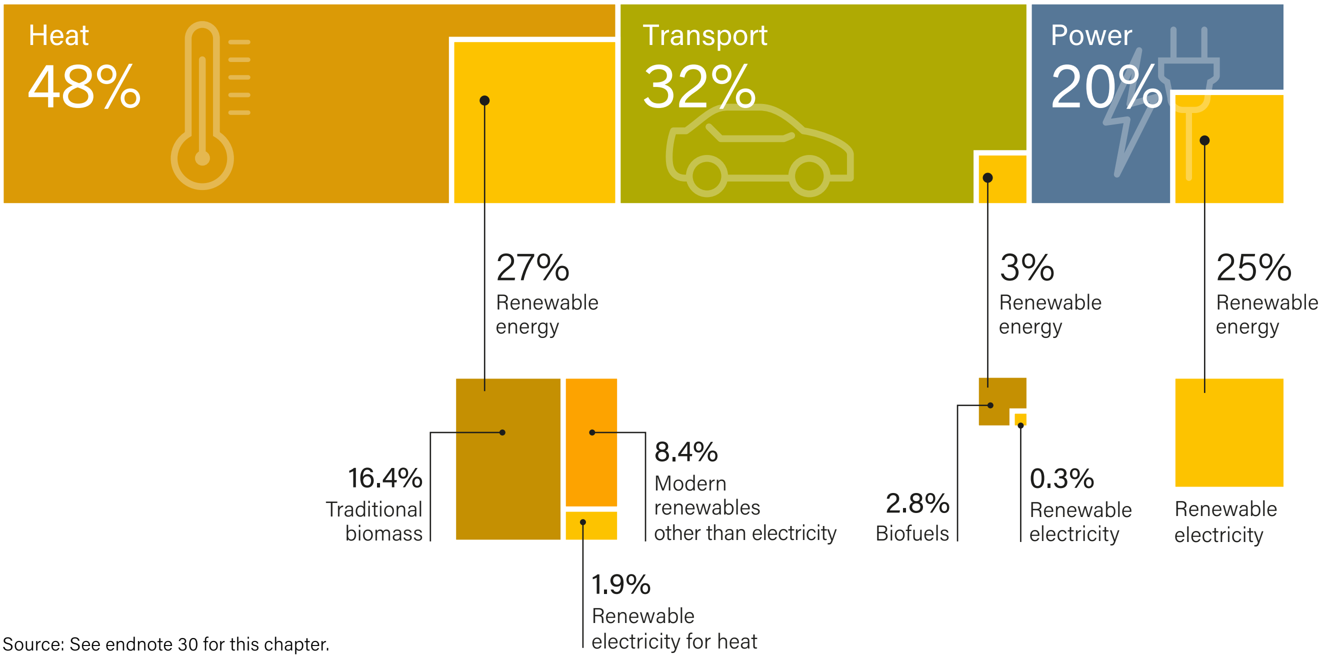
Source: See endnote 23 for this chapter.

Progress in the renewable heating and cooling[i] and transport sectors continues to be relatively slow, despite a number of initiatives to boost the role of renewables and the electrification of heating and transport.[25] Renewable heating and cooling has received much less attention from policy makers than renewable power generation and has been identified as the "sleeping giant of renewable energy potential" for the past decade.[26] The supply of modern renewable heat increased 20.5% in the period from 2007 to 2015, whereas renewable electricity generation increased 56.6% during this period.[27]

In the area of transport, the vast majority of global energy needs within the sector are still met by oil (92%), with small proportions met by biofuels (2.8%) and electricity (1.3%).[28] As of 2015, modern bioenergy (excluding traditional use of biomass) remained the leader by far in the contribution of renewable energy to transport, and accounted for the majority of renewable heat.[29] However, the lack of advancement and attention in these sectors does not reflect relative importance: as of 2015, heating and cooling accounted for 48% of TFEC, followed by transport (32%) and electricity consumption (20%).[30] (→ *See Figure 3.)*

i "Heating and cooling" in this chapter refers to thermal applications including climate control/space heating, heat for industrial use, cooking, agricultural drying, etc.

FIGURE 3. Renewable Energy in Total Final Energy Consumption, by Sector, 2015



Source: See endnote 30 for this chapter.

Strong growth continued in the renewable power sector in 2017. Solar PV capacity installations were remarkable — nearly double those of wind power (in second place) – adding more net capacity than coal, natural gas and nuclear power combined.[31] Growth has been uneven among renewable energy technologies, with the vast majority of capacity added being solar PV, wind power and hydropower. *(→ See Market and Industry chapter.)*

Sector coupling – the interconnection of the power, heating, cooling and transport sectors in order to integrate higher shares of renewable energy – gained increased attention during the year.[32] Electrification of heating and transport, although currently small (particularly in transport) is seen as providing a pathway to the expansion of renewable energy (and an accompanying reduction in carbon emissions), and specifically to assist with integration of large shares of variable renewable energy (VRE).[33] China, for example, is encouraging the electrification of residential heating, manufacturing and transport in regions that have high concentrations of renewable power to reduce curtailment of wind power, solar PV and hydropower, as well as to combat air pollution.[34] A number of US states are examining options for electrification of the transport, industrial, residential and commercial end-use sectors to allow for increasing the overall renewable energy share.[35]

Global investment in renewable power and fuels in 2017 totalled USD 279.8 billion (excluding hydropower plants larger than 50 megawatts (MW)), up 2% from 2016 but 13% below the all-time high in 2015.[36] Nearly all of the investment was in solar PV (57%) and wind power (38%).[37] The costs of these rapidly growing technologies have fallen so quickly that renewable energy capacity installations in 2017 exceeded those in 2016 despite lower absolute investment, as each dollar represents more capacity on the ground.[38] Developing and emerging economies accounted for 63% of total renewable energy investment, a higher share than developed countries for the third year in a row, with China alone accounting for 45% of global investment.[39] Investment in 2017 held steady or trended upwards in Latin America and the United States but fell 30% in Europe, where it has been in decline since about 2010.[40] *(→ See Investment chapter.)*

Private sector investment and procurement decisions are playing a key role in driving renewable energy deployment. As of early 2017, 48% of the US-based Fortune 500 companies had targets for emissions reduction, energy efficiency or renewable energy (or combinations thereof); 10% of companies had a specific renewable energy target, and 23 companies had a target for 100% renewable energy.[41] Such targets have led to the expansion of corporate power purchase agreements (PPAs): during 2017, corporate entities worldwide contracted an estimated 5.4 gigawatts (GW) of new renewable power generating capacity, up 26% from 2016.[42]

Although US and European markets continued to account for the bulk of corporate renewable energy sourcing, corporate sourcing of renewable electricity has spread to regions around the world, in countries as diverse as Burkina Faso, Chile, China, Egypt, Ghana, India, Japan, Mexico, Namibia and Thailand.[43] By early 2018, more than 130 leading global corporations had joined the RE100 initiative – a network of corporations committed to using 100% renewable electricity – up from 87 corporations in 2016.[44] *(→ See Feature chapter.)*

Shareholder pressure and the rising competitiveness of the renewables sector also has resulted in increased investment in renewable energy by the fossil fuel industry.[45] Large oil corporations more than doubled their number of acquisitions, project investments and venture capital stakes in renewable energy in 2016 relative to 2015, and 49% of all deals over the past 15 years involved renewable energy, the majority of which included solar PV.[46] However, these companies' investment in renewables remains limited compared to their spending on fossil fuels.[47]

Some oil companies and many other energy companies also have started investing in distributed renewables for energy access (DREA[i]) systems in developing and emerging economies.[48] DREA systems continued to play an important role in providing electricity access to households in remote areas in 2017 and to increasing access to clean cooking. Renewable energy stand-alone and mini-grid systems accounted for some 6% of new electricity connections worldwide between 2012 and 2016.[49] Additionally, the number of clean cook stoves distributed more than tripled in 2016 compared to 2015, although the majority (71%) of these were liquefied petroleum gas, followed distantly by wood and charcoal (23%), with modern renewables making up the remainder.[50] The synergies between energy efficiency and renewable energy are particularly salient for improving access to modern energy services at least cost, as integrating super-efficient appliances, for example, can reduce the annualised system cost by up to 30%, despite higher upfront appliance costs.[51] *(→ See Distributed Renewables chapter.)*

In all sectors, renewable energy support policies continued to play a crucial role. The number of countries with renewable energy targets and support policies increased again in 2017; targets were in place in 179 countries at the national and/or sub-national level (up from 176 countries in 2016), and several jurisdictions made their existing targets more ambitious.[52] However, policy support continues to lag in the renewable heating and cooling and transport sectors. *(→ See Policy Landscape chapter and **Reference Tables R3-R11.**)*

Sub-national governments contributed significantly to renewable energy deployment in 2017: an increasing number of communities, cities and regions introduced 100% renewable energy targets during the year. Further, the number of cities powered by at least 70% renewable electricity more than doubled between 2015 and 2017, from 42 to 101, including Auckland, Brasilia, Nairobi and Oslo.[53]

The number of cities powered by at least 70% renewable electricity

more than doubled

between 2015 and 2017

At the global level, international climate negotiations continued to intersect with renewable energy policy. Of the 168 parties that had submitted Nationally Determined Contributions (NDCs) under the Paris Agreement by the end of October 2017, 109 of these included quantified renewable energy targets, and a further 36 referred to renewable energy action.[54] However, during climate negotiations[ii] in Bonn, Germany in 2017, parties did not yet agree on how NDCs should be organised, delivered and updated, leaving uncertainty on how national renewable energy commitments would be ramped up.[55]

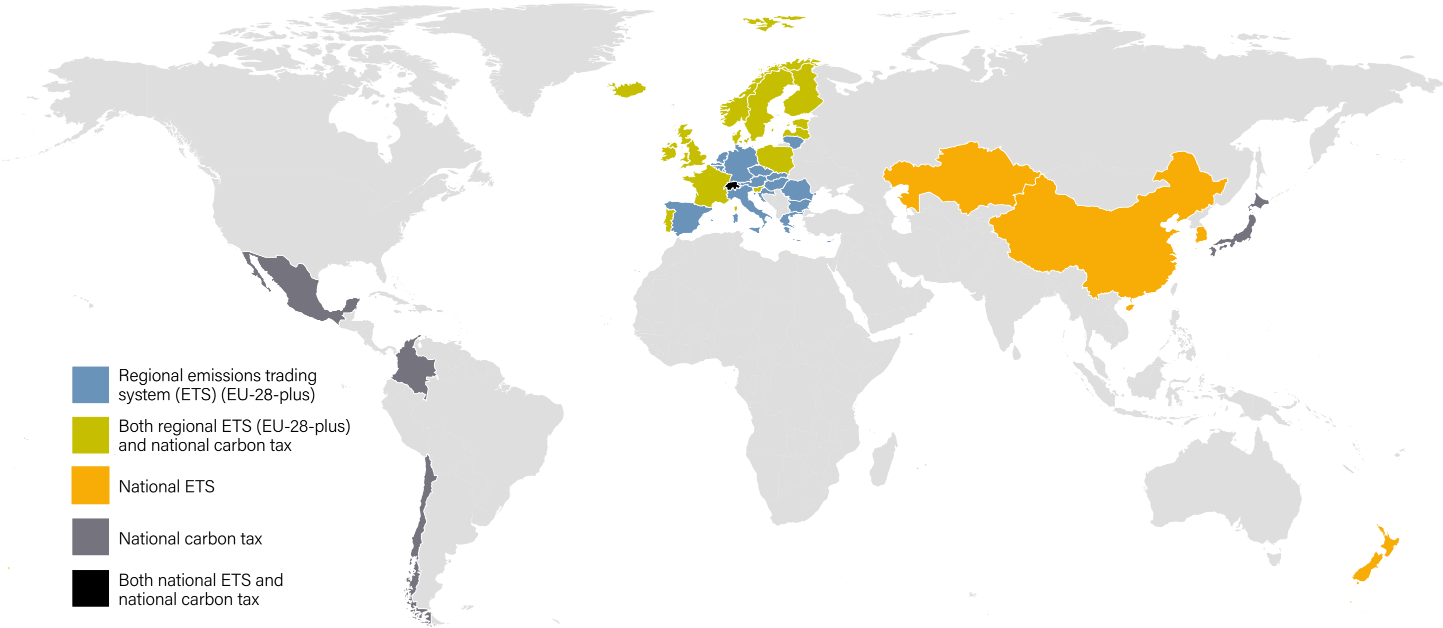
Carbon pricing policies, if well designed, may incentivise the deployment of renewable energy technologies by increasing the comparative cost of higher-emission fuels and technologies through the inclusion of at least some externalities.[56] The number of jurisdictions worldwide with carbon pricing policies in place stood at 64 by year's end, up from 61 in 2016.[57] *(→ See Figure 4.)* As of April 2018, between 20% and 25% of global greenhouse gas emissions were covered by an explicit carbon price, up from 13% at the end of 2016, with the increase due mainly to the entry into force of China's scheme.[58]

i DREA systems are renewable-based stand-alone and off-grid single home or mini-grid systems, independent of a centralised electricity grid, that supply modern energy services to households. They provide a wide range of services – including lighting, operation of appliances, cooking, heating and cooling – in both urban and rural areas of the developing world.

ii These negotiations took place at the 23rd Conference of the Parties (COP23) to the United Nations Framework Convention on Climate Change.

FIGURE 4. Carbon Pricing Policies, 2017

NATIONAL POLICIES



Source: See endnote 57 for this chapter.

The Chinese policy includes carbon taxes, as well as emissions trading, among some 1,700 power companies that collectively emit more than 3 billion tonnes of carbon dioxide (CO_2) annually.[59] For comparison, in 2016, the European Union's Emissions Trading Scheme (EU ETS) covered around 1.7 billion tonnes of CO_2.[60] In late 2017, EU members reached agreement on EU ETS reforms to increase the scheme's impact; these included an agreement to reduce the number of emissions certificates issued and to accelerate the cancellation of surplus certificates.[61] The Carbon Pricing in the Americas initiative, launched in 2017, includes members from North, Central and South America and aims to strengthen the implementation of carbon pricing as a central policy instrument in order to advance action on climate change, the shift to "clean" energy, innovation and the promotion of sustainable economic development.[62]

Developments in the wider energy landscape in 2017 have affected the context in which renewable energy is developing. Low fossil fuel prices continued to pose a challenge to renewable energy markets during the year, especially in the heating and transport sectors.[63] The Brent crude oil price averaged around USD 54 per barrel in 2017, which was about half the average price of the 2011-2014 period but still nearly double the average price during the 1996-2005 period.[64] Natural gas prices also have been relatively low in Europe, Japan and the United States in recent years.[65]

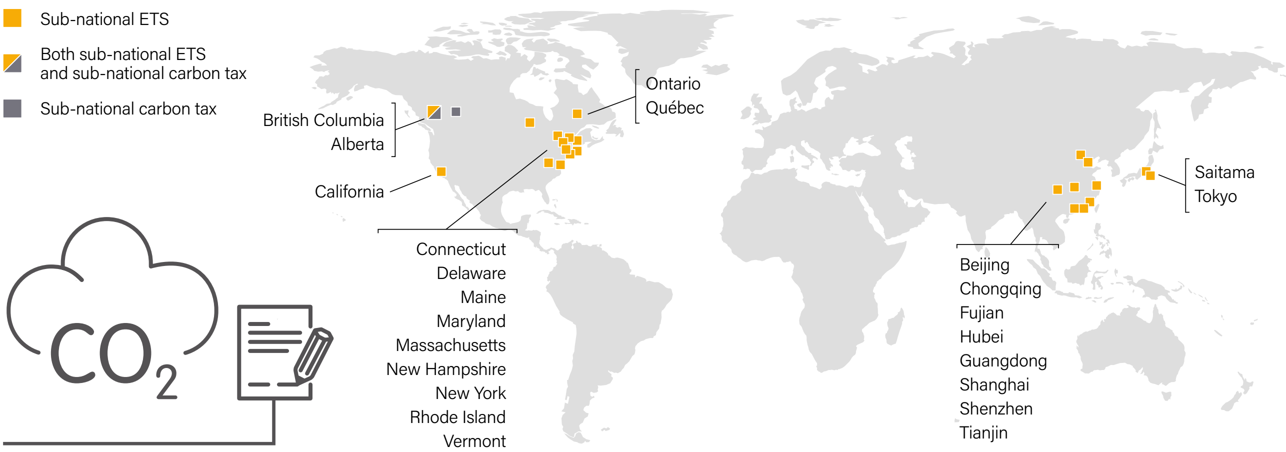
Global coal consumption increased an estimated 1% in 2017, reversing a two-year decline.[66] This was due almost entirely to an increase in coal-fired electricity generation, and would have been even higher if not for a reduction in coal use in industry and buildings.[67] Constructing a new coal-fired power plant, with a lifetime of approximately 40 years, can both lock in carbon-intensive generation and lock out renewable power. Globally, 654 GW of new coal plants are in development throughout the world.[68]

Direct global subsidies to fossil fuels were estimated to be at least USD 360 billion in 2016, a 15% reduction from 2015 but more than double the estimated subsidies to renewable power generation, at USD 140 billion.[69] In 2017, the Group of Twenty (G20) reaffirmed its 2009 commitment to phasing out "inefficient fossil fuel subsidies", yet progress is slow and large investors, insurers and civil society have called for both increased transparency and acceleration of the process.[70] The main obstacles identified include the lack of a clear definition for "inefficient subsidies", the absence of mandatory reporting and the lack of timelines for the phase-out commitments.[71]

At the same time, however, an increasing number of companies that own, develop or operate coal power plants shifted away from the coal business during 2017.[72] Utilities in Africa, Australia, China, Europe, India and the United States have signalled their intention to move out of fossil fuel generation and into large-scale renewables, and some are already doing so.[73] For example, the French-owned utility ENGIE sold off coal and natural gas assets worth EUR 15 billion (USD 18 billion) between the start of 2016 and the end of 2017, and will re-invest EUR 22 billion (USD 26 billion) by the end of 2018 in energy efficiency and renewables.[74] Enel (Italy) moved from 25% renewable energy capacity in 2010 to 43% at the end of 2016, and electric utilities in 26 out of the 28 EU member states agreed to build no more coal-fired power plants from 2020 onwards and to decarbonise Europe's electricity supply by 2050.[75] The Port of Amsterdam,

FIGURE 4. Carbon Pricing Policies, 2017 (continued)

SUB-NATIONAL POLICIES



Source: See endnote 57 for this chapter.

which handles some 16 million tonnes of coal per year, also announced plans to stop processing coal by 2030.[76]

The following sections discuss key developments and trends in renewable energy in 2017 by sector.

Fossil fuel subsidies were more than **double** the estimated subsidies for renewable power generation in 2016

HEATING AND COOLING

Energy for heating and cooling accounts for nearly half of global total final energy consumption. This is split roughly equally between heat for industrial processes and heat for use in buildings.[77] Demand for space cooling – supplied mostly by electricity via air conditioners – accounts for about 2% of TFEC but is growing rapidly, especially in emerging economies.[78] Renewable energy can contribute to the heating and cooling sector in three ways: through the direct combustion of biomass (both modern and traditional), through direct use of geothermal and solar thermal energy, and by contributing to the electricity supply when it is used for heating or cooling.

Heat consumption remains heavily fossil fuel-based. The largest share of renewable heating is associated with traditional biomass for heating and cooking in developing countries, which accounts for some 16.4% of global heat demand.[79] This traditional use of biomass – often in open fires or very inefficient indoor stoves – leads to significant health problems and is often linked to unsustainable levels of fuelwood collection. In developing countries in particular, energy access efforts focus on providing clean cooking solutions to replace such practices. (→ *See Distributed Renewables chapter.)* Only 10.3% of the heat used worldwide in 2015 was produced from modern renewables, including renewably generated electricity.[80] However, there is increasing appreciation of the role that renewables can play in heating.

Renewable energy can serve thermal demand when supplied by electricity, either directly or through the use of heat pumps. Electricity is estimated to account for more than 7% of total heat demand in buildings and industry, with about one-quarter of this estimated to be renewable.[81] Further electrification of heating received increasing attention in 2017, for example in the United States and China.[82] Interest also is rising in using electricity from solar PV for heat to increase self-consumption in the face of reductions in feed-in tariffs.[83]

Direct use of modern renewables in the heating and cooling sector involves the use of more-efficient bioenergy combustion, and the direct use of solar and geothermal heat. The heat can be supplied directly to industrial processes, individual buildings or to a larger number of users through the use of district heat systems. Trends in the use of modern renewable energy for heating vary by technology, although the relative shares of the main renewable heat technologies remained stable during the past few years: after modern bioenergy, the greatest contributors are renewable electricity, solar thermal and geothermal energy.[84]

In the buildings sector, the need is primarily for relatively low-temperature heat – typically in the range of 40 to 70 degrees Celsius (°C) – for space and water heating. Heat may be supplied via onsite equipment or through a district heat network. Renewable energy systems can provide individual heating in residential and medium-size office buildings, either as stand-alone systems or in addition to existing central heating systems, and can provide thermal energy for district heat systems.

The most common use of solar thermal in buildings is for domestic water heating, and solar heat also is used for space heating in single-family houses. Geothermal extraction also offers great potential for district heating applications (as well as for power production). In Europe, where increasingly efficient building stock can be heated at relatively low supply temperatures (40° C or less for new efficient buildings), interest is rising in the use of both geothermal and solar thermal for district heating. *(→ See Geothermal and Solar Thermal sections in Market and Industry chapter.)*

The industry sector similarly has a need for low- and medium-temperature heat (for example, for drying), although some industries require process heat at much higher temperatures – including steam at several hundred degrees Celsius and high-temperature direct heat for use in kilns by the mineral industries, for example.[85] High-temperature heat remains more complicated with renewables, and further research and innovation are still under way to overcome technical challenges.[86] Most renewable heat for industry, as for buildings, is supplied by bioenergy.[87] *(→ See Figure 16 in Market and Industry chapter.)*

Although additional bio-heat[i], solar thermal and geothermal capacities were added in 2017, growth in these markets is slow. *(→ See sections on Biomass Energy, Solar Thermal Heating and Cooling, and Geothermal Power and Heat in Market and Industry chapter.)* Heat markets are complex and fragmented, which poses a challenge to policy making, and multiple barriers – both economic and non-economic – impede the uptake of renewable heat.[88] While policy options exist to address many of these barriers, policy makers have devoted much less attention to renewable heat than to renewable electricity: at the end of 2017, 48 countries had targets in place for renewable heat, compared to 146 for electricity.[89] *(→ See Policy Landscape chapter.)* In addition, fossil fuel heating systems sometimes have lower capital costs, which, combined with low fossil fuel prices, can discourage a shift to renewable systems, particularly since energy prices generally do not include the externalities of fossil fuel systems such as carbon emissions and air quality.[90]

District heating and cooling systems are an important enabling technology for the use of renewables. District heating can combine different sources of heat and can play a positive role in the integration of VRE, including through the use of electric heat pumps. *(→ See Integration chapter.)* District heat systems supply about 11% of global space and water heating needs and are particularly suitable for use in densely populated regions that have an annual heating demand of four or more months, such as in the northern latitudes of Asia, Europe and North America.[91] Most district heat systems today are fuelled by either coal or natural gas, with the renewable energy share ranging from only 1% in China and Japan to 42% in Denmark.[92]

Examples exist of high levels of penetration of renewables in district heating, however. Sweden, for example, has a share of 90% renewables and recycled heat in its heating supply.[93] European countries completed 10 new or renovated geothermal district heating plants in 2017.[94] Driven by government support, solar district heating became more important in an increasing number of countries in Europe and elsewhere.[95] Globally, bioenergy accounts for about 95% of renewable energy supplied to district heating.[96] *(→ See Market and Industry chapter.)*

i Bioheat is heat from bioenergy.

Although not as widely adopted as district heating, district cooling is attracting growing interest and can be fuelled entirely or in part by renewables. District cooling networks (such as those in Paris and Helsinki) generally produce chilled water in centralised energy plants, which is then distributed via underground pipes to provide air conditioning to buildings.[97]

Modern renewable energy accounted for

10.3 %

of total global energy consumption for heat in 2017

Renewables thus far have played a small role in providing cooling services in general (aside from their overall role in electricity supply), yet great potential exists. Locations with high cooling demand often also have good solar availability, creating the possibility for cooling using either solar PV systems or direct options such as solar absorption chilling.[98] However, in many countries in Asia, cooling demand peaks or remains high in the evening, resulting in pressure on the grid and the need for energy for cooling from sources other than solar PV.[99]

Energy demand for cooling is growing rapidly, and access to cooling (including refrigeration) is an issue for health and well-being, particularly in the developing world.[100] In addition to the new Cooling for All initiative of SEforALL, the Kigali Cooling Efficiency Program (launched in 2017) aims to support implementation of the Kigali Amendment to the Montreal Protocol and the transition to efficient and clean cooling solutions for all.[101]

Developments in the renewable heat and cooling sector occurred in most regions of the world in 2017:

Latin America: Modern renewable energy supplied an estimated 25% of heat demand in 2016 (another 14% was from traditional biomass); most heat demand in the region is for industrial use.[102] A few countries rely heavily on renewable sources for industrial heat (mainly bioenergy, but also solar and geothermal), including Paraguay (90% of industrial heat supplied by renewable energy), Uruguay (80%), Costa Rica (63%) and Brazil (48%).[103] In 2017, Brazil met around 50% of its industrial heat demand with biomass, the highest share in the world.[104] The country also was the fourth largest market for solar thermal collectors.[105] ***(→ See Reference Table R20.)***

Europe: The EU continued to produce the most heat from modern renewables of any region in 2016, with the majority consumed in buildings.[106] The contribution of modern renewables to heat is growing as a result of mandatory renewables targets in the EU Renewable Energy Directive (RED) and the inclusion of heat in the National Renewable Energy Action Plans of member countries.[107] In November 2017, the energy committee of the European Parliament adopted changes to the RED to 2030, including a recommendation to increase the share of renewables in heating and cooling by 1% annually.[108] An estimated 19% of the EU's total heating and cooling demand was met by renewable sources (primarily solid biomass) in 2016, up from 15% in 2010.[109] In 2017, seven European countries were among the top 10 countries worldwide for additions to solar water heating capacity.[110] New solar thermal or geothermal district heat capacity came online in Austria, France, Germany, Italy, the Netherlands, Romania, Sweden and Serbia.[111]

North America: The region remained the world's second largest producer of renewable heat, with renewables meeting just over 10% of heat demand.[112] However, growth in the renewable heating sector is slow, due in part to a decline in the use of renewables in industry, reflecting changes in production patterns in key sub-sectors such as pulp and paper.[113] The United States ranked fifth worldwide for solar water heating collector capacity additions in 2017.[114] The country is seeing increased interest in renewable heat strategies and in the electrification of heat to allow greater penetration of renewable electricity, as evidenced by a number of US studies.[115] In Canada, installations of bioenergy systems for heat increased 42% in 2016 compared to 2015.[116]

Asia: In 2017, China made high-profile commitments to replacing coal as a main source for heating by enacting a coal ban for 28 cities and emphasising an enhanced role for renewables. In addition, several renewable heating-related targets were established in the country's 13th Five-Year Plan.[117] China is home to the largest new solar thermal system for industrial heating completed during 2017.[118] India also has a strong market for solar thermal applications, with installations of solar thermal collectors up approximately 25% in 2017.[119] Asia was again the largest market for solar thermal-driven chillers, with solar thermal cooling installations commissioned in China, India and Singapore.[120] Biogas for cooking also expanded further in south-central and south-eastern Asian countries, including Bangladesh, Cambodia, Indonesia and Nepal.[121]

Africa: Most heat demand in Africa is for cooking, with the majority supplied from traditional biomass, which can have serious impacts on health and generally is not sustainably produced.[122] *(→ See Distributed Renewables chapter.)* South Africa and Tunisia were among the top 20 countries worldwide for installations of solar collectors during 2017, ranking 14th and 18th, respectively.[123] ***(→ See Reference Table R20.)*** The use of biogas for cooking continued to grow in sub-Saharan Africa, namely in Ethiopia, Kenya and Tanzania.[124]

Middle East: Although the contribution of renewables to heating and cooling in the region is very small, interest is rising in developing solar thermal solutions for cooling.[125] Some early demonstration cooling plants were constructed in the region.[126] In late 2017, Phase 1 of a solar thermal plant delivered the first steam for enhanced oil recovery to the Amal West oil field in southern Oman.[127] *(→ See Solar Thermal Heating and Cooling section in Market and Industry chapter.)*

TRANSPORT

Energy for the transport sector makes up nearly one-third of total final energy consumption globally.[128] The transport sector is made up of several sub-sectors, including road transport (urban, long-distance, freight), marine, aviation and rail transport. Despite gains in efficiency, global energy demand in the transport sector increased 39% between 2000 and 2016, a rise attributed to the increased movement of freight globally and to the overall increase in transport demand in emerging and developing countries, among other factors.[129]

The 2015 Paris Agreement helped put transport on the climate agenda and marked the beginning of more serious dialogue on decarbonisation in the sector. Twenty-one voluntary stakeholder initiatives on sustainable, low-carbon transport were created in the follow-up, and in 2017 they converged into the Transport Decarbonisation Alliance, a multi-stakeholder alliance comprising countries, cities, regions and private sector entities committed to ambitious action on transport and climate change.[130] In addition, planning was initiated in 2017 for emissions reduction in the internationally governed maritime and aviation sectors, both of which rely almost exclusively on the use of fossil fuels.[131] New CO_2 standards were adopted for aircraft in 2017, and a climate change strategy was adopted for shipping by early 2018.[132]

Road transport – in particular the light-duty vehicle market – was affected in 2017 by the revelation of efforts by at least one major automaker to circumvent emissions control requirements.[133] In 2017, five countries announced their intention to ban sales of new diesel and petrol cars – by 2030 (India, the Netherlands and Slovenia) and by 2040 (France and the United Kingdom).[134] Late in the year, a coalition of corporations from China, Europe and the United States launched EV100, a new campaign to accelerate the uptake of EVs and associated infrastructure.[135] In addition to the introduction of EV100 and other initiatives (such as EV30@30), 2017 was a breakthrough year for car manufacturers announcing electric product lines.[136]

All of these developments have helped foster a more holistic view of decarbonisation strategies, with increased recognition of the importance of incorporating renewable energy, transitioning to new transport modes and reducing the overall need for transport – in addition to improving vehicle fuel efficiencies and emission standards, the main focus so far.[137]

The entry points for renewable energy in the transport sector are: the use of 100% liquid biofuels (including advanced biofuels) or of biofuels blended with conventional fuels; natural gas vehicles and infrastructure converted to run on upgraded biomethane; and the use of electricity for transport (provided that the electricity is itself renewable), either directly in EVs or for the production of synthetic fuels, in particular hydrogen pathways. Some renewable energy carriers can be used in the internal combustion engines of conventional vehicles, whereas others require the use of alternative vehicles.

Renewable energy makes up about
3.1%
of total global energy consumption for transport

Biofuels (principally ethanol and biodiesel) make the greatest contribution to renewable transport by far, supplying 2.8% of world energy consumption for transport (as of 2015).[138] Approximately 1.3% of transport needs are supplied by electricity, with just over one-quarter of that estimated to be renewable electricity (as of 2015).[139] Global ethanol production increased 2.5% in 2017 compared to 2016, and biodiesel production remained relatively stable, following a 9% increase in 2016.[140] *(→ See Market and Industry chapter.)*

Growth in the use of biofuels is slow, held back by policy uncertainties related to feedstock sustainability and by slow progress in bringing forward new technologies that can produce fuels for markets such as aviation. *(→ See Box 2 in Policy Landscape chapter.)* In 2017, the BioFuture Platform saw 19 countries agree to scale up their bioenergy commitments and develop sustainable biofuels targets, and the Mission Innovation Sustainable Biofuels Challenge was launched and aims to stimulate and co-ordinate efforts to bring new sustainable biofuels to the market.[141]

Opportunities for other renewable energy applications are opening up due to the increasing electrification of both rail and road transport, and to the slow increase in the use of hydrogen and synthetic fuels for transport in some countries.[142] Further electrification of transport has the potential to create a new market for renewable energy and to ease the integration of VRE,

provided that market and policy settings ensure the effective harmonisation of charging patterns with the requirements of the electricity system. *(→ See Integration chapter.)*

Even so, the renewable contribution from electricity is small, accounting for about 10% of all renewable transport, with biofuels contributing the remainder.[143] Although the use of electricity in transport previously was limited mainly to trains, light rail and some buses, in 2017 there were signs of the entire sector opening to electrification, as fully electric passenger cars, scooters and bicycles became more commonplace in many locations, and as prototypes were released for electric heavy-duty trucks, planes and ships.[144] Electric passenger vehicles on the road passed the 3 million mark in 2017.[145]

The uptake of electric mobility helps to increase the use of renewable energy in transport only if renewables play a significant (and growing) role in the generation of electricity. Already, examples exist of countries and cities – including the Netherlands and the cities of Delhi (India) and Santiago (Chile) – supplying both heavy and light rail with renewable electricity.[146] However, only Austria and Germany had policies in 2017 to explicitly stimulate the use of renewable electricity in EVs, by linking financial and fiscal incentives for electric mobility to the use of renewable electricity.[147] While only limited examples are available of direct policy linkages between EVs and renewable electricity, many countries have targets for both EVs and renewable electricity, which is likely to result in increased use of renewable energy for transport as more EVs come onto the roads while more renewable energy becomes available for EV charging. *(→ See Figure 15 in Policy Landscape chapter.)*

Marine transport consumes around 12% of the global energy used in transport and is responsible for approximately 2% of CO_2 emissions.[148] The International Maritime Organisation's Marine Environment Protection Committee approved a roadmap (2017-2023) to develop a strategy for reducing greenhouse gas emissions from ships.[149] Multiple entry points for renewable energy are possible in this sector: the use of biofuels in existing engines (the most immediate option), the use of synthetic fuels or hydrogen produced with renewable electricity in modified engines, direct incorporation of wind power (sails) or solar energy, and electrification to the extent that the electricity is renewable. In 2017, China launched the world's first all-electric cargo ship, and two large ferries in Sweden were converted from diesel to electricity.[150] In September 2017, the Maritime and Port Authority of Singapore, BHP and GoodFuels Marine signed a letter of intent to collaborate on a biofuels pilot project in Singapore, which is expected to be carried out in 2018.[151]

Aviation accounts for around 11% of the total energy used in transport.[152] In 2016, the International Civil Aviation Organisation adopted an agreement to mitigate greenhouse gas emissions in the aviation sector, and by the end of 2017, 107 countries representing 91.8% of air traffic had submitted State Action Plans.[153] The Action Plans support the production and use of sustainable aviation fuels, specifically drop-in biofuels[i] produced from biomass and different types of organic waste.[154] In 2017, Norway announced a target of 100% electric short-haul flights by 2040; assuming that this target is achieved, much of the

electricity is likely to be renewable if the country maintains its current high share of electricity from renewable sources (97% from hydropower and 1% from wind power in 2016).[155]

Rail accounts for around 1.9% of the total energy used in transport and is the most highly electrified transport sector.[156] The share of electricity in this sector was an estimated 39% in 2015, up from 29% in 2005.[157] However, about one-fourth of the electricity is estimated to be renewable, contributing 9% of rail energy.[158] Some jurisdictions are opting to increase the share of renewables in rail transport to well above the share in their power sectors. For example, the Dutch railway company NS announced in 2017 that it had achieved its 2016 target to power all electric trains with 100% renewable electricity.[159] Biofuels also are used in the rail sector: in 2017, the Netherlands announced that 18 new trains fuelled with biodiesel were being brought into service.[160]

Road transport accounts for 67% of global transport energy use, with passenger vehicles representing two-thirds of this.[161] Regional trends related to renewable energy in road transport during 2017 include:

Asia: Biofuel production in the region increased 2.4% in 2017, well below the increase of more than 12% seen in 2016.[162] Several Asian countries remain in the top 15 countries for biofuels production globally, including China, Thailand, Indonesia, Singapore and India. *(→ See Bioenergy section in Market and Industry chapter and* ***Reference Table R15.****)* India's first biomethane-fuelled bus started operation in 2017.[163]

Countries in the region also were increasingly active in electric mobility in 2017, although not directly tied to renewables in most cases. EV sales in China increased 69% and accounted for just under half of the global total; elsewhere in the region, India announced an EV target, Thailand approved a new EV support policy, and Malaysia announced its ambition to become a "marketing hub" for EVs.[164] Although most countries in the region do not require that their electrified vehicles use renewable electricity, many have renewable electricity targets that will effectively determine the "share" of renewable electricity for these vehicles.[165]

i 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.

Europe: Policy support for and public opinion regarding first-generation biofuels continued to be uncertain, with ongoing discussions in the region over the role of bioenergy in the EU's RED between 2020 and 2030. Overall biofuel production fell slightly in 2017 despite a rise in production of hydrotreated vegetable oil (HVO).[166] Europe is home to three of the world's four largest producers of biomethane for vehicle fuel – Germany, Sweden and Switzerland – and the region's biomethane production increased 12% between 2015 and 2016.[167] Sales of EVs in Europe increased 39% in 2017 compared to 2016 and accounted for nearly one-quarter of global sales.[168] Norway leads the region in total EV sales and market penetration.[169] The increase in the number of EVs on Europe's roads, alongside increasing renewable electricity generation, brings opportunities for further decarbonisation of transport.[170]

North America: The United States continued to be the world's largest producer and user of biofuels, supported both by agricultural policy and by the federal Renewable Fuel Standard. Production of ethanol increased by close to 2.8% in 2017 relative to 2016, and a record average blend rate of 10.08% was achieved.[171] The United States is the largest market globally for biomethane as a transport fuel, and production, which grew nearly six-fold between 2014 and 2016, increased another 15% in 2017.[172] North America was the third largest regional market for EVs after Europe and China, and EV sales in 2017 were up 27% in the United States and 68% in Canada (Canada being the smaller market of the two).[173] *(→ See Electric Vehicles section in Integration chapter.)*

Latin America: Biofuel production in the region grew 2% in 2017, after remaining stable in 2016.[174] Biodiesel production increased 9% in 2017, building on an 11% rise in 2016, and ethanol production was stable.[175] In Brazil, biodiesel production increased 12.9%, following a 4.4% decline in 2016.[176] The market for EVs in South and Central America is still at a very early stage, but some new initiatives emerged. For example, Argentina announced a new support policy for EVs and plans for 220 EV charging stations, and Uruguay launched the first electric route in Latin America, with six charging stations at 60-kilometre intervals.[177] In the case of Uruguay, which gets 98% of its electricity from renewable energy, its electric mobility strategy is part of a larger national goal to increase the share of renewables in the country's energy mix.[178]

Africa: Production and use of biofuels in Africa are still at very low levels, although some signs of growth were apparent. Biofuel production increased 28% (from very low levels) in 2017, up from 17% in 2016.[179] In Nigeria, the state oil corporation signed an agreement with the government of the state of Kebbi to build a new ethanol plant to help meet the government mandate on automotive biofuels production, and in Zambia, Sunbird Bioenergy Africa launched a programme to secure feedstock for an ethanol project for the transport fuel market to provide 15% of the country's petroleum requirements.[180] Some early sales of EV passenger cars occurred in South Africa, and the country's first electric bus was launched in Cape Town.[181]

POWER

Total renewable power capacity **more than doubled** in the decade 2007-2017

Renewable power generating capacity saw its largest annual increase ever in 2017, with an estimated 178 GW installed worldwide, raising total capacity by almost 9% over 2016.[182] Solar PV led the way, accounting for nearly 55% of newly installed renewable power capacity.[183] More solar PV capacity was added in 2017 than the net additions of fossil fuels and nuclear power combined.[184]

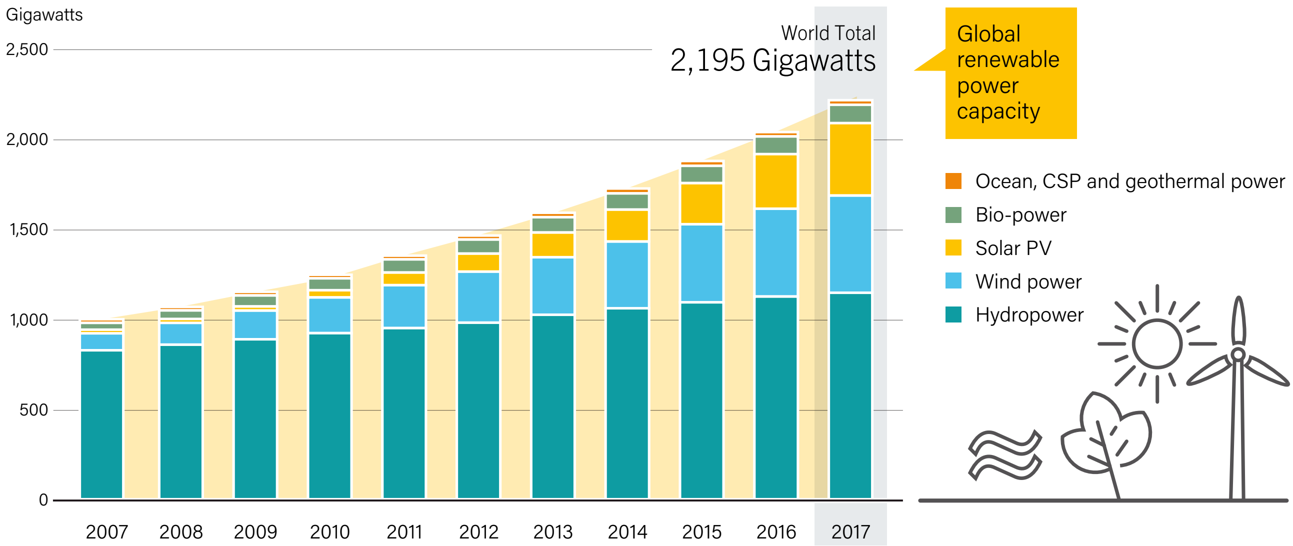
Wind and hydropower accounted for most of the remaining renewable capacity additions, contributing more than 29% and nearly 11%, respectively.[185] ***(→ See Reference Table R1.)*** Total renewable power capacity more than doubled in the decade 2007-2017, and the capacity of non-hydropower renewables increased more than six-fold.[186] *(→ See Figure 5.)*

Overall, renewable energy accounted for an estimated 70% of net additions to global power capacity in 2017, up from 63%[i] in 2016.[187] By year's end, global renewable power capacity totalled around 2,195 GW – enough to supply an estimated 26.5% of global electricity, with hydropower providing about 16.4%.[188] *(→ See Figure 6.)*

Ongoing capacity growth and geographical expansion of renewable power technologies are driven by a number of factors, including rising electricity demand in some countries, targeted renewable energy support mechanisms and continuing cost declines (particularly for solar PV and wind power). *(→ See Market and Industry chapter and Sidebar 2.)*

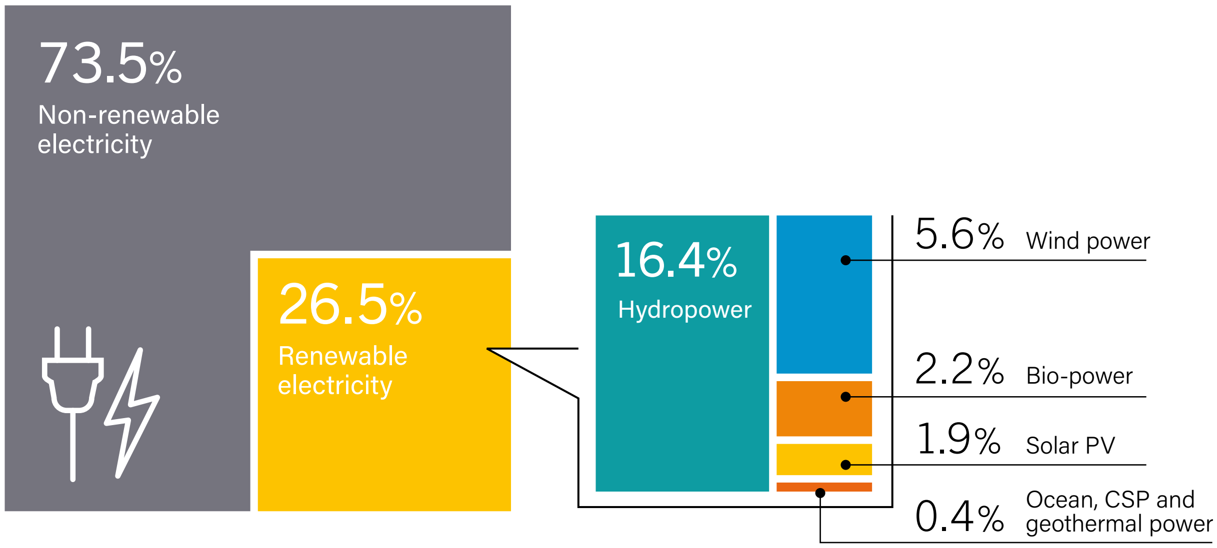
i The estimated shares for 2016 and 2017 are derived from different sources (see endnote 187), and therefore the difference may not represent an absolute increase. However, it is an indication that renewable energy's share of net capacity additions rose significantly in 2017 relative to 2016.

FIGURE 5. Global Renewable Power Capacity, 2007-2017



Source: See endnote 186 for this chapter.

FIGURE 6. Estimated Renewable Energy Share of Global Electricity Production, End-2017



Source: See endnote 188 for this chapter.

The cost-competitiveness of renewable power generation (unsubsidised) continued to improve in 2017. While the average global levelised costs of energy (LCOE) for the more mature technologies – bio-power, geothermal and hydropower – have remained relatively stable in recent years, solar and wind power have seen years of steady cost declines and are becoming ever more competitive for meeting new electricity generation needs.[189] The global weighted average LCOE of utility-scale solar PV fell 73% between 2010 and 2017, and onshore wind power has become one of the most competitive sources of new generation.[190] Offshore wind power and concentrating solar thermal power (CSP) prices also fell over this period, with their global weighted average LCOEs declining 18% and 33%, respectively.[191] *(→ See Table 3 in Market and Industry chapter.)*

Renewable energy tenders in 2017 resulted in record low bid prices[i] for both solar PV and wind power in several countries, with bids as low as USD 30 per megawatt-hour for onshore wind power and for solar PV.[192] Reductions in bid prices in the offshore wind power sector also were remarkable in several European countries.[193]

Although the use of VRE generation linked to battery storage is not widely deployed, wind power-plus-storage and solar PV-plus-storage have started to compete with natural gas peaking plants in some markets.[194]

During the year, the community energy sector in some countries experienced challenges in locations where it traditionally has been strong, for example in Germany and the United Kingdom.[195] This is due primarily to the shift in policies from feed-in tariffs (FITs)

i For multiple reasons, tender prices may be lower than LCOEs. For example, bids may include annual adjustments, and tender conditions might include the provision of grid connection to developers. In addition, bids reflect expected future rather than current costs.

to tenders, which tend to favour large corporate players over community actors.[196] However, the number of community wind power projects is rising in some countries outside of Europe.[197] In Australia, for example, the community energy sector expanded significantly from just 2 projects in 2014 to more than 70 in 2017, with community investment of some USD 24 million and more than 90 active community energy groups.[198] Community energy projects also are on the rise in Japan, where the total capacity of community solar PV projects almost doubled in 2017, to 86 MW.[199]

The top country for total installed renewable power capacity at the end of 2017 was China, followed distantly by the United States, Brazil, Germany and India, which moved ahead of Canada.[200]

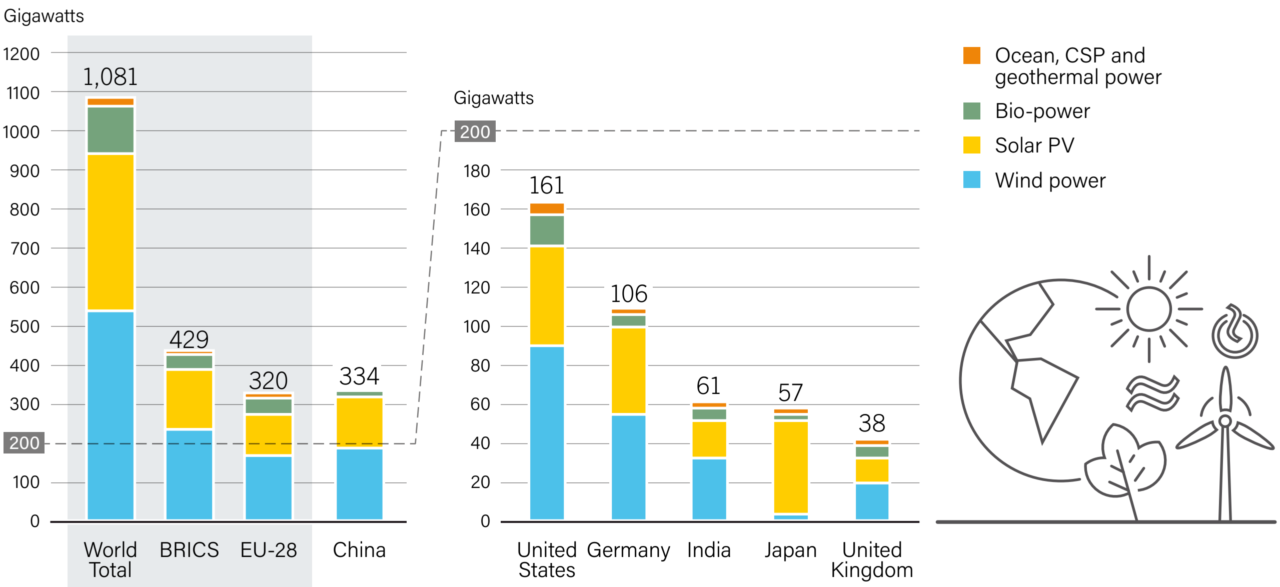
China alone was home to nearly 30% of the world's renewable power capacity – totalling approximately 647 GW, including about 313 GW of hydropower.[201]

Considering only non-hydropower[i] capacity, the top countries were China, the United States and Germany, followed by India, Japan and the United Kingdom.[202] *(→ See Figure 7 and* ***Reference Table R2.****)*

The world's top countries for non-hydro renewable power capacity per inhabitant were Iceland (more than 2.1 kilowatts (kW) per inhabitant), Denmark (nearly 1.6 kW), Germany and Sweden (both approaching 1.3 kW).[203]

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

FIGURE 7. Renewable Power Capacities* in World, EU-28, and Top 6 Countries, 2017



Note: BRICS = Brazil, the Russian Federation, India, China and South Africa. *Not including hydropower.

Source: See endnote 202 for this chapter.

An estimated 17 countries generated more than 90% of their electricity with renewable sources in 2017.[204] Although most of these countries are supplied almost completely by hydropower, in three of them – Uruguay, Costa Rica and Ethiopia – wind power also provides a significant contribution.[205]

An estimated 17 countries generated more than

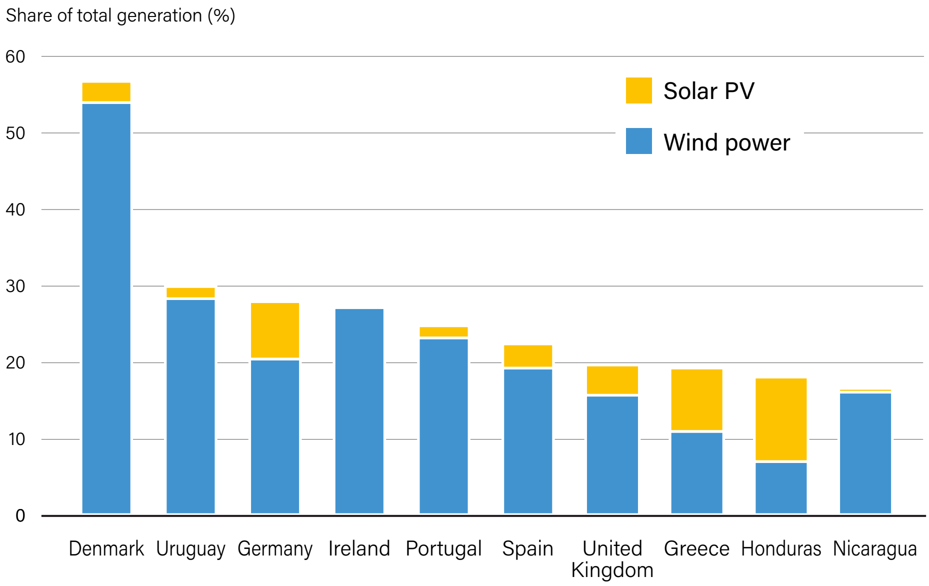
90 %

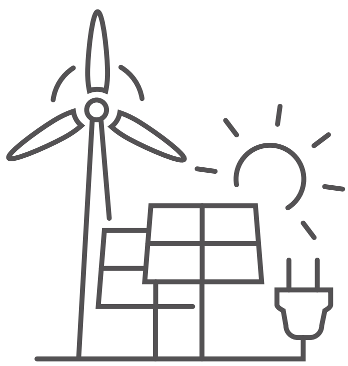
of their electricity with renewable sources in 2017

Several countries are successfully integrating increasingly larger shares of variable solar PV and wind power into electricity systems by improving regulations and market design to reward flexibility, and by improving transmission and interconnection so as to broaden balancing areas. In some cases, countries also are investing in energy storage capacity (mostly pumped storage). Countries leading the way in VRE penetration include Denmark (nearly 53%), Uruguay (28%) and Germany (26%); Ireland, Portugal and Spain also have VRE penetration levels above 20%.[206] *(→ See Figure 8 and Integration chapter.)*

A number of countries and regions integrated much higher shares of VRE into their energy systems as instantaneous shares of total demand for short periods during 2017. They include, for example, South Australia, which generated more than 100% of load from wind power alone and 44% of load from solar PV alone on two separate occasions; Germany (66% of load from wind and solar power combined); the US state of Texas (54% of load from wind power alone); and Ireland (60% of load from wind power alone).[207]

FIGURE 8. Share of Electricity Generation from Variable Renewable Energy, Top 10 Countries, 2017





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

Source: See endnote 206 for this chapter.

Curtailment of wind and solar power can be considered an indicator of challenges with grid integration of VRE. Such challenges have led to high curtailment rates in China, the world's largest market for wind power and solar PV.[208] In 2017, however, average curtailment for wind power in China was reduced to 12%, down from 17% in 2016, and average curtailment of solar PV was 6-7%, down 4.3 percentage points compared to 2016.[209] Elsewhere, jurisdictions that have relatively high shares of VRE have successfully introduced measures – such as market design to increase flexibility or transmission planning to ensure export ability – to reduce curtailment to low levels.[210]

Falling technology costs (particularly for solar PV) – combined with advances in technologies to manage mobile payment systems – have enabled renewables to play a growing role in providing energy access.[211] In developing and emerging economies, as well as in isolated areas such as islands or isolated rural communities (where electricity prices tend to be high if they are not heavily subsidised), existing energy supplies may be unreliable whereas renewable energy resources can be plentiful, making renewable electricity more competitive relative to other options.[212]

Off-grid stand-alone systems and mini-grids represented about 6% of new electricity connections worldwide between 2012 and 2016, and continued to provide access for new populations in 2017.[213] Distributed systems are estimated to be the least-cost option to supply electricity to nearly three-quarters of the people living in remote areas of sub-Saharan Africa – the population that is considered the most difficult to serve worldwide.[214] *(→ See Distributed Renewables chapter.)*

Throughout 2017, noteworthy developments took place in the renewable power sector in most regions of the world, although progress is uneven:

Asia: Renewable power has grown most notably in Asia, particularly China. The region continued to be the global leader in renewable power capacity, accounting for 75% of global solar PV additions and for 48% of global wind power additions in 2017.[215] New solar PV capacity in both China and India surpassed new coal installations for the first time.[216] China remained the world leader in installed capacities of hydropower, onshore wind power and solar PV, and became the world's largest producer of bioelectricity in 2017, with a 23% increase over 2016.[217] India nearly doubled its solar PV capacity, which exceeded the country's annual wind power installations for the first time.[218]

Renewable energy accounted for an estimated

70 %

of net additions to global power capacity in 2017

Indonesia led the world with new geothermal power generation capacity, and Turkey was among the top countries for capacity additions in solar PV, wind power, geothermal (second, after Indonesia) and hydropower.[219]

Europe: Growth has slowed in recent years in several countries in Europe. However, in 2017, for the first time, electricity generation from non-hydropower renewables (wind, solar and biomass) overtook lignite and hard coal generation, and renewables generated 30% of the region's electricity.[220] For comparison, just five years before, coal generation was more than twice the generation from wind, solar and biomass power combined.[221]

Continuing an ongoing trend of renewables accounting for rising shares of new power capacity each year, 85% of newly installed power capacity in the EU was renewable.[222] Wind power and solar PV accounted for three-fourths of the annual increase in renewable power capacity, and offshore wind power represented around 20% of the total European wind power market in 2017.[223] Growth has become more uneven geographically, however, with only two countries – Germany and the United Kingdom – accounting for 57% of the EU's renewable capacity expansion between 2014 and 2017.[224]

After ongoing debate, the European Parliament voted in January 2018 for a new European Renewable Clean Energy Target of 35% by 2030, which applied to the overall energy mix for all sectors and likely would result in more than 50% renewable electricity.[225] However, concern remains that new coal power will be allowed to receive subsidies via capacity payments, and that priority dispatch for wind and solar power will be abandoned.[226]

North America: In the United States, renewable energy accounted for 18% of total electricity generation, up from 15% in 2016.[227] Direct corporate and utility purchases of renewable electricity are playing an increasing role in the sourcing of renewable electricity.[228] The United States leads globally in this area, accounting for 60% of all renewable PPA capacity by the end of 2017.[229] *(→ See Feature chapter.)* Although the growth in US renewable capacity overall was lower in 2017 than in 2016, cumulative solar PV capacity still increased 26% in 2017.[230] In Canada, overall growth in nonhydropower renewable capacity has slowed significantly, from nearly 30% in 2014 to around 4% in 2017.[231]

Latin America and the Caribbean: In Latin America, the overall non-hydropower renewables growth remained strong in 2017, and markets for wind power, solar PV and other renewable technologies are emerging in many countries in the region.[232] Renewable energy sources (mostly hydropower) accounted for nearly two-thirds of the region's electricity supply in 2016.[233] In Uruguay, the share of VRE increased sharply in a short time period, from 1% in 2013 to 28% in 2017.[234] Honduras and Nicaragua also have achieved high VRE shares, at 17% and 15%, respectively.[235] Brazil has been the region's largest market for wind power for some time and led the regional market for solar PV in 2017, becoming the second country in the region (after Chile) to exceed 1 GW of solar installations.[236] Chile ranked third globally for new geothermal power capacity, and Honduras and Mexico also added some capacity.[237]

Africa: Overall growth in renewable power capacity is concentrated in a limited number of countries in Africa.[238] Non-hydropower renewable power capacity in the region grew an estimated 9% overall in 2017.[239] The top countries for cumulative non-hydropower renewable capacity were South Africa, Egypt and Kenya.[240] South Africa was the only country worldwide to bring new CSP capacity online in 2017, leading led the global market for the second year running.[241] Across Africa, interest is growing in solar PV as a means to diversify the energy mix, meet rising energy demand and provide energy access.[242] In East and West Africa, decentralised energy service companies have established a thriving market for off-grid solar PV: pay-as-you-go (PAYG) companies raised about USD 260 million in capital in 2017, up 19% from 2016, and served more than 700,000 customers through contracts based on mobile payment systems.[243] *(→ See Distributed Renewables chapter.)*

Oceania: Australia generated 17% of electricity from renewable energy in 2016, with about 10% of this from non-hydropower sources.[244] After four years of declines, the country's growth rate in non-hydro renewable power capacity increased to 12% in 2016 and reached 16% in 2017.[245] Australia was one of the world's top installers (seventh) of solar PV capacity in 2017, and the country ranked fifth globally for total capacity per inhabitant.[246] New Zealand generated 85% of its electricity from renewable energy in 2016, with well over half of this from hydropower and most of the rest from geothermal power; other renewable power sources have not grown substantially in the country.[247]

Middle East: Markets in the Middle East have not yet taken off significantly, although promising signs of market development were seen in 2017.[248] The share of renewable generation in the region is very low (around 2.5%), with non-hydropower renewables providing less than 0.6%.[249] However, in 2017, Saudi Arabia held a solar PV tender and began the process of holding wind power tenders, and several countries added renewable energy targets or increased the ambition of existing targets.[250] A large pipeline of solar PV and CSP projects also exists in the region, with projects under construction in Israel, Jordan, Kuwait, Saudi Arabia and the United Arab Emirates.[251]

SIDEBAR 1. Jobs in Renewable Energy

The renewable energy sector employed, directly and indirectly, approximately 10.3 million people in 2017[i]. This figure includes 1.5 million jobs in large-scale hydropower, for which only an estimate of direct employment is available[ii]. *(→ See Figure 9.)*

Employment in the renewable energy sector is influenced by a large number of factors, including falling technology costs, changes in labour productivity, corporate strategies and industry restructurings, industrial policies to enhance domestic value creation, and market developments in renewable energy.

Solar photovoltaics (PV) was again the largest employer, primarily because installations of solar PV dominated new renewable energy installations by a large margin. *(→ See Market and Industry chapter.)* This was followed by jobs in biofuels, large-scale hydropower, wind energy, and solar thermal heating and cooling. *(→ See Table 1.)*

Global employment in solar PV was estimated at 3.4 million jobs in 2017, 9% higher than in 2016. As the leading PV manufacturer and market, China accounted for two-thirds of these jobs, or some 2.2 million. India registered strong growth in grid-connected installations, with an estimated 92,000 jobs in this segment[iii]. The United States, by contrast, recorded the first decline ever in solar PV employment, reflecting a slowing pace of installations as well as policy uncertainties. Solar PV employment also declined in Japan and in the European Union (EU).

Biofuels employment totalled an estimated 1.9 million jobs. Brazil continued to have the largest biofuels workforce, but the numbers continued to be affected by rising mechanisation[iv]. In Southeast Asia, the agricultural supply chain for biofuels production remained labour-intensive. A decline in biofuels employment in Indonesia was offset in part by gains in Malaysia, Thailand and the Philippines. Changes in biofuels employment do not necessarily equate to net gains or losses because feedstock supplies can be switched between different end-uses.

An estimated 1.1 million people worked in the wind power industry in 2017, a 0.6% decline from 2016 that reflected a slower pace of new capacity additions. Wind employment in China was almost unchanged – at 510,000 jobs – as a decline in new installations was compensated by growth in the labour-intensive offshore sector. Germany and the United States reached new records in wind employment; India, the United Kingdom and Brazil were other significant employers. Supply chains have become more globalised as more countries attempt to build domestic capabilities.

Global employment in solar thermal heating and cooling was estimated at 807,000 jobs in 2017, a 2.6% decrease from 2016. This reflects a decline in new installations in China (the dominant market and a major exporter) and in Brazil, India and the EU. *(→ See Market and Industry chapter.)*

Overall, most renewable energy employment was in China, Brazil, the United States, India, Germany and Japan.

China remained the undisputed leader in renewable energy employment, with nearly 4.2 million jobs. Solar PV was by far the main source of job creation in the country's renewables sector. Except for a decline in solar thermal heating and cooling, China's employment in renewable energy technologies remained essentially unchanged.

Biofuels continued to be Brazil's mainstay, with close to 0.8 million jobs out of a total 1.1 million in the country's renewables energy sector. Although the ethanol industry continued to shed jobs, the biodiesel industry was on the rise.

In the United States, the decline in solar jobs was offset by gains in wind power and biofuels for an overall 1% increase. Wind power employment gained 3% in 2017, and both ethanol and biodiesel jobs increased.

In India, employment in the solar sector has been driven by rapid capacity growth. Although the country remained highly dependent on panel imports, it had an estimated 164,000 jobs in solar PV in 2017 – up 36% over 2016 – mostly in installation and in operations and maintenance. Wind power employed an estimated 60,500 people in India in 2017.

In 2016 (latest data available), the number of renewable energy jobs in the EU reached 1.27 million, up from 1.19 million in 2015[v]. The solid biomass and wind power sectors were the largest employers, followed by biofuels. Solar PV employment continued to shrink, dipping to just below 100,000 jobs.

Germany remained in the lead in Europe. After four years of retrenchment, it posted a gain in 2016, to 332,000 jobs[vi]. Wind power, geothermal energy and bioenergy all added jobs, but the solar industry continued to shed them.

Solar PV represented a significant source of jobs in the renewable energy sectors of a number of countries, including – in Asia – Bangladesh, Japan, Malaysia, the Philippines, the Republic of Korea, Singapore and Turkey, as well as other countries such as Australia, Mexico and South Africa.

i This sidebar is drawn from International Renewable Energy Agency (IRENA), ***Renewable Energy and Jobs – Annual Review 2018*** (Abu Dhabi: 2018). Data are principally for 2016 and 2017, although dates vary by country and technology, including instances where only earlier information was available. Where possible, employment numbers include direct and indirect employment; induced employment is not included. Jobs figures should be regarded as indicative, as estimates draw on a large number of studies with different underlying methodologies, uneven detail and data quality, and varying definitions of renewable energy employment.

ii 10 MW is often used as a threshold for small- versus large-scale hydropower; however, this is inconsistent across countries. Jobs estimates are based on IRENA's employment factor approach.

iii Using an employment factor method.

iv The ethanol figure is from a government database, whereas the biodiesel estimate uses employment factors. The overall figure includes an approximation of equipment manufacturing employment.

v The principal source (EurObserv'ER, *The State of Renewable Energies in Europe*, 2017 Edition (Brussels: 2018)) has switched from a survey to input-output analysis. EU jobs figures were adjusted where more detailed national data were available. Only ground-source and hydrothermal heat pumps are included.

vi Employment numbers for Germany are revised from earlier reports based on an input-output study commissioned by the German government.

TABLE 1. Estimated Direct and Indirect Jobs in Renewable Energy, by Country and Technology

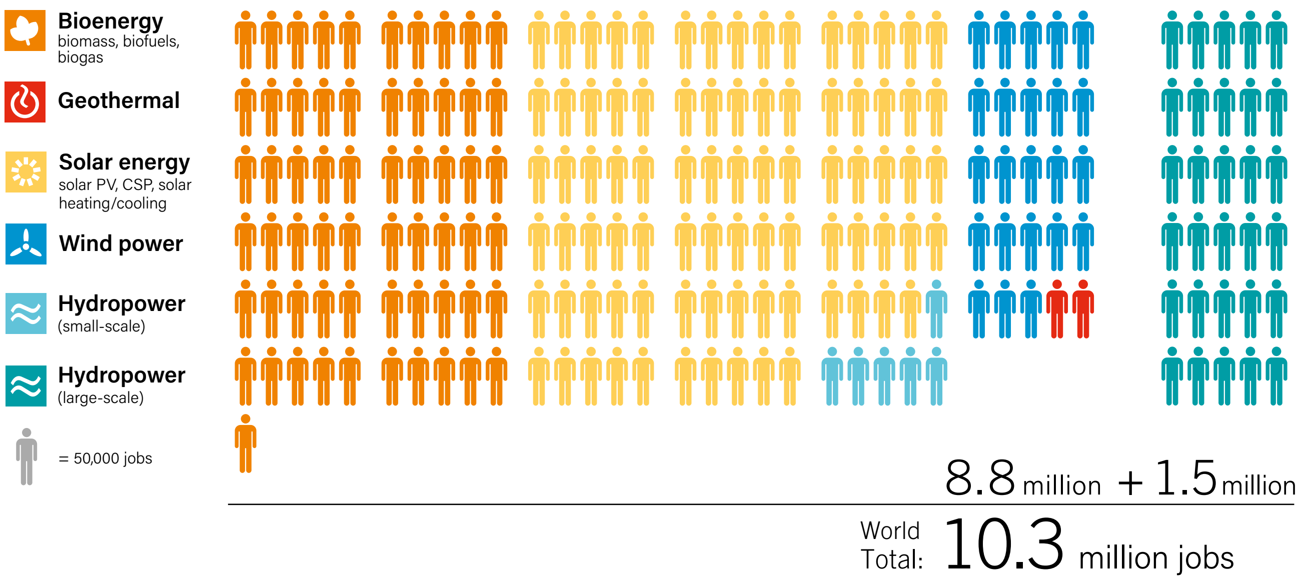
	World	China	Brazil	United States	India	Japan	Germany	Total EU[k]
	Thousand jobs							
Solar PV	**3,365**	2,216	10	233	164	272	36	100
Liquid biofuels	**1,931**	51	795[g]	299[h]	35	3	24	200
Wind power	**1,148**	510	34	106	61	5	160	344
Solar thermal heating/cooling	**807**	670	42	13	17	0.7	8.9	34
Solid biomass[a, b]	**780**	180		80[i]	58		41	389
Biogas	**344**	145		7	85		41	71
Hydropower (small-scale)[c]	**290**	95	12	9.3	12		7.3[j]	74[l]
Geothermal energy[a, d]	**93**	1.5		35		2	6.5	25
CSP	**34**	11		5.2			0.6	6
Total	**8,829[f]**	**3,880**	**893**	**786**	**432**	**283**	**332**	**1,268**
Hydropower (large-scale)[e]	**1,514**	312	184	26	289	20	7.3[j]	74[l]
Total (including large-scale hydropower)	**10,343**	**4,192**	**1,076**	**812**	**721**	**303**	**332[j]**	**1,268**

Note: Jobs estimates generally derive from 2016 or 2017 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] Power and heat applications. [b] Traditional biomass is not included. [c] Although 10 MW is often used as a threshold, definitions are inconsistent across countries. [d] Includes ground-source heat pumps for EU countries. [e] Large-scale hydropower includes direct jobs only, so the table underestimates employment for this technology relative to others. [f] Totals include waste (28,000 jobs), ocean energy (1,000 jobs) and non-technology-specific jobs (8,000). [g] About 225,400 jobs in sugarcane processing and 168,000 in ethanol processing in 2016; also includes a rough estimate of 200,000 indirect jobs in equipment manufacturing in 2016, and 202,000 jobs in biodiesel in 2017. [h] Includes 237,000 jobs in ethanol and about 62,200 jobs in biodiesel in 2017. [i] Based on employment factor calculations for bioelectricity and combined heat and power (CHP). [j] Combines small- and large-scale hydropower. [k] All EU data are from 2016 and include Germany. [l] EU hydropower data combine small- and large-scale facilities; hence the regional total with large-scale hydropower is the same as the total without it. Figure is derived from EurObserv'ER data, adjusted with national data for Germany, the United Kingdom and Austria, as well as IRENA calculations.

Source: IRENA

FIGURE 9. Jobs in Renewable Energy



Source: IRENA

02

El Llano Wind Park, Chubut, Argentina

In 2017, Argentinian aluminium producer Aluar started to build its 110 MW El Llano wind park in Chubut, Argentina. The construction is expected to finish in 2019, with 31 wind turbines. Located close to the company's facilities, the plant will provide electricity for aluminium smelting, helping the company comply with the Argentinian mandate for large electricity consumers, thus acquiring more than the required 8% of their power consumption from renewable sources.

POLICY LANDSCAPE

Increasing renewable energy deployment contributes to multiple policy objectives, including boosting national energy security and economic growth, creating jobs, developing new industries, reducing emissions and local pollution, and providing affordable and reliable energy for all.[1] Policy makers continue to promote renewable heating and cooling, renewable transport technologies and renewable power by implementing a range of policies including targets, regulations, public financing and fiscal incentives as well as, increasingly, complementary policies enacted together. ***(→ See Table 2.)*** As of year-end 2017, 179 countries had renewable energy targets at the national or state/provincial level, up from 176 the previous year.[2]

The interaction of policy, cost reductions and technology development has led to rapid change in the energy sector, prompting both proactive and reactive responses from policy makers. Market and regulatory environments are being adjusted, with many countries introducing mechanisms designed to accelerate investment, innovation and the use of smart, efficient, resilient and environmentally sound technology options.[3] Renewable energy policies are just one component of broader energy sector policies, such as fossil fuel subsidies or carbon pricing mechanisms.

The challenges and opportunities, as well as the suite of policies adopted, vary widely by region and country, and also by level of government. In more mature renewable energy markets, policy makers are starting to grapple with integrating rising shares of distributed and variable renewable energy (VRE) into power systems that were developed primarily for centralised fossil fuel, nuclear and hydropower generation. Policy makers also are dealing with the challenges posed by traditional grid-connected consumers who are producing their own electricity and wish to feed their surplus generation into the grid. To advance the integration of VRE, some policy makers have begun to adopt policies that increase the electrification of the thermal (heating and cooling) and transport sectors. To increase access to modern energy services, many policy makers in developing countries are designing mechanisms to maximise the potential of renewable energy-powered micro-grids as an alternative to expanding traditional centralised power networks, especially in rural areas where expanding the grid is not cost effective. (→ *See Distributed Renewables chapter.*)

87 countries

have economy-wide targets for renewable energy share of primary or final energy

Policy makers at the sub-national level often play a leading role in renewable energy policy, with the re-emergence of more decentralised energy systems spurring the engagement of city and local officials. Many have used the direct control over planning policies – including building regulations and purchasing authorities – that their national-level counterparts may lack to shape energy pathways for their communities. Local commitments to renewable energy frequently are driven by the economic benefits deriving from renewable energy, as well as by the potential for climate change mitigation, improved local air and/or water quality, and local job creation.

Cities regularly lead on efforts to deploy innovative technologies in the power sector and may be key drivers for transitioning other energy end-use sectors by promoting electric vehicle (EV) integration, modernising public transport fleets and mandating the use of biofuels or solar water heating to meet municipal heating needs. Lessons learned at the local level often inform the development of national policy.

The following sections provide an overview of renewable energy policy developments in 2017 by end-use sector. The chapter has evolved to keep pace with emerging trends in the energy sector, such as the need for more systematic sector coupling and integration of VRE. The examples featured are intended to provide a snapshot of developments and trends in renewable energy policy in 2017 and are not intended to be a comprehensive list of all policies enacted to date. In addition, the chapter does not attempt to 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 chapter *Distributed Renewables for Energy Access*.

TRENDS IN 2017

Many historical trends remained unchanged in 2017, with the growth of renewable energy around the world spurred by a combination of targeted public policy and advances in energy technologies. A trend is emerging towards coupling of the thermal (heating and cooling), transport and power sectors, as well as towards increasing linkages between renewable energy and energy efficiency, although such measures remain limited.

New cross-sectoral integrated policies were introduced in 2017 in several countries. Indonesia outlined goals for reducing energy intensity[i] by 17% across the industry, transport, residential and services sectors and for achieving a 23% renewable share of primary energy by 2025.[4] Switzerland also introduced new cross-sectoral policies in 2017.[5] *(→ See Box 1.)* By end-2017, 87 countries had economy-wide renewable energy targets for either primary or final energy, and Ukraine increased its target during the year.[6] ***(→ See Reference Tables R3 and R4.)***

Direct policy support for renewable energy, as in past years, continued to focus primarily on power generation, with direct support for renewable technologies lagging in the heating and cooling and transport sectors. *(→ See Figure 10 and* ***Reference Tables R5-R11.****)* However, efforts to increase renewable energy

i Energy intensity is the amount of primary energy per unit of economic output (usually gross domestic product).

BOX 1. Integrated Policy Spotlight: Switzerland Energy Strategy 2050

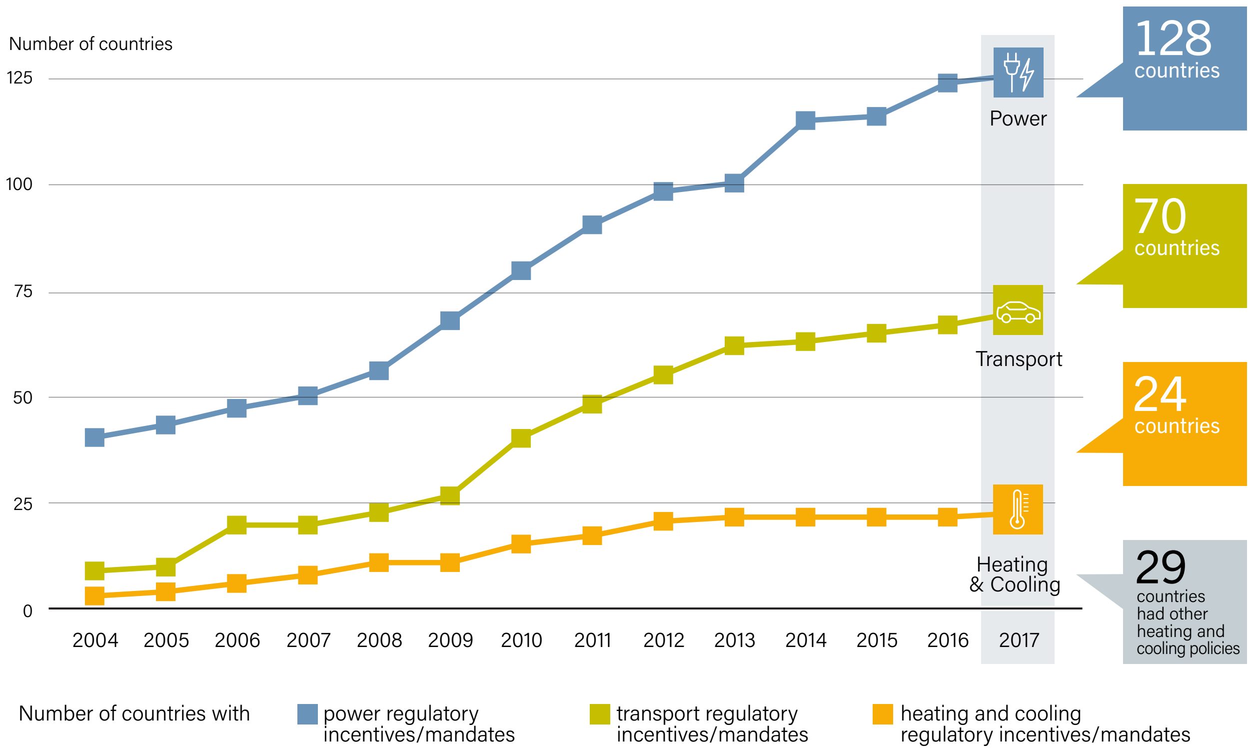
On 21 May 2017, approximately 58% of voters in Switzerland voted to approve a nationwide increase in renewable energy use and a scaling back of the country's nuclear sector. The referendum was a first step towards implementing a sweeping energy strategy that outlines goals through 2050. The strategy seeks to harmonise efforts under three key pillars: 1) saving energy and improving efficiency, 2) promoting renewable energy and 3) phasing out nuclear power.

Switzerland has pledged that renewable energy and energy efficiency will play a growing role in its energy mix and has placed a moratorium on new nuclear power plants (nuclear accounted for 32% of Swiss electricity production in 2016). The overall strategy aims to decrease dependency on imported fossil fuels, reduce the environmental impact of the energy sector, increase investment in the country and foster job creation.

Renewable and energy efficiency technologies will be supported by revenue raised from electricity consumers as well as from the existing fossil fuel tax. The framework includes provisions for revising permitting of renewable energy systems, as well as market and incentive schemes to advance renewable energy integration. The strategy also calls for new technical solutions, including the deployment of smart meters, as well as for action to reduce transmission congestion and to adopt an increasingly decentralised energy supply system.

Source: See endnote 5 for this chapter.

FIGURE 10. Number of Countries with Renewable Energy Regulatory Policies, by Sector, 2004-2017



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/premiums, tendering, net metering and renewable portfolio standards. Tendering is counted cumulatively. Heating and cooling policies include solar heat obligations, technology-neutral heat obligations and renewable heat feed-in tariffs. Some countries with regulatory policies for heating and cooling also have other heating and cooling policies. Transport policies include biodiesel obligations/mandates, ethanol obligations/mandates and non-blend mandates. For more information see Table 2.

Source: REN21 Policy Database.

Insufficient policy support
persists for renewables in heating and cooling and transport

in heating, cooling and transport benefit from rising shares of renewable power to the extent that electricity is used in these sectors. A focus also is emerging on integrating VRE into existing energy systems, which may necessitate sector coupling

The European Union (EU) was the only regional entity to adopt a collective regional commitment to renewable energy in 2017.[7] The EU's Clean Energy for All Europeans package covers the energy market, renewable energy and efficiency policies, and will use a common reporting framework to measure the impact of policies on the power system as well as on emission goals.[8] The first legislative element of the package, on energy efficiency, was passed in 2017.[9] The debate around the next round of European energy targets extending to 2030 continued throughout the year, with the European Parliament voting in January 2018 in favour of a goal for renewables to meet 35% of regional energy demand by 2030.[10]

Local government continues to play a leading role in the global energy transition, as demonstrated by the ambitious targets that many have set, with hundreds of jurisdictions having made commitments to 100% renewable energy or electricity by end-2017. ***(→ See Reference Table R14.)*** These targets typically take one of two forms: either the establishment of a renewable energy goal for energy use across the municipality, or a commitment to use renewable energy for government-controlled energy generation and consumption. Municipal leaders in Japan released the Nagano Declaration in 2017 committing to work towards 100% renewable energy for cities and regions across the country.[11] New 100% renewable energy or electricity targets were established in 8 US cities in 2017, bringing the nationwide total to 48, of which 5 had already met their 100% goals by year's end.[12]

Cities also have taken collective action to aggregate the impacts of their commitments. In 2017, more than 250 US mayors committed to the US Conference of Mayors' goal of 100% renewable energy by 2035 (although these have not all been enacted in legislation yet).[13] In Germany, over 150 districts, municipalities, regional associations and cities had committed to 100% renewable energy by the end of 2017 through the 100% Renewable Energy Regions network.[14] Initiatives such as C40 Cities also are driving collaboration, allowing cities to share practices to advance their energy transitions.[15]

RENEWABLE ENERGY LINKAGE TO CLIMATE CHANGE POLICIES

Many commitments to advance renewable energy have been made through climate change policies worldwide, which often feature specific renewable energy and energy efficiency goals. *(→ See Table 2.)* Increasingly ambitious climate targets in some jurisdictions will require action across all energy end-use sectors, even in cases where specific energy targets are not included. In 2017, 25 C40 member cities from across the world established goals to reach net-zero emissions by 2050.[16] New Zealand also proposed a target of net-zero carbon by 2050, and four out of seven Australian states or territories introduced net-zero emissions targets for 2050.[17]

Specific mechanisms such as carbon taxes, the elimination of fossil fuel subsidies, and emissions trading schemes often are used to meet carbon reduction goals. *(→ See Figure 4 in Global Overview chapter.)* The impact of each of these policies on the renewable energy sector varies widely. Historically, renewable transport fuels or technologies for renewable heating and cooling, for example, have been more likely to benefit from carbon pricing mechanisms than have renewable power generating technologies, although this is not always the case.[18]

In 2017, China launched the world's largest emissions trading scheme, with the first phase of the new cap-and-trade programme focusing on the country's power sector.[19] In the United States, the nine northeast states that make up the Regional Greenhouse Gas Initiative agreed to reduce power plant greenhouse gas emissions across the region 65% by 2030.[20] Additionally, the 19 member countries of the BioFuture Platform, a global network aiming to fight climate change through scaling up deployment of modern sustainable low-carbon transport options, made a formal commitment to develop targets for biofuels to address the climate impacts of the energy-transport nexus.[21]

The social cost of carbon also can be used to promote low-carbon energy sources in energy sector regulation.[22] In 2017, public utility commissions in the US states of Colorado and Minnesota both issued rulings requiring that a cost of USD 43 per tonne be considered by utilities when they plan new power plants.[23]

TARGETS

85 countries, states or provinces have targets for
more than
50%
renewable electricity

Targets remain one of the primary means that policy makers use to express their commitment to renewable energy deployment. Targets take many forms, including goals for achieving a specified contribution of renewable generation (or capacity), mandates (such as renewable portfolio standards, or RPS) that call for the sourcing of specific shares of renewable energy, and capacity goals for specific renewable technologies. The majority of targets continue to focus on renewable energy in the power sector. As of year-end 2017, more than 150 countries had renewable power-related targets in place at the national level. ***(→ See Reference Tables R8-R10.)***

Targets for renewable shares of heating and cooling and transport energy use have been introduced to a much lesser degree, in place in 48 and 42 countries, respectively, by year's end. *(→ See Figures 11 and 12, Table 2 and* ***Reference Tables R5, R8 and R9.****)*

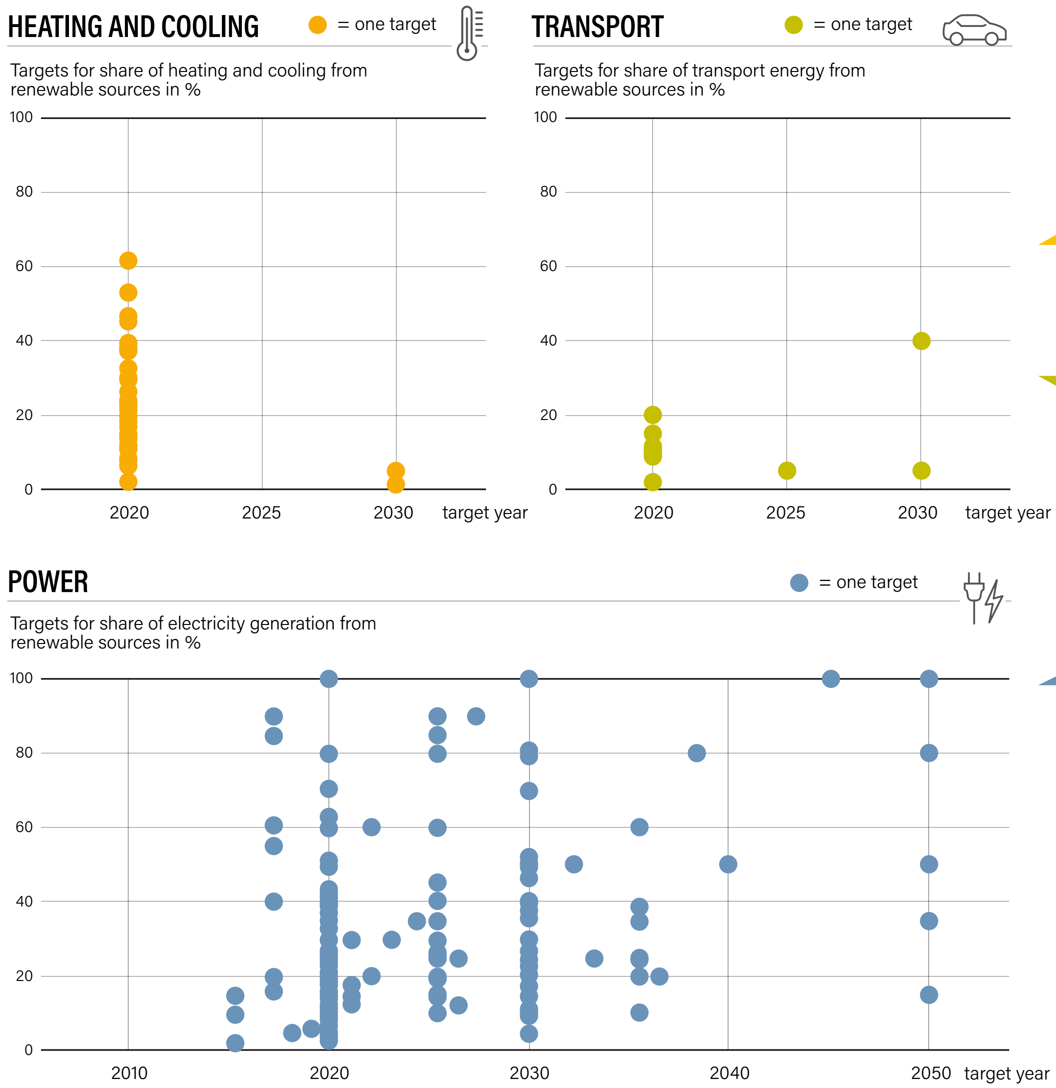
Many countries are increasing the ambition of their renewable electricity commitments. During 2017, Cabo Verde set a target for 100% renewable power by 2025, bringing to 90 the total number of countries, states and provinces that have targets for 50% or more of their electricity from renewables.[24]

Other countries, such as the Republic of Korea, also increased their targets, although not to as high as 50% renewable electricity.[25] The Altai Republic (Russian Federation) introduced its first renewable target, for 150 megawatts (MW) of solar photovoltaics (PV) by 2021.[26]

China established new technology-specific targets under its 13th Five-Year Plan for Renewable Energy, including a goal to increase wind power capacity to 210 gigawatts (GW) as part of the broader goal to increase total renewable power capacity to 680 GW by 2020.[27] At the sub-national level, Flanders (Belgium) increased its solar and wind power targets by one-third, and Karnataka (India) tripled its solar power target from 2 GW to 6 GW by 2022.[28]

In the United States, 29 states, the District of Columbia and 3 territories have established targets through renewable portfolio standards. Although no new states added or removed RPS policies in 2017, Maryland increased and accelerated its RPS to 25% by 2020 (up from 20% by 2022), and Massachusetts created requirements for offshore wind power and solar PV procurement.[29] Efforts to increase RPS goals in California and Nevada were not successful.[30]

FIGURE 11. National Sector-Specific Targets for Share of Renewable Energy by a Specific Year, by Sector, in Place at End-2017



Most national targets focus on the power sector, where the level of ambition is typically higher than for heating and cooling and for transport.

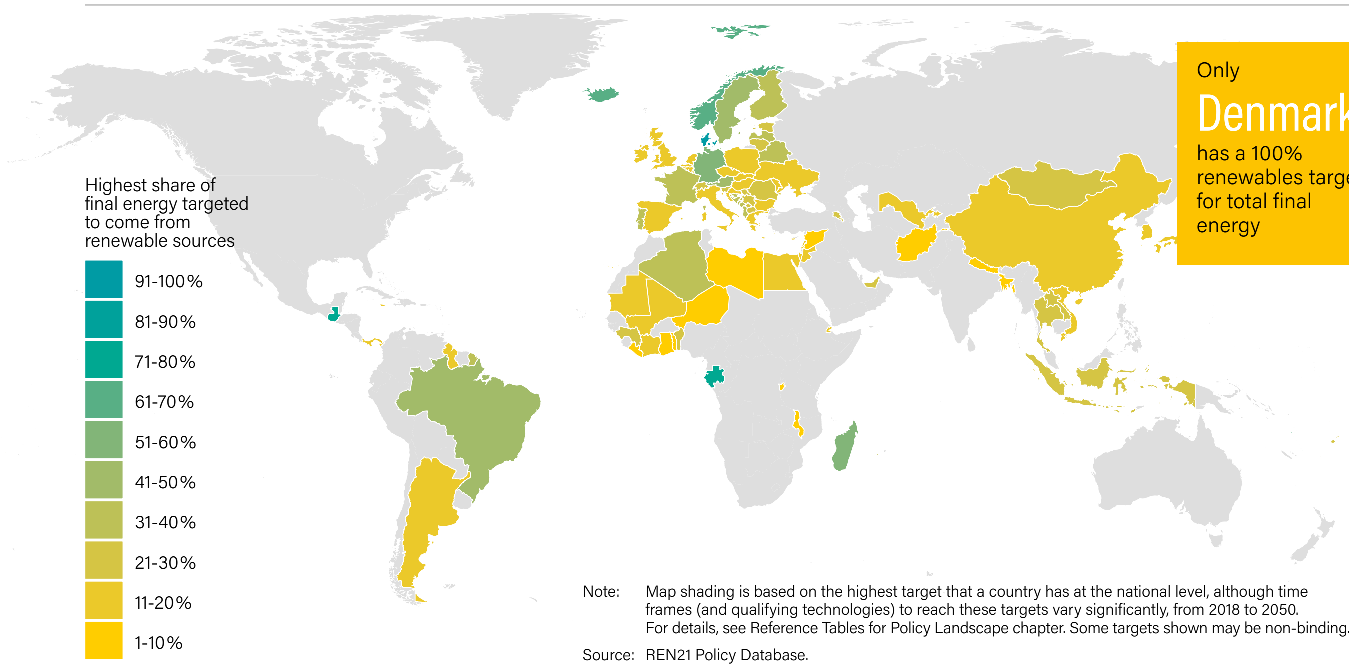
48 countries have national targets for renewable energy in heating and cooling.

42 countries have national targets for renewable energy in transport.

146 countries have national targets for renewable energy in power.

Note: Each dot can represent more than one country and is based on the highest target that a country has set at the national level. Figure includes only countries with targets in these sectors that are for a specific share from renewable sources by a specific year, and does not include countries with other types of targets in these sectors. The total number of countries with any type of target for renewable energy (not specific to shares by a certain year) is 48 in heating and cooling, 42 in transport and 146 in power. Some targets shown may be non-binding.

FIGURE 12. National Targets for Share of Renewable Energy in Final Energy, by a Specific Year, in Place at End-2017



Only **Denmark** has a 100% renewables target for total final energy

Note: Map shading is based on the highest target that a country has at the national level, although time frames (and qualifying technologies) to reach these targets vary significantly, from 2018 to 2050. For details, see Reference Tables for Policy Landscape chapter. Some targets shown may be non-binding.

Source: REN21 Policy Database.

HEATING AND COOLING

BUILDINGS

The buildings sector, unlike other sectors, often sees a close alignment between policies for renewable energy and energy efficiency, in which measures are routinely aimed at both increasing renewable energy supply and reducing energy demand.

Building energy codes are one of the most common policy tools used to promote renewable energy and energy efficiency in the sector. Mandatory and voluntary energy codes for buildings exist in more than 60 countries worldwide.[31] Mandates can focus on the required use of specific technologies – such as solar water heaters or energy-efficient cooling appliances – to source specific shares of energy or electricity needs from renewable sources, or can be framed in terms of performance standards for either maximum energy use or greenhouse gas creation[i].

Policies often focus on new construction or refurbishment. However, certain jurisdictions have adopted codes, standards or mandates requiring renewable energy or energy efficiency to be integrated into existing buildings, regardless of whether refurbishment is occurring.[32] Policies have been enacted at the national, sub-national and local levels, including in some of the most populous cities in the world. By end-2017, at least 145 countries had enacted some kind of energy efficiency policy, and at least 157 countries had enacted one or more energy efficiency target. *(→ See Figure 13.)*

In 2017, the Indian Ministry of Power updated the country's Energy Conservation Building Code to establish new energy efficiency standards and a range of mandates for the share of hot water demand met by solar power.[33] The code promotes passive energy building design, efficient lighting and renewable energy technologies and applies to buildings with a peak load of 100 kilowatts (kW) and above.[34]

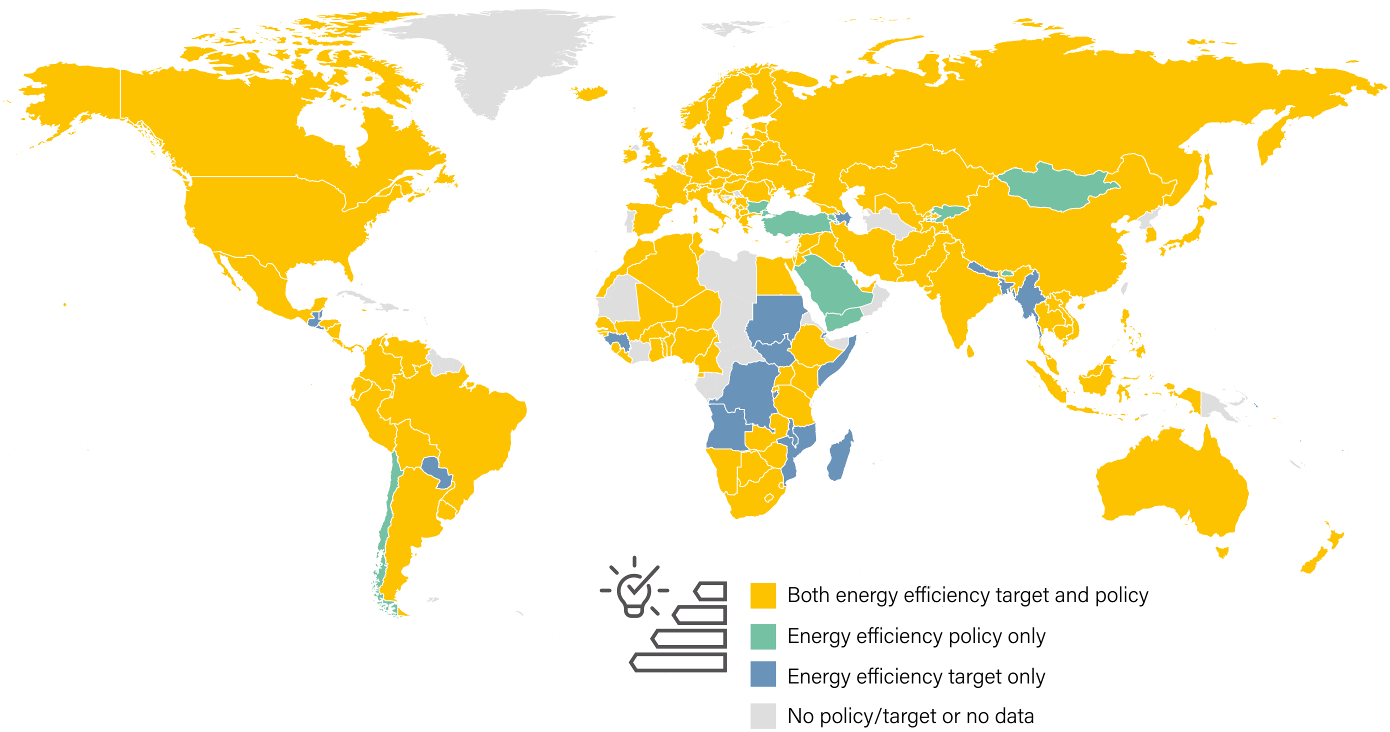
Voluntary standards were announced in British Columbia (Canada) in 2017, establishing a four-step process to transition to the construction of net-zero-energy ready buildings.[35]

Incentives for the deployment of renewable or energy savings technologies are used regularly in the buildings sector. In 2017, Hungary began offering interest-free loans to homeowners that deploy energy efficiency or renewable energy technologies – including solar thermal, solar PV and biomass boilers – under a EUR 370 million (USD 457 million) programme.[36] The Former Yugoslav Republic of Macedonia extended and expanded a programme that reimburses up to 30% of system costs for household solar water heaters; in addition, the country supports solar thermal for space heating and cooling through a reduced value-added tax levy.[37]

The EU funded much of an EUR 1.4 million (USD 1.7 million) solar district heating installation in Serbia.[38] Germany established a new subsidy scheme designed for solar, biomass or waste heat linked to district heating to meet over 50% of annual demand; under the new mechanism, suppliers are eligible for grants that cover up to 60% of the cost of feasibility studies and up to 50% of the costs of new investment.[39] The Hungarian government launched a call

i For example, energy use or greenhouse gas emissions per square metre of floor area; this may be specific to a service (for example, heating and cooling) or may be for the building as a whole.

FIGURE 13. Countries with Energy Efficiency Policies and Targets, End-2017



Source: REN21 Policy Database.

for applications for a USD 50 million fund designed to promote biomass and geothermal district heat networks.[40] Slovenia provided subsidies for 35% to 55% of the investment cost for private companies and public authorities investing in renewable energy for district heat networks.[41] Andalusia (Spain) adopted a Sustainable Construction programme that provides incentives for 30% to 85% of the investment costs for solar thermal systems, as well as support for solar PV and efficiency measures such as building insulation and lighting improvements.[42]

At the sub-national level, the US state of New York announced a USD 15 million programme to encourage the installation of ground-source heat pumps, and the state of Oregon set a building code requirement for all new-build residential and commercial buildings to be "solar ready" by 2020 and 2022, respectively.[43] The city of Chicago mandated that all of its public buildings be powered entirely by renewable energy by 2025, making it the largest city in the world to adopt such a requirement.[44]

Elsewhere, the city of Seoul (Republic of Korea) requires all new public apartments to install solar PV as of 2018, while existing buildings receive subsidies covering approximately 75% of the installation fee for solar PV.[45]

Specific subsets of buildings also were targeted for support, with government buildings or other public facilities often the focus of these mechanisms. For example, Indonesia aims to transform 1,000 existing mosques into eco-mosques by 2020, with a plan to promote renewable power generation technologies such as solar PV and biogas in addition to resource efficiency measures.[46] In Croatia, a grant scheme for public institutions to fund all energy efficiency and renewable energy technologies for building renovation was enacted in 2017.[47] The Non-Domestic Renewable Heat Incentive in the United Kingdom provides financial incentives to increase investment in renewable heat technologies including biomass, geothermal and solar thermal by the public and non-profit sectors, as well as by businesses.[48]

Renewable energy and energy efficiency policies are routinely integrated into **building codes**

INDUSTRY

Renewable energy for industrial use faces specific challenges that have slowed deployment, including finance, risk (both financial and energy supply), technology maturity and lack of information or awareness.[49] In some countries, the regulatory framework for energy production limits the ability of generators to operate as third-party power producers[i],[50] Well-designed policies would help overcome these challenges, and policy makers have begun to enact mechanisms to provide financial assistance for project development, regulatory reforms to allow or facilitate self-generation, and guarantees to address project risks.[51]

Specific mechanisms to increase renewable energy use for industrial processes are not commonplace, but some examples exist. In 2017, Mexico launched an inter-institutional platform to promote solar process heat.[52] Tunisia extended its Prosol Industry programme to provide financial support to industrial facilities looking to use renewable energy.[53] And Argentina revised market rules to allow large consumers to meet their renewable power requirements through direct supply contracts with private generators.[54] Loan guarantees can be used to advance deployment as well in cases where investments are perceived as risky, as in France where the government has provided incentives to industry for the use of technologies such as geothermal heating and cooling.[55]

i This means that the entity may not export electricity, so renewable generation may be sub-optimally sized.

TRANSPORT

Renewable fuels and electric mobility can decrease reliance on fossil fuels, and – along with the promotion of fuel efficiency, public transport or smart planning options to reduce transport needs – they can provide an avenue for increasing national energy security and reducing local air pollution.[56] The transport sector accounts for more than half of global oil demand.[57] This has made transport an important target of transformation for the ever-growing list of jurisdictions seeking to achieve a 100% renewable energy share. Of course, electrification or hydrogen-based transport is only renewable to the extent that the electricity (or hydrogen production) is from renewable generation. An example of policies aiming to ensure an increased renewable share is the US state of California's requirement that 33% of hydrogen fuel dispensed into fuel cell vehicles be produced from renewable sources.[58]

Several jurisdictions are seeking to better integrate renewable solutions in their transport sectors. For example, in Europe 10% of transport fuels consumed in each EU member state must come from renewable sources by 2020.[59] If the proposed European renewable energy goal is adopted, this will be increased to 14% by 2030.[60]

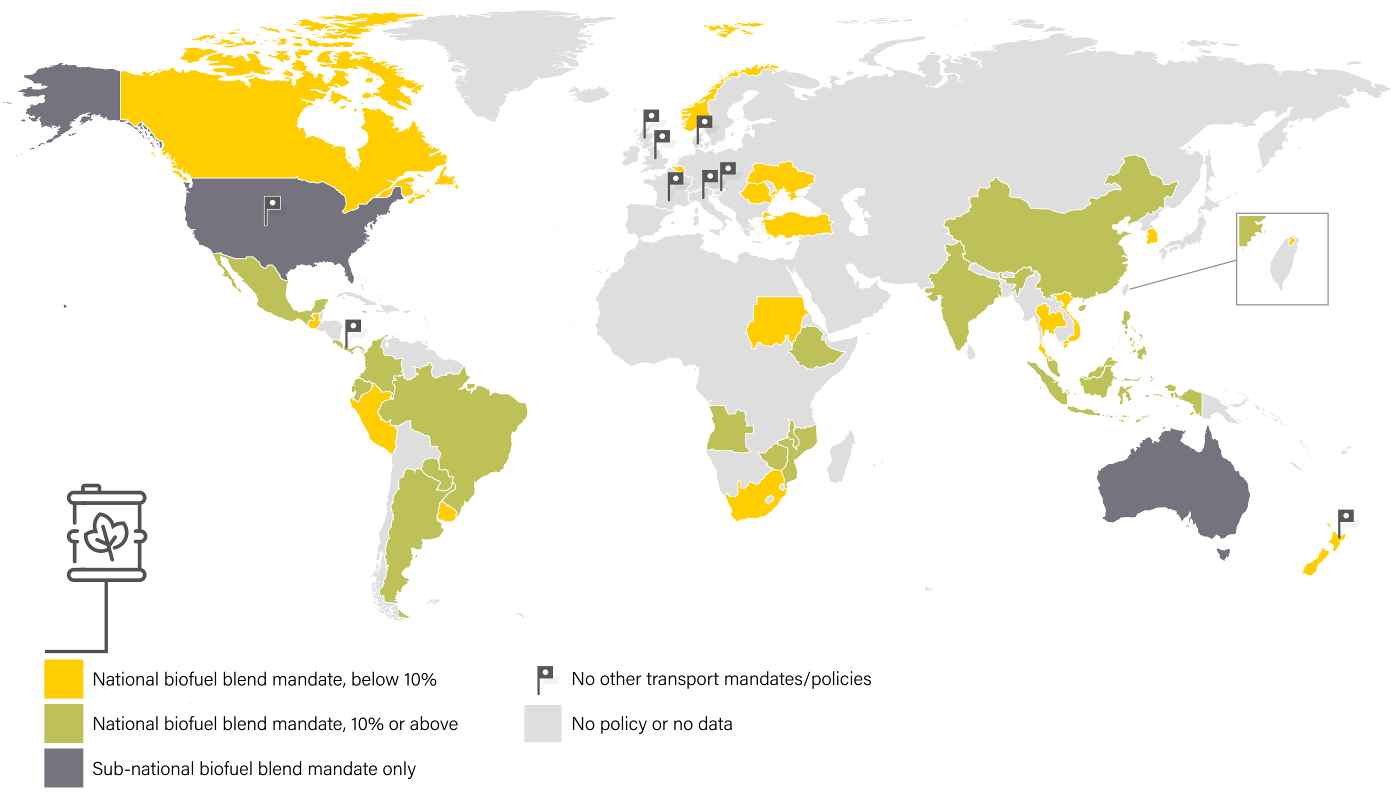
Policies to promote renewable energy in the transport sector continued to focus primarily on road transport, especially at the national level. Other sub-sectors such as rail, aviation and shipping have drawn comparably less policy attention despite also being large energy consumers. However, action at the local level is rapidly expanding the traditional focus on road transport, with many cities taking steps to integrate renewable solutions into public transport fleets, including city rail systems. *(→ See Rail, Aviation and Shipping section in this chapter.)*

ROAD TRANSPORT

Biofuels, electrified transport, and fuels such as hydrogen all have potential for the future transport energy mix. Their deployment is particularly critical to the growing list of jurisdictions that have announced plans to ban some or all fossil fuel vehicles from their streets.

Biofuel blend mandates remain one of the most widely adopted mechanisms for increasing renewable fuel use in the road transport sector. These mandates are prevalent across all geographic regions and countries at all economic development levels. As in past years, in 2017 national and sub-national governments continued to require specific shares of biodiesel or ethanol to be blended into transport fuels. *(→ See Figure 14 and* ***Reference Table R7.****)* However, concerns remain about the sustainability of some biofuels.[61] *(→ See Box 2.)*

FIGURE 14. National and Sub-National Renewable Transport Mandates, End-2017



Note: Shading shows countries and states/provinces with mandates for either biodiesel, ethanol or both.
Source: REN21 Policy Database.

BOX 2. Policy Debate: Biofuel Feedstocks

The debate over the use of crop-based biofuel feedstocks continued in 2017, especially in Europe. The air quality benefits from biofuels relative to fossil fuels vary according to the fuel used and the vehicle type; however, analysis indicates that biofuels can reduce carbon monoxide, hydrocarbons and particulate matter emissions. In many countries biofuels also reduce the need for fuel imports, promoting energy security and reducing cost and vulnerability to fluctuations in the international fuels market.

However, critics have challenged the perception of biofuels as a sustainable energy source due to factors including food availability, cost to consumers, potential land-use concerns and the sustainability of fuel sources used for biofuel production. Life-cycle emissions impacts, including emissions from indirect land-use change, are one of the chief concerns cited by many who have challenged the use of traditional biofuels for fuelling transport. This concern is hotly debated, with proponents on both sides of the debate finding a wide range of results for life-cycle emissions, depending on assumptions. For example, proponents of biofuels contend that even with impacts of land-use changes, ethanol results in lower greenhouse gas emissions than petrol, while biofuel critics have contended that biodiesel results in greater climate impact when emissions from indirect land-use change are accounted for.

The debate has transitioned to the policy arena. For example, Norway was considering removing the mandate for E20 (a 20% ethanol blend) that was both agreed to and achieved in 2017. Similar concerns have led to the adoption of policies and measures aimed at promoting sustainability. Organisations such as the Roundtable on Sustainable Biomaterials, a network of governments, biofuel producers and other entities, have developed certification schemes to evaluate the social and environmental sustainability of biofuels. In 2017, the European Parliament voted to introduce a single certification scheme to evaluate the sustainability of palm oil entering the EU market.

More commonly, biofuel promotion policies have begun to include specific requirements for the use of next-generation cellulosic biofuels. In the EU, the Renewable Energy Directive for 2030 proposed by the European Commission in 2017 included a target of 3% for advanced biofuels and a cap of 7% on first-generation biofuels. Similar requirements for the use of advanced biofuels have already been adopted at the national level in the EU, for example in Italy.

Source: See endnote 61 for this chapter.

In 2017, ethanol blend mandates were enacted or revised in five countries around the world. At the national level, Argentina increased its mandate to E12, Romania increased its mandate from E4.5 to E8 for 2018, and Zimbabwe returned its mandate to E10 after a temporary reduction to E5 in response to supply challenges.[62] Mexico raised the limit on ethanol content from E5.8 to E10 except in the cities of Guadalajara, Mexico City and Monterrey; however, the move has been halted temporarily by the courts.[63] At the sub-national level, Queensland (Australia) enacted an E3 blend mandate.[64]

New or revised biodiesel mandates also were enacted during 2017, although to a lesser extent than those for ethanol. In South America, Brazil's mandate for B8 went into effect, which was increased to B10 in early 2018, and Colombia increased its mandate for specific regions of the country from B8 to B9.[65] Elsewhere, New Zealand increased the maximum blend for methanol from 1% to 3% and for biodiesel from 5% to 7%.[66] In the United States, Minnesota doubled the state biodiesel mandate to B20 effective May 2018.[67] Slovenia mandated that 10% of all heavy-duty trucks must run entirely on biodiesel.[68]

Fiscal incentives for biofuel production as well as grants for the development of second-generation biofuels remain a fixture of many transport fuel support schemes. In 2017, the Canadian province of Alberta allocated CAD 63 million (USD 50 million) for grant funding to bioenergy projects producing biodiesel, ethanol, and solid biomass- and biogas-based electricity generation.[69]

Other jurisdictions have set goals or incentives for electric or fuel-efficient vehicles. More policy announcements were made in 2017 than in any previous year, and the level of ambition has continued to increase.[70] Although numerous measures have been adopted in recent years to scale up the use of electric vehicles, few efforts have been made to directly link renewable electricity production and EV use or to ensure that EVs work to support the integration of renewable energy into energy supplies.[71] As of October 2017, at least 60 countries as well as 40 cities or regions had targets and/or plans for electric mobility.[72] Also in 2017, the 10 member countries of the Electric Vehicles Initiative launched the EV30@30 Campaign, setting a collective goal of a 30% market share for EVs among all passenger cars, light commercial vehicles, buses and trucks by 2030.[73]

In 2017, Slovenia announced a ban on the registration of new diesel and petrol cars after 2030.[74] The United Kingdom and France announced their intention to ban the sale of all diesel and petrol cars and vans by 2040, and the Scottish government announced a target year of 2032 for the same.[75] The Dutch government confirmed plans in late 2017 to require that all new cars be emission-free by 2030.[76] India announced a target to sell only EVs by 2030, and aims to deploy 5 million to 7 million EVs by 2020.[77] Norway aims to eliminate the sale of fossil fuel vehicles by 2025 through a set of incentives.[78] China aims for EVs and plug-in hybrids to account for at least 20% of auto sales by 2025, and in September 2017 it announced that it was working on a plan to phase out fossil fuel vehicles.[79]

Governments also are supporting EVs through public procurement. In the United States, approximately 20 cities formed a partnership in 2017 to collectively procure EVs for public vehicle fleets.[80] In 2017, India held its first national EV tender when the Energy Efficiency Services Limited called for bids for 10,000 EVs to be used by government agencies and departments.[81] In November 2017, the Indian government announced that it would provide grants of up to INR 1.05 billion (USD 16.4 million) each to "Smart Cities" of more than 1 million people for EVs to be used for mass transport; it also announced plans to provide funds to develop charging infrastructure in selected cities.[82] By the end of 2017, Shenzhen (China) had successfully electrified its entire fleet of 16,000-plus public buses.[83]

For a discussion of policy linkages between renewable energy and EVs, see the section on *Sector Coupling and System-Wide Energy Transformation* in this chapter.

RAIL, AVIATION AND SHIPPING

Rail transport, aviation and shipping provide critical services to move people and goods around the world. However, policies that target the use of renewable fuels or electric mobility tied to renewable power are less common in these sectors than in road transport.

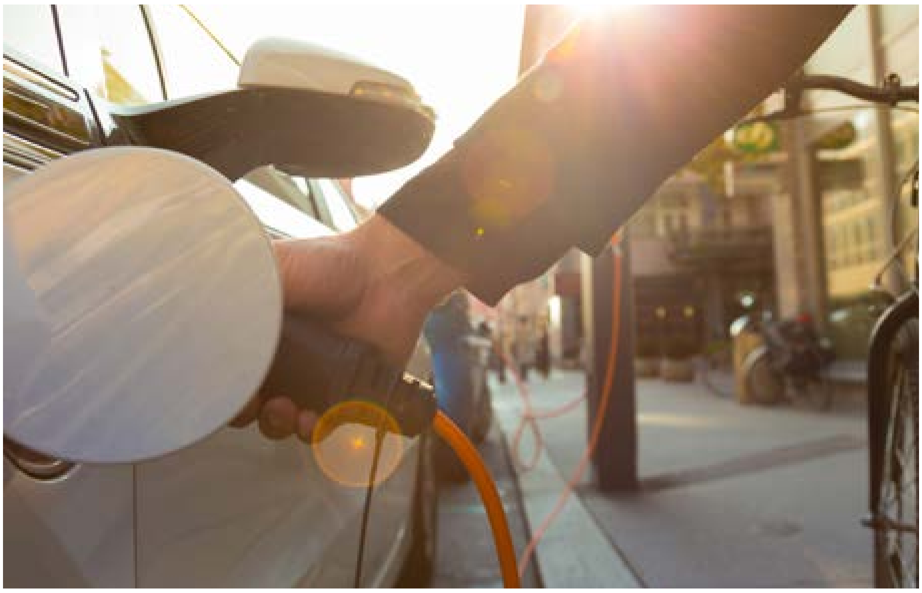
As of 2013, the rail transport sector was responsible for 2% of global transport energy use.[84] The sector differs from other transport sub-sectors that remain largely dependent on petroleum-based products because it sources more than one-third of its energy from electricity.[85]

Policy makers are slowly supporting the integration of renewable energy into rail transport systems, particularly at the municipal level. In the United States, the Bay Area Rapid Transit system, which provides public rail service to California's San Francisco Bay Area, set a requirement that 50% of the rail system's power come from renewable energy by 2025 (compared to a state-wide target of 50% renewable electricity by 2030) and 100% by 2045.[86]

Few direct support policies target the use of renewable fuels in the aviation sector, which accounts for 11% of final transport energy consumption, as aviation fuels generally are not included in transport mandates for biofuels.[87] The exception is Indonesia, which in 2017 introduced a 2% renewable jet fuel mandate, which is set to increase to 5% by 2025.[88] A proposed European directive would require aviation biofuels to count more highly in the contributions towards the region's renewable transport target.[89] In addition to the new policy developments in 2017, the Netherlands, Norway and the United States also have policies in place from prior years aimed at promoting alternative jet fuel production.[90] As of year-end 2017, five renewable jet fuels[i] were certified for blending with traditional petroleum jet fuels.[91]

Unlike in the road and rail transport sectors, only limited near-term electrification alternatives exist in aviation.[92] However, Avinor, the public operator of Norwegian airports, announced in January 2018 that all flights under 1.5 hours are targeted to be entirely electric by 2040.[93]

At least
60 countries
and 40 cities or regions have targets and/or plans for electric mobility



i As with other road transport fuels, renewable jet fuels can be produced through biological, chemical and thermal processes.

POWER

Grid-connected renewable energy systems often receive support through financial incentives and measures such as feed-in policies, tenders[i] or net metering[ii], which have contributed to the deployment of renewable generation. As renewable energy technologies and markets have matured, policy makers have grappled with new challenges related to integrating VRE – into power systems, and they have adjusted existing policy mechanisms and developed new ones.

Many countries are moving away from, or reducing their use of, traditional centrally fixed, price-based mechanisms. This is particularly true of feed-in policies, which were foundational elements of many renewable support programmes. Developed countries have followed the lead of emerging economies such as Brazil and South Africa by turning to more competitive systems, such as renewable energy tenders.[94] In Europe, a multi-tiered system has developed, partly in response to European Commission State Aid guidelines through which large-scale projects or specified power supply profiles are awarded through tenders, while smaller-scale projects continue to be supported through feed-in policies.

In Germany, Renewable Energy Act amendments first released in 2016 entered into force in 2017, extending tendering mechanisms to cover offshore wind power and technology-neutral tenders and introducing financial support for solar PV systems on residential multi-apartment buildings.[95] The feed-in tariff (FIT) remains for solar PV and wind power projects less than 750 kW and for biomass projects less than 150 kW.[96] Non-EU countries in Europe also have followed this trend, for example Moldova, which established a tendering system for large-scale projects and continued to support smaller projects with a FIT in 2017.[97] Elsewhere, both Egypt and Pakistan announced plans to switch from feed-in policies to tenders for renewable energy.[98]

Driven in part by the continued shift from FITs to tenders, renewable power tenders were held in more than 29 countries in 2017. ***(→ See Reference Table R13.)*** In some instances, onshore wind power and solar PV have set record low prices in national tenders and have proven to be competitive with conventional energy technologies.[99] *(→ See Solar PV and Wind Power sections in Market and Industry chapter.)*

In Europe, France announced plans to tender 3 GW of onshore wind power, increased its annual tender target for solar PV from 1.45 GW to 2.45 GW, held a 200 MW solar and wind power tender to evaluate the competitiveness of the technologies and announced winners of a 51 MW self-consumption tender for feeding excess generation to the grid.[100] Poland held its first-ever tender for renewables; the Russian Federation awarded tenders for 520 MW of solar PV and 1.7 GW of wind power capacity; and Spain awarded approximately 8 GW of primarily wind power and solar PV projects.[101]

i Tendering (also called auction/reverse auction or tender) is 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. Individual tenders may vary by qualifying technology, capacity offered, etc., and may be evaluated on both price and non-price factors.

ii Net metering is a regulated arrangement in which utility customers with on-site electricity generators can receive credits for excess generation that is fed into the grid, which can be applied to offset consumption. 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.

BOX 3. Policy Spotlight: Vietnam Solar PV Promotion

In April 2017, Vietnam established its first comprehensive policy designed to promote solar PV. The new scheme aims to address energy security concerns stemming from the country's use of coal and hydropower generation by enacting mechanisms to spur solar PV deployment.

The policy outlines both regulatory and financial measures. These include targeted price-based mechanisms – for example, a FIT for ground-mounted solar PV plants and net metering for residential rooftop solar PV systems, which allow developers to sell power only to the Vietnam Electricity Corporation. The policy also includes tax exemptions, establishes technical requirements, provides for government-allocated land for solar PV projects and sets guidelines for the development of national and provincial plans for solar power. Since the issuance of the new policy, at least 1,200 MW of large-scale solar PV projects have been announced.

Source: See endnote 108 for this chapter.

Elsewhere, Israel held its first two solar PV tenders.[102] In India, tenders were held at both the national and state levels; two rounds for onshore wind energy were held nationally, contracting a total of 2 GW, with the lowest bids below USD 40 per megawatt-hour (MWh).[103] In the United States, the state of Massachusetts held the first offshore wind power tenders in the country.[104] Tenders also were held during the year in Argentina, Armenia, Australia, Ethiopia, Madagascar, Malaysia, the Netherlands, Saudi Arabia, Senegal, Sri Lanka, the United Kingdom and Zambia, among other countries.[105]

Feed-in policies, and the fixed price and dispatch certainty that they provide, still play a role in efforts to scale up renewable power in many countries, particularly to provide support for smaller-scale projects and specific technologies.

Two countries adopted new feed-in policies in 2017, increasing the number of countries with such policies in place to 113.[106] ***(→ See Reference Table R12.)*** Zambia launched its 200 MW FIT strategy targeting small and medium-sized renewable energy projects of 20 MW or smaller, with a goal of diversifying power generation and increasing energy access in rural areas.[107] Vietnam adopted a feed-in scheme that provides grid-connected solar PV plants with guaranteed 20-year tariffs of USD 0.091 per kilowatt-hour.[108] *(→ See Box 3.)*

Developed countries continued to revise existing feed-in polices in 2017. To advance a national goal of 11% renewable energy by 2020, Luxembourg extended its 15-year FIT for solar PV installations larger than 30 kW and provided an investment subsidy plus a 15-year FIT for systems of up to 30 kW.[109]

Germany widened the target group for its FIT for small-scale projects to include extending benefits to renewable generation and consumption in rental properties, referred to as landlord-to-tenant electricity supply.[110] The United Kingdom established a new FIT rate for anaerobic digestion.[111] At the sub-national level, the SMART programme in the US state of Massachusetts replaced the previous tradable credits programme to give solar PV developers of 5 MW or less a long-term, stable floor price

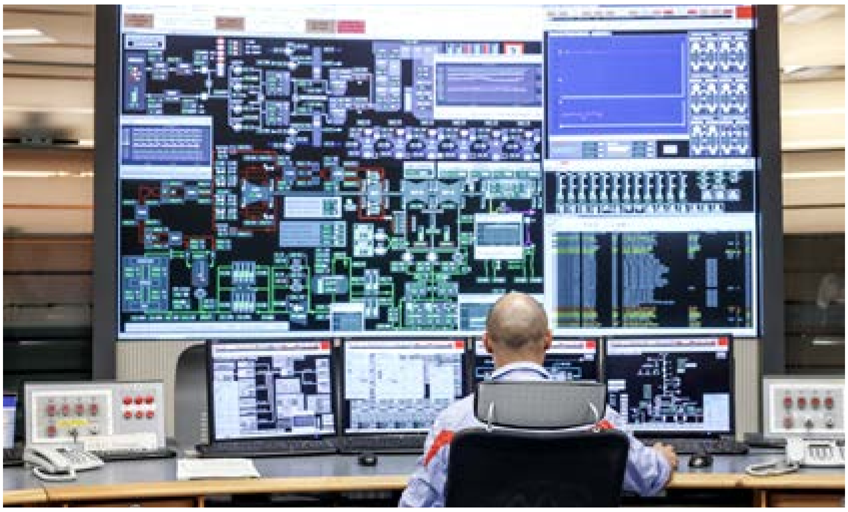
BOX 4. Demand-side Management Initiatives

Distributed energy resources – including demand response, distributed renewable energy technologies and energy storage – can increase system flexibility and reduce demand on the system at peak periods. Development of resources to manage demand and supply imbalances can assist with the integration of VRE, as VRE and demand variability can present similar challenges to the energy system. New policies to enhance the use of distributed resources to meet peak demand in 2017 included:

Australia: In December 2017, the Australian Energy Regulator introduced a Demand Management Incentive Scheme (DMIS) aimed at encouraging distribution network businesses to invest in demand management as an alternative to traditional investment in network infrastructure poles and wires. The Regulator expects the scheme to result in investment of up to AUD 1 billion (US 780 million) in demand management over five years commencing in 2019. The scheme allows distribution network businesses to recover from customers up to half the cost of demand management activities that are cost effective (that is, less costly than new network infrastructure). The DMIS is in addition to the existing revenue cap regulation that decouples network revenues from energy throughput. Measures that could be supported by the DMIS include demand response, energy efficiency, energy storage and local generation.

United States: California passed a new law in 2017 requiring utilities to plan for the deployment of "non-emitting" resources – including demand-side management as well as energy storage and renewable energy technologies – to serve peak demand. Also in 2017, Massachusetts announced nearly USD 5 million in grants to support demand-reduction initiatives aimed at curbing peak demand.

Source: See endnote 127 for this chapter.



At least 157 countries had **energy efficiency** targets as of end-2017

for electricity generated, and Ontario (Canada) awarded FIT support to solar PV, biogas and landfill gas projects.[112]

Consistent cuts to feed-in rates have occurred across the globe in recent years. In 2017, for example, China reduced FIT rates for utility-scale solar PV, with reductions dependent on the region.[113] At the sub-national level, Karnataka (India) reduced its FIT for wind power, and Chinese Taipei reduced its FIT for solar PV and wind and increased its FIT for geothermal power by 5%.[114]

Net metering or net billing policies, which let grid-connected consumers who generate their own electricity sell what they do not use on-site to the grid, are often a key tool for promoting the use of small-scale systems, primarily rooftop solar PV. These policies have been particularly prevalent in developed and emerging economies.

New net metering policies were enacted during 2017 in Albania, Argentina, Bahrain, Moldova and Tanzania, and Namibia's net metering policy came into force.[115] Existing net metering programmes also were expanded during the year. Cyprus expanded eligibility under its existing scheme to biomass and biogas power plants.[116] Lithuania amended its net metering programme as part of an effort to install 200 MW of new solar PV capacity by 2020.[117] Mauritius opened phase two of its net metering programme, providing for the installation of up to 2 MW of new solar PV systems.[118] Pakistan expanded net metering from a few cities to the entire country.[119]

Battles continued in legislative and regulatory bodies as well as in the judicial system, pitting proponents of net metering against its detractors, often electric utilities. The United States has seen some of the most contentious battles over net metering, a policy that is in place in 42 US states and territories, and these debates continued in 2017.[120] In Nevada, the state Public Utilities Commission (PUC) mandated the implementation of net metering that had been halted in 2015.[121] In New Hampshire, consumer groups, utilities and the solar power industry worked together to develop a new net metering framework for the state, resulting in a compromise among the parties that included new, lower net metering rates set by the state PUC.[122] In Arizona, regulators reduced net metering rates for new rooftop solar PV customers.[123] The Indian state of Gujarat established maximum capacities for eligible rooftop solar PV systems.[124]

Virtual net metering, which allows off-site generation to qualify for net metering payments, is beginning to emerge as an alternative to rooftop net metering schemes. Greece implemented virtual net metering in 2017, allowing farmers and certain public entities (including schools, hospitals and local governments) to claim credit for electricity fed into the grid from solar PV systems located far from the point of consumption.[125] The US state of Rhode Island adopted virtual net metering alongside provisions to streamline permitting and grid connection of solar PV systems.[126]

INTEGRATING POLICIES

The integration of high shares of VRE into energy systems requires the modification of policies, standards, and market and regulatory frameworks to effectively harness the benefits that can be derived from renewables, while ensuring system reliability and security of supply. Policy makers and regulators in some jurisdictions are taking a leading role in attempting to address the need for increased flexibility in the grid.

Integration policies require a wide variety of technical concepts, ranging from fast frequency response and synthetic inertia to enabling grid service provision from demand-side management and distributed energy resources.[127] *(→ See Box 4 and Integration chapter.)*

Several Australian initiatives during 2017 were intended to address the issue of maintaining system security, including reviews of both technical and market system requirements.[128] The Australian Energy Market Operator proposed a new rule on generator requirements for maintaining security and published a working paper on fast frequency response to provide guidance on the services that may be valuable in a transforming energy market.[129] The federal government announced the development of a National Energy Guarantee, intended to combine regulation of emissions reduction and reliability by tasking electricity retailers with purchasing sufficient flexible generation to maintain reliability and sufficient low-emission generation to meet climate targets, although concerns exist that this will hamper renewable development by replacing the specific renewable energy target.[130] South Australia announced an energy plan to improve power system security, reliability and market competition, and submitted rule changes to develop new markets and processes to manage frequency control and inertia as the state moves towards its target of 50% renewable power by 2025.[131]

In India, Andhra Pradesh and Rajasthan became the fifth and sixth states (along with Chhattisgarh, Jharkhand, Karnataka and Uttarakhand) to introduce forecasting and scheduling regulations to increase the accountability of solar and wind power generators and to ease the integration of large-scale VRE; three other states published draft regulations in 2017.[132]

Renewable energy systems themselves can assist with the integration of VRE through the provision of grid services, for example, synthetic inertia from wind turbines or voltage regulation from inverters. *(→ See Integration chapter.)* In the United States, Hawaii's PUC authorised the activation of new smart inverter functions for solar PV and storage systems, and California mandated that all inverters connected to the grid – whether for residential and commercial rooftop solar PV, battery systems or EVs – must be smart inverters so that utilities can communicate with them as needed.[133]

Policies promoting the deployment of enabling technologies also are an element of VRE integration. *(→ See Integration chapter.)* Many of these policies have focused largely on the promotion of energy storage technologies, often in conjunction with new renewable generation from solar PV. For example, in 2017 Germany increased the budget available for funding energy storage systems combined with small-scale solar PV.[134] The Czech Republic continued to require each kW of solar PV installed to be coupled with at least 5 kW of storage capacity, and introduced a USD 20.3 million programme that provides subsidies to cover part of the costs of buying and installing these systems.[135]

In the United States, Massachusetts committed to deploying 200 MWh of energy storage by 2020, increased its solar PV incentive for systems that include energy storage and awarded USD 20 million in grants to support community storage projects.[136] New York became the fourth US state (following California, Massachusetts and Oregon) to commit to an energy storage target.[137] Maryland became the first state in the country to offer a tax credit for energy storage systems at residences and businesses.[138] Nevada enacted a suite of energy storage and grid modernisation policies, including the addition of energy storage as a qualifying technology in the state's RPS.[139] California increased the funds available annually for energy storage-related rebates.[140] New York City became the first US municipality to adopt an energy storage target, calling for 100 MWh of storage capacity by 2020.[141]

China released its first national-level policy document to guide development of the energy storage industry, including plans for non-pumped storage projects, driven in part by a desire to increase renewables penetration and to reduce VRE curtailment.[142] In addition, China's 13th Five-Year Hydropower Plan calls for increasing the country's pumped storage capacity to 40 GW by 2020.[143]

SECTOR COUPLING AND SYSTEM-WIDE ENERGY TRANSFORMATION

Policies that promote sector coupling can provide economy-wide benefits. This coupling can occur by linking renewable power directly to heating and cooling or transport, or by using renewable power-to-gas. These efforts can maximise the benefits of renewable energy sources while helping to better integrate renewable energy into all sectors.

Policies that promote sector coupling between electricity, transport, and heating and cooling can provide economy-wide benefits and assist in increasing the overall renewable energy share. *(→ See Integration chapter.)* Policy makers are starting to look at the energy system as a whole, introducing policies that are cross-sectoral.

These efforts are often organised under national energy strategies. For example, during 2017 France announced a plan to invest EUR 20 billion (USD 24 billion) between 2018 and 2022 in an energy transition plan, with about half of the funds (EUR 9 billion; USD 11 billion) going to energy efficiency improvements and the remainder going to renewable energy and to advance the shift to clean vehicles.[144]

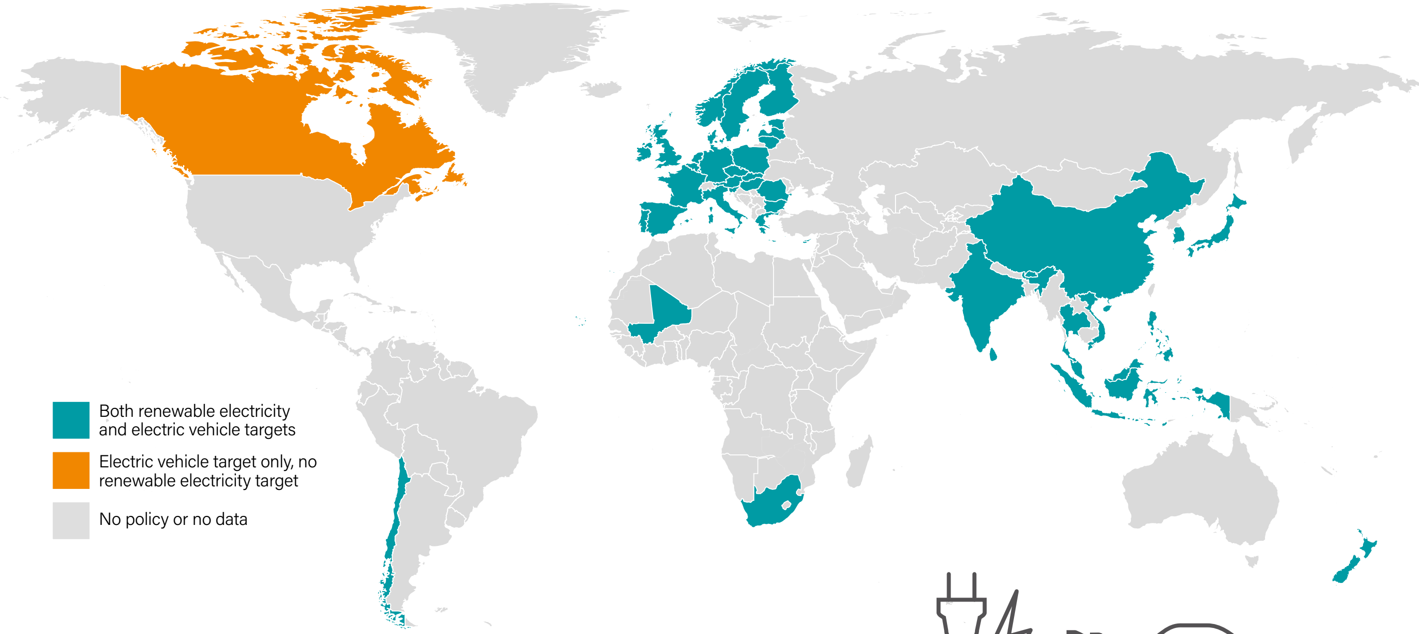
In China, with an eye towards reducing the curtailment of VRE and meeting a new goal of eliminating curtailment altogether by 2020, the National Energy Administration is promoting renewable energy consumption by: encouraging power generators to trade with heating companies; gradually eliminating coal-fired industrial boilers and shifting residential heating to natural gas or electricity; improving transmission capacity from provinces that have surpluses of solar and wind power to population centres; and reforming the electricity market, which historically has not taken into account marginal costs when prioritising dispatch.[145] In 2017, China announced plans to introduce a system to steer solar PV investments to regions with lower rates of curtailment.[146]

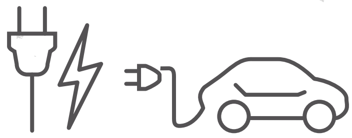
While examples of direct policy linkages between EVs and renewable electricity are limited, a number of jurisdictions have adopted policies to encourage or mandate the use of renewable energy in EVs. Austria offers a purchase price premium for EVs charged with 100% renewable electricity, and in 2017 Germany established an EUR 300 million (USD 370 million) tendering programme providing grants for the deployment of EV charging infrastructure that sources electricity from renewables.[147] The city of Pittsburgh (United States) announced that charging stations for its new EV fleet would be powered by a 100 kW solar PV array.[148]

However, countries with targets for both EVs and renewable energy in power may encourage the use of renewable deployment for transport. *(→ See Figure 15.)* Costa Rica, where the electricity system is 98% renewable, announced tenders for EVs to be powered by the country's electric grid.[149] Similarly, Sweden's new climate policy draws on the country's existing low-emission power sources to decarbonise transport by increasing electric mobility as well as biofuel use.[150]

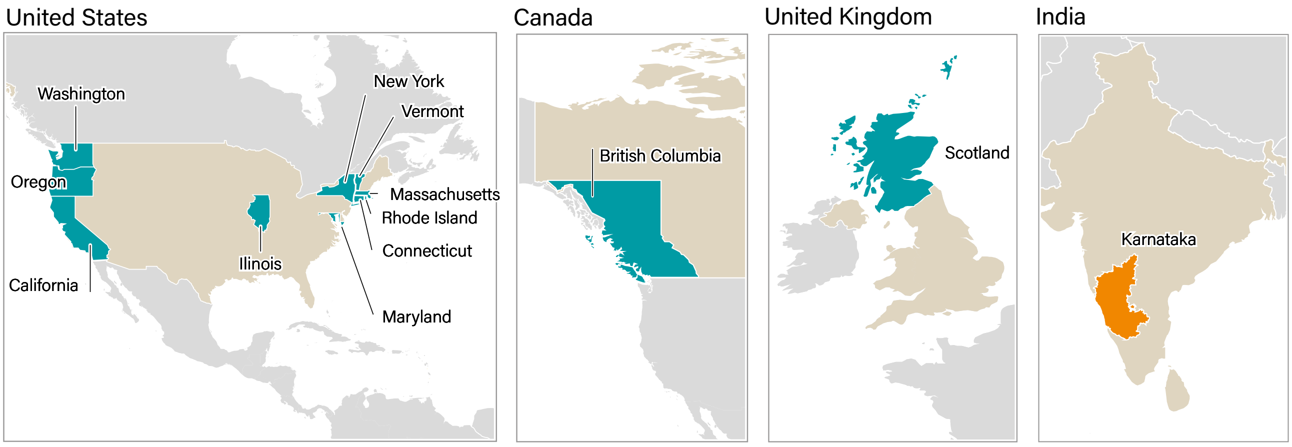
FIGURE 15. Targets for Renewable Power and/or Electric Vehicles, End-2017

NATIONAL TARGETS

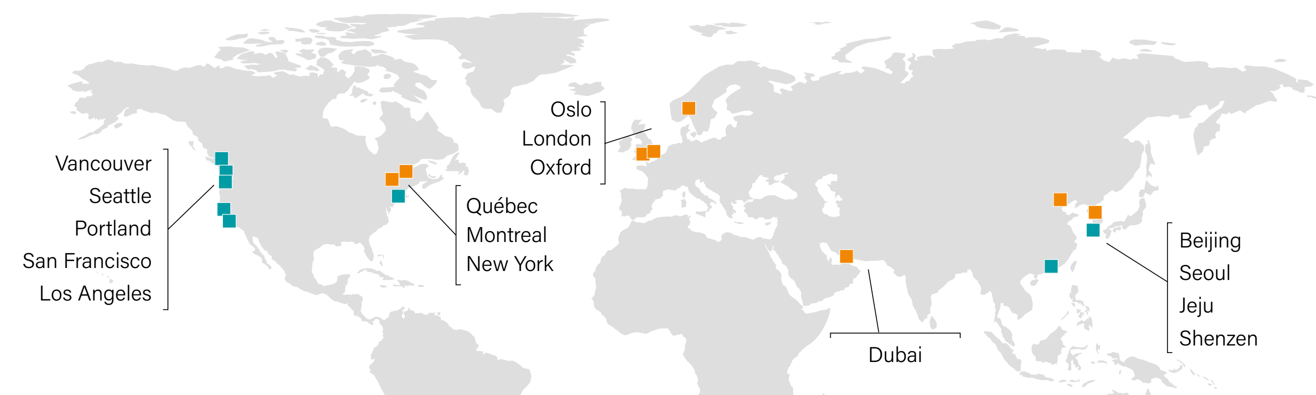




SUB-NATIONAL TARGETS



CITY TARGETS



Note: Targets for Norway and the United Kingdom are national-level final energy targets. 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. 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: REN21 Policy Database.

■ **Table 2.** Renewable Energy Support Policies

Country	Renewable energy targets[7]	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/ premium payment	Electric utility quota obligation/ RPS	Net metering/ billing	Transport obligation/ mandate	Heat obligation/ mandate	Tradable REC	Tendering	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												
Australia	P	●	◖	●	◖	◖ ☆	◖	●	◐				●
Austria	E, P, HC, T		●			●		●		●			● ★ [6]
Bahamas, The	P												
Bahrain	P	●			● ★								●
Barbados[1]	P	●			●						●		●
Belgium	E, P, HC, T			◖	◖	●		●	●	●	●		◖
Brunei Darussalam	P												
Canada	P*	●	◖ ☆	◖	◖	●			◐	●	●		●
Chile	E, P	●		●	●			●	○	●[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, HC, T		●			● ☆	●	●	○	●[6]	●		●[6]
Germany	E, P, HC, T		● ☆			●	●	●	○	●	●		● ☆ [6]
Greece	E, P, HC, T		●	●	● ☆	●	●	●	●	●	●		●
Hungary	E, P, HC, T		●			●			●[6]		●		● ☆ [6]
Iceland	E					●							
Ireland	E, P, HC, T	●	●			●	◖	●	●				
Israel	E, P	●	●	●	●		●		○		●		●
Italy	E, P, HC, T		●		●	●	●		●	●	●		●[6]
Japan	E, P	●	●					●	○		●		●
Korea, Republic of	E, P ☆			●	●	●	●	●		●	●	●	●[6]
Kuwait	P	●							●				
Latvia	E, P, HC, T		●		●	●			●		●		
Liechtenstein			●										
Lithuania	E, P, HC, T		●	●	● ☆	●					●		●
Luxembourg	E, P, HC, T		● ☆			●							●
Malta	E, P, HC, T		●		●	●					●		●[6]
Monaco													
Netherlands	E, P, HC, T		●[6]		●	● ☆		●	○	●[6]		●	●[6]
New Zealand	P	●			◖	● ☆							●
Norway	E, T	●		●		● ☆		●	●		●		●[6]
Oman									○				
Palau	E, P	●		●									
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, HC, T					●	●	●	○	●		●	●[6]
St. Kitts and Nevis													
Sweden	E, P, HC, T		●	●		●		●		●	●		●
Switzerland	E ☆		●				●	●			●		●[6]
Trinidad and Tobago	P	●								●	●		
United Arab Emirates	E, P	●		◖	◖		◖		◖			◖	◖
United Kingdom	E, P, T, HC		● ☆ [6]	●		●		●	○		●	●	●[6]
United States[4]	P* ☆		◖	◖ ☆	◖ ☆	●	◖	◖	◐	●	●		● ☆ [6]
Uruguay		●			●	●	●		●		●	●	●[6]

Note: Please see key on last page of table.

■ **Table 2.** Renewable Energy Support Policies (continued)

Country	Renewable energy targets[7]	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/ premium payment	Electric utility quota obligation/ RPS	Net metering/ billing	Transport obligation/ mandate	Heat obligation/ mandate	Tradable REC	Tendering	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	●	●						●			●	●
Argentina	E, P	●	●		● ★	● ☆			○	●	●	●	●
Azerbaijan	P	●											●
Belarus	E		●	●							●		●
Belize	P	●							●				
Bosnia and Herzegovina	E	●	●						●				
Botswana									○		●		●
Brazil	E, P	●			●	● ☆	◖		●	●	●		●
Bulgaria	E, P, HC, T		●			●							●[6]
China	E ☆, P, HC	●	● ☆	●		◖	●		●	●	●	●	●
Colombia	P					●				●	●		●
Costa Rica	P	●	●		●	●			●		●		
Croatia	E, P, HC, T		●			●							● ☆[6]
Cuba	P												
Dominica	P												
Dominican Republic	P		●		●				●	●	●		●
Ecuador	P	●	●			●			●		●		●
Equatorial Guinea													
Fiji	E, P	●								●	●		
Gabon	E, P												
Grenada	E, P	●			●						●		
Guyana	E, P	●									●		
Iran	P	●	●							●		●	●
Iraq	P	●							●				
Jamaica	E, P	●			●	●			●	●	●		
Kazakhstan	P	●	●					●					●
Lebanon	E, P, HC	●			●						●		●[6]
Libya	E, P, HC, T										●		
Macedonia, FYR	E, P, HC, T		●								●[6]		● ☆[6]
Malaysia	P	●	●	●		●			○		●		●
Maldives	P	●	●						●				
Marshall Islands	P	●									●		
Mauritius	P	●			● ☆				●		●		●[6]
Mexico	P, HC				●	● ☆			○	●			●
Montenegro	E, P, HC, T	●	●			●							
Namibia	P	●					●						
Nauru													
Panama	E, T	●	●		●	●			●	●	●	●	
Paraguay	P	●				●					●		
Peru	P	●	●	●	●	●			●		●		●
Romania	E, P, HC, T			●		● ☆		●					●[6]
Russian Federation	P	●	●						○				●
Samoa	E, P												
Serbia	E, P, HC, T		●			●							● ☆
South Africa	P	●		●		●	●		●[6]		●		●
St. Lucia	E, P	●			●						●		
St. Vincent and the Grenadines[1]	P	●			●								
Suriname		●			●				●				
Thailand	E, P, HC, T	●	●			●					●	●	●
Tonga	P												
Turkey	P	●	●			●			○				●
Turkmenistan													
Tuvalu	P												
Venezuela	P												

Note: Please see key on last page of table.

Table 2. Renewable Energy Support Policies (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	Transport obligation/ mandate	Heat obligation/ mandate	Tradable REC	Tendering	Fiscal Incentives and Public Financing: 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		●				●							●
Armenia	P	●	●		●				○				●[6]
Bangladesh	E, P	●							●		●		●
Bhutan	E, 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		●							○	●	●	●	●
Georgia													●[6]
Ghana	E, P	●	●	●	●	●		●			●		●
Guatemala	E, P	●			●	●			●	●	●		
Honduras	P	●	●		●				●	●	●		
India	P, HC	●	◖ ☆	●	◖ ☆	● ☆	◖	●	○	●	●	●	●[6]
Indonesia	E ☆, P	●	● ☆	●		●			●	●	●		●
Jordan	E, P, HC, T	●	●		●		●		●		●		●
Kenya	P, HC	●	●		●		●		●		●	●	●
Kiribati	P												
Kosovo	E, 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		●									●		
Nicaragua	P		●							●	●		●
Nigeria	P	●	●	●					●		●		●
Pakistan			● ☆		● ☆			●			●		●
Palestine, State of[5]	P		●		●				●		●		
Papua New Guinea	P												
Philippines	P	●	●	●	●	●			●	●	●	●	●
São Tomé and Príncipe	P												
Solomon Islands	P												
Sri Lanka	P	●	●	●	●	●			○		●	●	●
Sudan	P	●				●							
Swaziland													
Syria	E		●		●				●	●			
Tajikistan	P	●	●								●		●
Timor-Leste	P												
Tunisia	P	●			●						●		●[6]
Ukraine	E, P ☆, HC, T	●	●		●	●					●		●[6]
Uzbekistan	E ☆, P								●				
Vanuatu	E, P	●	●								●		
Vietnam	E, P, T	●	● ★	●	● ★	●		●		●	●		●
Yemen	P	●											
Zambia		●	● ★						○		●		●

Note: Please see key on last page of table.

Table 2. Renewable Energy Support Policies (continued)

Country	Renewable energy targets[7]	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/ premium payment	Electric utility quota obligation/ RPS	Net metering/ billing	Transport obligation/ mandate	Heat obligation/ mandate	Tradable REC	Tendering	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, T												
Benin	E, P												
Burkina Faso	P	●							●	●	●	●	
Burundi	E												
Central African Republic													
Chad													
Comoros	P												
Congo, Democratic Republic of	P												
Eritrea	P												
Ethiopia	P					●			○				
Gambia	P	●									●		
Guinea	E, P	●									●		
Guinea-Bissau	E, P												
Haiti	P	●											●
Korea, Democratic People's Republic													
Liberia	E, P	●				●					●		
Madagascar	E, P	●							○		●		
Malawi	E, P, HC	●				●	●		●		●		●
Mali	E, P	●									●		●
Mozambique	HC	●				●					●		●
Nepal	E, P	●	●					●	●	●	●		●
Niger	E, P	●									●		
Rwanda	P	●	●						●	●	●		●
Senegal	P	●	●	●	●				○		●		
Sierra Leone	P, HC												
Somalia													
South Sudan	P												
Tanzania	P	●	●		● ★						●	●	●
Togo	E, P	●									●		
Uganda	P, HC, T	●	●						●		●		●
Zimbabwe		●				● ☆					●		●

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

- ★ New
- ☆ Revised
- ● (grey) 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 2017
- ◖ (open) Sub-national tender held in 2017

[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. 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] Some targets shown may be non-binding.

Note: Countries are organised according to annual gross national income (GNI) per capita levels as follows: "high" is USD 12,236 or more, "upper-middle" is USD 3,956 to USD 12,235, "lower-middle" is USD 1,006 to USD 3,955 and "low" is USD 1,005 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 March 2018. Only enacted policies are included in the table; however, for some policies shown, implementing regulations may not yet be developed or effective, leading to lack of implementation or impacts. Policies known to be discontinued have been omitted or marked as removed or expired. Many feed-in policies are limited in scope of technology.

Source: See endnote 2 for this chapter.

03

MARKET AND INDUSTRY TRENDS

Solar panels on UPS facility in Parsippany, New Jersey, United States

In 2017, United Parcel Service of America (UPS) expanded its investment in solar energy as an owner/operator of solar assets at at least eight facilities in the United States. The estimated USD 18 million investment in 26,000 solar panels and related infrastructure at the facilities supplies about half of the daily energy needs of each building and resulted in a nearly five-fold increase in solar power generation at UPS facilities – equivalent to the energy needed to electrify some 1,200 US homes annually. The company also has invested in alternative fuel and advanced technology vehicles and fuelling stations globally since 2009 – from pedal power and electric-assisted bicycles in dense urban areas, to electric and hybrid-electric vehicles, to renewable natural gas.

MARKET AND INDUSTRY TRENDS

BIOENERGY

Biomass energy (bioenergy) can be produced from a wide range of feedstocks of biological origin using a number of different processes to produce heat, electricity and transport fuels (biofuels). Many bioenergy conversion pathways are well established and fully commercial, while others are still at the development, demonstration and commercialisation stages.[1]

If the traditional use of biomass[i] is included, bioenergy contributed an estimated 12.8% (46.4 exajoules (EJ)) to total final energy consumption in 2016.[2] Modern bioenergy (excluding the traditional use of biomass) contributed 5% to final energy consumption.[3] *(→ See Figure 16.)*

Bioenergy plays an expanded role in many low-carbon scenarios and can be particularly useful in the long-haul transport sector, where other energy alternatives may not be readily available.[4] An expanded role for bioenergy remains the subject of debate and sometimes controversy regarding the sustainability of production and use. *(→ See Box 2 in Policy Landscape chapter.)* However, there is increasing consensus that when produced and used in a sustainable way, bioenergy can contribute to reductions in greenhouse gas emissions and provide a range of other environmental, social and economic benefits.[5]

In 2017, a number of initiatives were advanced to expand sustainable bioenergy development, including the newly established 20-country BioFuture Platform to promote the expansion of a sustainable bioeconomy[ii], and the Sustainable Biofuels Innovation Challenge, which is part of the global Mission Innovation programme and has 22 participating countries.[6]

BIOENERGY MARKETS

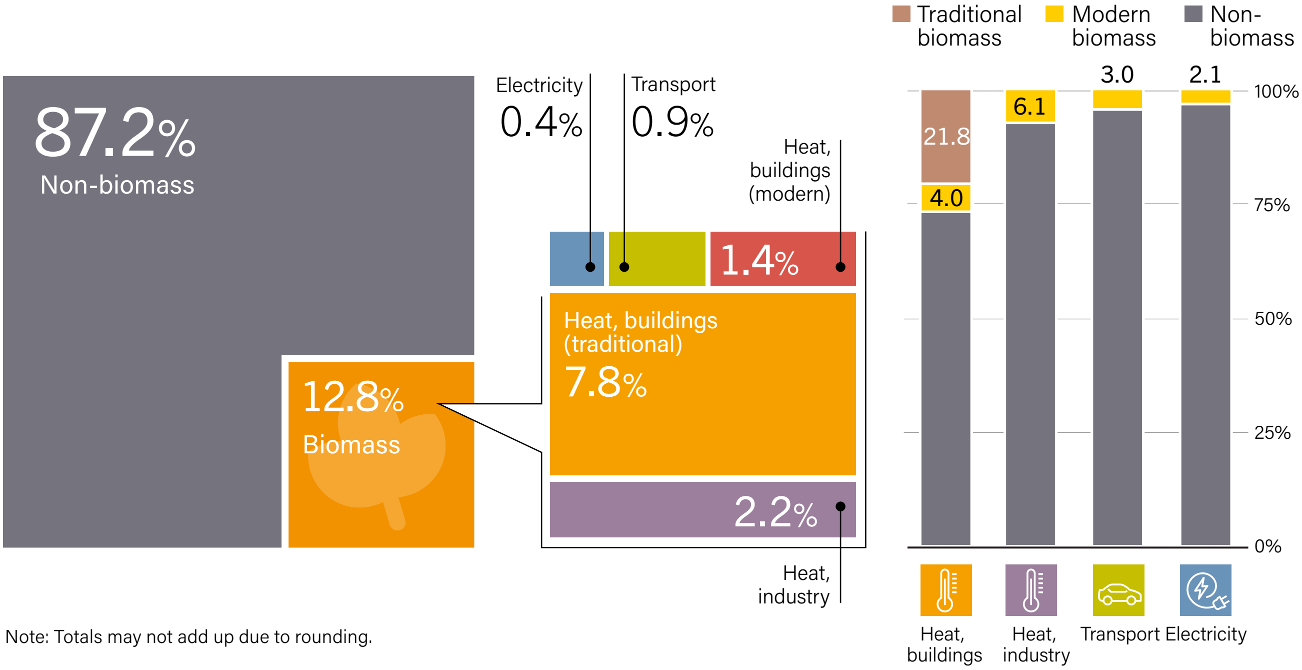
Bioenergy markets are greatly influenced by the policy contexts of specific countries and regions. During 2017, several countries implemented policies to support bioenergy production and use. For example, in Brazil, the RenovaBio initiative is expected to lead to a significant increase in bioenergy production and use.[7] Also in 2017, India launched a major initiative to enhance the level of domestic production and use of biofuels (including advanced biofuels produced from agricultural residues).[8] In contrast, debate has continued within the European Union (EU) about the role of bioenergy in the EU Renewable Energy Directive, with constraints to be introduced on "food-based" biofuels.[9] Uncertainties also remain around the future of the US Renewable Fuel Standard (RFS).[10] These varying policy climates greatly affect market developments.

The contribution of bioenergy to final energy consumption for heat in buildings and industry exceeds its use in electricity and transport, even when the traditional use of bioenergy is excluded; however, the electricity sector has seen the highest rate of growth in bioenergy consumption.[11] *(→ See Figure 16.)*

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.

ii The bioeconomy comprises those parts of the economy that use renewable biological resources from the land and sea to produce food, materials and energy.

FIGURE 16. Shares of Bioenergy in Total Final Energy Consumption, Overall and by End-Use Sector, 2016



Note: Totals may not add up due to rounding.

Source: See endnote 3 for this section.

Bio-heat Markets

Bioenergy as solid fuels (biomass), liquids (biofuels) or gases (biogas or biomethane) can be used to produce heat for cooking and for space and water heating in the residential sector, in traditional stoves or in modern appliances such as pellet-fed central heating boilers. At a larger scale, it can provide heat for public and commercial premises as well as for industry, where it can provide either low-temperature heat for heating and drying applications or high-temperature process heat. Bioenergy also can be used to co-generate electricity and heat via combined heat and power (CHP) systems, either on-site in buildings or distributed from larger production facilities via district energy systems, to provide heating (and in some cases cooling) to residential, commercial and industrial buildings.

The traditional use of biomass to supply energy for cooking and heating in simple and usually inefficient devices is still the largest use of bioenergy. Given the serious negative health impacts of such use, and the unsustainable nature of much of the supply of such biomass, there is an emphasis on reducing traditional biomass uses as part of the efforts to improve energy access. *(→ See Distributed Renewables chapter.)* Because the supply of biomass for traditional use is informal, obtaining accurate data on its use is difficult.[12]

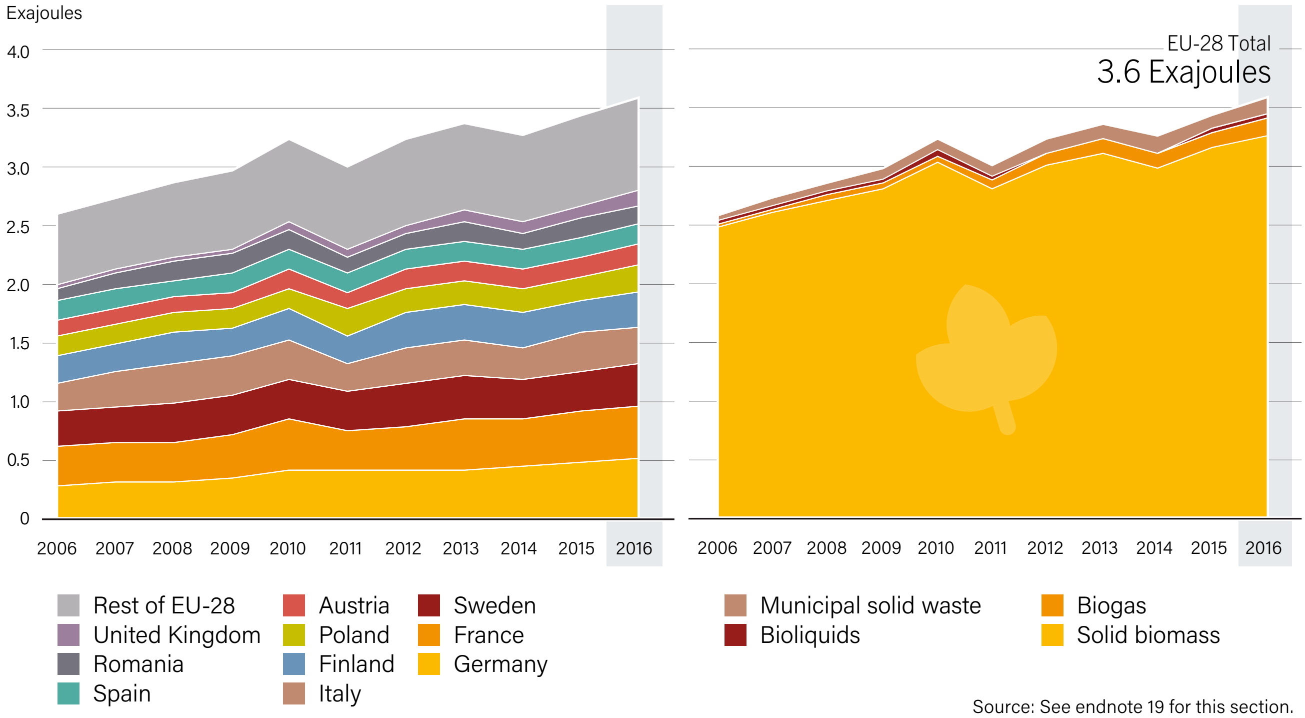
The amount of biomass used in traditional applications has grown slowly, from 27.7 EJ in 2005 to an estimated 28.4 EJ in 2016.[13] However, the share of traditional biomass in total global energy consumption has been declining gradually for several years, from 9.2% of total final energy consumption (TFEC) in 2005 to an estimated 7.8% of TFEC in 2016.[14] *(→ See Figure 2 in Global Overview chapter.)*

In 2016, modern bioenergy applications provided an estimated 13.1 EJ of heat in terms of final energy consumption, of which 7.9 EJ was used in industrial applications.[15] The global residential and commercial sectors consumed 5.2 EJ of bioenergy in 2016, used mainly for space heating in buildings.[16] The total installed heat capacity of modern bioenergy increased to an estimated 314 gigawatts-thermal (GW_{th}) in 2017.[17]

Europe is the largest consumer of modern bio-heat by region. EU member states have promoted the use of renewable heat in both buildings and industry in order to meet mandatory national targets under the Renewable Energy Directive.[18] The EU used an estimated 3.6 EJ of bio-heat in 2016 (latest data available).[19] *(→ See Figure 17.)* The majority of this was supplied from solid biomass (91%), with additional approximately equal contributions (4% each) from biogas and from municipal solid waste[i] (MSW).[20]

i Municipal solid waste contains a significant proportion of biomass materials (food wastes, used wood, etc.), and the energy produced from this part of the waste is usually considered to be renewable. The proportion of renewable energy supplied varies according to the specific waste composition, but a value of 50% is often used as a default. Given the potentially toxic nature of the flue gases from such fuels, plants using MSW should be fitted with stringent emission control systems to avoid adverse impacts on air quality.

FIGURE 17. Consumption of Heat from Bioenergy in the EU-28, by Country and Fuel Source, 2006-2016



Source: See endnote 19 for this section.

Germany is the largest consumer (0.52 EJ) of bio-heat in the EU, followed by France (0.45 EJ), Sweden (0.36 EJ), Italy (0.32 EJ) and Finland (0.30 EJ).[21] Since 2007, the consumption of heat from bioenergy in the EU has increased by over 30%.[22] The fastest-growing market over this period is the United Kingdom, where bio-heat consumption has risen more than five-fold with support under the UK's Renewable Heat Incentive Scheme.[23]

Heat supplied from bioenergy accounts for around 6.8% of all industrial heat consumption.[24] Total bioheat consumption in industry has been stable in recent years, concentrated in bio-based industries such as the pulp and paper sector, timber and the food and tobacco sectors.[25] More than 50% of global industrial use of bio-heat continues to occur in three countries: Brazil, India and the United States.[26] Brazil is the largest user of bioenergy for industrial heat production (1.4 EJ) due to the use of bagasse in CHP applications in the sugar industry, the use of residues in the pulp and paper industry and the use of charcoal in the iron and steel industry.[27]

India is the second largest user of bioenergy for industrial heat production, particularly in the sugar industry.[28] Bioenergy use in industry in North America has been falling, compensated by gains in Asia and South America, reflecting changes in production patterns in key industry sectors, especially pulp and paper.[29]

China used some 8 million tonnes of biomass (equivalent to 120 petajoules (PJ)) in the industrial sector in 2016 (latest data available), and the country's 13th Five-Year Plan indicates that this will increase to 30 million tonnes (450 PJ) by 2020.[30] The use of biomass for heating is seen as a way to reduce local pollution by replacing coal in heating applications, and to provide heat in the country's north during periods of gas shortage.[31]

Modern use of bio-heat in buildings is concentrated in North America and the EU. The market for wood pellets for domestic and commercial heating was essentially unchanged in 2017 at 14.0 million tonnes.[32] Most of the pellets were used in Europe (11.1 million tonnes) – with the leading markets in Italy, Germany and France – followed by North America (2.9 million tonnes, with sales in the United States down 4% to 2.6 million tonnes).[33]

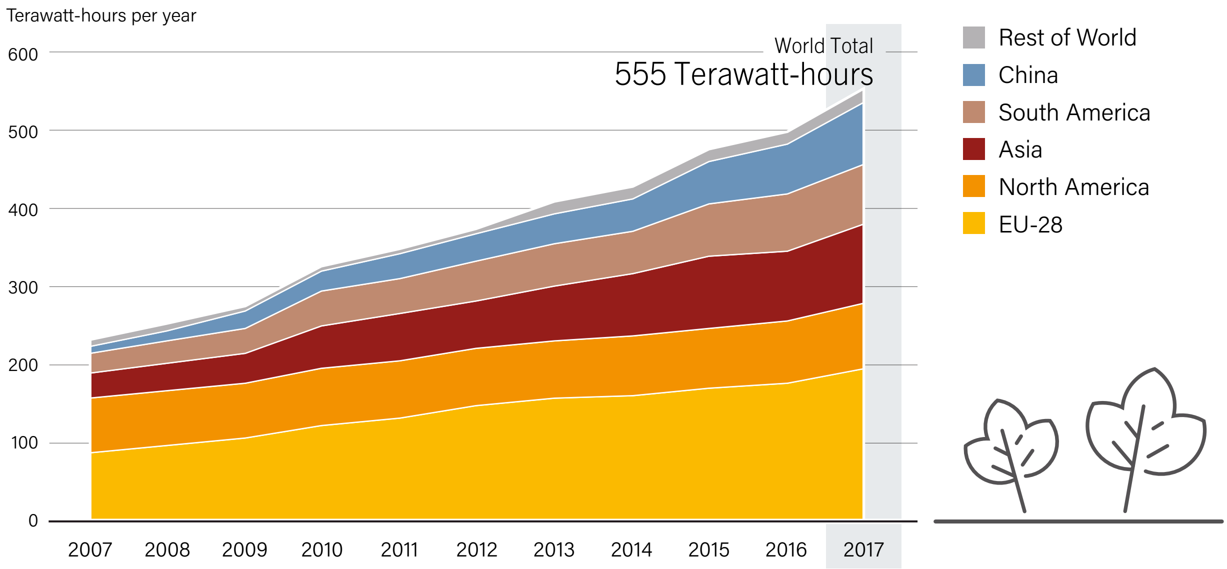
Bioelectricity Markets

Global bioelectricity (electricity generation from bioenergy) capacity increased 7% between 2016 and 2017, to 122 gigawatts (GW).[34] Total global bioelectricity generation rose 11% in 2017 to 555 terawatt-hours (TWh).[35] China has now overtaken the United States as the largest producer of bioelectricity; the other major producers are Brazil, Germany, Japan, the United Kingdom and India.[36] *(→ See Figure 18.)*

In Europe, the leading region for bioelectricity generation, generation rose 11% in 2017 compared to 2016, driven by the Renewable Energy Directive and maintaining the strong growth of the previous decade.[37] Europe's largest bioelectricity producer is Germany, where capacity increased 4% in 2017 to 8.0 GW, with significant rises in biogas, biomethane and sewage gas capacity.[38] Bioelectricity generation in Germany rose 1% (51 TWh), with a 2% rise in biogas and methane generation offsetting reductions from other biomass feedstocks.[39]

The United Kingdom's bioelectricity capacity increased by 241 megawatts (MW) in 2017 to 6.0 GW, due primarily to increases in wood-based generation capacity, anaerobic digestion and waste-to-energy.[40] The country's bioelectricity generation rose 6% in 2017 to 31.8 TWh, with growth in large-scale generation based on solid biomass fuels including wood pellets, anaerobic digestion and MSW, offset in part by reductions in landfill gas generation and in co-firing of biomass with coal.[41] Generation also is estimated to have grown strongly in Finland, Ireland, Poland and Sweden during 2017.[42]

FIGURE 18. Global Bio-Power Generation by Region, 2007-2017



Source: See endnote 36 for this section.

China has become the world's largest bioelectricity producer, as generation grew 23% in 2017 to 79.4 TWh, and capacity increased from 12.1 GW to 14.9 GW.[43] This growth is in response to revised objectives in the 13th Five-Year Plan, which set a capacity target for renewables of 23 GW by 2020.[44] The combustion of agricultural wastes and MSW accounted for most of the total bioelectricity generation.[45]

The United States has the second highest level of bioelectricity generation, although generation has been relatively flat for the last decade in the absence of strong policy drivers and because of increasing competition from other sources of renewable electricity generation. Generation rose only 2% in 2017 to 69 TWh (up from 68 TWh in 2016).[46] US bioelectricity capacity decreased slightly despite the commissioning of 268 MW of new capacity, as some existing capacity was retired.[47]

Brazil is the largest producer of bioelectricity in South America, with capacity rising 5% in 2017 to 14.6 GW and generation rising 4% to 49 TWh.[48] Nearly 80% of the biomass-based electricity generation in Brazil is fuelled by bagasse, which is produced in large quantities in sugar production.[49]

In Asia (beyond China), bioelectricity capacity and generation continued to rise strongly in Japan, stimulated by a generous feed-in tariff.[50] The country's capacity for dedicated biomass plants increased 14% to reach 3.6 GW in 2017, and generation totalled some 37 TWh, a 16% increase from 2016.[51] India's total bioelectricity capacity increased 10% in 2017 to 9.5 GW, and generation rose 8% to 32.5 TWh.[52]

Transport Biofuel Markets

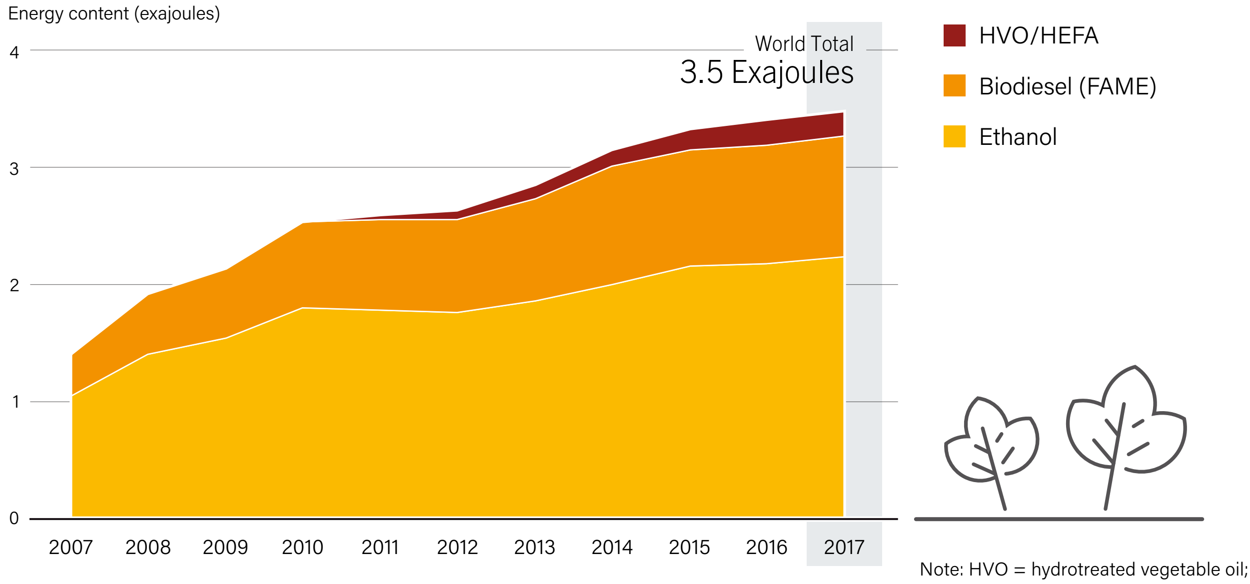
Biofuels production and use are very concentrated geographically, with more than 80% of production and use taking place in the United States, Brazil and the EU combined.[53] In 2017, global biofuels production rose around 2.5% compared to 2016, reaching 143 billion litres (equivalent to 3.5 EJ).[54] The United States and Brazil remained the largest biofuel producers by far, followed by Germany and then Argentina, China and Indonesia.[55]

The main biofuels produced were ethanol, biodiesel (fatty acid methyl ester or FAME fuels), and fuels produced by treating animal and vegetable oils and fats with hydrogen (hydrotreated vegetable oil (HVO) / hydrotreated esters and fatty acids (HEFA)), as well as a growing contribution from biomethane in some countries[i]. An estimated 65% of biofuel production (in energy terms) was ethanol, 29% was FAME biodiesel and 6% was HVO/HEFA.[56] *(→ See Figure 19.)* The use of biomethane as a transport fuel, while growing rapidly, contributed less than 1% of the biofuel total.[57]

Production, consumption and trade in biofuels are affected by several factors including growing conditions in the producing countries, the policy and market environments, as well as import tariffs and other measures affecting international trade.

i All references to ethanol in the GSR refer to bioethanol, that is, ethanol derived from biomass. Ethanol is produced principally from sugar- and starch-containing materials including corn, sugar cane, wheat and cassava. After pre-treatment 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, "Hy-dro-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 the Bioenergy text for further details and references.

FIGURE 19. Global Trends in Ethanol, Biodiesel and HVO/HEFA Production, 2007-2017



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

Source: See endnote 56 for this section.

Global annual production of ethanol increased 3.8% between 2016 and 2017, from 101 billion litres to 105.5 billion litres.[58] The United States and Brazil maintained their leads in ethanol production, together accounting for 84% of global production in 2017.[59] The next largest producers were China, Canada and Thailand.[60]

US ethanol production rose 2.8% to 60 billion litres during the year, following a good corn harvest.[61] More than 90% of this fuel was used in the United States – with a record average blend rate of 10.08% – to meet the annual volume requirements under the US Environmental Protection Agency's (US EPA's) final Renewable Fuel Standard (RFS2) allocations.[62] The remaining fuel was exported to more than 60 countries.[63]

Ethanol production in Brazil was stable in 2017 at 28.5 billion litres, despite high global sugar prices favouring sugar production.[64] The fuel was used mainly within Brazil but some was exported, for example to the United States.[65]

China continued to rank third for ethanol production globally in 2017 and produced an estimated 3.3 billion litres, a 4% increase over 2016.[66] China aims to shift to an E10 ethanol/gasoline blend by 2020, which would push demand up by a factor of at least four.[67] The country's ethanol production has grown, based largely on maize (70%) but with significant contributions from cassava (25%) and molasses from sugar beet and sugar cane (5%).[68]

Ethanol production in Canada, which ranked fourth globally in 2017, increased 3% to 1.7 billion litres.[69] In Thailand, the fifth largest producer, production increased 23% to 1.5 billion litres.[70]

Global trade patterns for ethanol have been changing, in part in response to rapidly rising demand in China and to the introduction of protective import tariffs in several countries. In 2015, China became a major importer of ethanol, especially from the United States; however, as domestic production in China increased, the country introduced tariff barriers in early 2017 that greatly reduced these imports.[71] Brazil also introduced an import quota in 2017 aimed at US-produced ethanol; if the quota is exceeded, an import tariff is imposed.[72]

Biodiesel production is more geographically diverse than ethanol production and is spread among many countries. Although Europe was the highest-producing region in 2017, the leading countries for biodiesel production were the United States (16% of global production), Brazil (11%), Germany (9%), Argentina (9%) and Indonesia (7%).[73] Global biodiesel production rose around 1% to 36.6 billion litres in 2017.[74] The increase was due mainly to increases in the United States, where production grew 1.6% to 6 billion litres in response to improved opportunities for biodiesel in the RFS.[75] Biodiesel production in Brazil increased 13% in 2017 to reach a record 4.3 billion litres, with the blending level of biodiesel in diesel rising to 9%.[76] Germany was again the largest European producer at 3.5 billion litres.[77] In Argentina, biodiesel production increased 8% to 3.3 billion litres, and in Indonesia production fell 10% to 2.5 billion litres in 2017.[78]

International trade in biodiesel was greatly affected by changing import tariffs. The United States introduced "anti-dumping" tariffs on imports from Indonesia and Argentina.[79] In Europe, however, the EU ended tariffs on imports of biodiesel in 2017.[80]

HVO/HEFA, produced by treating vegetable oils and animal fats (including wastes and residues) with hydrogen, have fuel properties that are closer to those of fossil-based fuels and that can be tailored to particular end-uses. Production is concentrated in Finland, the Netherlands, Singapore and the United States.[81] Global production of HVO grew an estimated 10% in 2017, from 5.9 billion litres to 6.5 billion litres.[82]

The United States is the largest market for biomethane, and production of the fuel has been stimulated in the country since 2015, when biomethane was first included in the advanced cellulosic biofuels category of the EPA's RFS, thereby qualifying for a premium.[83] US biomethane consumption grew nearly six-fold between 2014 and 2016, then increased another 15% in 2017 to some 17.4 PJ.[84]

In Europe, the other globally significant market for biomethane for transport, consumption increased 12% between 2015 and 2016, to 6.1 PJ (latest data available).[85] Production and use were concentrated in Sweden (4.7 PJ), where methane production from food wastes is encouraged as part of a sustainable waste reduction policy, and where use of biomethane as a transport fuel is prioritised over its use for electricity production or for injection into gas grids.[86] Germany (1.3 PJ) was Europe's second largest user of biomethane for transport in 2016.[87]

BIOENERGY INDUSTRY

Bioenergy requires a more complex supply chain than other renewable energy technologies, including feedstock suppliers and processors as well as transport of the fuel to end-users. The required equipment includes specialised biomass harvesting, handling and storage equipment in addition to appliances and hardware components to convert biomass to useful energy carriers and energy services. Many of the necessary technologies are well developed and commercially available; however, the bioenergy industry – with support from academia, research institutions and governments – is making progress in bringing new technologies and fuels to the market.[88]

Solid Biomass Industry

A very diverse set of industries is involved in growing, harvesting, delivering, processing and using solid biomass to produce heat and electricity, ranging from the informal supply of traditional biomass, to the locally based supply of smaller-scale heating appliances, to regional and global players involved in large-scale district heating and power generation technology supply and operations. Using biomass to produce electricity and/or heat can involve the use of fuels close to their source, such as MSW, residues from agricultural and forestry processes, and purpose-grown energy crops.

The fuels also can be processed and transported to be used where markets are most profitable – notably, through the international trade in biomass pellets that often are used for large-scale generation, either by co-firing in coal-fired power stations or for burning in dedicated utility-scale plants. The energy can be used for heating, for electricity generation or for both, through the use of CHP systems.

Bagasse and other agricultural residues are commonly used to produce heat and power around the world, especially in Brazil. This technology is being deployed to a larger extent in more countries, and several new plants were commissioned or under development in 2017. For example, in Sierra Leone, Sunbird Bioenergy Africa successfully commissioned the country's first bioenergy plant (32 MW), using a variety of feedstocks (bagasse, napier grass, sorghum, miscanthus and wood chips) to supply an agricultural estate, with surplus power sold to the national grid.[89] In Mexico, a 50 MW bagasse plant was completed (commissioned in February 2018) to supply power and heat to the sugarcane mill; any excess energy will be exported to the grid.[90] A 1.8 MW plant fuelled with rice husks is being developed in the Ayeyarwaddy region of Myanmar.[91]

80%

of all biofuels are produced and used in the United States, Brazil and the EU

The use of MSW as a fuel for electricity or heat production is very well established, for example in Europe and Japan.[92] This practice often is driven by efforts to improve waste management and to avoid sending the MSW to landfill, as much as to provide renewable energy. Energy generation from MSW is being deployed more widely in a number of emerging and developing countries where urbanisation has led to rising waste production and thus to waste disposal problems.

In China, producing energy from waste is used widely as an alternative to landfill, and waste-to-energy plants also are starting to be developed in other parts of Asia and in Africa. For example, in Addis Ababa, Ethiopia, construction began in 2017 on a waste-to-energy plant that will process 1,400 tonnes of municipal waste a day and generate 185 gigawatt-hours (GWh) of electricity annually, enough to meet the power demands of 25% of the city's households.[93] And in Chonburi, Thailand, the international waste management firm Suez (France) began work on an 8.63 MW industrial waste-to-energy power plant that will process some 100,000 tonnes of waste each year.[94]

Global production and trade in wood pellets for industrial use (mostly in power stations) and for heating continued to expand[i], with production reaching some 30 million tonnes in 2017.[95] Some 14 million tonnes was used for residential and commercial heating markets that year – notably in Italy, Germany and Sweden – but the market did not grow significantly.[96] Recent developments include the commissioning of Helsinki, Finland's largest pellet-fired boiler – which uses 21 tonnes of wood pellets per hour to generate heat for apartment blocks – by the Finnish company Helen in February 2018.[97]

The other 16 million tonnes of wood pellets was used in the industrial sector, mostly for power generation, a growth of more than 20% since 2016.[98] Europe is the major market for this use, dominated by the United Kingdom, which used 7.5 million tonnes of wood pellets for power generation in 2017.[99] UK-based Drax – the world's largest bio-electricity generator and pellet user – has already converted three coal generation units (totalling 1.9 GW) to biomass pellets, and is converting a fourth.[100] The company also has invested heavily in pellet production to secure its supplies, and in 2017 it opened a plant in the US state of Louisiana that can produce 45,000 tonnes of pellets annually.[101] Denmark is the second largest European market for wood pellet use, at 2.7 million tonnes.[102]

Markets also have developed rapidly in the Republic of Korea and in Japan, where combined pellet production totalled some 2.6 million tonnes in 2017 and is expected to exceed 10 million tonnes by 2020 as projects under construction come online.[103] In 2017, developers in Japan rushed to get bioelectricity projects approved before the expected reduction in the feed-in

i There is still no consensus about the sustainability of such large-scale supply of wood pellets, although most large-scale use is subject to certification. For a discussion of the main issues, see IEA, *Technology Roadmap: Delivering Sustainable Bioenergy* (Paris: 2017), pp. 48-55, http://www.iea.org/publications/freepublications/publication/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf.

tariff at year's end.[104] By mid-2017, more than 800 projects with a total capacity of 12.4 GW had won government approval, nearly double Japan's biomass target for 2030.[105]

In 2017, the Finnish company Valmet was contracted to install a 112 MW power plant in Kishiru, Japan, based on a circulating fluidised bed system for co-firing coal and biomass, including wood pellets and crushed palm kernel shells (PKS).[106] Andritz (Austria) will supply a boiler using PKS and wood pellets to produce 50 MW of electricity for export to the grid in Ichihara, 30 kilometres east of Tokyo.[107] Toshiba Corporation (Japan) started commercial operation of a 50 MW biomass power plant using PKS in Omuta, in Fukuoka prefecture, to produce electricity for the grid; the company plans to import 0.2 million tonnes of PKS per year, mainly from Indonesia.[108]

Japanese companies involved in bioenergy production from biomass pellets are taking steps to ensure adequate fuel supply imports.[109] For example, Sumitomo, the country's largest pellet importer, has undertaken efforts to secure supply by taking financial stakes in several pellet-producing companies worldwide.[110] In 2017, Sumitomo acquired a 48% share in Canada's second largest pellet producer, Pacific Bioenergy.[111] It also has interests in Brazil, where it has taken a stake in Cosan Biomassa, a company that plans to make pellets from sugarcane residue.[112]

The United States is the largest producer and exporter of wood pellets.[113] As of end-2017, the country had the capacity to produce 10.7 million metric tonnes (11.8 million short tons) of pellets annually in 87 plants.[114] Actual production in 2017 was 5.3 million tonnes (5.8 million tons), of which 4.7 million tonnes (5.2 million tons) was exported, mainly to Europe (primarily the United Kingdom).[115] Other major producers and exporters of wood pellets included Canada and Latvia.[116]

Liquid Biofuels Industry

The production of liquid biofuels has been growing slowly and depends heavily on the policy and regulatory climate, which varies greatly by region. In Brazil, the RenovaBio initiative has been a strong promoter of the country's biofuels industry, while in the United States the future of the national RFS remains unclear.[117] In the EU, uncertainties continue around the future of biofuels between 2020 and 2030 under the Renewable Energy Directive, with the likelihood of a cap on conventional biofuels based on feedstocks that also can be used as food, and an increasing emphasis on advanced biofuels.[118] In India and China, biofuels are being given more priority, with a medium-term emphasis on advanced biofuels.[119]

Despite the policy uncertainty, US production of ethanol and biodiesel continued to grow to serve domestic and export markets, and ethanol exports reached a record high in 2017.[120] Some investment in new capacity also occurred. For example, Poet (United States) increased the production capacity of its Ohio-based ethanol facility from 265 million litres to 568 million litres (70 million gallons to 150 million gallons) per year; Cargill (United States) was building a "state of the art" biodiesel plant in the state of Kansas; and World Energy (United States) and Biox (Canada) commissioned a new biodiesel facility in Houston, Texas.[121]

In Brazil, a USD 115 million corn ethanol facility opened in the Mato Grosso region in August 2017, capable of producing some 227 million litres (60 million gallons) of ethanol per year.[122]

By contrast, Europe's second largest ethanol plant (and the United Kingdom's largest), operated by Vivergo in East Yorkshire, was taken offline in December 2017 for the foreseeable future because of market uncertainties including a lack of progress in the United Kingdom in developing concrete proposals for a 10% ethanol blend (E10) in petrol, and because of EU plans to constrain the use of "food-based" biofuels.[123] Archer Daniels Midland (United States) mothballed its biodiesel facility in Mainz, Germany in early 2018 after the removal of EU import tariffs on Indonesian biofuels.[124]

While most efforts to promote biofuels in transport are led by policy and regulation, the Below 50 initiative, launched in Europe in 2016 under the auspices of the World Business Council for Sustainable Development, aims to promote demand for biofuels that offer a carbon reduction of more than 50% compared to fossil fuels.[125] The initiative brings together the entire supply chain from feedstock producers to users such as transport fleet operators. By the end of 2017, more than 20 international companies had subscribed to the initiative, and it had expanded to hubs on four continents.[126]

In regions outside of the main markets (North and South America, Europe, China and India), development of biofuels production is held back by the lack of effective supporting policies and technical capacity; however, some promising signs of industry activity were apparent in 2017. In Nigeria, the state oil corporation signed a memorandum of understanding with the Kebbi State Government to build an ethanol plant based on cassava and sugarcane feedstocks, and to produce 84 million litres of ethanol per year.[127] In Zambia, Sunbird Bioenergy Africa launched a programme to encourage growers to plant cassava to supply feedstock for an ethanol project that will provide 120 million litres of ethanol per year (equivalent to 15% of Zambia's petroleum requirements), highlighting the long lead-time associated with the need to establish a supply chain for biofuels projects.[128] In Indonesia, a waste-to-ethanol project is under way that will process food waste into bio-products such as ethanol (2.3 million litres), animal feed and fertiliser.[129] And in Thailand, St1 (Finland) announced its cooperation with Ubon Bio Ethanol (Thailand) to launch a pilot project to produce ethanol from cassava waste.[130]

Worldwide efforts to demonstrate the production and use of advanced biofuels continued in 2017. These aim to respond to the policy requirement to produce fuels that demonstrate improved sustainability performance – including better life-cycle carbon savings than some biofuels produced from sugar, starch and oils, as well as fuels with less impact on land use (for example, from wastes and residues).[131] Advanced biofuels also can have properties enabling them to replace fossil fuels directly in transport systems ("drop-in biofuels"), including in applications such as aviation, or for blending in high proportions with conventional fuels. A number of different pathways to produce advanced biofuels are under development and include bio-based fuels in the form of ethanol, butanol, diesel jet fuel, gasoline, methanol and mixed higher alcohols from an array of feedstocks.[132]

The market for new biofuels in 2017 was led by HVO/HEFA, followed by ethanol from cellulosic materials such as crop residues, and by fuels from thermochemical processes including gasification and pyrolysis.[133]

Production of HVO/HEFA fuels (based on feedstocks including used cooking oil, tall oil[i] and others) continued to increase in 2017, mainly through increases in production ramped from existing production capacity, and with growing emphasis on using non-food feedstocks.[134] For example, Neste (Finland), which owns three large-scale renewable HVO diesel production facilities in Singapore, the Netherlands and Finland, announced plans to both increase the capacity of its existing facilities to 3 million tonnes (3.7 billion litres) by 2020 by improving productivity at these sites, as well as to add a further 1 million tonnes of capacity in Singapore.[135] And UPM (Finland), which produces HVO from tall oil at its Lappeenranta biorefinery, announced plans to carry out an environmental impact assessment as the first stage of developing a new Finnish plant that would use a wider range of biomass raw materials to produce 500,000 tonnes of renewable diesel fuel.[136]

The US Renewable Energy Group, which has 14 production sites in the United States and Germany, announced plans in 2017 to increase the capacity at its Geismar, Louisiana plant by 178 million litres (47 million gallons) per year.[137] Valero Energy Corporation and Darling Ingredients Inc. (both United States) are expanding their Diamond Green Diesel production facility in Norco, Louisiana from 605 million litres to 1,040 million litres (160 million gallons to 275 million gallons) of renewable diesel annually, and announced plans in 2017 to further increase capacity to 2,080 million litres (550 million gallons).[138]

The emerging cellulosic ethanol industry saw mixed progress in 2017, with large-scale production growing but remaining limited to only a small number of facilities. The volume of cellulosic ethanol that qualified under the US RFS increased by a factor greater than 2.5 in 2017; however, production still reached only some 38 million litres.[139] Two commercial-scale flagship plants closed in 2017: after the merger of DuPont and Dow (both United States), the plant producing ethanol from corn stover in the US state of Nevada was mothballed, and the Chemtex plant in Crescentino, Italy was closed following the failure of the parent company Gruppo Mossi Ghisolfi (Italy).[140]

Elsewhere, production increased at a number of existing plants including Brazil's Raizen plant, which was expected to double its production to 14 million litres of cellulosic ethanol in 2017, and at the country's Granbio plant.[141] Poet-DSM (United States) announced that the critical pre-treatment phase of its Liberty plant in Emmetsburg, Iowa, which produces ethanol from corn residues, was operating successfully, opening the way to sustained production.[142] The integrated production of ethanol from cellulosic residues such as corn kernels in conventional corn ethanol plants in the United States is expanding. Five plants, with a total capacity of nearly 2 billion litres (500 million gallons) and based on technology developed by Edeniq (United States), were approved by the US EPA in 2017.[143]

In Europe, Borregaard (Norway) produced some 20 million litres of cellulosic ethanol in 2017 – along with a range of other products – at its biorefinery in Norway.[144] A number of new plants also were announced in 2017, including an investment in a plant by Clariant (Switzerland) that will produce 50,000 tonnes of cellulosic

i Tall oil is a mixture of compounds found in pine trees and is obtained as a byproduct of the pulp and paper industry.

China

overtook the United States in 2017 as the world's largest producer of bioelectricity

ethanol in south-western Romania.[145] Clariant also licensed its technology to Enviral (Slovak Republic), which plans to build a 50,000 tonne per year plant in the Slovak city of Leopoldov.[146]

India's Ministry of Petroleum and Natural Gas announced plans to build at least 12 commercial-scale advanced biofuel plants – mainly to produce cellulosic ethanol from the large volumes of plant residues in the country – in order to help reduce fossil fuel import dependency, reduce pollution from in-field burning of crop residues, and improve energy security and independence.[147] Plans are progressing to build these plants based on Indian and international expertise. For example, Bharat Petroleum Company selected Praj Industries (both India), which opened a large-scale cellulosic ethanol plant in 2017, to build a 37 million litre per year facility in Bargarh in the state of Odisha, using biomass feedstock sourced from the local farming community.[148]

Commercialisation of thermal processes such as pyrolysis and gasification also advanced in 2017. Enerkem (Canada) adapted its commercial-scale gasification plant in Edmonton, Alberta, which processes 300 tonnes per day of sorted municipal wastes, to produce ethanol instead of methanol, and the fuel qualifies for use as cellulosic ethanol under the US RFS.[149] Additional plants based on this technology are under development in the Netherlands, where Enerkam, along with Air Liquide (France), AkzoNobel (Netherlands) and the Port Authority, agreed to provide initial funding to develop a project in Rotterdam; and in China, where the Sinobioway Group (China) has provided an equity stake in a joint venture company that aims to develop the Chinese market for this technology.[150] In addition, Ensyn (Canada) has been successfully providing fuels from its Ontario-based pyrolysis plant to US customers, qualifying under the US RFS2 programme.[151]

In Norway, a first-of-its-kind demonstration plant is being developed based on hydro liquefaction technology, which subjects solid biomass to high temperatures and pressures. The clean fuel company Steeper Energy (Denmark and Canada) will license its proprietary Hydrofaction technology to Silva Green Fuel, a Norwegian-Swedish joint venture. With an investment of USD 76.8 million, the plant will use wood wastes and produce a hydrocarbon product that can be converted to renewable diesel or jet fuel.[152] Licella (Australia) is in a joint venture with the forestry company Canfor (Canada) to produce and upgrade bio-crude produced by a hydrothermal liquefaction process in the Canadian province of British Columbia, and has announced plans to build a plant in Australia.[153]

Although the use of biofuels in aviation is seen as a long-term priority, the quantity of biofuels used in aviation is still a very small fraction of total fuel use in the sector.[154] In 2017, a number of airlines and airports made progress in using biofuels for long-haul flights, securing appropriate fuels and making biofuels available at key airports. Virgin Australia procured aviation fuels from Gevo (United States), and Chicago's O'Hare airport also used fuel from Gevo to supply biofuel for eight airlines using the airport for a trial period.[155] Qantas signed a long-term supply contract with Agrisoma (France) to supply fuels based on carinata oil seed, and carried out a trans-Pacific flight from Los Angeles to Melbourne using a 10% blend of carinata-based biofuels.[156] China's Hainan Airlines also made a trans-Pacific flight from Beijing to Chicago using biofuel derived from waste cooking oil.[157]

Interest in the use of biofuels in marine applications increased in 2017, pushed by the short-term requirement to reduce sulphur emissions from ships in coastal regions, as well as by longer-term carbon targets.[158] Several projects aim to demonstrate the use of biofuels in the marine sector. For example, GoodFuels (Netherlands) collaborated with the Dutch Coast Guard to supply biofuels for use in its ships, and collaborated with Heineken and Nedcargo (both Netherlands) to demonstrate the use of biofuels on inland waterways, transporting beer from a brewery in Zouterwoude to Rotterdam.[159] Following initiatives by the US Navy – the Great Green Fleet – the Australian navy has been trialling biofuels in its fleet (particularly to facilitate joint US/Australian operations).[160]

Biofuels also are being used increasingly as a fuel in rail transport. In the Netherlands, Arriva (Netherlands) is supplying 18 new trains fuelled with biodiesel that are being brought into service.[161] Indian Railways is experimenting with the use of biodiesel, compressed biogas and ethanol on its networks.[162]

Gaseous Biomass Industry

Biogas (a mixture principally consisting of methane and carbon dioxide, CO_2) can be produced by the anaerobic digestion of a range of biological materials including the organic fraction in MSW, food wastes, sewage, animal manures, liquid industrial effluents and crops grown specifically to be digested. Biogas also is produced as waste decays in landfill sites (landfill gas) and can be collected for fuel use, thereby reducing emissions of methane, a potent greenhouse gas that can be a safety hazard as well.

Biogas also can be upgraded to biomethane by removing the CO_2 and other gases, enabling its use more easily in transport and for injection into natural gas pipelines. Biomethane production has been growing, but different end-uses are favoured in different countries.[163] For example, in the United States and Sweden biomethane is produced mainly for transport applications, but in the United Kingdom it is used mostly as a pipeline gas.

In the United States, biogas is produced mainly from landfill gas for use in power generation.[164] However, a growing trend is to upgrade the gas to biomethane for use in transport, where it qualifies as an advanced biofuel. Although this sector grew some 15% in 2017, this is a significant slowdown from the six-fold increase between 2014 and 2016.[165]

Biogas production in Europe is focused mainly on the anaerobic digestion of agricultural wastes (including animal manures) and, increasingly, on the digestion of recovered food wastes (for example, in Sweden and the United Kingdom).[166] More than 500 biomethane facilities now exist in Europe.[167] However, progress in some markets (such as the United Kingdom) has slowed because of regulatory changes affecting tariffs available for electricity, heat and biomethane production. Biogas production also is seen as an important tool to reduce corporate carbon footprints. For example, the Swedish beer manufacturer Carlsberg converted its brewery in Falkenerg, Sweden to 100% biogas in 2017.[168]

In India, in addition to 4.9 million small-scale biogas digesters used for household energy production *(→ see Distributed Renewables chapter)*, biogas production increasingly is seen as a constructive way to deal with municipal and food wastes and agricultural residues. Capacity for large-scale biogas production in India increased to 300 MW by the end of 2017.[169] In a project developed in Palava City, Mumbai in 2017, the gas produced from the digestion of MSW is cleaned and used for power generation, and the facility also produces bio-fertiliser.[170]

Although small-scale biogas digesters are being deployed around the world, the production and use of biogas at the medium and larger scales in other regions is not well developed. However, significant potential exists – for example, from agricultural residue, manure and vinasse[i] residue from sugar ethanol production in Brazil – and some larger-scale plants started operating in 2017.[171] In Durazno, Uruguay the agricultural company EDL began expanding its digester plant to produce up to 8 MW of electricity from cattle manure feedstock at a facility that produces dried milk.[172] Kenya's Olivado plant, which produces oil from avocados, is installing a biogas system that will reduce its waste streams and make the plant self-sufficient in energy, producing 1.5 GWh annually.[173]

Bioenergy with Carbon Capture and Storage or Use

Many low-carbon scenarios depend on the capture and storage of carbon dioxide produced when bioenergy is used to produce heat, electricity or transport fuels.[174] Removal from the atmosphere of such CO_2 is seen as having a double benefit that leads to "negative emissions". Although interest in such options is increasing, in the absence of strong policy drivers that might make such projects economic and socially acceptable, only a very limited number of large-scale projects are demonstrating this technology.[175] The option of producing biochar[ii] alongside bioenergy production is also being investigated as a means to sequester carbon.[176]

In 2017, operations started at the Illinois Industrial CCS Project, owned and operated by Archer Daniels Midlands and the first large-scale project to combine carbon capture and storage with a bioenergy feedstock. The Decatur, Illinois project will capture 1 million tonnes of CO_2 annually from the distillation of corn into ethanol.[177] The CO_2 will be compressed and dehydrated, then injected on-site for permanent storage at a depth of some 2.1 kilometres.[178]

Also being studied is the feasibility of capturing and storing the CO_2 produced at an existing municipal waste incinerator in Oslo, Norway, where the waste heat produced is used for district heating.[179] More than 400,000 tonnes of CO_2 could be captured and stored in the offshore carbon storage facilities under development.[180]

A further possibility is to recycle the carbon captured from bioenergy production via chemical or biological processes to form fuels or chemicals, using hydrogen from sustainable low-carbon sources, such as from the electrolysis of water using renewable electricity (bioenergy with carbon capture and use, or BECCU). These options do not have "negative emissions" because the CO_2 is released when the produced fuels are used.[181] Although few large-scale projects exist that use CO_2 from bioenergy processes in this way, a number of examples have emerged in Belgium, Germany, Iceland and India where CO_2 from non-bioenergy sources is being recovered and used to make hydrocarbon fuels.[182] While such processes do not produce biofuels, the products also reduce carbon emissions and can be an important way to demonstrate the technology that will be needed for BECCU projects and to improve the overall efficiency with which biomass can be used.[183]

i Vinasse is an organic residue left after distillation to produce ethanol.

ii Biochar is defined here as charcoal produced intentionally from wood in order to sequester carbon. Biochar may be used as a soil conditioner.

GEOTHERMAL POWER AND HEAT

GEOTHERMAL MARKETS

Geothermal resources provide electricity and thermal energy services (process heat, space heating and cooling). Total useful energy in 2017 was an estimated 613 PJ[i] (or 170 TWh), with electricity and thermal output each providing approximately equal shares.[1] However, estimates of thermal energy consumption (also known as "direct use") are somewhat uncertain due to lack of data. Some geothermal plants produce both electricity and thermal output for various heat applications.

An estimated 0.7 GW[ii] of new *geothermal power* generating capacity came online in 2017, bringing the global total to an estimated 12.8 GW.[2] Indonesia and Turkey both continued to lead for new installations and accounted for three-quarters of the new capacity during the year.[3] Other countries adding capacity (in order of scale) were Chile, Iceland, Honduras, Mexico, the United States, Japan, Portugal and Hungary.[4] *(→ See Figure 20.)*

The countries with the largest amounts of geothermal power generating capacity at the end of 2017 were the United States, the Philippines, Indonesia, Turkey, New Zealand, Mexico, Italy, Iceland, Kenya and Japan.[5] *(→ See Figure 21.)*

Indonesia had another good year, adding about 275 MW of new capacity and ending 2017 with 1.8 GW.[6] After decades of development, commercial operations started at the first two of three 110 MW sections of the Sarulla plant. The plant is the country's first geothermal combined-cycle[iii] unit.[7] Indonesia also placed into operation the fourth and last unit of the 220 MW Ulubelu plant, which by year's end met 25% of electricity demand in the Lampung region of southern Sumatra.[8] Geothermal power supplies about 5% of Indonesia's electricity.[9]

Turkey's net additions were at least 243 MW, for a total of 1.1 GW.[10] The country's largest single installation ever was the first unit of Kizildere III, commissioned in 2017 with a capacity of 99.5 MW.[11] Upon completion in early 2018, the plant became Turkey's largest geothermal power plant (165 MW).[12] The country's last geothermal plant to come online in 2017 was the 33 MW Melih binary-cycle[iv] plant.[13]

Turkey has developed most of its geothermal capacity in just five years, with more than 800 MW added between 2013 and 2017.[14] Strong growth in the Turkish geothermal sector has been attributed to supporting policies enacted more than a decade ago.[15] Turkey met 2.1% of its electricity demand in 2017 with geothermal power.[16] At year's end, Turkey had an additional 271 MW under construction and a further 527 MW under development.[17]

Chile ranked third globally for new capacity installations during the year. The country's 48 MW Cerro Pabellón is reportedly the first geothermal power plant commissioned in South America; it is located in the Atacama Desert at a record (for geothermal facilities) altitude of 4,500 metres above sea level. As is the case for several

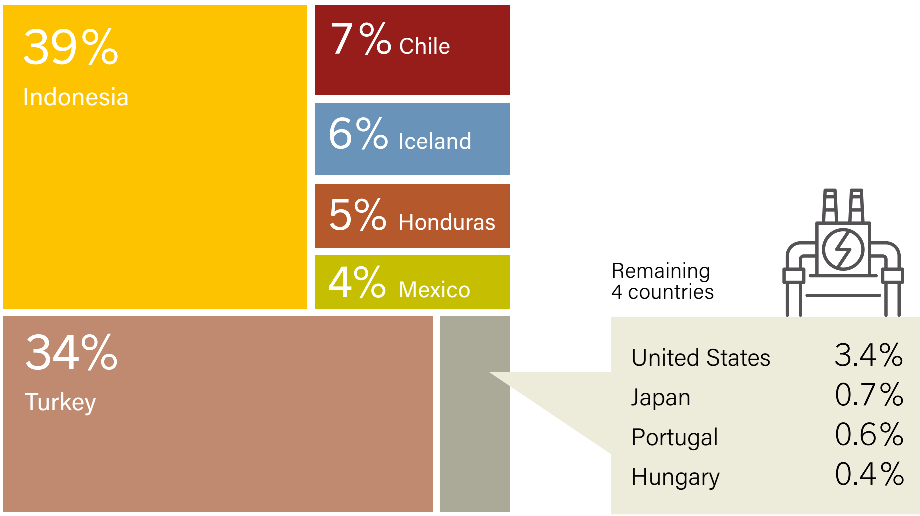
i This does not include the renewable final energy output of ground-source heat pumps. *(→ See Integration chapter.)*

ii In this section, units MW and GW refer to electric power capacity, and MW_{th} and GW_{th} refer to thermal capacity.

iii 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.

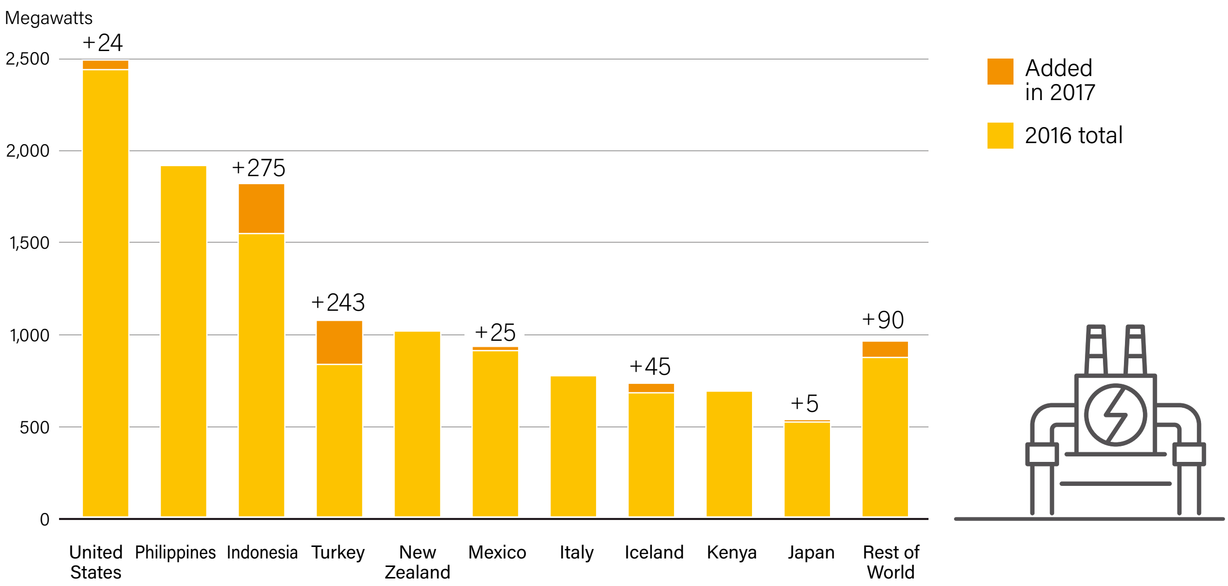
iv In a binary plant, the geothermal fluid heats and vaporises a separate working fluid that has a lower boiling point than water; the fluid drives a turbine to generate electricity. Each fluid cycle is closed, and the geothermal fluid is re-injected into the heat reservoir. The binary cycle allows an 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.

FIGURE 20. Geothermal Power Capacity Global Additions, Share by Country, 2017



Source: See endnote 4 for this section.

FIGURE 21. Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2017



Source: See endnote 5 for this section.

projects completed in 2017, the plant's two units utilise a binary cycle, where the geothermal fluid is reinjected into the reservoir in a closed loop while a separate working fluid drives the turbines.[18]

Two plants came online in Central America in 2017, including the first geothermal plant to be built in Honduras. The realisation of the 35 MW Platanares facility was aided by 2007 legislation to promote renewable electricity generation, which grants the plant a 10-year income tax exemption.[19]

Mexico saw the completion of another 25 MW$_{net}$[i] unit at the Los Humeros complex, bringing the country's total installed operational capacity to 916 MW.[20] As of 2017, Mexico had 224 production wells across five separate geothermal fields, which met 1.7% (5.9 TWh) of the country's electricity needs during the year.[21]

In Iceland, the first (45 MW) of two stages of the 90 MW Þeistareykir geothermal power plant came online during the year, with a second turbine expected to be completed in 2018.[22] A total of 18 production wells were drilled to supply enough steam for the equivalent of 100 MW of power capacity.[23] Iceland derives over 27% of its electricity from geothermal sources, with some 710 MW of geothermal power capacity, some of which provides thermal co-generation for district water and space heating (see below).[24]

Japan saw the start of the 5 MW Takigami binary plant in 2017, bringing total capacity to 527 MW.[25] Despite its significant resource potential, development of geothermal energy in Japan has been tempered by concerns about safety and potential unintended economic and environmental consequences, including its possible adverse effects on hot springs.[26] The focus of geothermal development is on relatively small projects, which are supported by a favourable feed-in tariff and by exemption from environmental impact assessments for plants smaller than 7.5 MW.[27]

The United States is the global leader for installed geothermal power capacity, but expansion remains slow. One 24 MW unit – the Tungsten Mountain plant in Nevada – came online, and two 30 MW units were retired.[28] Total capacity was around 2.5 GW$_{net}$ at year's end, and geothermal power generated about 16 TWh during the year, accounting for 0.4% of US net generation.[29]

The Tungsten Mountain plant utilises a new turbine design that allows the use of a single energy converter in place of two. This design reduces capital expenditure per unit of power and is expected to curtail operating costs significantly, while also increasing both efficiency and unit availability.[30] The project also is notable for its innovative use of directional drilling to achieve sufficient permeability[ii]; this was instrumental in the ultimate success of the project.[31] The fact that this was the only plant to come online in the United States, following a year with no capacity additions, has been attributed in part to low natural gas prices as well as to the perennial challenges of geothermal development: long project lead-times, high development costs and associated economic risk.[32]

The Philippines is second only to the United States for total geothermal power capacity in operation (1.9 GW).[33] Much like the United States, however, the country has not seen significant geothermal expansion in recent years. No new capacity came online in 2017, but in early 2018 the country completed its first new geothermal capacity since 2014, the 12 MW Maibarara-2 extension.[34]

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).

ii A viable geothermal system requires a combination of three characteristics: sufficient heat, water and flow (the last made possible by relative permeability of the sub-surface rock).

Geothermal

direct use increased by an estimated 1.4 GW_{th} of capacity in 2017

Around the world, a handful of other plants came into service in 2017. These include the 4 MW Pico Alto binary plant on the Portuguese island of Terceira, in the Azores, which meets 10% of electricity demand for the island's 56,000 inhabitants, and Hungary's first geothermal heat and power plant (Turawell), which combines 3 MW of power capacity with 7 megawatts-thermal (MW_{th}) of thermal output.[35]

Elsewhere, plans were in progress during 2017 to develop additional capacity. Several volcanic islands in the Caribbean, struggling with some of the world's highest electricity prices, are eager to displace costly fossil fuel imports with local geothermal energy. In late 2017, the EU provided EUR 12 million (USD 14.4 million) in grant funding to support geothermal development in the Eastern Caribbean.[36] Exploratory drilling on the island of Nevis was under way in late 2017.[37]

In China, the central government plans to increase the use of geothermal energy in cities to reduce local air pollution and greenhouse gas emissions.[38] As of 2015 (latest data available), China had less than 30 MW of geothermal power capacity, mostly in Tibet, but the country's 13th Five-Year Plan for geothermal energy calls for an additional 500 MW by 2020.[39]

Geothermal direct use – direct thermal extraction for heating and cooling[i] – increased by an estimated 1.4 GW_{th} of capacity in 2017, for an estimated global total of 25 GW_{th}.[40] Direct use capacity has grown by an annual average of 6% in recent years, while direct heat consumption has grown by an annual average of 3.5%.[41] The difference is explained in part by relatively rapid growth in geothermal space heating, which exhibits below-average capacity utilisation.[42]

Space heating (including via district heat networks) is one of the largest and fastest growing sectors for direct use of geothermal heat, although swimming pools and other public baths may still be the largest single-application category.[43] These two broad markets – space heating and pools – command around 80% of both direct use capacity and consumption.[44] The remaining 20% is for applications that include domestic hot water supply, greenhouse heating, industrial process heat, aquaculture, snow melting and agricultural drying.[45]

China is the most significant user of direct geothermal heat.[46] Other top users of direct geothermal heat (in order of scale) are Turkey, Iceland, Japan, Hungary, the United States and New Zealand, which, together with China, accounted for approximately 76% of direct geothermal use in 2015.[47] The ranking of top countries for capacity differs slightly (and includes India and Italy) due to differences in applications and capacity utilisation.[48]

During 2017, geothermal direct use capacity was added in several locations across Europe and in China. Developments in other markets are less clear due to lack of consolidated data. European countries completed 10 new or renovated geothermal district heating plants in 2017. France accounted for six of these; two were completed in the Netherlands and one each in Italy and Romania.[49]

For decades, geothermal district systems in the Paris metropolitan area have utilised the heat of the Dogger aquifer, which lies at a depth of about 2,000 metres. At least four district heat systems in the area expanded their geothermal capabilities during 2017. The 32-year-old network of Chevilly-L'Haÿ-Villejuif opened a new production plant that boosted the geothermal share of the system to 70%.[50] The communities of Dammarie-les-Lys and Trempley-en-France also added additional geothermal heat to existing district heat systems, and the City of Cachan replaced 34-year-old wells with two new bores.[51] The latter used an innovative process, drilling horizontally into the aquifer below the surface.[52]

Development of geothermal for heat also continued in China, including expansion in the Xiongan New Area (Hebei province), which was said to have increased geothermal and other renewable heating by 10 million m^2 in 2017[ii,53] China's central government targets a significant increase in the sustainable use of geothermal resources to reduce air pollution while also protecting water resources. Under the 13th Five-Year Plan, China aims to increase direct use of geothermal heat five-fold by 2020.[54] In late 2017, the government specified a target equivalent to 70 million tonnes of coal by 2020, of which 40 million tonnes of coal equivalent would be for heating purposes (and the remainder presumably for electricity generation).[55]

Territories bordering the Arctic Circle have never been major sources of fresh vegetables, but in 2017 Iceland was finalising plans to start the export of produce to continental Europe, grown with the aid of heat and lighting sourced from geothermal energy.[56]

GEOTHERMAL INDUSTRY

The geothermal industry in 2017 remained constrained by various sector-specific challenges, such as long project lead-times and high resource risk, but technology innovation continued and prompted optimism about future prospects. The industry focused on advancing technologies to reduce development risk and to cost-effectively tap geothermal resources for heat and power in more locations, as well as to reduce the potential environmental consequences of geothermal energy production.

Among the various renewable energy technologies, geothermal energy is not unique in having to contend with high upfront project costs. However, the inherent high risk of geothermal exploration and project development, and the lack of adequate risk mitigation, continues to be a focus of attention for the industry.[57] The uncertainty about the geothermal resource in any given location often stands in the way of mobilising enough capital, especially private capital, to fund the expensive exploratory drilling that must occur at the outset to establish the size, temperature and other parameters that define the viability of a resource.[58]

i Direct use refers here to deep geothermal resources, irrespective of scale, as distinct from shallow geothermal resource utilisation, specifically ground-source heat pumps. (→ See Heat Pumps section in Integration chapter.)

ii The source for the expansion in renewable heating in China expresses the change in terms of floor area of heated space rather than units of energy.

New methods of resource exploration and extraction are helping to overcome some of the economic and technical challenges that otherwise stand in the way of further development. Continuing technology innovation, particularly in the United States and Europe, has raised the prospect of exploration and development of geothermal resources that previously were out of reach, even in areas with an average or low geothermal gradient, by reaching deeper into the earth and by better means of heat extraction.[59]

Work also continued in 2017 on the development of resource mapping tools to reduce the cost and economic risk inherent to the pursuit of sufficient temperature and water flow to generate electricity[i]. The US government committed USD 5 million to advance the development of a mapping tool that aims to better predict the presence of viable geothermal resources.[60]

In the United States, what is referred to as deep direct-use (DDU) is an emerging research area that envisions the use of relatively low-temperature geothermal heat, attained at great depth, to meet moderate thermal demand in regions that are not rich in conventional hydrothermal resources.[61] In 2017, the US Department of Energy provided funding for six DDU research projects to conduct feasibility studies of low-temperature deep-well geothermal systems, highlighting DDU as a potentially efficient and cost-effective alternative to high-temperature electricity generation and to fuel combustion for space heating and cooling.[62]

US government-funded research also continued to focus on enhanced (or engineered) geothermal systems (EGS) with multiple national labs and universities engaged in a collaborative effort to advance the technology. The ultimate objective is to make geothermal energy utilisation more geographically diverse, thereby allowing the resource to be a major contributor to domestic energy supply.[63] EGS involves fracturing the sub-surface rock formations to enhance permeability and flow to form a geothermal reservoir that is productive enough to be viable.[64]

In Europe, ongoing technological advancement in deep geothermal extraction is believed to offer great potential for district heating applications as well as for power production because the region's increasingly efficient building stock can be heated at relatively low supply temperatures (40° C or less for new efficient buildings).[65] In addition, low-temperature (binary) conversion technologies further improve the viability of (low-temperature) deep geothermal sources for combined heat and electricity production in more locations.[66]

Emissions mitigation technologies also continued to receive attention in 2017. Carbon dioxide (CO_2) and hydrogen sulphide (H_2S) are unwelcome by-products of conventional open-loop[ii] geothermal energy extraction. While CO_2 emission rates from geothermal plants are generally small compared to fossil fuel plants, in some instances they can be significant and even exceed those of coal-fired power plants.[67] The recognition of very significant CO_2 emissions from Turkey's geothermal plants has prompted efforts to assess technical challenges and opportunities related to the capture and reinjection of those emissions.[68]

Iceland's CarbFix project has made headway in tackling CO_2 emissions, demonstrating that more than 95% of injected CO_2 can be bound as carbonate minerals within a period of two years, depending on local geology.[69] Building on these advances, Swiss company Climeworks partnered with the Icelandic geothermal company Reykjavik Energy to combine direct-air capture of CO_2 with the geological CO_2 sequestration technology used in the CarbFix project in Iceland. The aim is to provide carbon removal capabilities to offset unavoidable CO_2 emissions, irrespective of their source.[70]

Research continues to show promise for sequestration of H_2S as well. Up to 62% of H_2S injected in basaltic rock solidifies (mineralises), provided that the rate of injection and solution acidity and temperature remain within ideal parameters. H_2S reinjection and sequestration in geothermal systems is considered a technically feasible option that is more economical than alternatives commonly used in the industry.[71]

There also is growing interest in producing geothermal energy from abandoned oil and gas wells or from abandoned mines to mitigate incremental drilling costs, which are a significant portion of the total cost of any geothermal project.[72] In the United Kingdom, researchers investigated in 2017 the possibility of heating homes with flood waters found in abandoned coal mines; while not a new idea, it has potential applications in regions with a long history of mining operations near cities and towns.[73] In oil-rich Alberta, Canada, a study was launched during the year to ascertain the economic feasibility of tapping the thermal energy found in oil wells for space heating and to spur new industry, inspired by examples in the United States.[74]

Geothermal brine can contain relatively high penetrations of rare earth minerals and metals, and the recovery of these materials could add value to geothermal resource extraction.[75] With US state and federal funding, SRI International (United States) is developing technology to recover the valuable metal lithium from geothermal brines, with the rate of recovery exceeding 90%.[76] In 2017, some companies in Canada announced the development of a filtration method to separate metals and minerals, including lithium, from geothermal brine. A reported advantage of this low-energy technology is that it does not require a reduction in brine temperature to work effectively.[77]

Some partnerships and mergers took place in 2017 among geothermal energy technology- and project developers. Ormat Technologies (United States) acquired geothermal plant operator and developer U.S. Geothermal Inc., along with its 45 MW of capacity in the western United States, as well as Viridity Energy Inc., a demand-response, energy management and storage operator.[78] Technology providers Atlas Copco (Sweden) and Egesim (Turkish subsidiary of Siemens) announced a partnership to provide joint geothermal power plant solutions in Turkey.[79]

i A hydrothermal resource must offer a combination of sufficient heat and water flow to generate enough steam to be economically viable for electricity generation.

ii 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

Global additions to hydropower capacity in 2017 were an estimated 19 GW, bringing total capacity to approximately 1,114 GW[i,1] While significant, this is the smallest annual increment seen over the last five years.[2] The leading countries for cumulative capacity – China, Brazil, Canada, the United States, the Russian Federation, India and Norway – remained the same as in the past several years, and together they represented about 63% of installed capacity at year's end.[3] *(→ See Figure 22 and* ***Reference Table R17.****)* Generation from hydropower, which varies annually with hydrological conditions[ii], was an estimated 4,185 TWh worldwide in 2017, up about 2% over 2016.[4] Global pumped storage capacity (which is counted separately) increased about 2% in 2017.[5]

China remained the perennial leader in commissioning new hydropower capacity, accounting for nearly 40% of new installations in 2017, and was followed by Brazil, India, Angola and Turkey. Other countries that added significant capacity included Iran, Vietnam, the Russian Federation and Sudan.[6] *(→ See Figure 23.)* China also led for installations of pumped storage capability during the year, followed by Switzerland and Portugal.[7]

China added 7.3 GW of hydropower capacity in 2017 (excluding pumped storage), for a year-end total of 312.7 GW.[8] The projects completed in 2017 represented investment of CNY 61.8 billion (USD 9.8 billion), which was virtually identical to the previous year.[9] Hydropower generation during the year, at 1,190 TWh, was up marginally from 2016.[10] Pumped storage capacity grew by 1.8 GW to 28.5 GW, and a further 39 GW was under construction at year's end.[11] China's development plans reflect the potential value of pumped storage in alleviating the country's curtailment of wind power and solar PV generation.[12]

Global additions to **hydropower** capacity in 2017 were an estimated 19 GW

Hydropower development remained relatively strong across the rest of Asia as well. Vietnam completed the 260 MW Trung Son plant, which is intended to provide flood protection and irrigation needs as well as to generate electricity to promote local economic development. The project was designed to minimise social and environmental impacts and is Vietnam's first large-scale hydropower project to receive funding from the World Bank.[13]

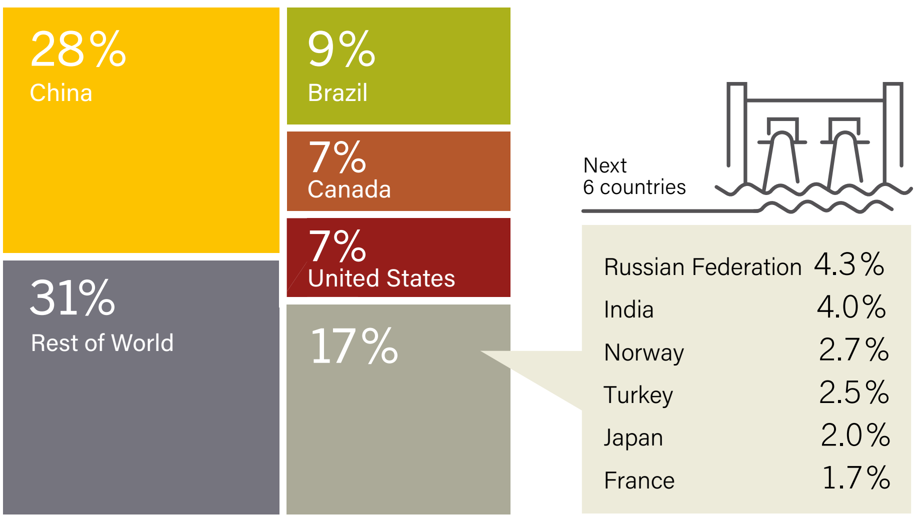
India brought into commercial operation 1.9 GW of new hydropower capacity in 2017, for a year-end total of 44.6 GW.[14] The bulk of the additional capacity came from a 1.2 GW project on the Teesta River, which was completed several years behind schedule.[15] Due to additional delays in completing associated transmission infrastructure, the plant's output was severely restricted in its first year of operation.[16]

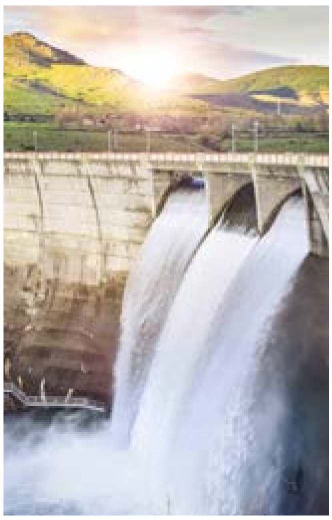
Nearly half (6.3 GW) of all large-scale hydropower projects in India were facing delays or other challenges as of early 2017.[17] Generation was 136 TWh for the year, an increase of 5.6% over 2016.[18]

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 use of storage capacity (reservoirs) to balance variable renewable electricity generation and for managing water supply, as well as market conditions, such as the price of competing sources of energy.

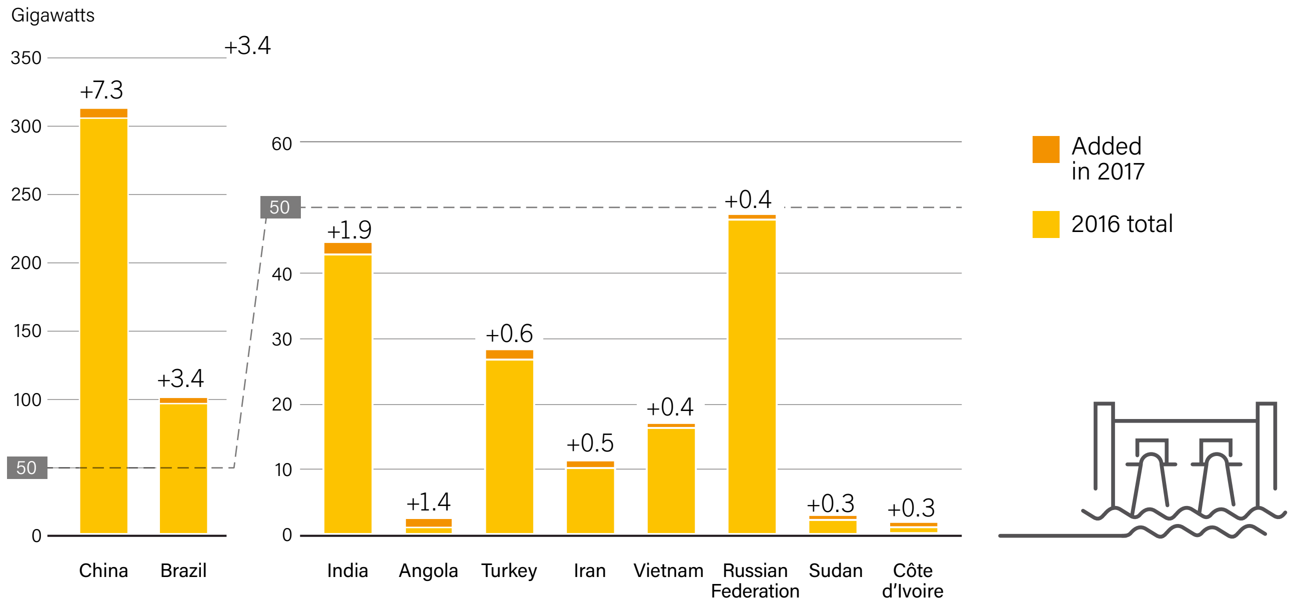
FIGURE 22. Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2017





Source: See endnote 3 for this section.

FIGURE 23. Hydropower Capacity and Additions, Top 10 Countries for Capacity Added, 2017



Source: See endnote 6 for this section.

Pakistan's new 147 MW Patrind hydropower plant takes advantage of the natural difference in elevation between the Kunhar and Jhelum rivers by connecting them with a 2.2 kilometre tunnel, some 8 kilometres above their confluence. The high natural sediment load from the Himalayan headwaters is expected to pose challenges to the project and will be managed with a bypass tunnel. The project, owned by interests in the Republic of Korea, received certified emissions reduction credits under the Clean Development Mechanism (CDM), in line with Korean efforts to promote CDM projects abroad.[19] Pakistan also made progress on some smaller installations, such as the 7.6 MW Marala plant and the 2.6 MW Machai project.[20]

Farther to the west, the 450 MW Rudbar project was completed in Iran, in line with national efforts to reduce electricity generation from fossil fuels and to reduce harmful emissions. The project added to the country's existing hydropower capacity of more than 10 GW.[21] It was funded largely by Chinese interests that expressed a desire to intensify such industrial co-operation with Iran in accordance with China's "Belt and Road" initiative.[22] Iran also commissioned the first of three 70 MW units at the Darian plant.[23]

Turkey expanded its hydropower capacity by 0.6 GW in 2017, bringing total installed capacity to 27.3 GW.[24] Even so, hydropower generation in Turkey contracted 12.7% during 2017, to 58.5 TWh, due to severe drought.[25]

Brazil remains the largest hydropower producer in South America and ranked second globally for new installations in 2017. Approximately 3.4 GW was added for a year-end total of 100.3 GW.[26] The 3.6 GW Santo Antônio run-of-river[i] plant was completed in early 2017, with the last five of 50 bulb[ii] turbines placed in service.[27] Construction of the 11.2 GW Belo Monte plant continued to advance (4.5 GW completed at year-end), with four of the larger 611 MW turbines along with two smaller units installed during the year.[28] The project has faced setbacks due to its alleged impacts on local communities and, in 2017, to a revocation of its operating licence, pending action to address the developer's failure to satisfy project requirements.[29] Nonetheless, it is expected that Belo Monte will be completed by 2019.[30]

Following some improvement in 2016, Brazil's hydropower output was down 3.8% in 2017, to 401 TWh (accounting for 70% of total generation), due to drought in parts of the country and to low reservoir levels.[31] The decline in output prompted a national surcharge on electricity rates late in the year and an increase in electricity imports from neighbouring countries.[32]

Other developments in South America included the completion of Bolivia's largest hydropower plant to date: the multipurpose 120 MW Misicuni plant.[33] The plant represents 7% of the country's power capacity, and its reservoir will serve to improve local municipal water supply.[34] Peru expanded its hydropower portfolio with three run-of-river projects of less than 20 MW each, following the completion of two large projects in 2016 (totalling about 1 GW).[35] Colombia completed eight units of less than 20 MW each, for a total of 11.7 GW in operation.[36]

In Africa, Angola made significant progress on two large hydropower plants. The Laúca project saw two of its 334 MW turbines come online, with the remainder of the 2.1 GW plant expected to be completed in 2018.[37] In addition, the recently

i "Run-of-river" projects generate electricity at the rate of natural (and variable) river flows, while projects incorporating reservoirs store water to compensate for variability in flow, to increase "head" (difference in elevation) for greater power, and possibly for reasons such as flood control, irrigation, general water supply and drought mitigation. Some run-of-river projects do incorporate dams that provide some minimal storage capacity and flexibility of operation but that may be insufficient to provide flood control and some other water management services.

ii A bulb turbine is a sealed unit that encapsulates both the turbine and generator and is placed directly in the water stream. See US Department of Energy, "Types of hydropower turbines", https://www.energy.gov/eere/water/types-hydropower-turbines, viewed April 2018.

renovated Camcambe plant was expanded by 700 MW.[38] These projects are part of a concerted effort to increase electrification to 60% by 2025.[39] Only 35% of the Angolan population had access to electricity in 2016, and many people relied on diesel generators.[40]

As part of an effort to double its generating capacity by 2020 (from the current capacity of about 2 GW), Côte d'Ivoire in 2017 inaugurated its largest hydropower project, the 275 MW Soubré.[41] The country plans to improve its electrification rate (63% in 2016) while increasing the share of hydropower and other renewables in its electricity mix, which is dominated by natural gas.[42]

Sudan inaugurated its 320 MW Upper Atbara and Setit Dam project in 2017, increasing the country's installed capacity by 13%.[43] The project is linked to an agreement that allows Saudi Arabia to cultivate land in the vicinity of the dams.[44] Meanwhile, thousands of displaced local families have complained about the government's lack of commitment to compensate them for farmland lost to the project.[45]

Tensions in the region persisted between Ethiopia and its downstream neighbours Sudan and Egypt over the feared impacts of Ethiopia's Grand Renaissance Dam (6 GW) on water flows in the Nile.[46] The dam for the project, which was 60% complete and ready to start storing water as of early 2018, has raised concerns about restricted sediment flow, which could potentially exacerbate relative sea-level rise in the Nile delta.[47]

The United States continued to rank third globally for installed hydropower capacity, but recent expansion has been relatively modest, with a net five-year growth of 1.7% (1.3 GW) through 2017.[48] The country added a net of 145 MW in 2017, for a year-end total of 80 GW.[49] Following years of suppressed output due to drought in the southwestern United States, generation improved for the second consecutive year, rising 12% relative to 2016 to 300 TWh.[50] Improvement was noted in all parts of the country, but particularly in the state of California.[51] To the north, Canada saw the completion in British Columbia of two run-of-river facilities (25 MW and 81 MW), which comprise the Upper Lillooet River Hydro Project.[52]

The Russian Federation has long been among the top countries for hydropower capacity, and has seen a net five-year growth in installed capacity of 5.4% (2.5 GW).[53] During 2017, the country's stated hydropower capacity increased by 364 MW for a total of 48.4 GW.[54] Most of that added capacity was tied to the inauguration of the 320 MW Nizhne-Bureyskaya hydropower plant in the Russian Far East, where a majority of the country's projects under construction are located. Following a flood in the Amur River basin in 2013, the design of the plant was modified for improved flood control.[55] Overall hydropower generation (179 TWh) in the Russian Federation was stable relative to 2016.[56] However, reservoir levels declined in some regions, such as the Far East, resulting in increased utilisation of thermal power plants in 2017.[57]

Energy storage capability of hydropower facilities has long been a critical component of modern energy infrastructure, supporting reliability and efficiency of energy systems. Hydropower reservoirs can (passively) store energy by reducing output when other sources are plentiful, which allows natural flows to raise the energy potential in the reservoir, thereby achieving effective storage. Conversely, pumped storage can directly absorb surplus power off the grid.[58]

Growing penetration of variable renewable energy (VRE) is increasing interest in additional electricity storage capacity.[59] Pumped storage hydropower is the dominant source of large-scale energy storage, accounting for an estimated 96% of global energy storage capacity.[60] *(→ See Integration chapter.)* Global pumped storage capacity rose by more than 3 GW in 2017, for a year-end total of an estimated 153 GW[i].[61] New capacity was installed in China, Portugal and Switzerland.[62]

Two large pumped storage plants were completed in China. The five remaining reversible turbine generators of the Liyang facility were operational by the end of 2017 (one unit came online in

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. The total global pumping capability in 2017, including mixed plants, may be as high as 164 GW, with pure pumped storage portion of that total being 119 GW, from International Renewable Energy Agency, personal communication with REN21, April 2018.

2016), for a total of 1.5 GW of pumping capability.[63] China also completed the first 300 MW of a 1.2 GW storage plant in Shenzen City, the country's first large-scale pumped storage facility to be built within an urban environment.[64]

In Europe, three (mixed) pumped storage plants entered service; each was an open-loop system that combines pumping capability with conventional hydropower generation from natural flows. The Veytaux hydropower plant in Switzerland, originally built in 1971, saw its capacity double in 2017 with the addition of two 120 MW generators. The expanded plant can pump water from Lake Geneva to the Hongrin reservoir – 880 metres higher in altitude – at a capacity of 420 MW.[65]

Portugal's 780 MW Frades II and 263 MW Foz Tua pumped storage plants both entered service in 2017.[66] The two variable-speed 390 MW pump turbines of Frades II are the largest of their kind in Europe. They can respond faster to changing demands of the grid than can conventional turbines with fixed speeds, and are more stable against voltage drops.[67] Many projects in Europe are incorporating variable-speed turbines for flexibility and wider operating range, particularly to accommodate rising penetration of VRE.[68] A severe drought in Portugal during 2017 underscored the importance of pumped storage and hydropower reservoirs for secure energy supply and stable electricity prices, as well as for adequacy of water supply. Subsequently, Portugal began to consider interconnecting its dam infrastructure and increasing the storage capacity of existing dams.[69]

The hydropower industry focused on **modernisation and digitalisation** of existing and new facilities

HYDROPOWER INDUSTRY

Among the priorities of the hydropower industry in 2017 were continued advances towards more sustainable development of hydropower resources, and ongoing modernisation efforts and digitalisation of existing and new facilities.

The hydropower industry and the World Bank Group (a historically significant funder of hydropower projects in developing countries) affirmed their commitment to the responsible development of hydropower projects, both large and small.[70] The World Bank noted the potential for hydropower to provide impressive development benefits if implemented in a socially, financially and environmentally sustainable way.[71] The World Bank Group's International Finance Corporation (IFC) declared that the integration of environmental and social risks at the early stages of project planning is imperative for sustainability and allows for broad economic benefits beyond energy generation alone.[72]

Climate change resilience also has emerged as a key consideration in project assessments at the World Bank. In 2017, the Bank set out to draft guidelines (to be finalised in 2019) that would be designed to ensure that both existing and future hydropower projects are resilient to climate-related risks.[73] These risks include physical, operational and economic threats to the viability of hydropower infrastructure caused by dramatic shifts or extreme variability in hydrological conditions, as well as related social and environmental risks.[74]

In 2017, the IFC worked with the governments of Myanmar and Lao PDR to integrate strategic environmental and social assessments into country-wide evaluations of water resources development, prioritising broad stakeholder engagement.[75] Both countries, along with Cambodia, China, Thailand and Vietnam, share the riches of the Mekong River, where large hydropower projects have altered river flows significantly, raising concerns about associated impacts on aquatic ecosystems, agriculture and fisheries in downstream territories.[76]

The Hydropower Sustainability Assessment Protocol, introduced in 2011, has gained prominence as a global standard for evaluating hydropower projects from inception to construction and operation. In 2017, three project assessments were published under the Protocol, all for projects implemented in Europe.[77] One of these was an ex-post evaluation of the 690 MW Kárahnúkar project in Iceland. Completed in 2007, it is the country's largest and most controversial power project, in part because of wilderness areas lost due to land inundation by several reservoirs and to a change in river flows.[78] The plant was found to meet standards of best practice across most of the topics assessed.[79]

In late 2017, Sustainable Energy for All (SEforALL) and the International Hydropower Association (IHA) signed an agreement to consult on the concept of a Hydropower Preparation Facility, which would aid national governments in prioritising potential hydropower projects according to their assessed sustainability, before putting them out to tender to the private sector.[80] In addition to identifying the most viable projects in the context of sustainability and local needs, SEforALL and the IHA expect that such preliminary screening may improve the prospects for project funding by reducing the high upfront costs and risks associated with early-stage preparations of hydropower projects.[81]

Many hydropower facilities around the world are decades old, and some have been around – in some form – for over a century. Modernisation and rehabilitation of existing plants is a significant part of industry operations and serves to extend plant life, to increase maintenance intervals and reduce associated costs and downtime, and to improve reliability. Modernisation also can increase a plant's efficiency, power output, flexibility within the energy system, ability to provide grid support, and resilience to climate change.[82]

Digitalisation of hydropower facilities is one aspect of modernisation efforts on existing plants as well as being a feature of new construction. *(→ See Digitalisation sidebar in Integration chapter.)* This involves the implementation of advanced simulation, monitoring and control technologies that allow plant operators to observe and respond to all aspects of plant operating conditions in a more timely and effective manner. The objective is improved efficiency of operations and maintenance, greater plant reliability, and more flexible integration with the operations of other generating facilities, including VRE.[83]

Some of the major hydropower technology leaders continued to expand their capabilities in digitalisation during 2017. For example, Voith Hydro (Germany) introduced a virtual (or "augmented") reality application to remotely visualise and analyse plant conditions, which in turn allows for an optimised repair and service plan.[84] GE (United States) has used computer-generated digital simulations of plant components along with actual measurements to identify weaknesses, with the ultimate aim of providing real-time recommendations on corrective action.[85] Andritz (Austria) offers a digital solution for enhancing operation and maintenance of hydropower plants. The system has been useful in making well-informed decisions on whether and when to refurbish plant components and on how to optimise specific configurations for efficient operation.[86]

Total asset finance[i] of large (>50 MW) hydropower projects in 2017 is estimated to have been USD 45 billion, and another USD 3 billion for small projects.[87] This is about double the asset finance reported for 2016.[88] Most of the 2017 financing (USD 28 billion) is represented by a single project: the 16 GW Baihetan project in China, to be completed by 2022.[89]

GE's renewable energy segment continued to show growing revenues in 2017, due in part to higher hydropower-related sales, but hydropower still comprised only one-tenth of the revenues that the company generated from wind power.[90] Andritz Hydro reported that the market environment continued to be difficult, and placed the bulk of the blame on low electricity prices and low energy prices in general.[91] The company noted very moderate investment activity among power companies that own and operate hydropower facilities, particularly for plant upgrades, with a continued decline in new orders (down 12%) and sales (down 10%) for 2017.[92]

Voith Hydro saw fewer contracts awarded than expected in 2017; sales remained stable (down 1%) relative to 2016, but new orders dropped by 15%.[93] The company anticipates a positive impact on orders from growing demand for pumped storage, highlighting China in particular, where several pumped storage facilities were in the pipeline by late 2017.[94]

i Defined by capturing the whole value of a project at the moment of final investment decision.

OCEAN ENERGY

OCEAN ENERGY MARKETS

Ocean energy[i] remains a largely untapped renewable energy source, despite decades of development efforts.[1] Of the approximately 529 MW of operating capacity at the end of 2017, more than 90% was represented by two tidal barrage facilities.[2] Ocean energy technologies deployed in open waters (excluding tidal barrage) had a good year, as both tidal stream and wave energy deployments saw new capacity come online, much of it launched in the waters of Scotland. The year ended with net[ii] capacity additions of at least 4 MW, for a year-end total of 17 MW of tidal stream and 8 MW of wave energy capacity.[3]

Aside from means of energy conversion (tidal, wave, etc.), ocean energy technologies can be classified by their general development stage. Tidal range facilities, such as Sihwa and La Rance[iii], use relatively mature and well-established in-stream turbine technologies that also are used in run-of-river hydropower projects. *(→ See Hydropower section in this chapter.)* The United Kingdom's proposed 320 MW Swansea Bay tidal barrage project received a favourable independent review in early 2017, but concerns have been raised about its cost and potential ecological impact, and it continued to await government approval by year's end.[4]

Other open-water technologies, such as tidal stream and wave energy converters, are generally in an earlier stage of development, with various prototypes deployed.[5] Tidal stream technologies are probably closest to technological maturity and have shown a significant convergence around the use of horizontal-axis turbines, combined with a variety of mooring techniques.[6] The first tidal turbine arrays (a cluster of multiple interconnected turbines) were being deployed in 2017.[7]

Conversely, wave energy technology development shows very little technological convergence, due in part to the diversity of the wave resource and the complexity of extracting energy from waves.[8] Wave energy converter demonstration projects are mostly in the pre-commercial stage.[9] Developers of ocean thermal energy conversion and salinity gradient technologies are also far from commercial deployment, having launched only a few pilot projects.[10]

Europe saw significant deployment activity for ocean energy devices in 2017, and notable developments were found around the world.[11] However, the development of ocean energy has been slower than expected. Markets for these nascent technologies are still driven predominantly by government support, and effective international co-operation has played an important role.[12] Challenges to commercial success have included financing obstacles in an industry characterised by relatively high risk and high upfront costs and the need for improved planning, consenting and licensing procedures.[13]

OCEAN ENERGY INDUSTRY

Optimism prevailed in the industry in 2017, particularly in Europe, where some technologies advanced enough to be on the brink of commercialisation. The industry started constructing its first manufacturing plants, promising greater production scale and cost reductions.[14]

By one count, over 90 tidal energy technology developers around the world were advancing various technologies during 2017, with about half of them focusing on horizontal-axis turbines.[15] Meanwhile, well over 200 companies were developing wave energy converters of various types, with point-absorber[iv] devices being the most common approach.[16]

Scotland continued to be the centre of tidal energy developments in 2017. Scotland's MeyGen tidal stream energy project completed the initial leg of its first phase, with all four 1.5 MW horizontal-axis turbines delivering power to the grid by early 2017.[17] By late in the year, the project had fed 2.6 GWh of electricity to the grid and was close to entering its planned 25-year operational phase.[18] As of early 2018, MeyGen's developers had received full consent to expand the project up to 86 MW (the offshore lease on the site permits up to 398 MW), with installation expected to continue into 2019.[19]

Also in Scotland, Nova Innovation (United Kingdom) installed in Shetland's Bluemull Sound a third 100 kilowatt (kW) direct-drive turbine in what the company claimed was the world's first grid-connected tidal array (the first two turbines were launched in 2016).[20] Nova Innovation led a group of industrial, academic and research organisations in securing EU funding in support of ocean energy technology, for a total of EUR 19.3 million (USD 23.1 million).[21] Some of the funds will support expansion of the Bluemull Sound array to six turbines, with the expectation that it will provide enough insight into operational performance to reduce the costs of tidal energy and boost the confidence of potential investors.[22]

Another tidal energy developer to receive EU support in 2017 was Scotrenewables Tidal Power (United Kingdom). The company's 2 MW SR2000 device, first installed in 2016 at the European Marine Energy Centre (EMEC) in Orkney, Scotland, operated at full power as it underwent a test programme in 2017.[23] The unit supplied power to the grid in high-sea conditions, providing the equivalent of 7% of the electricity demand of the Orkney Islands (more than 1.2 GWh by the end of the year).[24] The SR2000 incorporates two 1 MW horizontal-axis turbines (each with a 16-metre rotor diameter) that are mounted on a floating hull platform.[25]

In Cherbourg, France, Naval Energies started building a facility to manufacture tidal turbines, with a planned production capacity of 25 units per year. The plant, which will produce 2 MW open-centre turbines by OpenHydro (a subsidiary of Naval Energies, previously DCNS Energies) in partnership with EDF

i Ocean energy refers to any energy harnessed from the ocean by means 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 energy used in this report does not include offshore wind power or marine biomass energy.

ii Each year, various tidal and wave energy projects under development undergo removals and redeployments.

iii 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).

iv 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 15.

Energies Nouvelles of France, is expected to mark the start of an industrial phase in the tidal energy sector and to launch the commercialisation of the technology.[26] Seven of those turbines were scheduled for deployment at the Normandy Hydro Project at Raz Blanchard, starting in 2018.[27]

Also in France, tidal turbine developer Guinard Energies carried out a demonstration of its 3.5 kW P66 turbine. The small design of the turbine aims to simplify installation and maintenance in isolated areas, including hybrid applications with solar PV and batteries.[28]

Wave energy also advanced in 2017, with pilot and demonstration projects found in the waters of several countries, including China, Spain and Sweden.

In China, the 100 kW Sharp Eagle wave energy demonstration project was redeployed in 2017, with upgrades to better serve the power needs of remote islands.[29] Earlier tests had indicated wave energy conversion efficiency above 20%, yielding as much as 1.8 MWh per day.[30]

A new air turbine by Kymaner (Portugal) underwent tests at the Mutriku wave power plant in the Bay of Biscay, Spain. The device harnesses wave-driven compressed air, a technology known as an oscillating water column.[31] Nearby, Oceantec (Spain) celebrated the first full year of testing on its MARMOK-A-5 30 kW floating wave energy converter at the Biscay Marine Energy Platform, where it demonstrated its survivability in winter seas and 85% availability to generate electricity.[32]

Several Swedish companies are developing both wave and tidal energy devices. Waves4Power completed a grid connection on its WaveEL wave energy buoy off the coast of Norway.[33] Seabased discontinued development at its demonstration project, the Sotenäs wave energy park, to focus on commercial project markets where the technology can already be competitive. The company noted that its point-absorber devices were proven to be highly efficient.[34]

Government support of ocean energy, whether through direct funding or through research and infrastructure support, remains a critical element in ongoing development. In Europe, for example, various project and research funding opportunities (including MaRINET2 and FORESEA[i]), as well as the availability of testing facilities, are made possible by regional, national and local government entities.

Supported by the European Commission's Horizon 2020 programme, MaRINET2 announced its first set of awards totalling EUR 1.3 million (USD 1.6 million) to support technology developers of offshore wind, wave and tidal energy projects.[35] The FORESEA project also made several awards to technology developers in 2017.[36] Launched in 2016, FORESEA provides competitive funding opportunities to ocean energy technology companies to test their devices in real sea conditions at test centres in France, Ireland, the Netherlands and the United Kingdom.[37]

Wave Energy Scotland, formed in 2014 as a subsidiary of the Highlands and Islands Enterprise of the Scottish government to ensure that Scotland maintains a leading role in ocean energy, had awarded GBP 28 million (USD 37.8 million) to 62 projects in 11 countries by the end of 2017.[38] All projects focused on key components, such as novel wave energy converters, power take-off devices (PTOs)[ii], structural materials and manufacturing processes, and control systems.[39]

Government support

remains critical to ongoing development in the ocean energy industry

The United States has focused its support for ocean energy in the area of wave energy converters. In 2017, the US Department of Energy (DOE), in co-operation with Oregon State University, worked on finalising plans for the Pacific Marine Energy Center South Energy Test Site to be completed by 2021, with space to accommodate 20 grid-connected wave energy converters.[40] The DOE also announced an additional USD 12 million in 2017 to advance wave energy, allocating support to four projects including two that will test and validate wave energy converters in open waters and two that will address early-stage development challenges.[41]

One of the challenges for ocean energy developers is to devise efficient and cost-effective PTO devices that can cope with the unique demands of ocean energy. With the aim of eliminating the need for hydraulic components in PTOs, DOE-funded research yielded a prototype magnetically geared generator that could be ideal for low-speed, high-torque applications such as wave energy conversion.[42] Other successful DOE-funded research during 2017 aimed to make the components used in tidal energy devices more durable and efficient, to reduce operating costs, and to advance commercialisation.[43]

In late 2016 through mid-2017, Chinese authorities released several edicts on energy and technology innovation, including the 13th Five-Year Plan on Ocean Energy. The specific targets for ocean energy include the development of new demonstration and testing facilities, the construction of island projects and a capacity target for the installation of 50 MW by 2020.[44]

In 2017, the European Commission published a report to shed light on the reasons for past failures in ocean energy development and on the lessons that might be drawn from experience. The report calls for a "covenant" between the industry and the public sector that would seek: co-ordinated evaluation of technology development; certification, performance guarantees, standardisation and accreditation; a consistent policy framework and alignment of public funding activities; a staged support structure with strict conditions; and the application of performance criteria to assess technological and sectoral readiness, all for a more selective and targeted support.[45]

As the ocean energy industry draws closer to commercialisation, questions remain regarding potential impacts on marine life.[46] Based on current knowledge, the deployment of single devices appears to pose very small risk to the marine environment, but only actual experience with large commercial arrays will reveal any risk that they represent. More research, data collection and sharing are needed to establish accurate risk assessment, which is a prerequisite for well-informed consent and permitting requirements.[47]

i Funding Ocean Renewable Energy through Strategic European Action.

ii A PTO 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.

SOLAR PHOTOVOLTAICS (PV)

SOLAR PV MARKETS

The year 2017 was a landmark one for solar photovoltaics (PV): the world added more capacity from solar PV than from any other type of power generating technology. More solar PV was installed than the net capacity additions of fossil fuels and nuclear power combined.[1] In 2017, solar PV was the top source of new power capacity in several major markets, including China, India, Japan and the United States.[2] Globally, at least 98 GW_{dc}[i] of solar PV capacity was installed (on- and off-grid), increasing total capacity by nearly one-third, for a cumulative total of approximately 402 GW.[3] *(→ See Figure 24.)* On average, the equivalent of more than 40,000 solar panels was installed each hour of the year.[4]

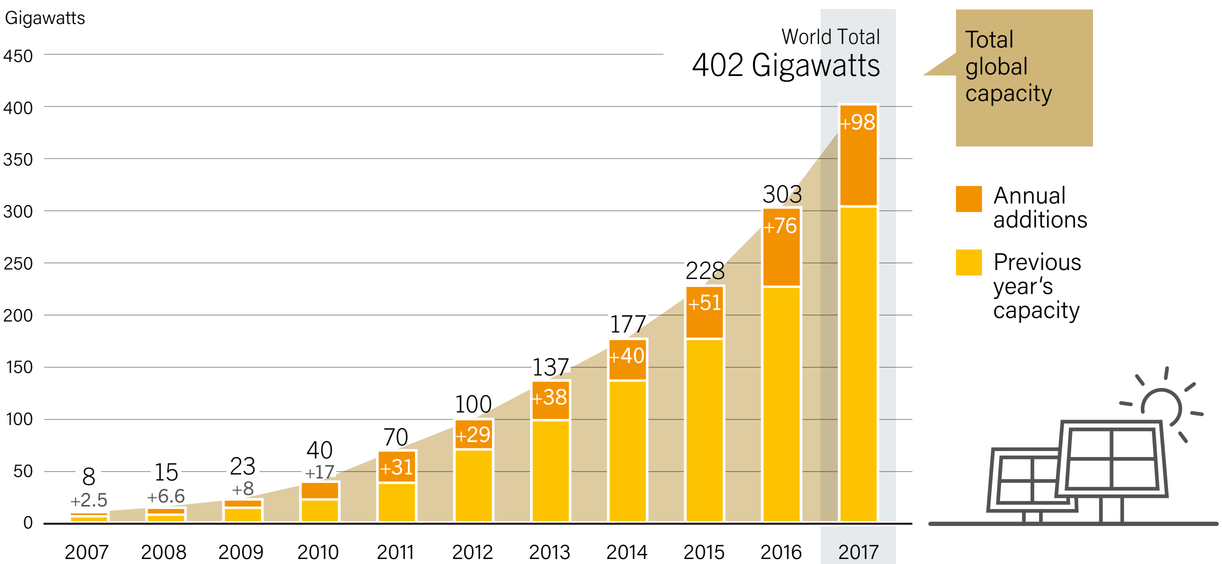
The significant market increase relative to 2016 was due primarily to China, where new installations were up more than 50%.[5] India's market doubled, while other major markets (Japan and the United States) contracted.[6] For the fifth year running, Asia eclipsed all other regions, accounting for 75% of global additions.[7]

Solar PV
was the top source of new power capacity in several major markets

The top five national markets – China, the United States, India, Japan and Turkey – were responsible for nearly 84% of newly installed capacity; the next five were Germany, Australia, the Republic of Korea, the United Kingdom and Brazil.[8] For cumulative capacity, the top countries were China, the United States, Japan, Germany and Italy, with India not far behind.[9] *(→ See Figure 25.)* Despite the heavy concentration in a handful of countries, new markets are emerging and countries on all continents have begun to contribute significantly to global growth.[10] By the end of 2017, every continent had installed at least 1 GW and at least 29 countries had 1 GW or more of capacity.[11] The leaders for solar PV capacity per inhabitant were Germany, Japan, Belgium, Italy and Australia.[12]

i The GSR endeavours to report all capacity data in direct current (DC). See endnotes and Methodological Notes for further details.

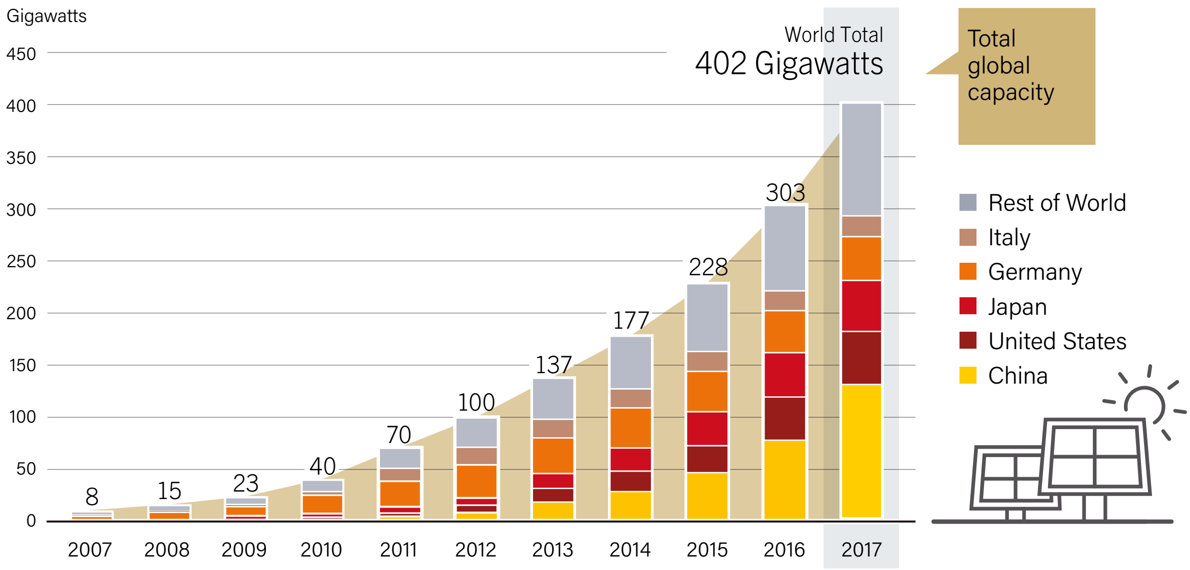
FIGURE 24. Solar PV Global Capacity and Annual Additions, 2007-2017



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

Source: IEA PVPS. See endnote 3 for this section.

FIGURE 25. Solar PV Global Capacity, by Country or Region, 2007-2017



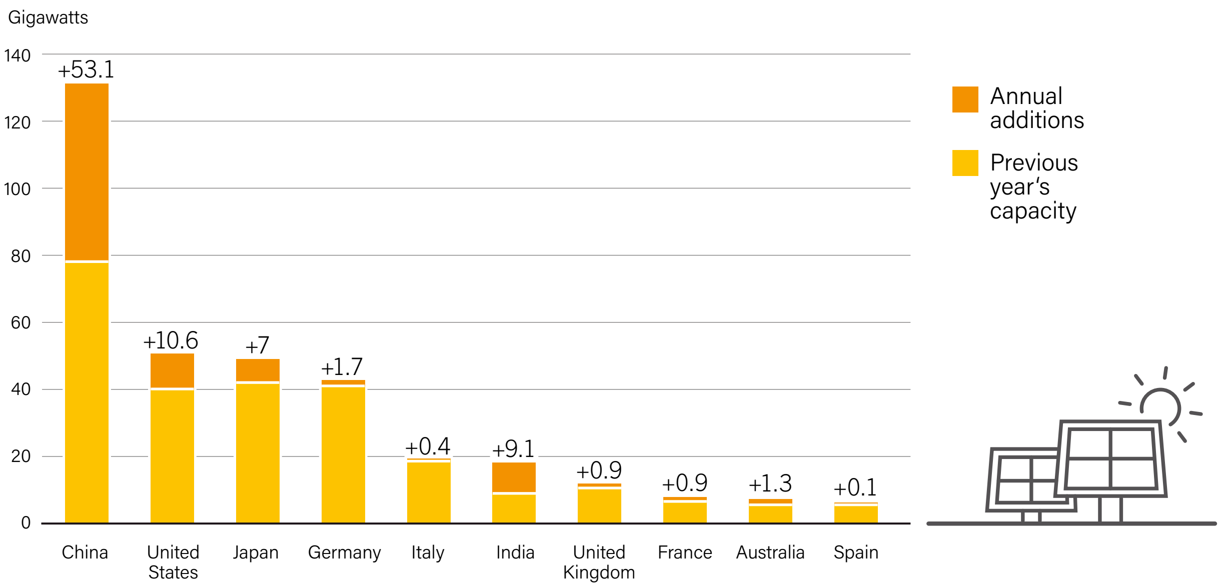
Note: Data are provided in direct current (DC).

Source: See endnote 9 for this section.

Globally, market expansion was due largely to the increasing competitiveness of solar PV combined with the rising demand for electricity in developing countries, as well as to the increasing awareness of solar PV's potential to alleviate pollution, reduce CO_2 emissions and provide energy access.[13] Solar PV also is meeting growing interest in some countries in producing electricity locally.[14] Nevertheless, most global demand continues to be driven largely by government incentives and regulations.[15] Challenges remain to be addressed before solar PV can become a major source of electricity worldwide, although several countries – including Germany, Greece, Honduras and Italy – already meet significant portions of their electricity demand with solar PV.[16]

In 2017, China surpassed all expectations, adding more solar PV capacity (nearly 53.1 GW) than was added worldwide in 2015 (51 GW).[17] For the first time, solar PV was China's leading source of new power capacity.[18] By year's end, total installations approached 131.1 GW, far surpassing the government's minimum target for 2020 (105 GW), announced in 2016 with the aims of advancing economic development, poverty alleviation and environmental protection.[19] *(→ See Figure 26 and* ***Reference Table R6.****)* Because China accounts for more than half of global demand and manufacturing, developments there can have a wide-reaching impact on the solar PV sector.[20]

FIGURE 26. Solar PV Capacity and Additions, Top 10 Countries, 2017



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

Source: See endnote 19 for this section.

China's market continued to be driven by government policy in 2017.[21] Unlike 2016, when a rush of projects came online in advance of a mid-year feed-in tariff (FIT) cut, followed by a lag in the second half of the year, a robust rate of new installations was maintained throughout 2017.[22] A healthy second half of the year was fuelled by projects not completed by a mid-year FIT adjustment, as well as by anticipation of the looming expiration of several provincial and local incentives, and yet another downward FIT adjustment at year's end.[23]

While most capacity additions in China continued to be in large centralised projects, there was an evident shift toward so-called distributed[i] solar PV.[24] About 19.4 GW of distributed capacity was added in 2017, up from 4.2 GW in 2016, for a cumulative total of 30 GW; new rooftop systems saw a three-fold increase relative to 2017, to 2 GW installed during 2017.[25] The government has increased its emphasis on distributed projects – particularly rooftop systems for self-consumption – in an effort to lessen the burden on transmission capacity and to reduce curtailment.[26]

The year also saw a clear shift from sparsely populated regions with high rates of curtailment in China's northwest towards major demand centres. The central and eastern regions accounted for 27.7% and 20%, respectively, of newly installed capacity in 2017.[27] Distributed solar PV installations were naturally more concentrated in areas of greater population, with the eastern provinces of Zhejiang, Shandong and Anhui accounting for nearly 46% of distributed additions.[28]

Preliminary data show that China's curtailment of solar PV averaged 6-7% in 2017, down 4.3 percentage points relative to 2016.[29] Curtailment was concentrated mainly in two provinces, both of which saw substantial reductions: Xinjiang's curtailment rate fell 9.3 percentage points to average 22% for the year, and Gansu's rate was down 9.8 percentage points to 20%.[30] Even as curtailment rates declined, evidence emerged that air pollution, specifically particulate matter, in China (and elsewhere) is reducing solar panel output significantly.[31] Even so, solar PV in China generated 118 TWh in 2017 (up nearly 79% over 2016) – representing approximately 1.9% of the country's total electricity generation – and penetration rates in five provinces ranged from 5.5% to 16.5%.[32]

The United States remained a distant second to China for new installations in 2017, adding 10.6 GW for a total of 51 GW.[33] For the second consecutive year, solar PV represented the country's leading source of new generating capacity (based on net additions).[34] California again led for capacity added (5.2 GW), followed by North Carolina (1 GW) and Florida (0.4 GW).[35] Several states, including California, reached or exceeded 10% solar PV penetration in 2017.[36]

Overall, however, the US market contracted by 30% relative to 2016 due to several factors, including interconnection delays, a slowdown in maturing markets (including California) as well as rising solar PV equipment prices[ii] and political uncertainty – both due primarily to an impending decision about federal duties on imported solar cells and modules.[37] Reversing a multi-year trend of continuous expansion, US installations declined in both the residential (down 16%, to 2.2 GW) and utility-scale (down nearly 40%, to 6.2 GW) sectors during 2017.[38] Only the non-residential (commercial) sector expanded relative to 2016 (up 28%, to 2.1 GW), driven largely by end-of-year policy deadlines.[39]

Whereas most US solar procurement was driven by state mandates until 2015 and 2016, by early 2017 almost all new procurement of

i "Distributed" solar PV in China includes ground-mounted systems of up to 20 MW that comply with various conditions, in addition to commercial, industrial and residential rooftop systems. Distributed generation consists largely of commercial and industrial systems and, increasingly, floating projects and, to a lesser extent, residential systems. See endnote 24.

ii A rush to purchase modules in the second half of the year, in advance of a possible tariff on imports, pushed up module prices in the United States; overall, they were up 14% for the year, from GTM Research and Solar Energy Industries Association, *U.S. Solar Market Insight: 2017 Year in Review, Executive Summary* (Boston: March 2018), p. 15, https://www.greentechmedia.com/research/subscription/u-s-solar-market-insight.

China
added more solar PV capacity in 2017 than the world installed in 2015

large-scale projects was due to voluntary utility and corporate sourcing.[40] *(→ See Feature chapter.)* While some electric utilities are fighting for revisions or elimination of supportive policies, such as net metering, others aim to diversify their businesses and increase profits by investing in solar PV projects in response to solar PV's increasing cost-competitiveness with natural gas generation.[41] In 2017, more than 6.2 GW of utility solar PV capacity was brought online in the United States; by year's end, 2.3 GW was under construction and a further 14.6 GW was contracted through power purchase agreements (PPAs).[42]

India placed third for new installations in 2017, adding a record 9.1 GW, more than double the 4 GW installed in 2016.[43] By year's end, India had 18.3 GW of total capacity and ranked sixth globally for cumulative capacity.[44] Solar PV was the country's top source of new power capacity (followed by wind power), accounting for an estimated 45% of new installations in 2017, and ahead of new coal capacity for the first time.[45] The states of Telangana and Karnataka were home to about half of new solar PV installations, each adding more than 2 GW, followed by Andhra Pradesh and Rajasthan. Telangana became India's first state to pass 3 GW of installed solar PV.[46]

Demand for large-scale solar projects in India has been driven by rapidly falling prices combined with strong policy support in several states and at the national level since 2014.[47] In 2017, large ground-mounted systems accounted for about 91% of solar PV additions.[48] Rooftop solar is India's fastest growing sector, but it remains a small market segment – approximately 0.8 GW was added in 2017, for a year-end total of 1.7 GW.[49] The rooftop market is driven largely by commercial, industrial and government facilities seeking to reduce their electricity bills, as few residential customers can afford the upfront costs.[50] Growth also has been restrained because many state distribution companies have refused to purchase surplus solar power from commercial and industrial rooftop installations, and some states ban net metering, prompting customers to install sub-optimally sized systems.[51]

In the final quarter of 2017, India's market growth slowed due to lack of transmission infrastructure (particularly in the north and south), flat power demand, rising panel costs domestically *(→ see Industry text in this section)* and uncertainty raised by the possibility of new duties on imported panels.[52] Several tenders were postponed due to lack of interest among prospective bidders, in response to record-low bids early in the year and rising module prices.[53] To address private sector concerns about the slowing project pipeline (10.6 GW of utility-scale capacity at year's end) and the lack of a clear roadmap, the government announced plans to tender an additional 67 GW of solar capacity by early 2020.[54]

Japan's market contracted (by 13%) for the second year running but still ranked fourth globally for additions, with an estimated 7 GW installed for a total capacity exceeding 49 GW.[55] Demand for large-scale projects fell due to a reduction in the national FIT.[56] To reduce costs, in 2017 Japan began shifting to tenders for systems of 2 MW and larger.[57] In the country's first solar auction, project approvals totalled less than 10% of the government's capacity tender due to its high hurdles for participation.[58]

Shipments of panels for residential applications in Japan also were down for the fourth consecutive year but nonetheless accounted for roughly 1.1 GW of new installations.[59] Interest in residential solar-plus-storage options continued to increase, with an estimated 25,000 systems installed in 2017.[60] The number of community solar PV projects also rose during the year, with total capacity almost doubling to 86 MW, up from 45 MW in 2016.[61]

Japan saw little curtailment of solar PV in 2017, and only in some islands of the Kyushu area, where the solar PV share of peak demand reached 71% for a short period of one day.[62] Kyushu's utility has managed high shares of variable renewable energy by controlling thermal generation and through the use of pumped storage.[63] For all of Japan, solar PV accounted for an estimated 5.7% of total electricity generation in 2017, up from 4.8% in 2016 and 2.7% in 2015.[64]

Elsewhere in Asia, Turkey installed a record 2.6 GW, more than doubling its total capacity to 3.4 GW at year's end.[65] The Republic of Korea added more than 1 GW for the first time.[66] In Thailand, government-issued PPAs have been in decline, but an increasing number of companies are installing rooftop solar PV for self-consumption.[67] Armenia entered the solar market in 2017, completing its third large-scale solar PV plant by year's end.[68] Other countries in the region have seen rapid growth, but from a small base.[69] In many Southeast Asian countries, although solar PV is cost-competitive with fossil fuels, demand is suppressed by government subsidies for fossil fuels.[70]

The EU added an estimated 6 GW of solar PV capacity in 2017, for a year-end total of nearly 108 GW.[71] The market is still in transition but is progressing towards reduced dependence on traditional FIT-based government support.[72] Falling costs and advances in technology are creating demand for rooftop and ground-mounted applications.[73] Demand in the region is driven increasingly by tenders, as well as by self-consumption where supportive policy frameworks are in place.[74] Several utility-scale plants were under development and being planned during the year in Italy, Portugal, Spain and the United Kingdom, including the United Kingdom's first unsubsidised solar PV-plus-storage facility.[75] However, few projects based on PPAs and corporate sourcing have been realised in Europe due to regulatory limitations.[76]

The leading EU markets were (in order of market size) Germany, the United Kingdom, France and the Netherlands.[77] All saw growth relative to 2016, with the exception of the United Kingdom, which lost its regional lead for capacity additions.[78] Germany added almost 1.7 GW (well below the government target of 2.5 GW) for a year-end total of 42.4 GW.[79] About half of the residential systems installed in Germany during 2017 were combined with storage capacity, up from around 41% in 2015 and 14% in 2014.[80] Repowering of Germany's existing systems (replacing older modules with new, more powerful ones to increase yield) is in a very early stage but increasing rapidly.[81]

In the United Kingdom, new installations fell 54% relative to 2016, to around 0.9 GW, due mainly to closure of the Renewable Obligation Certificates window and to a significant reduction (in 2016) in FIT payments for new installations.[82] France and the Netherlands each added nearly 0.9 GW, while Spain's installations were up 145% over 2016, to 0.1 GW (mostly in rooftop projects).[83] Spain, which was once a solar PV powerhouse, held a solar tender to catch up with 2020 EU targets, and saw more than 3.5 GW of capacity allocated to future projects.[84] Elsewhere on the continent, the Russian Federation added 115 MW for a total of 250 MW.[85]

Utilities in Australia are grappling with the rapid growth of solar PV. The country added a record 1.3 GW in 2017, for a total capacity of 7.2 GW, as residential and commercial customers responded to a continued rise in electricity prices and to the improving economics of solar energy.[86] The residential market again accounted for the majority of Australia's new installations (64%), but the number and capacity of commercial rooftop systems expanded at an unprecedented rate.[87] By year's end, almost 1.8 million rooftop solar PV installations (residential and commercial) were in operation, accounting for the vast majority of Australia's cumulative capacity.[88]

About 29% of dwellings in South Australia and 27% in Queensland had solar PV installations by early 2018, with substantial shares in several other states and territories as well.[89] In September 2017, South Australia's demand for electricity from the grid hit several record lows at mid-day due to increased output from rooftop solar systems.[90]

Distributed solar-plus-storage has become cheaper than retail electricity from the grid in several regions of Australia.[91] In 2017, an estimated 40% of new solar rooftop installations included energy storage systems, amounting to almost 20,800 battery installations, mostly in the residential sector; this was up from 6,750 battery installations in 2016 and 500 in 2015.[92] Battery storage also is being used alongside some large-scale plants that were under construction in Australia during 2017.[93]

Latin America and the Caribbean together still represent a small portion of global demand, but markets are expanding quickly and large companies are flocking to the region with expectations of massive growth.[94] By end-2017, a significant amount of capacity was in the pipeline following tenders in Argentina, Brazil, Chile and Mexico.[95] Most installations have occurred via large-scale PPAs, but distributed solar PV has experienced significant growth in Brazil and in Mexico, where high electricity prices and net metering provide an incentive to switch to solar PV.[96] Brazil became the region's second country (after Chile) to exceed 1 GW of installed solar PV capacity, adding nearly all of it in a single year (0.9 GW) for a total of 1.1 GW.[97] With this, Brazil moved up to rank tenth globally for capacity added in 2017, although the country accounted for only about 1% of global additions.[98] *(→ See Figure 27.)*

Chile has struggled with transmission restrictions, which have slowed the connection of new projects, but new transmission infrastructure was expected to ease congestion by year's end.[99] Chile maintained its lead in the region, adding nearly 0.7 GW in 2017 for a total of 1.7 GW.[100] Also in 2017, Colombia commissioned its first solar park (9.8 MW) on the site of a former coal-fired power plant; the country is turning to solar energy to diversify its electricity mix, which is heavily dependent on hydropower.[101]

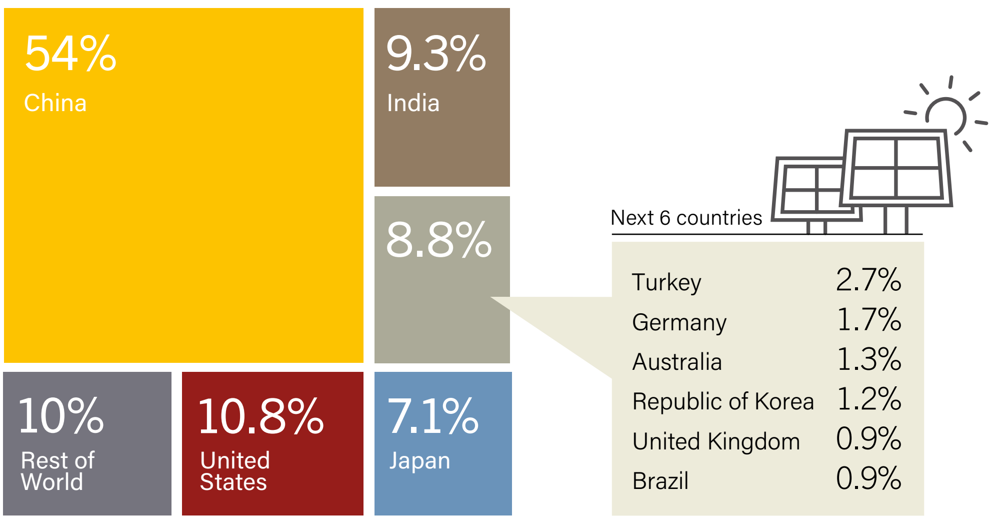
After years of announcements without much market growth in the Middle East, 2017 and early 2018 saw some real progress.[102] Many countries increased existing targets or put forth ambitious new ones, driven by rapidly falling solar technology costs, the desire to diversify their energy mix, and climate change objectives.[103] The region's second large-scale plant (200 MW) was completed in the United Arab Emirates (UAE).[104] Jordan connected the world's largest project in a refugee camp (12.9 MW) and at year's end had several big projects under development.[105] In October, Saudi Arabia held a tender for 300 MW of solar PV and, in January 2018, announced plans to launch tenders for 3.3 GW of solar PV during the year.[106]

Across Africa, interest is growing in solar PV as a means to diversify the energy mix, meet rising demand and provide energy access.[107] The top countries for cumulative capacity were South Africa with 1.8 GW (added 13 MW) and Algeria (added 50 MW for a total approaching 0.4 GW).[108] In these and other African countries, most capacity is in large-scale projects.[109] Several countries brought large plants online in 2017, and many more had projects being planned or under construction.[110] However, rapidly falling costs, new business models and a global quality certification scheme for pico-scale solar products have combined to enable the emergence of projects of all sizes.[111] As of 2016 (latest data available), more than 59 million people in Africa (second only to Asia) were using off-grid solar energy in the form of solar lamps and solar home systems, and via mini-grids.[112] *(→ See Distributed Renewables chapter.)* Investment in many of Africa's solar projects, large and small, has been advanced by international financing organisations.[113]

While demand is expanding rapidly for off-grid solar PV in Africa and other regions, grid-connected systems continue to account for the vast majority of existing and newly installed solar PV capacity worldwide.[114] Among grid-connected systems, distributed applications (residential, commercial and industrial rooftop systems) have struggled to maintain a roughly stable global market (in terms of capacity added annually) since 2011, but the market for distributed capacity increased somewhat in 2017.[115] Centralised large-scale projects comprise the major share of capacity added each year (77% in 2017), driven largely by the use of tenders and by the availability of low-cost capital.[116]

The size and number of large projects continued to grow during 2017. By year's end, at least 196 solar PV plants of 50 MW and larger were operating in at least 28 countries, with the UAE joining the list during the year.[117] The total capacity of such plants that came online in 2017 was more than 4.6 GW.[118] Planning or construction began on very large projects in nearly every region

FIGURE 27. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2017



Source: See endnote 98 for this section.

Based on projects completed in 2017, the global weighted average LCOE of large-scale solar PV plants is

down 73 %

since 2010

of the world, including: a 221 MW project in Portugal, reported to be Europe's largest unsubsidised solar PV project; a 102 MW solar-plus-storage plant in Japan; and a 300 MW project in Argentina.[119] Considering plants of 4 MW or larger, more than 70 countries had projects installed by year's end, and the total global capacity of these facilities was approaching 140 GW.[120]

Floating photovoltaic projects also are growing in both number and scale. Since 2015, more than 100 plants have begun operation worldwide atop hydropower reservoirs, industrial water sites, aquaculture ponds and other water bodies.[121] The benefits of putting solar modules atop water bodies include increased economic output per unit of land, improved output (due likely to the cooling effect of water on solar panels) and reduced water evaporation.[122] Japan leads for the number of floating plants, due in part to the country's FIT policy combined with the limited roof and ground space for solar PV systems.[123] Other countries with projects include China, with approximately 400 MW of floating capacity, India, the Republic of Korea and Brazil, where the country's first floating project was completed in 2017.[124]

Back on land, solar PV cells and modules are being integrated into an increasing number of consumer products as well as building materials. These range from appliances (such as refrigerators and televisions for off-grid markets) to fabrics, and from electric vehicles and roadways to tiles for building facades and roofing.[125] A school building in Copenhagen, Denmark, completed in 2017, is covered in more than 12,000 solar tiles, which are expected to meet over half the electricity demand of the campus.[126]

Solar PV plays an increasingly important role in electricity generation in several countries. In 2017, solar PV accounted for 10.3% of total generation in Honduras and significant shares also in Italy (8.7%), Greece (7.6%), Germany (7%) and Japan (5.7%).[127] At the end of 2017, at least 22 countries – including China and India – had enough solar PV capacity to meet 2% or more of their total annual electricity demand, and enough capacity was in operation worldwide to produce close to 494 TWh of electricity per year.[128]

SOLAR PV INDUSTRY

The year 2017 was characterised by a number of prominent themes, including: record-low auction prices driven by intense competition; thinning margins for producers and developers alike (for a variety of reasons, including the shift in many countries from FITs to tenders); continued consolidation in the industry among manufacturers and developers; a host of trade-related disputes; and continuing advances in technology.[129] Module prices continued to fall in 2017, but at a slower pace than in 2016, with average global prices down an estimated 6% for the year, to USD 0.39 per watt.[130] Installed costs also declined globally over the course of 2017.[131]

Based on projects completed during the year, by one estimate the global weighted average levelised cost of energy (LCOE) from large-scale solar PV plants was USD 100 per MWh, down 73% since 2010.[132] At this level, solar PV is competing head-to-head with fossil fuel power sources in many locations, and doing so without financial support.[133] *(→ See Sidebar 2.)* The US government announced in early 2017 that the national SunShot Initiative target for 2020 had been achieved, with the US average price of utility-scale solar PV (based on installed costs) below USD 60 per MWh; however, the average price rose again during the year due to a pending decision on import tariffs.[134]

Solar PV auctions around the world in 2017 resulted in bids[i] at new record lows, with bidding in some markets below USD 30 per MWh for projects to begin operations from about 2019.[135] Argentina, Chile, India, Mexico, Saudi Arabia and the Emirates of Abu Dhabi and Dubai (UAE) all saw very low bids for solar PV in 2017.[136] The year also brought national record low bids for tenders in Germany, for example, where average winning bids fell nearly 50% over two years, to below EUR 50 per MWh (USD 60 per MWh) in late 2017.[137] The United States saw what was estimated to be the country's cheapest PPA ever arranged, for a 150 MW project in Texas to be operational in 2020.[138]

Around the world, low bids were due to a variety of factors, including the low cost of components, expectations that technology costs would continue to fall, increased competition among developers and a relatively low weighted average cost of capital due to declining risk perception.[139] Further, in some countries, bids have become increasingly competitive due to expected low operating costs in locations with excellent solar resources and, in some cases, the necessity to compete with low wholesale electricity prices.[140]

Downward pressure on prices and slim margins made 2017 another challenging year for many solar manufacturers and developers, causing further consolidation in the industry.[141] Mergers and acquisitions continued as companies aimed to capture value in project development or to move into new markets (locations or applications), or simply to survive in an increasingly

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; International Energy Agency Photovoltaic Power Systems Programme, *Trends in Photovoltaic Applications 2017: Survey Report of Selected IEA Countries Between 1992 and 2016* (Paris: 2017), p. 61.

competitive environment.[142] For example, NSP, Gintech and Solar Tech (all Chinese Taipei) announced that they would merge to create what might be, at least temporarily, the world's second largest cell manufacturer.[143] By one estimate, solar project acquisition increased 67% in 2017, to 20.4 GW, and the number of corporate merger and acquisition transactions increased from 68 in 2016 to 71.[144]

Cutthroat pricing that is not necessarily reflective of cost has forced some manufacturers out of business.[145] In 2017, manufacturers Suniva (US-based but primarily Chinese-owned) and Germany's SolarWorld[i] both filed for bankruptcy in the United States and appealed for trade relief (which ultimately led to the US adoption of tariffs in early 2018).[146] Chinese cell manufacturer ET Solar filed for bankruptcy at year's end.[147] SunEdison (United States), once reported to be the world's largest renewable energy company, won final approval for a bankruptcy plan that left nothing for shareholders.[148] Impacts were felt beyond the manufacturing sector, with shrinking or shifting markets affecting developers and installers in some key countries. For example, three of the largest US installers shifted away from the residential market or went bankrupt.[149] In Japan, 50 companies went bankrupt in the first half of the year, compared with 23 during the same period in 2016, due to a slowdown in deployment.[150]

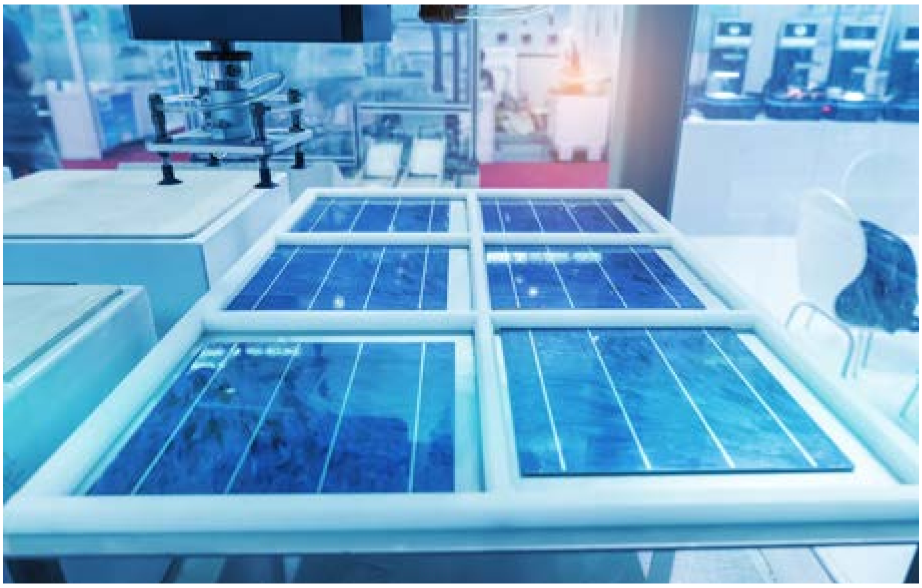
The need to drive down manufacturing and project development costs has raised concerns that manufacturers and developers could be pushed to cut corners, and that quality could be compromised.[151] In turn, this concern is prompting developers of large-scale projects to invest increasingly in rigorous quality assurance programmes to secure return on their investment.[152]

Although some manufacturing facilities closed, many were opened or expanded during the year to meet demand in local markets or to evade trade duties.[153] On balance, global production capacity of crystalline silicon cells and modules rose in 2017.[154] Preliminary estimates of 2017 production capacity exceeded 100 GW for cells (up 23% over 2016) and 107 GW for modules (up 28%).[155] Thin film production increased by an estimated 6%, accounting for 5% of total global PV production (down from 6% in 2016 and 8% in 2015).[156]

China continued to dominate global production in 2017, for the ninth year running.[157] Asia accounted for 90% (and China 66%) of global module production, and China alone was home to about 60% of cell production capacity.[158] Europe's share of module production stayed flat, at about 6% in 2017, and the US share remained at 2%.[159] The top 10 module suppliers[ii] shipped an estimated 57 GW in 2017, or nearly 60% of the total.[160] JinkoSolar, Trina Solar (both China) and Canadian Solar (Canada/China) were in the top three for the third consecutive year, and were followed by JA Solar (China) and Hanwha Q Cells (Republic of Korea); GCL, LONGi, Risen Energy, Shunfeng and Yingli Green, all based in China, rounded out the top 10.[161]

Several countries imposed anti-dumping and countervailing duties on imported solar cells and modules in 2017 and early 2018 to protect domestic manufacturing: Turkey published a list of China-based manufacturers that are subject to a new anti-dumping fee; the EU extended import tariffs on solar cells and modules from China, Chinese Taipei and Malaysia and, later in 2017, set minimum import tariffs on Chinese solar products; India opened an investigation into the potential dumping of solar products from Chinese equipment makers and imposed a duty on glass for solar panels from China; and the United States considered, and in early 2018 adopted, tariffs on imported cells and modules from most solar manufacturing countries to provide domestic manufacturers relief from alleged unfair trade practices.[162]

The threat of import tariffs in the United States spurred hoarding of solar panels and drove up module prices in the second half of 2017.[163] The construction of some US projects was cancelled or delayed while awaiting the tariff decision.[164]



Tenders around the world saw new **record-low bids** for solar PV in 2017

i In early 2018, SolarWorld filed for insolvency again, this time in Bonn, Germany, from Frank Asbeck, "SolarWorld ist erneut pleite", Zeit Online, 28 March 2018, http://www.zeit.de/wirtschaft/2018-03/frank-asbeck-solarworld-insolvenz.

ii 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.

In India, solar PV bid prices fell to new lows in early 2017, due to intense competition caused by slowing demand, and to the expectation that module prices would continue to fall.[165] Record-low winning bids brought the price of new solar PV to half that of new coal and even below that of existing coal plants, leading to suspension or cancellation of tenders for new coal capacity.[166] However, high demand in China and the United States, coupled with a reduced supply of polysilicon in China, made it difficult to secure solar panels and pushed up prices in India from May onwards; increased taxes and the threat of import duties on solar panels further compounded the challenges.[167] In response, several developers in India delayed procurement or sought to exit low tariff commitments.[168] In addition, in several instances, distribution system operators forced developers to renegotiate PPAs at lower prices.[169] In late 2017, China's Trina Solar was reconsidering construction of a planned manufacturing facility in India, for which it had already secured land, because the company claimed India's solar prices were too low.[170]

Even as falling prices have challenged many existing solar PV companies, low and predictable energy prices offered by solar PV, along with expanding markets, are luring new players to the industry. A growing number of utilities, particularly in Europe and the United States, are entering the sector through acquisition of companies and solar plants, and through project development.[171] For example, France's EDF announced in 2017 that it plans to develop an additional 30 GW of capacity by 2035, to align with a government goal of rebalancing the country's energy mix.[172] Fossil fuel companies (including Europe-based BP, Shell and Total, and Thai coal-mining giant Banpu) and even manufacturers of autos and batteries (including US-based Tesla and China's BYD) also increased their reach into the sector during the year.[173]

Industry's pairing of solar PV with storage remains limited but is expanding rapidly in some countries, particularly in Australia, Germany and Japan.[174] Solar-plus-storage also is used increasingly for providing energy access for people living off-grid and for mini-grids.[175] Wanting to get in on the ground floor, a number of companies – including solar PV manufacturers and installers, battery manufacturers and big-box stores – announced solar-plus-storage related plans in 2017.[176]

Innovations and advances continued in manufacturing, product performance and efficiency during the year.[177] They were driven largely by rapid price reductions, which have forced companies to decrease costs and to differentiate themselves, as well as by growing customer demands for increased functionality and a rising number of grid requirements in some countries.[178] In order to reduce manufacturing costs, for example, US-based First Solar decided in 2016 to discontinue its Series 4 and successfully unveiled its first functional Series 6 thin film module off the new production line in Ohio just one year later.[179]

Throughout 2017, new record cell and module efficiencies were achieved.[180] Passivated Emitter Rear Cell (PERC)[i] technology has become the new standard for the monocrystalline silicon solar cell variety because it increases efficiencies with modest investment.[181] In early 2018, LONGi of China announced a world record conversion efficiency of 23.6% with its monocrystalline PERC solar cells.[182] Efficiency gains from such advances have reduced the number of modules required for a given capacity, helping to reduce soft costs.[183]

i 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.

The drive to increase efficiencies and lower LCOEs, which is also supported by China's Top Runner programme[i], has pushed module manufacturers to develop advanced module technologies, such as multi-busbars[ii] and half-cut cells[iii].[184] Perovskites[vi] continued to achieve further improvements in stabilisation and efficiency (exceeding 20% in the laboratory) through ongoing R&D, although durability challenges remain, and start-up companies worked during the year to commercialise combined perovskite-silicon solar cells.[185] Development of options for integrating solar PV into building materials, including facades and glass blocks, also progressed.[186]

Advances in balance of systems technologies helped improve installation and overall performance.[187] Low bid prices have encouraged an increased focus on quality of modules, inverters and other system components.[188] Inverters[v] are the main source of failure in large-scale plants, and suppliers continued working in 2017 to improve their long-term reliability and performance.[189] Advances include the development of new materials, as well as increased use of data analytics to raise system yields for large-scale solar PV plants, and to provide capabilities such as power optimisation and energy storage for residential systems.[190] Increasingly, panel manufacturers are integrating inverters (and even storage) into their products through their own developments and partnerships, and inverter manufacturers (such as Huawei) are moving into solar project operations and maintenance (O&M).[191]

Increased competition in the large-scale solar PV sector has elevated the importance of advances in O&M in order to reduce associated costs and to ensure that plants perform at or above expectations.[192] As a result, O&M has grown into a stand-alone business segment.[193] Solar panel manufacturers and project developers are moving into the sector because they see its potential to provide stable revenue.[194] Significant challenges remain in many developed markets where O&M is exposed to growing price pressures and where there are inconsistencies in scope and quality of service, as well as in emerging markets that lack O&M skills and local capacity for manufacturing solar components.[195] However, O&M costs of large-scale projects have fallen rapidly and yield has increased in some countries due to clustering of projects and economies of scale, improved performance and reliability of inverters, evolution in plant and tracker designs, remote monitoring with new digital technologies (such as digital infrared cameras and drones) and robotic cleaning systems.[196]

Efforts to advance recycling processes continued during 2017, although there is relatively small demand for recycling of waste and solar panels (at end-of-life, or damaged or defective panels).[197] In addition to recycling's potential environmental benefits, the process can yield materials to be sold in global commodity markets or to be used for the production of new solar panels.[198] In the United States, thin film manufacturer First Solar, which offers recycling of its own products, is designing its panels to be conducive to recycling, and one of the country's largest electronics recyclers, ECS Refining, is ramping up its capability to recycle solar PV panels.[199] French environmental services provider Veolia announced plans in 2017 to build a solar module recycling facility in France.[200] Also in Europe, the trading of used modules increased during the year, particularly in Germany, where the market for repowering is starting to take off.[201]

Innovations and advances continued in solar PV manufacturing, product performance and

efficiency

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 parameters for cells, modules and inverters.

ii 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.

iii 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.

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.

v Inverters convert direct current electricity from solar panels to alternating current for the grid.

CONCENTRATING SOLAR THERMAL POWER (CSP)

CSP MARKETS

Concentrating solar thermal power (CSP)[i] saw 100 MW of capacity come online in 2017, bringing global capacity to around 4.9 GW.[1] (→ *See Figure 28 and* ***Reference Table R19.***) Several projects that were due to enter operation during the year were delayed until 2018 and later. Although global capacity increased by just over 2% in 2017, the CSP industry was active, with a pipeline of about 2 GW of projects under construction around the world, particularly in China and in the Middle East and North Africa (MENA) region.[2]

For the second year running, South Africa led the market in new additions in 2017, being the only country to bring new CSP capacity online.[3] Also for the second consecutive year, new capacity was confined to emerging markets, with no new capacity commissioned in the traditional markets of Spain and the United States. This latter trend is set to continue because all commercial CSP capacity under construction by the end of 2017 was located outside of Spain and the United States.[4]

An estimated 13 GWh of thermal energy storage (TES) based almost entirely on molten salts was operational in conjunction with CSP plants across five continents by the end of 2017.[5] (→ *See Figure 29.*) The vast majority of CSP plants still under construction will incorporate some form of TES, which continues to be viewed as central to the competitiveness of CSP because it improves the overall operational value[ii] of the technology through the provision of dispatchable or baseload power.[6]

Parabolic trough and tower technologies continued to dominate the market, with approximately 0.9 GW of trough systems and 0.8 GW of tower systems under construction by the end of 2017.[7] In addition, Fresnel plants totalling approximately 0.1 GW were at various stages of construction, mainly in China, but also small plants in France and India.[8]

South Africa commissioned the 100 MW Xina Solar One plant (with 5.5 hours of TES; 500 MWh[iii]) during the year, increasing total capacity by 50% to 300 MW.[9] A further 200 MW was under construction at year's end: the 100 MW Kathu Solar Park (4.5 hours; 450 MWh) was expected to commence operations in 2018, and the 100 MW Ilanga 1 facility (4.5 hours; 450 MWh) was scheduled for commissioning in 2020.[10] Several additional CSP projects under development faced ongoing uncertainty in 2017 as the state-owned utility, Eskom, continued to delay the signing of PPAs under the Department of Energy's Renewable Energy Independent Power Producer Procurement Program.[11] However, progress was made in April 2018, when the department signed 27 renewable project contracts with independent power producers, including one for a 100 MW CSP project.[12]

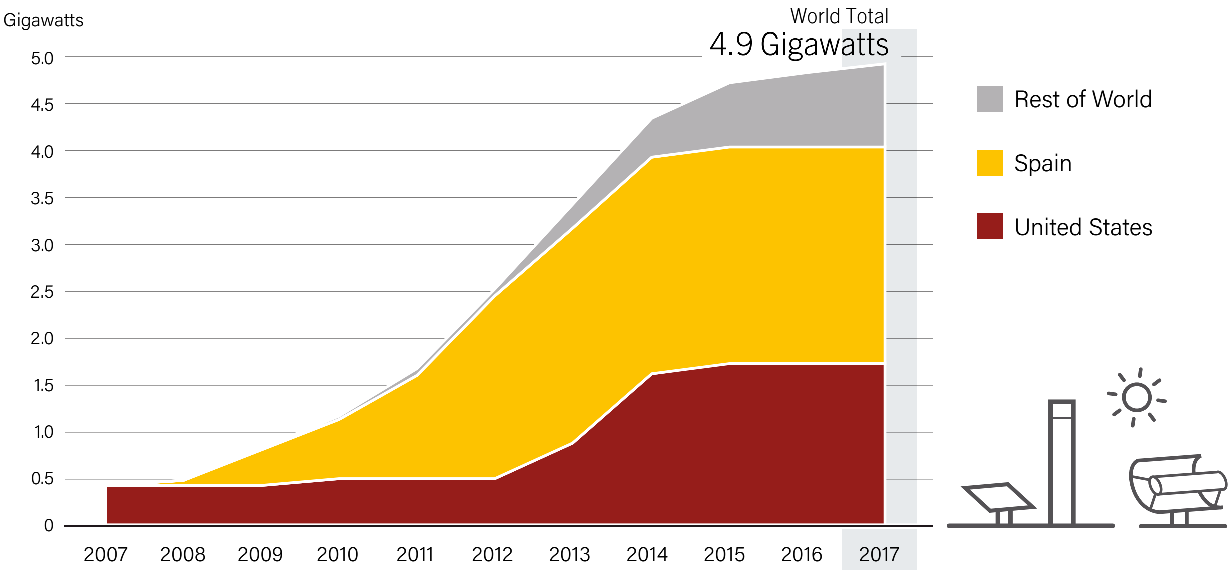
Although no other CSP capacity came online in 2017, several facilities were approaching commercial operation in countries with high direct solar irradiation levels. China's CSP market continued to gather momentum with the announcement of

i CSP is also known as solar thermal electric power.

ii The operational value of power generation and/or energy storage capacities is a measure of their ability to reduce the overall production costs of an electricity system.

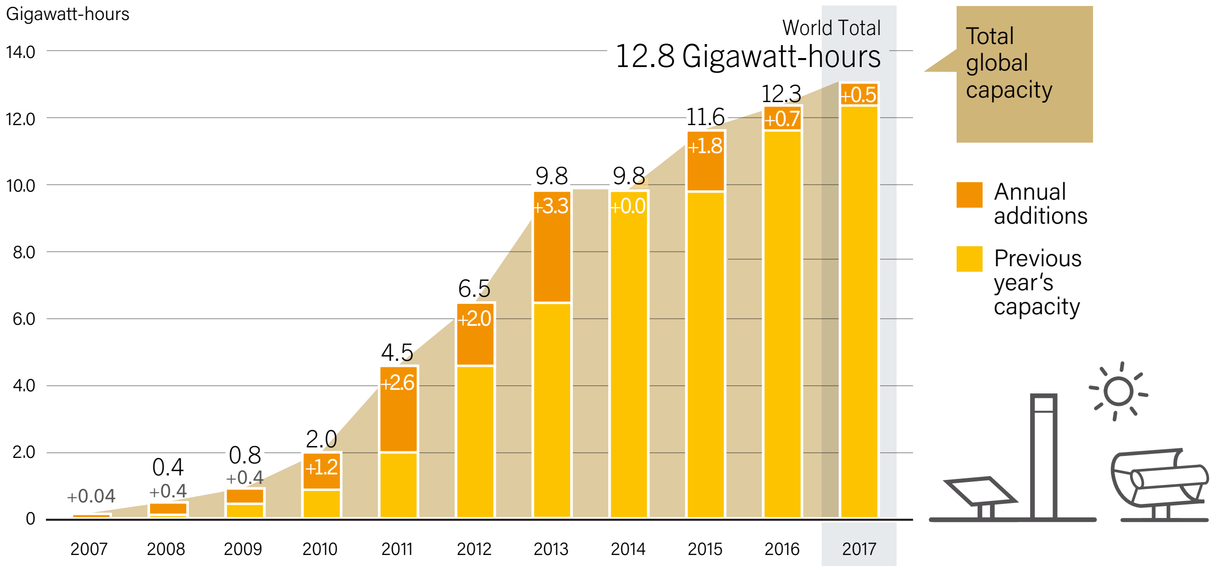
iii For CSP plants that incorporate TES, the hours of thermal storage and capacity are provided, in parentheses, in hours and in MWh. Where thermal storage capacity has been reported in hours, it is assumed that these are full load hours (i.e., hours of storage at full plant discharge capacity). This section has converted storage capacity stated in hours into MWh by multiplying peak plant capacity by the stated number of storage hours. Similarly, where sources report storage capacity in MWh the storage value in hours has been derived by dividing storage in MWh by peak plant capacity.

FIGURE 28. Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2007-2017



Source: See endnote 1 for this section.

FIGURE 29. CSP Thermal Energy Storage Global Capacity and Annual Additions, 2007-2017



Source: See endnote 5 for this section.

20 projects – including parabolic trough, tower and Fresnel facilities – with a combined capacity of 1 GW.[13] Although not all are expected to be constructed, five projects totalling 300 MW are targeting commercial operation before the end of 2018, which will qualify them for a higher FIT.[14] Several other projects are aiming for completion before the end of 2020.[15]

India was the only other country in Asia with CSP capacity under construction by the end of 2017, with the 14 MW Dadri Integrated Solar Combined-Cycle[i] plant expected to begin operation in 2018.[16]

Several countries in the MENA region had projects under construction that were expected to be completed in 2018. Two of the largest such plants were in Morocco, where the 200 MW Noor II facility (7 hours; 1,400 MWh) entered the final stages of construction during the year and commenced commissioning in early 2018.[17] The adjacent 150 MW Noor III plant (7 hours; 1,200 MWh) was also at an advanced stage of construction by year's end.[18] Once both plants are operational, Morocco's total capacity will exceed 0.5 GW.[19]

Israel's 121 MW Ashalim Plot B tower facility is due to commence operations in 2018.[20] The plant is located near the 110 MW Ashalim Plot A parabolic trough facility, which also was under construction during 2017.[21]

In Saudi Arabia, construction continued on the 43 MW Duba 1 ISCC facility and on the 50 MW Waad al Shamal ISCC plants.[22] Kuwait's 50 MW (10 hours; 500 MWh) Shagaya plant also progressed during 2017.[23] In the UAE, a CSP tender was awarded for what is expected to be the largest CSP facility in the world when completed. The 700 MW CSP plant in the Mohammed bin Rashid Al Maktoum Solar Park was designed to incorporate a 260-metre solar tower along with parabolic trough capacity and is expected to enter commissioning in 2020.[24]

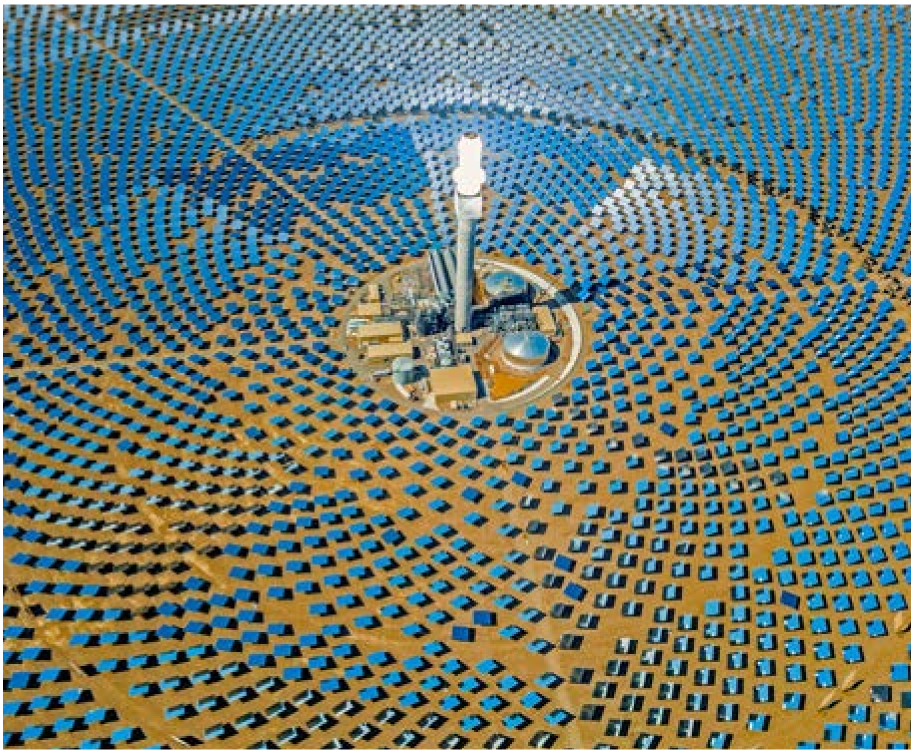
In Latin America, construction resumed at Chile's 110 MW (17.5 hours; 1,925 MWh) Atacama 1 plant.[25] Construction was halted in 2016 due to financial challenges faced by Spain's Abengoa, the initial developer and owner of the facility.[26] The plant is expected to enter operations in 2019.[27]

While Australia added no new capacity during 2017, the South Australian government signed a generation project agreement for the Aurora Power Plant, a 100 MW system (8 hours; 1,100 MWh) that is scheduled for completion in 2020.[28]

Some CSP activity continued in Europe in 2017. In Denmark, a hybrid combined heat and power facility that includes CSP technology, biomass boilers, heat pumps and oil-fired units began operations in early 2018.[29] The facility, which is connected to a district heating system, can alternate between providing heat and power at peak price periods, and heat only.[30] A 9 MW Fresnel facility was under construction in France's Pyrenees Orientales district.[31]

Spain remained the global leader in existing CSP capacity, with 2.3 GW in operation at year's end, followed by the United States with just over 1.7 GW.[32] Spain's CSP plants achieved a record output of 5.35 TWh in 2017.[33] Although these two countries accounted for over 80% of global installed capacity at the end of 2017, no capacity has entered commercial operation in Spain since 2013 and in the United States since 2015.[34] Neither country had new facilities under construction at year's end.[35]

i Integrated solar combined-cycle facilities are hybrid plants that utilise both solar energy and natural gas for the production of electricity.



CSP had a **landmark year** in 2017 in terms of bid tariffs in competitive tenders

CSP INDUSTRY

The year 2017 was a landmark one for CSP in terms of bid tariffs seen in competitive tenders, particularly in Australia, Chile and the UAE. In the Australian state of South Australia, a 150 MW plant (8 hours; 1,200 MWh) was awarded at a global record-low bid tariff capped at AUD 78 per MWh (USD 61 per MWh).[36] This bid tariff was 75% lower than the bid tariff for the Andasol CSP plant in Spain, which was the first commercial CSP plant with TES in the world and commenced operation in 2008.[37]

In Chile, successive rounds of solar auctions in March and October attracted bids for CSP with TES at USD 63 per MWh and under USD 50 per MWh, respectively.[38] In the UAE, a 700 MW project was awarded at a bid tariff of USD 73 per MWh.[39] TES will be incorporated in both the 100 MW trough (15 hours; 1,500 MWh) and 600 MW tower (10 hours; 6,000 MWh) sections of the plant.[40]

CSP developers have focused on TES as a key competitive advantage of CSP for providing competitively priced, dispatchable power.[41] This focus has been driven by the increasing cost-competitiveness of solar PV compared to CSP without TES, but also by the emerging role of CSP with TES as a viable competitor with traditional (gas, coal and nuclear) thermal power plants.[42]

The leading developers of projects either brought into operation or under construction in 2017 included ACWA Power (Saudi Arabia) and Abengoa (Spain). Numerous other developers from China, France, India, Israel, Saudi Arabia and South Africa also were active in the CSP industry.[43] Prominent engineering and construction companies working on CSP projects included (in order of MW developed or built in 2017) Sener (Spain), GE (United States), Abengoa (Spain), ACS Cobra (Spain), Acciona (Spain), TSK (Spain), Lanzhou Dacheng Technology Company (China), NWEPDI (China) and SunCan (China).[44]

The Chinese CSP industry in particular was boosted by the 20 "pilot" plants announced in September 2017.[45] China's programme has provided a launching pad from which at least five domestic CSP developers and contractors are entering the international marketplace.[46] For example, the UAE's Mohammed bin Rashid Al Maktoum Solar Park will be built in a partnership between China-based Shanghai Electric and ACWA Power.[47]

Abengoa (Spain), until recently the industry's largest developer and builder, continued with the implementation of its restructuring plan and the sale of assets aimed at achieving stability and avoiding insolvency after posting a USD 8 billion loss in early 2017.[48] This followed a few years of challenges arising from Spanish energy reforms in 2013, which included retroactive changes to renewable power contracts, a moratorium on new renewable power plants and the introduction of taxes on electricity sales.[49]

CSP price reductions have been driven by competition as well as technology cost reductions arising from research and development (R&D) activities, and less so by wide-scale adoption and economies of scale in manufacturing.[50] Critical R&D progress that played a role in the record-low CSP pricing observed in 2017 included improvements to heliostat designs that focused on using thinner glass, larger heliostat sizes, and more efficient and cheaper heliostat drives.[51]

R&D in CSP continued to receive public financial support in 2017. For example, the Dubai Electricity and Water Authority announced research funding of AED 500 million (USD 136 million), to be spent at the Mohammed bin Rashid Al Maktoum Solar Park by 2020.[52] The United States announced USD 62 million in R&D funding to reduce technological risk and to lower the average LCOE of CSP to USD 0.06 per kilowatt-hour (kWh) or less by the end of 2020 (without subsidies), despite the country's stalled CSP market.[53] In addition, the European Commission initiated funding for R&D focused on achieving a 40% reduction in CSP electricity supply prices by 2020 relative to 2013 levels.[54]

SOLAR THERMAL HEATING AND COOLING

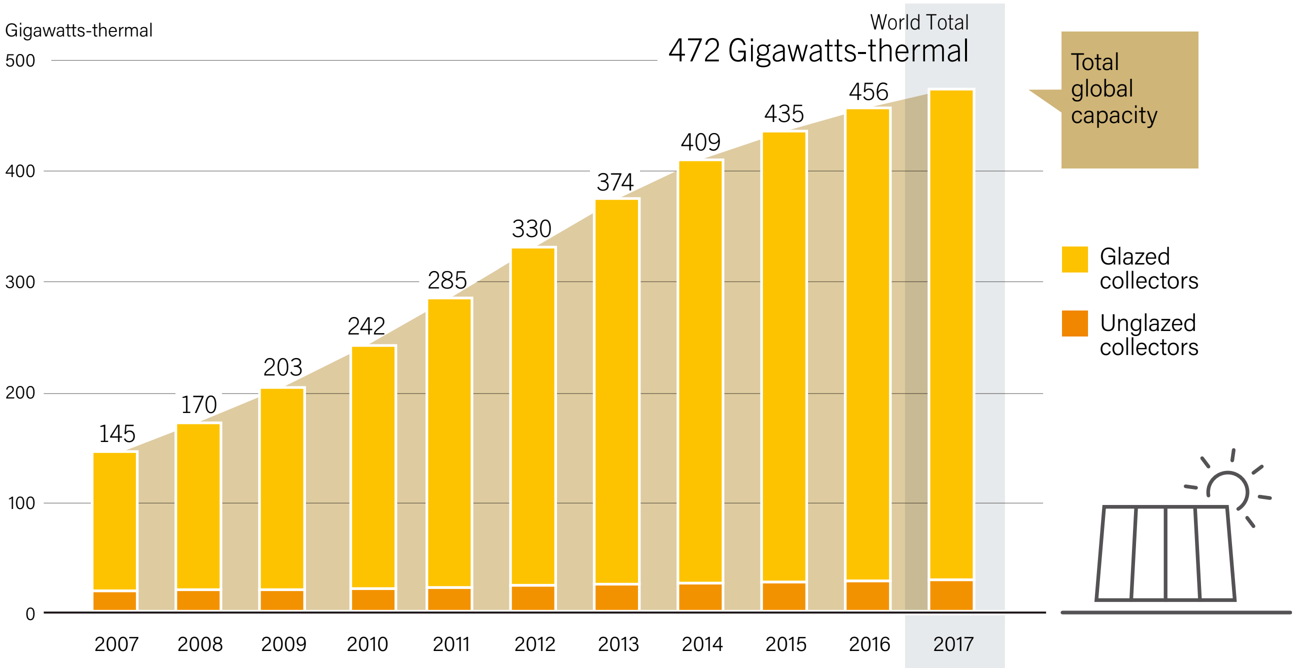
SOLAR THERMAL HEATING AND COOLING MARKETS

Solar thermal heating and cooling systems served millions of residential and commercial clients in 2017. Solar thermal technology was used for a wide range of applications: hot water, space heating and cooling, product drying, water desalination, direct steam provision for industrial processes and commercial cooking. Systems with glazed and unglazed collectors provided approximately 388 TWh (1,397 PJ) of heat annually by the end of 2017, equivalent to the energy content of 228 million barrels of oil.[1]

Globally, 35 GW_{th} of capacity of glazed (flat plate and vacuum tube technology) and unglazed collectors was newly commissioned in 2017, bringing the total global capacity to an estimated 472 GW_{th} by year's end.[2] *(→ See Figure 30.)* Gross additions for the year were down 4%, from 36.5 GW_{th} in 2016.[3] The contraction was due primarily to increasing competition with other renewable energy technologies in the residential sector – the primary sales channel for solar thermal technologies worldwide – and to low fossil fuel prices throughout the year, which negatively affected the commercial sector.[4]

The six leading countries for new installations in 2017 were again China, Turkey, India, Brazil (which dropped into fourth place behind India), the United States and Germany.[5] *(→ See Figure 31.)* Most of the top 20 countries for solar thermal installations in 2016 remained on the list in 2017. The exception was Denmark, which dropped from the ranks, leaving room for Tunisia. The top 20 countries for solar thermal installations with glazed and unglazed collectors accounted for an estimated 93% of the global market in 2017.[6]

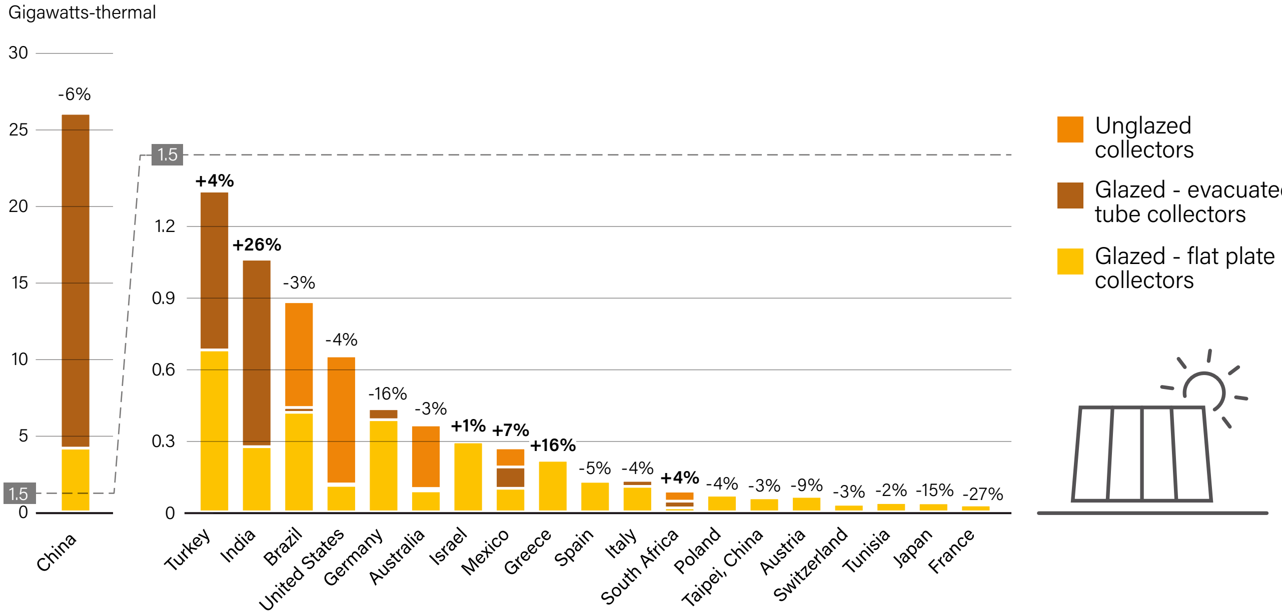
FIGURE 30. Solar Water Heating Collectors Global Capacity, 2007-2017



Note: Data are for glazed and unglazed solar water collectors, and do not include concentrating and air collectors.

Source: IEA SHC. See endnote 2 for this section.

FIGURE 31. Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2017



Note: Additions represent gross capacity added.

Source: See endnote 5 for this section.

In most of the top 20 countries, flat plate collectors dominated the market. In China and India, however, vacuum tube collectors accounted for more than two-thirds of 2017 additions, and in Turkey they accounted for about 50%.[7] Considering all new installations in the top 20 markets, vacuum tube collectors accounted for 73% (down from 75% in 2016), followed by flat plate collectors with 23% (up from 21% in 2016) and unglazed water collectors with 4% (unchanged).[8]

China was again the world´s largest solar thermal market by far. New collector installations in 2017 totalled 26.1 GW_{th} (37.26 million m^2) in China, 19 times greater than the total additions in the second largest market, Turkey.[9] China's rural retail market continued to decline during the year because of reduced construction activity and market saturation, but the decline has been increasingly offset by rising demand for solar space heating and solar water heaters for large real estate projects.[10] Therefore, the strong downward trend of recent years flattened somewhat in 2017, with new installations declining only 6% relative to 2016, which saw a 9% one-year market decline, following an even larger year-to-year contraction (-17%) in 2015.[11]

The transition from vacuum tube collectors to flat plate collectors accelerated in China during 2017, with new flat plate collector area increasing 13%, while the market for vacuum tube collectors decreased 9%.[12] The rise in sales of flat plate collectors in China is due to increasing demand for facade- and balcony-integrated applications, where flat plate collectors are safer and more aesthetic.[13]

New solar thermal applications, such as space heating and cooling, as well as industrial and agricultural applications, accounted for almost 10% of the collector area installed in China during 2017.[14] These included several large-scale solar space heating and cooling systems, such as a 1 MW_{th} installation for central heating in the Olympic sports centre in Shijiazhuang (Hebei province), a 2.2 MW_{th} system for residential heating in Hohehot (Inner Mongolia) and a 1.1 MW_{th} concentrating collector system to heat a sports office in Tianjin.[15]

This trend towards the use of solar thermal systems for space heating is accelerating. In December 2017, the Chinese National Development and Reform Commission issued a Clean Space Heating Plan (2017 to 2021) for northern China that calls for the replacement of coal boilers with solar water heaters or heat pumps to reduce air pollution.[16]

Turkey was again the second largest market for new installations, adding 1.35 GW_{th} (1.93 million m^2) in 2017, up 4% over 2016.[17] Solar water heater sales remained high, even without direct investment subsidies, due to a strong construction market.[18] Approximately 60% of new solar thermal capacity was installed in new buildings, primarily in the south and west of the country.[19] This was stimulated by Turkey's urban transformation programme, which entails replacing multi-family houses in urban areas with new earthquake-resistant high-rise buildings.[20]

As in previous years, vacuum tube collectors gained market share in Turkey's colder regions, such as middle and eastern Anatolia, accounting for about half of the country´s additions in 2017.[21] Natural circulation systems dominated Turkey's residential market, whereas forced circulation systems made up the majority of commercial installations in hotels, hospitals, stadiums and military bases.[22]

India's additions in 2017 were up 26% over the previous year's installations, to 1.06 GW_{th} (1.52 million m^2).[23] The market reached a new level of maturity following a brief period of contraction after the national incentive programme ended in 2014.[24]

Starting in 2016, India's national solar thermal industry association called for binding standards on imported vacuum tubes and vacuum tube collector systems, and in 2017 the initial impacts were apparent in the market.[25] Several states invited tenders for solar thermal systems and required certificates from the Bureau of Indian Standards, which were available only for flat plate collectors as of 2017.[26] As a result, flat plate collectors accounted for 26% of installations, up from 12% in 2016, with nearly 0.4 million m^2 sold by the small number of remaining flat plate collector manufacturers in India.[27]

Brazil installed 884 MW_{th} (1.26 million m^2) of glazed and unglazed collectors in 2017 to rank fourth for new capacity.[28] Whereas the pool heating market (unglazed) grew 15% relative to 2016, the flat plate collector market for domestic hot water applications declined 17%.[29] This represented a strong break from Brazil's high average annual growth rates (11%) for installations of glazed collectors between 2010 and 2015.[30] Constraints on the market included the national economic crisis, which reduced investment and purchasing power, and delays in implementing the next phase of the social housing programme Minha Casa Minha Vida. Vacuum tube collectors were again a niche market (2%), but the area added during the year was up 27% relative to 2016.[31]

The United States was the world's fifth largest market for all types of solar thermal collectors in 2017 (658 MW_{th}; 0.94 million m^2), and the largest market for unglazed collectors for swimming pool heating (536 MW_{th}).[32] The unglazed segment accounted for 81% of new additions in the United States during the year.[33] Despite continuing low oil and natural gas prices and an increasing focus on solar PV, new installations of all collectors dropped only 4%.[34]

For unglazed collectors, the United States was followed by Brazil (443 MW_{th}), Australia (266 MW_{th}) and Mexico (80 MW_{th}).[35]

A record number

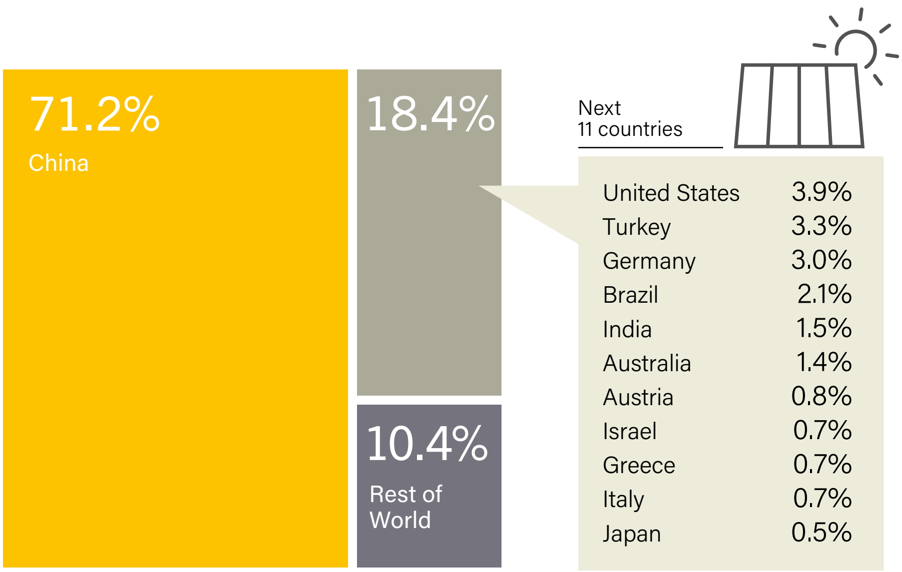
of new industrial solar heat systems were operating in 2017

California, Florida and Hawaii were the three key US states for solar thermal installations. California's relatively strong market was due to the California Solar Initiative – Solar Thermal, which was extended in May 2017 for 2.5 years and provides incentives for solar thermal systems that replace gas water heaters.[36] Other US states with attractive incentive programmes – including Arizona, Massachusetts and North Carolina – also contributed significantly to additions in 2017.[37]

Germany was again the world's sixth largest market, with additions of 437 MW_{th} (625,000 m^2) in 2017.[38] However, 2017 was the country's weakest year for solar thermal collector additions in more than a decade.[39] The market decrease (down 16%) was the result of a sharp decline in the sales of combi systems, which supply both space heating and hot water.[40] In contrast, the year saw record demand in Germany for heat pumps used for space heating, which attracted attention from installers and end consumers due to their high ratings within the European energy label.[41]

The top six countries for new installations in 2017 also were the top countries for cumulative capacity at the end of 2016 (latest data available), but in a different order. With its year-end total of 325 GW_{th}, China accounted for 71% of total global capacity (456 GW_{th}).[42] It was followed distantly by the United States, Turkey, Germany, Brazil and India.[43] (→ *See Figure 32.*)

FIGURE 32. Solar Water Heating Collectors Global Capacity in Operation, Shares of Top 12 Countries and Rest of World, 2016



Note: Data are for glazed and unglazed solar water collectors. Totals may not add up due to rounding.

Source: IEA SHC. See endnote 43 for this section.

Although most solar thermal capacity continued to be installed as solar water heaters in individual buildings, the use of *solar district heating technologies* expanded further during 2017, in an increasing number of countries. Driving factors included increased awareness of the potential for solar district heating to reduce carbon emissions in the heating sector (particularly in Europe), and the potential to avoid the negative health impacts of coal boilers in urban areas (mainly in Poland and China) by feeding solar thermal energy into coal-fuelled district heating networks.[44]

Globally, at least 296 large-scale solar thermal systems (each >350 kilowatts-thermal (kW_{th}), or 500 m^2) were connected to district heating networks or provided space heating for large residential, commercial and public buildings, for a total of 1.2 GW_{th} (1.74 million m^2) in operation by the end of 2017. These included glazed and concentrating solar thermal collectors.[45] *(→ See Figure 33.)*

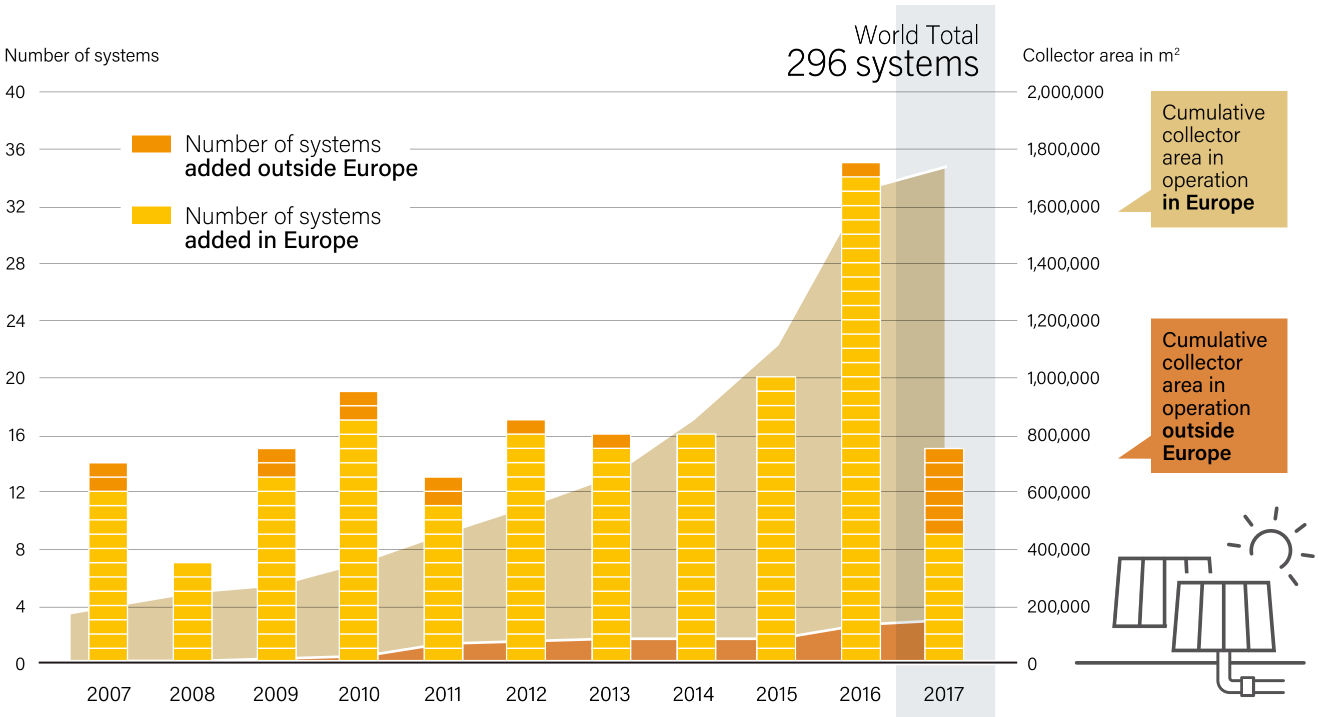
The vast majority (90%) of solar thermal capacity for district heating was in Europe, with Denmark alone accounting for 76% (932 MW_{th}) of the global total by the end of 2017.[46] Markets outside Europe had a total of 19 installations, with a cumulative 118 MW_{th} of capacity.[47] The world's two largest district heating plants both started operations in late 2016: a 110 MW_{th} flat plate collector field in Silkeborg, Denmark and a 52.5 MW_{th} parabolic trough collector system that heats 500,000 m^2 of living and commercial space near the town of Baotou in Inner Mongolia, China.[48]

In 2017, following Denmark's 2016 record for installations of solar thermal district heating systems (347 MW_{th}), the country brought online only two small plants and three extensions, increasing total capacity by 19.7 MW_{th} (26,636 m^2).[49] The significant decline in new capacity is due to project development requiring several years of planning. All new activities beyond 2016 were stalled because the new energy savings mandate for utilities was signed only at the end of 2016.[50] Consequently, although several new projects were launched during 2017, most could not be completed by year's end.[51]

Elsewhere in Europe during 2017, Austria brought online one new district heating plant (0.9 MW_{th}), Germany added two (totalling 1.3 MW_{th}), and Sweden added one (0.4 MW_{th}) as did Serbia (0.63 MW_{th}).[52] France's subsidy scheme for large-scale solar thermal projects, launched in 2015, saw its first results with the inauguration of the country's first large solar district heating field (1.6 MW_{th}) in December.[53]

With the growing recognition that solar thermal district heating may be the most cost-effective way to decarbonise the heating sector, several other countries in Europe have organised stakeholder workshops and studies on renewable/solar district heating. Increased awareness of solar district heating among Germany's municipal utilities resulted in the submission of a large number of applications under the country's newly enacted subsidy scheme (District Heating Network 4.0), which aims to increase the number of fourth-generation district heating networks.[54] The scheme provides grants for up to 60% of the costs of feasibility studies and up to 50% of investment in new district heating networks, as long as renewable sources (solar or biomass) or waste heat meet at least 50% of heating demand.[55]

FIGURE 33. Solar District Heating Systems, Global Annual Additions and Total Area in Operation, 2007-2017



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 45 for this section.

The top markets

for concentrating heat technologies in 2017 were Oman, China, Italy, India and Mexico

Also in 2017, Slovenia announced that it would fund 35-55% of the total cost (with the amount depending on the size of the investor) of new solar thermal or biomass plants connected to district heating systems.[56] In early 2018, Poland announced a financial support scheme for renewable district heating projects to reduce severe air pollution in several cities.[57]

Interest in solar district heating also expanded beyond Europe during 2017. A 0.5 MW_{th} solar district heating plant was inaugurated in the Kyrgyz Republic's capital city of Bishkek.[58] In Australia, a new 0.5 MW_{th} collector field started feeding into the district heating system of a large university campus.[59]

China is the world's largest market for district heating in addition to being the largest solar thermal market – a promising combination. In 2017, the Chinese central government conducted feasibility studies in more than 20 counties and cities in Tibet, where many houses lack space heating, and awarded funding for two sites.[60] By year's end, construction was under way for a parabolic trough collector field (12.6 MW_{th}) in Shenzha, and a 14 MW_{th} collector field with 15,000 cubic metres of pit storage was contracted (to be commissioned by the end of 2018) in the town of Langkazi.[61]

Concentrating collector technologies for heat and steam production have supplied only niche markets in recent years, and thus their capacity is not included in global and national capacity statistics. However, for the first time, data for new installations with concentrating collectors are available. In 2017, an estimated concentrating solar thermal capacity of 143 MW_{th} (204,487 m^2) was installed globally, with Oman (100 MW_{th}), China (15 MW_{th}), Italy (14 MW_{th}), India (2.8 MW_{th}) and Mexico (2.8 MW_{th}) being the largest markets.[62] These countries have good direct irradiation potential, which is critical for concentrating collector technologies. The majority of these installations are used for industrial applications (so-called solar heat for industrial processes, or SHIP), such as food and beverage production or textile and automotive manufacturing; in China, however, almost all systems are used for hot water and space heating of commercial buildings, and in India and Mexico some systems are used by large commercial heat consumers such as laundries, hotels and hospitals.[63]

The project in Oman was the largest concentrating collector system for industrial steam production constructed as of end-2017. The 100 MW_{th} parabolic trough collector field, placed in greenhouses for an enhanced oil recovery plant, was completed in 2017 and started solar steam production in early 2018.[64] This capacity corresponds to four steam-producing blocks – one-tenth of the final total plant size ordered by state-owned Petroleum Development Oman.[65] The construction of eight additional blocks (200 MW_{th}) was announced for completion in 2018.[66]

Projects that began operation in 2017 included two demonstration plants in Italy, each with a 10,000 m^2 concentrating collector array (7 MW_{th}), to heat thermal oil to 300 °C (backed up by biomass boilers) to increase the electrical efficiency of distributed power generation units.[67] In Mexico, 19 commercial systems with parabolic trough collectors (totalling 2.8 MW_{th}) were constructed to supply heat for manufacturing businesses, hotels and sport clubs.[68]

India was the first country worldwide (in 2010) to enact an incentive programme specifically for concentrating solar thermal technologies. However, as of 2017, the 30% investment subsidy was paid on a case-by-case basis, resulting in only a few new installations with a total of 2.8 MW_{th}.[69] This was a significant drop from 2016, when 18 MW_{th} of concentrated collector capacity was added.[70] As of early 2018, the government confirmed the extension of the investment subsidy scheme until 2020.[71]

In addition to concentrating collectors, flat plate and vacuum tube collectors are used increasingly to provide heat for industry around the world. Industry accounts for a significant portion of global heat demand, and solar energy is suitable for meeting needs in the low- to medium-temperature range (below 400 °C), which account for about 50% of industrial heat demand.

In 2017, *SHIP installations* had a record year, with at least 110 systems (135 MW_{th}) starting operations, raising the world total by 21% to 635 SHIP plants in operation by year's end.[72]

Not included in this statistic are 378 small SHIP units (totalling 1.6 MW_{th}) that were newly installed in the silk production centre of Sidlaghatta, in southern India, to enable a switch away from wood or briquettes used in traditional stoves.[73]

Drivers for market growth varied by region. In Mexico and Oman, for example, solar thermal heat was more cost-effective than heat from fossil fuel boilers, while in other countries, such as China, growth was driven by government policies and other incentives.[74] In China, solar heat is increasingly being used to replace coal-fired boilers in order to reduce air pollution. In 2016, the Chinese government established an ambitious target to meet 10% of industrial heat demand with solar thermal energy by 2020.[75] The largest new SHIP system worldwide completed during 2017 is a 2.3 MW_{th} vacuum tube collector installation that supplies heat for a factory in Tibet, China.[76]

In addition to the key SHIP markets of China, India, Mexico and Oman, 15 other countries saw such systems installed in 2017.[77] For example, the second largest SHIP plant completed during the year provides steam for a meat producer in Afghanistan. The 2.3 MW_{th} parabolic trough collector field was financed by the Asian Development Bank.[78]

Solar thermal air conditioning and cooling remained a niche market in 2017. As in past years, demand for solar thermal cooling systems was stimulated by three factors: the potential to reduce electricity consumption, including peak loads; the potential to use natural refrigerants, such as water, which is appealing to European customers in particular; and the ability to provide both heating and cooling, depending on the needs over the year.[79]

In the Middle East, several countries and regions – including Kuwait, Saudi Arabia and the Emirate of Dubai – are gradually removing subsidies for electricity, which in turn is generating demand for renewable cooling solutions (air conditioning accounts for the highest portion of household and commercial electricity bills).[80] In 2017, some early demonstration plants were constructed in the region (by European suppliers), including a small solar cooling unit (with a 10 kW sorption chiller) at a waste heat recovery company in Dubai and a solar thermal cooling system (using 234 m^2 of evacuated flat plate collectors) for a company in Kuwait.[81]

Asia was again the largest market for thermally driven chillers, even though only a handful of large solar energy-driven cooling systems were installed in the region in 2017 and early 2018.[82] India saw the completion of its first solar thermal air conditioning system in a public building driven by vacuum tube collector field (1,575 m^2), and IKEA Singapore completed installation of a solar thermal cooling system (2,475 m^2 flat plate collector field) in early 2018.[83]

China has ambitious objectives for solar cooling: its 13th Five-Year Plan calls for solar thermal energy to cover 2% of the cooling load in buildings by 2020.[84] Initial market impacts were seen in late 2017 with the announcement of plans for two large installations.[85]

In southern European countries that have cooling needs during summer months, solar thermal solutions that combine solar cooling with solar hot water have been shown to improve the economics of the solar investment.[86]

SOLAR THERMAL HEATING AND COOLING INDUSTRY

China was home to the largest collector manufacturers in 2017 for both key solar thermal technologies: vacuum tube and flat plate collectors. As in previous years, the manufacturers of vacuum tube collectors were all from China: Sunrise East Group (including the Sunrain and Micoe brands), Himin and Linuo Paradigma.[87] For the first time, however, Chinese companies also dominated the list of the world's largest flat plate collector manufacturers. The Austrian-based company Greenonetec, which held the top position for flat plate production until 2016, was relegated to second place by Sunrise East Group, and followed by Jinheng Solar (with its export brand BTE Solar) and Five Star, all of which are Chinese-based manufacturers.[88] Furthermore, Greenonetec has been majority-owned (51%) since May 2017 by the Chinese-based Haier Group, one of the largest manufacturers of household appliances in the world.[89]

Jinheng Solar, a flat plate collector manufacturer, responded to the expanding demand for flat plate collectors by building new automated collector production lines, more than doubling the factory's collector area production volume.[90] A new Chinese company, Sanqiaoneng, which manufactures highly efficient absorbers for flat plate collectors and concentrates on high-quality solutions for solar heating and cooling, was also launched in 2017.[91] The solar heating department of the Sunrise East Group reported a 44% increase in sales of flat plate collectors for commercial housing projects in southern China, although the company's total collector sales fell significantly in 2017 due to a substantial decline in the retail market for individual housing units.[92]

Elsewhere in Asia, two manufacturers of flat plates in Turkey and one in India were among the world's largest companies in the industry.[93] Increasing demand in India enabled Emmvee Solar Systems to re-enter the list of the 20 top flat plate collector manufacturers worldwide.[94]

Europe also was home to several of the largest flat plate collector manufacturers, with four based in Germany, two each in Greece and Spain, and one each in Italy and Poland.[95] Germany's Bosch Thermotechnik remained the largest entirely European-owned manufacturer of flat plate collectors in 2017. However, its sales were well below those of the top Chinese-based companies due to continuing contraction in Germany and the weak market in Brazil – two of the company's key markets.[96]

German and Austrian manufacturers, in particular, faced challenges during 2017 as a result of declining sales in domestic markets. Consolidation continued in Austria, where Sonnenkraft purchased its competitor Tisun in December 2017. Due to substantial debt accumulation, in early 2018 Sonnenkraft asked for Tisun to be put into administration.[97]

Despite the declining number of installations in key solar thermal markets worldwide, more manufacturers of solar collectors and storage tanks adapted their product lines and sales strategies successfully during 2017 in order to compete more effectively in the shrinking global market.[98]

Several export-oriented companies profited from increasing demand for solar water heaters in North Africa (where demand shifted from vacuum tubes to flat plate collectors), in Italy (due to an attractive national subsidy scheme) and in growing markets in the Middle East and in Central and South America.[99] Collector producers in Greece, for example, saw their total exports rise again in 2017, by 41% (to 325 MW_{th}), following a 14% increase in 2016, due to cost-competitiveness and the good reputation of their products.[100] The capacity of their exports exceeded domestic sales (221 MW_{th}).[101] Spain's three collector manufacturers – BDR Thermea, Delpaso Solar and Termicol – exported 88 MW_{th} of solar thermal collectors in 2017, an increase of 46% over 2016.[102]

The year 2017 saw International co-operation with experienced manufacturers supporting the design of new collector factories in China, Moldova and Uzbekistan. Sweden's Absolicon Solar Collector sold its production line for covered parabolic trough collectors to a newly formed Chinese joint venture, Heli New Energy, which combines knowledge of manufacturing and energy efficiency project development.[103] The Polish system supplier Makroterm supported the Moldovan company Raut in commissioning an assembly line for vacuum tube collectors in September.[104] The Turkish collector manufacturer Solimpeks consulted for the Uzbek Artel Group in the layout of a state-of-the-art collector and tank factory that went into operation in November.[105]

A strong and growing supply chain of around 80 turnkey SHIP suppliers helped to drive market growth in 2017.[106] However, despite the record number of installations during the year, less than half of them commissioned a project due to low fossil fuel prices, lack of awareness of the technologies and a consumer focus on the high upfront costs.[107]

Most manufacturers of large-scale thermally driven chillers (greater than 50 kW) are based in Asia, whereas European producers focus on chiller units between 5 and 50 kW. The number of solar thermal cooling system suppliers in Europe declined during 2017, largely because some chiller manufacturers shifted to combined solar PV-split air conditioning systems, which they consider to be more economical, especially in central Europe where the cooling season is short.[108] The remaining solar thermal cooling system suppliers in Europe continued to face challenges during 2017 due to high system costs and the increasing popularity of solar PV, which is simpler and more economical for space cooling at relatively small scale. However, some found demand in niche markets, such as commercial buildings in southern Europe (e.g., Italy and Spain).[109]

WIND POWER

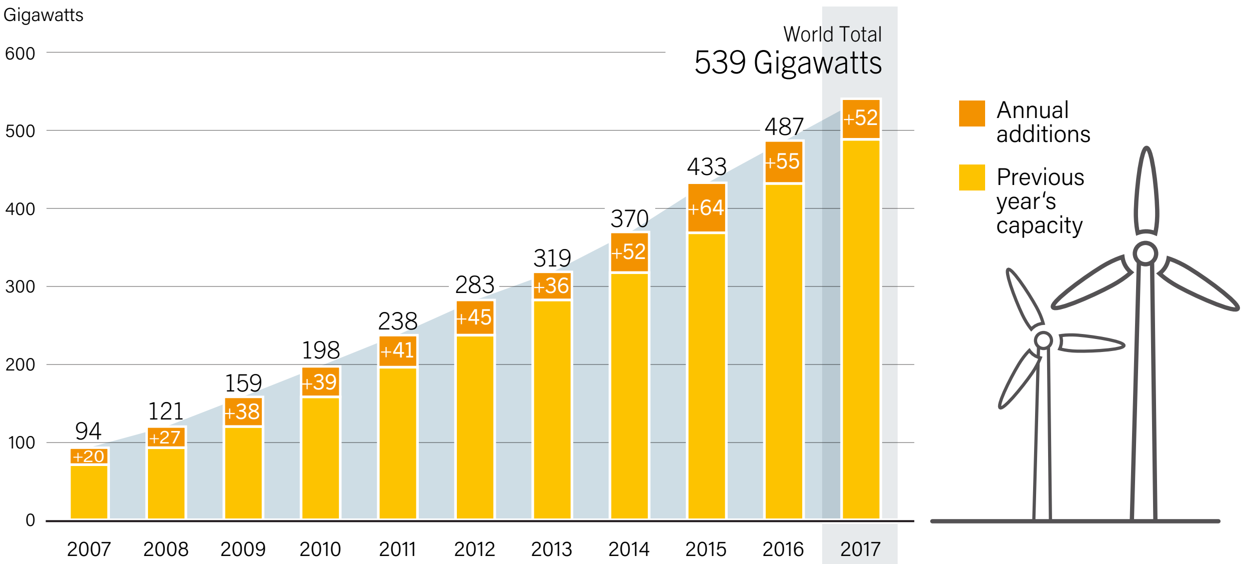
WIND POWER MARKETS

Wind power had a relatively modest year compared with 2015 and 2016, but still saw its third strongest 12-month period, with more than 52 GW added globally in 2017.[1] Cumulative capacity increased nearly 11%, to around 539 GW.[2] *(→ See Figure 34.)* As in 2016, a decline in Chinese installations accounted for much of the contraction, while several other markets, including Europe and India, had record years.[3] By the end of 2017, more than 90 countries had seen commercial wind power activity, and 30 countries – representing every region – had more than 1 GW in operation.[4] Nevertheless, for the first time in at least a decade, the trend towards greater diversification of markets reversed, with a concentration of new wind power capacity in a smaller number of markets.[5]

Strong growth in some of the largest markets (e.g., Germany, India and the United Kingdom) was driven by significant policy and regulatory changes, which pushed many developers to commission projects quickly to take advantage of expiring support schemes; elsewhere, deployment was driven by wind energy's cost-competitiveness and its potential environmental and other benefits.[6] Rapidly falling prices for wind power, both onshore and offshore, have made it the least-cost option for new power generating capacity in a large and growing number of markets.[7] Around the world, wind power is quickly becoming a mature and cost-competitive technology.[8]

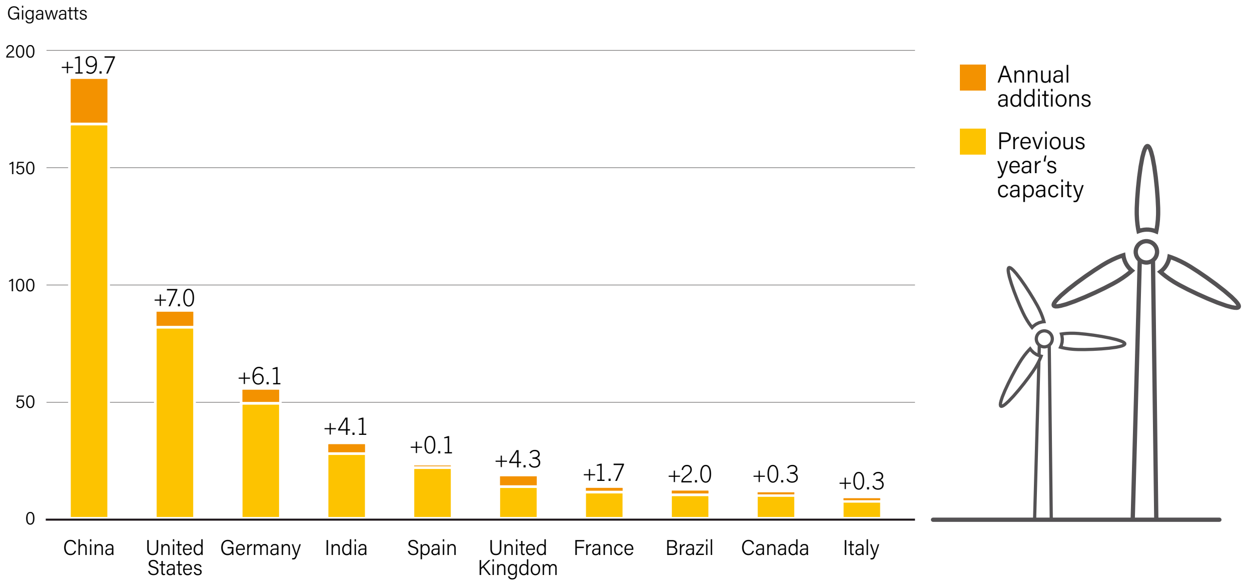
Asia was the largest regional market for the ninth consecutive year, representing nearly 48% of added capacity (with a total exceeding 235 GW by year's end), followed by Europe (over 30%), North America (14%) and Latin America and the Caribbean (almost 6%).[9] China retained its lead for new installations, despite

FIGURE 34. Wind Power Global Capacity and Annual Additions, 2007-2017



Source: See endnote 2 for this section.

FIGURE 35. Wind Power Capacity and Additions, Top 10 Countries, 2017



Note: Additions are net of decommissioning.

Source: See endnote 11 for this section.

a second year of contraction, and was followed distantly by the United States, Germany, the United Kingdom and India.[10] Others in the top 10 for additions were Brazil, France, Turkey, South Africa and Finland.[11] *(→ See Figure 35 and **Reference Table R21.**)* At year's end, the leading countries for total wind power capacity per inhabitant were Denmark, Ireland, Sweden, Germany and Portugal.[12]

China added nearly 19.7 GW in 2017, for a total installed capacity of approximately 188.4 GW.[13] The decline in new installations, for the second year running, was due primarily to restrictions on deployment in regions with high curtailment rates and to a shift in focus to lower wind speed areas to better harmonise wind power expansion with grid infrastructure investments and to reduce curtailment.[14] About 15 GW was integrated into the national grid and started receiving the FIT premium in 2017, with approximately 164 GW[i] considered officially grid-connected by year's end.[15]

Asia was the largest regional market for wind power for the

ninth

consecutive year

Although the northern and western provinces were still home to a significant portion of China's wind power capacity, new installations declined further in regions with the worst curtailment rates, and they continued to rise in some of the most populous provinces, with significant construction in low-wind speed regions of eastern, central and southern China.[16] The top provinces for capacity additions in 2017 were Shandong (2.2 GW), Henan (1.3 GW) and Shaanxi (1.1 GW), all of which are relatively close to demand centres.[17]

Overall, an estimated 41.9 TWh of potential wind energy was curtailed in 2017 in China – a national average of 12% for the year, down from 17% in 2016.[18] Most curtailment was concentrated in a handful of provinces, all of which saw significant reductions relative to 2016 in response to a number of policies, including those to expand electrification (especially of heating in industry), to encourage direct trade of renewable energy among large consumers and to construct new transmission lines.[19] Even with curtailment, wind power's share of total generation in China has increased steadily in recent years, reaching 4.8% in 2017 (up from 4% in 2016 and 3.3% in 2015).[20]

Elsewhere in Asia, India installed a record 4.1 GW to rank fifth for additions, and easily maintained its fourth-place global position for cumulative capacity, ending the year with more than 32.8 GW.[21] Record installations early in 2017 were due largely to a rush to capitalise on national incentives before they expired and to the country's transition from FIT-based PPAs to auctions.[22] But the pace of additions slowed significantly during the year due to an abrupt end to the generation-based incentives scheme and to a reduction in accelerated depreciation benefits, combined

i Statistics differ among Chinese organisations and agencies as a result of what they count and when. For more information, see endnote 15 for this section.

with a gap in auctions for new capacity (due at least in part to flat power demand); the results were decreased orders and factory closings.[23] Low bids in India's first tender led to the cancellation of state FIT schemes, and power producers came under pressure from states to renegotiate pricing.[24]

Turkey's 2017 installations were about half of those in 2016 due to business cycles, but the country again ranked among the top 10 globally for new capacity, adding almost 0.8 GW for a total approaching 6.9 GW.[25] Turkey ended the year with a round of tenders for 2.1 GW of wind power capacity.[26] Pakistan and Japan each added close to 0.2 GW, followed by the Republic of Korea (0.1 GW), with Mongolia, Vietnam, Thailand and Chinese Taipei adding relatively small amounts of capacity.[27]

The EU installed roughly 15.6 GW of gross capacity (15 GW net, accounting for decommissioning), up 25% over 2016 additions to a record high, bringing its total capacity to 168.7 GW (153 GW onshore and 15.8 GW offshore).[28] In a rush to beat a change in the EU regulatory framework (which required member states to introduce competitive auctions for the allocation of support as of 2017), the region saw record additions both onshore (12.5 GW) and offshore (3.2 GW).[29] Wind power represented an estimated 55% of new generating capacity added during 2017, and its share in the EU's total power capacity reached 18% (up from 12% in 2012).[30] By year's end, 16 EU member states had more than 1 GW each, and 9 had more than 5 GW.[31] For the EU as a whole, wind power generation in 2017 was up 12% over 2016, due in part to better wind resources, and it met about 11.6% of total electricity demand.[32]

Six EU countries – Germany, the United Kingdom, France, Belgium (0.5 GW), Ireland (0.4 GW) and Croatia (0.1 GW) – set records for newly added capacity in 2017.[33] Ireland added the most wind power capacity relative to its electricity consumption.[34] Finland (0.5 GW) also was among the top EU countries for installations as the last projects under its FIT came online.[35] In all, 17 countries added capacity, but the market was highly concentrated with the top three countries accounting for 80% of the EU's newly installed capacity.[36]

Germany was again the top installer in the region and the third largest globally, adding 6.6 GW (6.1 GW net) for a total of 56.1 GW (50.8 GW onshore and 5.4 GW offshore).[37] Germany's record year was largely driven by efforts to take advantage of guaranteed FITs as the country moved to a system of feed-in premiums with auctions for most installations (in line with European Commission requirements).[38] Wind energy generation increased 33% relative to 2016, due to an increase in total capacity (up 12%) and to improved wind resource conditions, and it accounted for nearly 19% of Germany's total net electricity generation in 2017.[39]

The United Kingdom added 4.3 GW (nearly 2.6 GW onshore and 1.7 GW offshore), increasing its total capacity by 29%, to 18.9 GW.[40] The significant increase (five times 2016 additions) was due largely to a dash to install projects prior to expiration of the Renewables Obligation Certificates framework for onshore installations.[41] France saw record additions (1.7 GW) for the second consecutive year, for a total approaching 13.8 GW.[42] Spain has added little since early 2013, when a moratorium was placed on public support for renewables.[43] In 2017, however, the country saw its largest increase (96 MW) in four years and held auctions for new capacity, with more than half (4.1 GW) going to wind power.[44] Sweden saw the year's largest corporate deal anywhere in the world, with Norsk Hydro committing to purchase most of the electricity from a 650 MW wind power project.[45]

Elsewhere in Europe, Norway added a record 0.3 GW, and Ukraine and Serbia each added some capacity.[46] The Russian Federation held a wind power tender in 2017 and commissioned its first commercial-scale wind farm in early 2018.[47]

North America ranked third globally for new capacity brought into operation in 2017. The United States held onto the second spot for annual additions (7 GW), although the market was down (by 15% relative to 2016) for the second consecutive year.[48] Much of the year's activity focused on partial repowering[i] (upgrading of existing projects).[49] The country also was second, after China, for cumulative capacity at year's end (89 GW) and for electricity generation from wind power.[50] Wind power ranked second after solar PV for net US capacity additions.[51]

i Partial repowering refers to the installation of new components (e.g., drivetrain or rotor) on an existing tower and foundation to improve performance.

Texas alone added 2.3 GW, for a year-end total of 22.6 GW; if Texas were a country, it would rank sixth worldwide for cumulative capacity.[52] Wind power accounted for nearly 15% of electricity generation in the state during 2017.[53] Utility-scale wind power accounted for more than 15% of annual generation in eight additional states, more than 30% in four states (including Iowa, at 36.9%) and 6.3% of total US electricity generation.[54]

Increasingly, economics are driving utilities, corporations and other actors in the United States to sign PPAs for wind energy or to invest in wind power projects directly.[55] PPAs totalling almost 5.5 GW were signed in 2017, up 29% over 2016.[56] Corporations and other non-utility customers accounted for 40% of contracted capacity; utilities signed the rest and announced plans to develop 4.2 GW of their own projects.[57] *(→ See Feature chapter for more on corporate sourcing.)* By year's end, an additional 13.3 GW of wind power capacity was under construction in the United States.[58]

To the north, Canada saw its market halved (to 0.3 GW) for the second consecutive year but remained among the top 10 countries for total capacity (12.2 GW).[59] Despite the decline in new installations, wind energy has represented Canada's largest source of new electricity generation for more than a decade.[60] The province of Ontario continued to lead in cumulative capacity, followed by Québec, while Prince Edward Island had the country's highest rate of wind energy penetration (29%).[61]

Latin America and the Caribbean added about 3.1 GW (down almost 13% relative to 2016) for a regional total of about 21.9 GW in at least 25 countries.[62] Brazil continued to rank among the global top 10, with about 2 GW commissioned in 2017, for a year-end total approaching 12.8 GW.[63] After a two-year lull, and following the cancellation of 0.3 GW-worth of construction licences from previous auctions (at the request of developers), Brazil resumed auctions in late 2017.[64] In the absence of auctions, private contracts with very competitive PPA prices helped to drive installations.[65] Wind power accounted for 7.4% of Brazil's electricity generation in 2017 (up from 5.9% in 2016).[66]

Other countries adding capacity in the region included Mexico, which ranked second regionally for new installations (0.5 GW) and for total capacity (4 GW), followed by Uruguay (added 0.3 GW), Chile (added 0.1 GW) and Costa Rica (added 59 MW).[67] Argentina completed little capacity in 2017, but investment increased significantly in response to government tenders, and the country ended the year with a project pipeline of at least 3 GW.[68]

Africa and the Middle East saw little new capacity enter operations in 2017.[69] South Africa was the only African country to commission wind power projects in 2017, adding about 0.6 GW for a total of 2.1 GW.[70] However, Kenya and Morocco had large projects, including Kenya's Lake Turkana wind farm, that were awaiting grid connection as of early 2018.[71] In the Middle East, Saudi Arabia took the first steps towards a competitive tender and inaugurated at least one commercial turbine, and Iran brought one 30 MW project online.[72] Jordan continued to lead the region for total capacity.[73]

The Oceania region had another quiet year. Only Australia added capacity (0.6 GW), bringing its total to about 4.6 GW by year's end, with significant additional capacity under construction and development.[74]

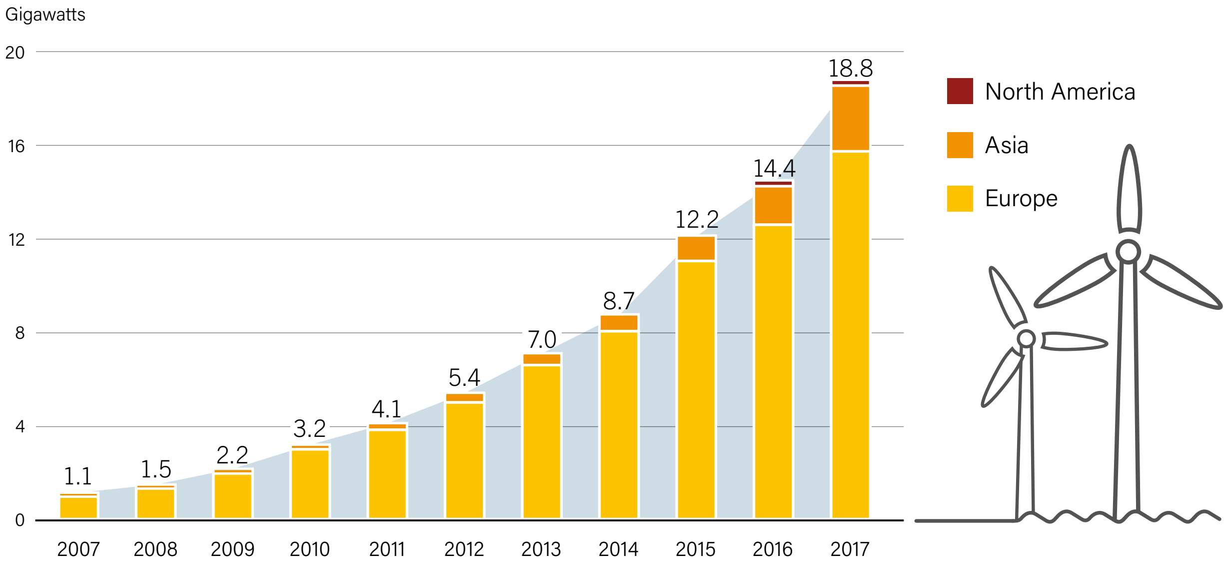
Although onshore wind power continues to account for the vast majority (more than 96%) of global installed capacity, nine countries connected a total 4.3 GW of offshore wind capacity during 2017, increasing total world offshore capacity 30%, to 18.8 GW.[75] The top countries for offshore additions were the United Kingdom (1.7 GW), Germany (1.2 GW), China (1.2 GW) and Belgium (0.2 GW).[76] Europe connected a record 3.1 GW, for a total approaching 15.8 GW, with an additional 1.9 GW awaiting connection at year's end.[77] Germany increased its offshore capacity by nearly one-third, Finland added its first commercial offshore plant, France installed a 2 MW floating demonstrator turbine, and Denmark decommissioned the world's first offshore wind farm (5 MW).[78] Hywind Scotland (30 MW), the world's first commercial floating project, was commissioned in October.[79]

Offshore wind had a record year with

4.3 GW

added, all in Europe and Asia

FIGURE 36. Wind Power Offshore Global Capacity by Region, 2007-2017



Source: See endnote 87 for this section.

China's offshore market started to take off in 2017. The country saw record installations for a total of nearly 2.8 GW at year's end, and a further 5 GW under construction.[80] After lagging for several years due to regulatory and jurisdictional issues, China's offshore sector is on track to meet a national target of 5 GW by 2020.[81] Elsewhere in Asia, capacity was added in Chinese Taipei (8 MW), which commissioned its first offshore project, in Japan (5 MW), which launched its first offshore tender, and in the Republic of Korea (3 MW).[82]

Although the United States added no new capacity, as of late 2017 there were 14 proposed offshore wind projects in various stages of development (totalling over 12.5 GW) spanning 10 states, and 5 northeastern states had enacted supporting policies.[83] In Australia, plans were announced for a 2 GW project off the coast of Victoria.[84]

A total of 17 countries (11 in Europe) had offshore wind capacity by the end of 2017, although 4 of these had only demonstration projects.[85] The United Kingdom maintained its lead for total capacity, with 6.8 GW at year's end, followed by Germany (5.4 GW), China (2.8 GW), Denmark (1.3 GW) and the Netherlands (1.1 GW).[86] Europe was home to about 84% of global offshore capacity (down from 88% in 2016), with Asia accounting for nearly all the rest.[87] *(→ See Figure 36.)*

The number of community and citizen-owned wind power projects also expanded during 2017.[88] Community wind power projects are on the rise in Japan, inspired by earlier movements in Denmark and Germany.[89] The United Kingdom saw in July what was believed to be the first UK transfer of an entire wind energy project (6.9 MW) from a commercial developer to community ownership.[90] The share of citizen ownership or investment remains high in Germany but has declined in recent years.[91] In 2017, Germany changed its tendering conditions to enable participation of community projects (with lower access barriers), and most capacity from the first three onshore auctions was awarded to projects that qualified as citizen energy. However, concerns arose that some projects might not be built and that many successful applicants were not traditional community entities (i.e., owned by local citizens).[92]

Small-scale[i] turbines continued to be used for a variety of applications (both on- and off-grid), including defence, rural electrification, water pumping and desalination, battery charging, telecommunications, and increasingly to displace diesel in remote locations.[93] The global market slowed in 2016 (latest data available) relative to 2015, with total capacity up an estimated 8.3%.[94] Approximately 1 million[ii] small-scale turbines, or over 1 GW, were operating worldwide by year's end (up from 935 MW at end-2015).[95]

While most countries have some small-scale turbines in use, the majority of units and of capacity operating at the end of 2016 was in China (459 MW), the United States (233 MW) and the United Kingdom (154 MW).[96] Capacity sales in the top markets have contracted in recent years in response to obstacles

i Small-scale wind systems generally are considered to include turbines that produce enough power for a single home, farm or small business (keeping in mind that consumption levels vary considerably across countries). The International Electrotechnical Commission sets a limit at approximately 50 kW, and the World Wind Energy Association (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.

ii Total number of units does not include some major markets, including India, for which data were not available. Taking this into account, more units are estimated to be operating worldwide, from WWEA, ***Small Wind World Report 2018*** (Bonn: forthcoming, 2018).

such as policy changes, an economic slowdown (China) and competition with solar PV.[97] China saw a steady decline from its 2009-2011 high until 2016, when its market size recovered to 2012 levels.[98] The UK market, in contrast, was down significantly in 2016 alongside caps on deployment and reduced payments under the UK FIT, and the US market (capacity) fell nearly 50% that year, to its lowest level since at least 2012 (although unit sales increased), due largely to a general downward trend in public incentives.[99]

During 2017, an estimated 561 turbines (totalling around 0.6 GW) were decommissioned.[100] Germany dismantled the largest number and capacity of turbines (all onshore), followed by Denmark, the Netherlands, the United States, Japan, Latvia, Finland, Chinese Taipei and Belgium.[101]

Wind power is providing a significant share of electricity in a growing number of countries. In 2017, wind energy covered an estimated 11.6% of EU annual electricity consumption and equal or higher shares in at least 8 EU member states, including Denmark, which met 43.4%[i] of its annual electricity consumption with wind power.[102] At least 13 countries around the world – including Costa Rica, Nicaragua and Uruguay – met 10% or more of their annual electricity consumption with wind power.[103] Uruguay saw its share of generation from wind power increase more than four-fold in just three years, from 6.2% in 2014 to 26.3% in 2017, and Nicaragua generated over 15% of its electricity with wind power.[104] Globally, wind power capacity in operation by the end of 2017 was enough to account for an estimated 5.6% of total electricity generation.[105]

WIND POWER INDUSTRY

The big story of 2017 was tumbling bid prices for wind power – both onshore and offshore – in several auctions around the world.[106] This was due to a number of factors, including technology innovation and scale, expectations of continued technology advances, lower financing costs (especially for European offshore wind power) due to lower perceived risk, as well as fierce competition in the industry.[107] Wind energy has emerged as one of the most competitive ways to add new generating capacity, and is less expensive than existing fossil power in a small but growing number of markets.[108] However, increased competition and the scramble for market share in 2017 came at the expense of profits throughout the supply chain, with several large manufacturers seeing their turbine orders increase but their profits decline.[109]

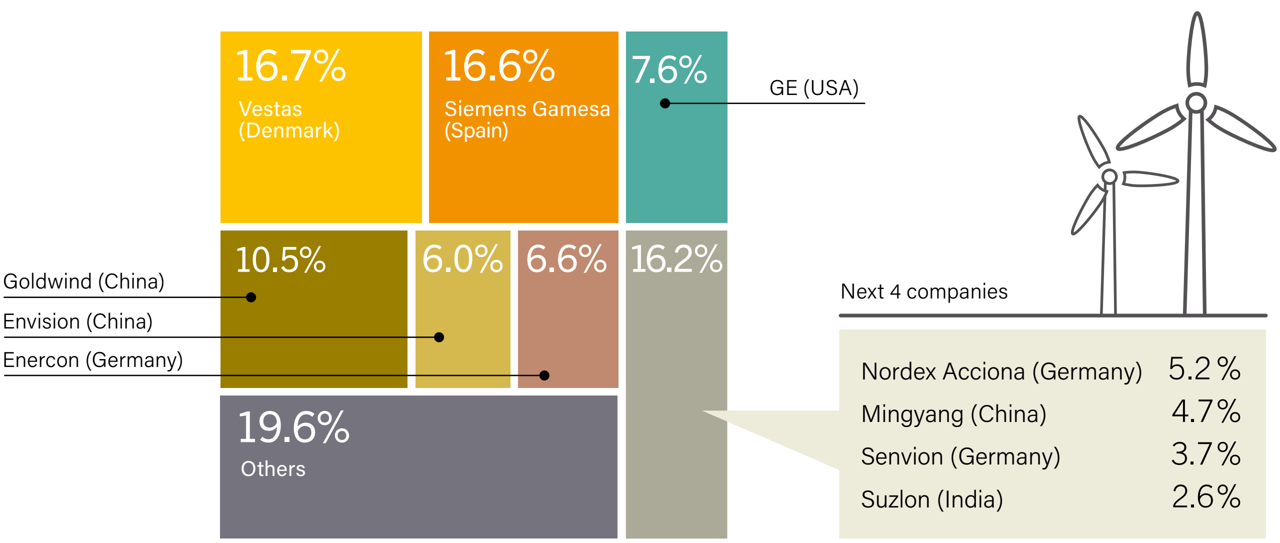
Auctions were held in more than 15 markets during 2017, and a total of about 25 GW of wind capacity contracts was awarded (including 5 GW offshore).[110] In markets as diverse as Canada, India, Mexico and Morocco, bid prices[ii] for onshore wind power were close to USD 30 per MWh.[111] A Mexican tender late in the year saw prices below USD 20 per MWh – a world record low and down 40-50% relative to Mexico's tenders in 2016.[112] Germany also saw a national record low of EUR 38 per MWh (around USD 45 per MWh) in November 2017.[113]

Reductions in bid prices in the offshore sector were particularly remarkable. Tenders in Germany (April) and the Netherlands (announced in December) in 2017 attracted "zero-subsidy" bids (to be paid market prices only) for offshore projects due to come online in 2024 and 2022, respectively.[114] Although no price

i Wind power accounted for 50.2% of net generation in Denmark during 2017 (see endnote 102). 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.

ii Note that bid prices 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.

FIGURE 37. Market Shares of Top 10 Wind Turbine Manufacturers, 2017



Note: Total does not add up to 100% due to rounding.

Source: FTI Consulting. See endnote 125 for this section.

subsidy will be provided, the governments of both countries pledged to cover grid connection costs; the Dutch government also shouldered some of the development risk and committed to establishing a national floor price for carbon.[115] In September, a UK auction saw bids as low as GBP 57.5 (USD 77.6) per MWh (including the costs of transmission assets) – half the price of contracts awarded for an offshore auction in 2015 – for projects to be completed in 2022-2023.[116] In the young US offshore market, the state of Maryland offered two developers USD 132 per MWh (for 368 MW to be online in 2020), 45% below the price of generation from the first US offshore wind farm (Block Island), which was completed in 2016.[117]

While the global shift to auctions is driving down the cost of wind power to utilities and ratepayers, it is causing fierce competition in the industry, forcing turbine manufacturers to look for ways to further reduce their costs and contributing to consolidation in the industry.[118] Several leading manufacturers around the world reduced jobs and closed factories during 2017, and many small or medium-sized turbine vendors were acquired, filed for insolvency or exited the industry.[119] German manufacturer Senvion announced a restructuring programme that included job cuts and factory closures, mostly in Germany.[120] Nordex (Germany) launched and completed a programme to reduce costs and invested in the development of new projects to strengthen sales.[121] Suzlon Energy (India) exited the Brazilian market.[122] Dutch turbine manufacturer Lagerwey was acquired by German manufacturer Enercon.[123] Siemens (Germany) and Gamesa (Spain) finalised their merger to create one of the world's leading wind power players, Siemens Gamesa Renewable Energy (Spain), and discontinued production of Adwen turbines.[124]

As competition intensified, the world's top 10 turbine manufacturers captured an increasing share of the market (nearly 80%, up from 75% in 2016).[125] *(→ See Figure 37.)* Vestas (Denmark) barely maintained its position as the largest supplier of wind turbines thanks to the company's wide global presence.[126] Siemens Gamesa followed closely, due largely to the merger of giants Siemens and Gamesa earlier in the year and to the company's presence in 35 countries in 2017.[127] China's Goldwind remained in third place, with domestic projects accounting for 90% of commissioned turbines.[128] US manufacturer GE dropped two steps to fourth, followed by Germany's Enercon, which had a record year thanks to a strong domestic market.[129] Most Chinese manufacturers saw their volumes drop in 2017 due to the rising market shares of Goldwind and Envision in a shrinking domestic market.[130]

While most wind turbine manufacturing takes place in China, the EU, India and the United States, the manufacture of components, such as blades, and the locations of company offices are spreading to be close to growing wind power markets, as companies seek to reduce transport costs and to access new sources of revenue.[131] Goldwind is expanding beyond China as demand slows at home; in 2017 it was the first Chinese turbine manufacturer to move into the Philippines.[132] European turbine makers – including Vestas, Nordex and Senvion – have invested in India, drawn by rapid growth.[133] Siemens Gamesa opened its third blade factory in India and launched Africa's first blade factory in Morocco.[134] LM Windpower (Denmark; part of GE) began production at a new blade manufacturing plant in Turkey to supply the rapidly growing market there, and opened its fourth blade factory in northeastern China.[135] Vestas announced plans to build its first blade manufacturing plant in the Russian Federation.[136] Manufacturers and service providers also are expanding into Argentina, Australia and the United States.[137]

Repowering has become a billion-dollar annual market, particularly in Europe and increasingly in the United States.[138] While most repowering involves the replacement of old turbines with fewer, larger, taller, and more-efficient and reliable machines at the same site, some operators are

The global shift to tenders is **driving down the cost** of wind power to utilities and ratepayers

switching even relatively new machines for larger and upgraded turbines (including software improvements) or are replacing specific components, such as blades (partial repowering).[139] Germany repowered an estimated 338 turbines with a total capacity of around 1 GW, and the United Kingdom (18 MW) and Portugal (10 MW) also repowered some projects.[140] 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.[141] An estimated 2.1 GW of US capacity was partially repowered during 2017.[142]

In response to rapidly falling offshore wind power prices in Europe, interest is rising elsewhere, prompting European manufacturers and developers to turn to new offshore markets, particularly Asia and the United States.[143] For example, Siemens Gamesa, Enercon, Ørsted (formerly Dong) and others have opened offices in Chinese Taipei to meet onshore demand and to help launch the country's offshore sector.[144]

Non-wind companies also continued to move further into the wind power sector. Electric utilities acquired wind power projects and service companies, created wind power subsidiaries, established partnerships to develop and operate wind power plants, and expanded into new regions.[145] Danish utility Dong Energy (for Danish Oil and Natural Gas) sold its oil and gas business to focus on offshore wind power and bioenergy, and changed its name to Ørsted to better reflect its transformation away from fossil fuels.[146] Swedish utility Vattenfall announced plans to invest USD 1.9 billion in wind power during 2017-2018, highlighting a shift from fossil fuels to renewables.[147] Russian nuclear power company Rosatom created a subsidiary for its wind power business and signed an agreement with Lagerwey to lay the foundation for a wind power industry in the Russian Federation.[148] In the United States, utilities continued to sign PPAs for wind power and increasingly turned their sights to owning and operating projects themselves.[149]

Large oil and gas companies – including Shell (Netherlands), Statoil (Norway), Total (France) and Eni (Italy) – as well as companies servicing the oil and gas industry, continued moving (back) into the wind (and solar) power sector to secure new sources of future revenue, and even challenged leading utility companies in competitive auctions.[150] Their primary interest is in the offshore industry, where their expertise is most transferable.[151] This development is apparent in Europe, where the oil and gas industry is winding down in some areas, and in the United States.[152]

In 2017, 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 gain or maintain market share.[153] By year's end, 7 of the top 10 turbine manufacturers had launched 4 MW turbine platforms[i] for use onshore, and the average size of turbines delivered to market in 2017 was more than 11% larger than in 2016, at more than 2.4 GW.[154] By region, average turbine sizes (including onshore and offshore) were highest in Europe (3.1 MW), due in part to the large offshore market, and lowest in Asia-Pacific[ii] (2.1 MW).[155] Significant differences in average turbine ratings can occur within regions; on land in Europe, differences result from regulatory restrictions on height, age of projects and/or wind speeds.[156]

Offshore wind power developers are relying on a dramatic increase in turbine scale – machines taller than the

Eiffel Tower

- to drive down their costs

Offshore, developers are taking advantage of larger turbines as soon as they become available.[157] The size of turbines as well as projects has increased rapidly in order to reduce costs through scale and standardisation.[158] 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 O&M costs and overall greater profitability.[159] Across Europe, the average capacity of newly installed turbines offshore was 5.9 MW in 2017, up 23% relative to 2016 and double compared to 10 years earlier.[160]

In 2017, Goldwind unveiled a new platform for 6 MW-plus offshore turbines suitable for low-, medium- and high-wind sites; MHI Vestas Offshore Wind unveiled an up-rated version of its 8 MW turbine that can achieve a rated power of 9 MW, and followed that with a 9.5 MW model only four months later; Senvion (Germany) announced plans for a machine 10 MW or larger by 2022; and Siemens Gamesa also was working to greatly increase the capacity of turbines for offshore use.[161] In early 2018, GE unveiled plans to invest more than USD 400 million over the next few years to develop a 12 MW turbine.[162] Looking to the future, developers are relying heavily on technological development, including dramatic increases in turbine scale – machines taller than the Eiffel Tower – to drive down their costs, further fuelling the push for these enormous machines.[163]

Such changes have driven capacity factors significantly higher within given wind resource regimes, onshore and offshore, creating further opportunities in established markets as well as new ones.[164] In the United States, for example, the average capacity factor of projects constructed in 2014-2015 (latest data available) was 42.5%, compared to an average of 32.1% for projects built between 2004 and 2011.[165] In Brazil, as new projects with better technology came online, the average capacity factor for all operational wind farms rose from 38.8% in 2015 to over 40.9% in 2016, and to 42.9% in 2017.[166] Capacity factors are rising offshore as well with the evolution to taller, larger machines.[167]

Most large manufacturers are focusing on tested and well-proven turbine platforms that provide flexibility and enable them to more easily develop turbines for specific markets while minimising costs.[168] Several new wind turbine models, for low and high wind locations, entered the market in 2017, including many adapted for specific country markets.[169]

i Turbine "platforms" refers to a basic "model" of turbine, which enables manufacturers to standardise components such as rotors, generators, towers or hubs for use across different wind turbines, thereby minimising the number of different components required. This streamlines the manufacturing and installation process, helping to reduce costs for manufacturers and to drive down the levelised cost of energy (LCOE). See endnote 154.

ii Asia-Pacific reflects the region provided in the original source and differs from the regional definitions across the rest of the GSR, which can be found at http://www.ren21.net/GSR-Regions.

Wind turbine manufacturers expanded their activities in digital solutions, as well as solar PV and energy storage, to tap into new revenue streams.[170] In 2017, GE unveiled software that boosts productivity and streamlines repairs, and Vestas began using operational efficiency software to help reduce costs.[171] Several manufacturers, developers and operators have begun using drones to inspect, and even clean, wind turbines, thereby improving worker safety and reducing costs.[172] As with solar PV, O&M has become a rapidly growing sector in the wind industry due to the increased number of turbines in operation and to the need to minimise down-time.[173]

Also in 2017, Siemens Gamesa won two contracts in India to develop large-scale solar PV projects, Brazil's largest wind company, CPFL Energias Renovaveis, set its sights on dominating the country's solar industry, and several companies around the world – including GE, Goldwind, Siemens Gamesa and Vestas – focused on hybrid wind-solar PV projects (some also with storage).[174] For example, Siemens Gamesa announced its first hybrid contract for a solar PV-wind power facility in India, and Vestas began constructing the first phase of the Kennedy Energy Park, Australia's first utility-scale wind, solar PV and energy storage hybrid project.[175]

Developers and increasingly manufacturers are incorporating battery storage into wind energy projects onshore and offshore.[176] To increase capacity factors and improve returns, Vestas has partnered with several energy storage companies to explore potential solutions for wind power-plus-storage.[177] In addition, manufacturers are developing innovative new technologies: in 2017, Siemens Gamesa began construction of a wind-to-heat energy storage system; Max Bögl (Germany) completed four turbines integrated with pumped storage (including reservoirs in the turbine tower foundations); Lagerwey (Germany) announced plans to build a turbine that will produce hydrogen directly; and GE partnered with US-based Microsoft to integrate batteries into its turbines for a project in Ireland.[178]

Other advances in 2017 include: Nordex launched a solution to reduce sound levels while increasing turbine yield; Vestas released a concept for a new tower design that will require less material, thereby facilitating tower transport and reducing costs; and Lagerwey began testing a climbing crane that builds a turbine while scaling its tower.[179] Innovations also continued in blade manufacturing processes and materials to improve their efficiency, increase annual production and reduce wind energy costs.[180]

A significant advance in the offshore sector is towards the deployment of floating turbines, which offer the potential to expand the areas where offshore wind power is viable and economically attractive because they can be placed where winds are strongest and most consistent, rather than where the seafloor topography is suitable.[181] The first commercial floating wind farm, Statoil's 30 MW Hywind Scotland project[i], began operation in 2017 near the coast of Aberdeen.[182] Challenges that remain for the floating sector include the development of an efficient supply chain and narrowing the range of potential platform designs.[183] Even so, floating turbines are moving beyond the demonstration phase and attracting significant investment, with a pipeline of projects in place in Europe and plans for projects elsewhere.[184]

The economics of offshore wind power have improved far faster than experts expected.[185] A new generation of turbines, maturation of the supply chain, cost reductions in industry logistics and shipping, as well as increased competition and

i The turbines used for Statoil's 30 MW Hywind Scotland project are built much like floating offshore oil drilling rigs, with the platforms anchored to the seabed. See endnote 182.

experience have reduced prices dramatically and made offshore wind power competitively priced in Europe.[186] In 2017, building on an agreement signed in 2016 by 10 northern European countries to co-operate to reduce the cost of installing turbines offshore, Belgium, Denmark and Germany supported a pledge to install 60 GW of new offshore capacity within the next decade.[187] These three countries joined with 25 companies in a pledge to work together to increase investment and further reduce costs.[188]

New offshore markets still face challenges that Europe and China have addressed, including building supply chains and associated infrastructure such as ports, rail links and installation vessels, as well as technology for electrical connections.[189] In 2017, the United States saw increased interest from European as well as domestic oil and gas companies in the development of infrastructure, and particularly installation vessels, for a domestic offshore wind power industry.[190]

Small-scale wind turbine production continued to be concentrated in just a few regions, with China, Germany, the United Kingdom and the United States accounting for more than half of global manufacturing; developing countries still play a minor role.[191] The number of producers in China and the United States has declined significantly in recent years, with manufacturers relying heavily on export markets.[192] In China, manufacturing, sales and employment related to small-scale wind turbines declined sharply in 2017 relative to 2016.[193] In the United States, 12 companies (9 of which were US-based) reported sales during 2016 (latest data available), compared with 31 companies in 2012; in 2016 alone, at least 5 small-scale wind turbine manufacturers (4 US-based and 1 Canadian) changed ownership or went out of business.[194]

Whether large- or small-scale, as turbines age and are repowered or dismantled the result is significant amounts of obsolete components, such as blades. The rapid evolution of turbine designs and the competitive marketplace are shortening turbine life cycles because products are quickly replaced with newer and larger machines.[195] The industry has begun to address this issue, with several companies working to reuse and recycle turbine hardware.

In the United States, for example, GE works with a company that recycles fiberglass and is converting used turbine blades into new products.[196] In Denmark, upon decommissioning of the Vindeby offshore wind farm, Ørsted planned to use the blades as a noise barrier and to use other components as spare parts.[197] In Spain, a pilot initiative was launched in 2017 to recycle turbine blades that are faulty or damaged, or that have been retired.[198] Across Europe, a demonstration project was initiated to develop new design and manufacturing processes that make it easier to recycle and extend the life cycle of composite products, which are used for numerous applications including wind turbine blades.[199]

→ *See Sidebar 2 and* ***Table 3*** on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.[200]

Floating wind turbines

offer the potential to expand the areas where offshore wind power is viable and economically attractive

SIDEBAR 2. Renewable Electricity Generation Costs in 2017

The average cost of electricity – measured in unsubsidised levelised cost of electricity (LCOE) – from renewable power generation technologies either is already very competitive or is continuing to fall to competitive levels for new projects commissioned in 2017[i]. Costs of the more mature geothermal, bio-power and hydropower technologies are relatively stable. Most of the recent reductions in cost have been associated with solar PV and wind power technologies; after years of steady cost declines, solar and wind power are becoming ever more competitive technologies for meeting new generation needs.

Three key drivers are increasingly important for reducing the cost of solar and wind power generation. These are: competitive procurement; a large and growing base of experienced and internationally active project developers; and ongoing technology improvements. Regulatory and institutional frameworks are transitioning to set the stage for competitive procurement of renewable power generation. In response, project developers are bringing to the international market their significant experience as well as their increasing access to international capital markets.

Particularly for solar and wind power, technology advances are improving efficiencies in manufacturing, reducing installed costs and improving the performance of power generation equipment. Innovations include larger wind turbines with greater swept areas, which enable them to harvest more energy from the same resource, and new solar PV cell architectures, which offer greater efficiency. At the same time, the maturity and the proven track record of these renewable technologies are lowering perceived project risk, which greatly reduces the cost of capital.

Bio-power, hydropower and geothermal power are all mature technologies that exhibit fairly stable cost profiles, although innovation in these technology groups continues. The estimated costs of these technologies, as well as of onshore wind power projects commissioned in 2017, were largely within the range of fossil fuel-fired electricity generation costs. Indeed, the LCOE[ii] for these technologies was estimated to be at the lower end of the LCOE range for fossil fuel options[iii].

The global weighted average LCOE of new hydropower plants commissioned in 2017 was around USD 50 per MWh. For new bio-power and geothermal power projects, the global average was approximately USD 70 per MWh.

Onshore wind power has become one of the most competitive sources of new generation. Wind turbine prices have fallen 37-56% since their peaks in 2007-2010, depending on the market. In combination with more modest reductions in balance-of-project costs, total installed costs for onshore wind power fell by a fifth between 2010 and 2017; at the same time, the global weighted average capacity factor for new projects increased from 27% to 30%. The LCOE of onshore wind power projects in 2017 fell to as low as USD 30 per MWh, with a global weighted average of USD 60 per MWh.

What has been truly remarkable, however, is the continued cost declines for solar PV. Driven by an 81% decrease in solar PV module prices since the end of 2009, along with reductions in balance of system costs, the global weighted average LCOE of utility-scale solar PV fell 73% between 2010 and 2017, to USD 100 per MWh[iv]. The global weighted-average capacity factor of commissioned utility-scale solar PV has risen since 2010, although this increase has been driven more by a growing share of projects in the sunbelt than by technology improvements. As a result of all these factors, solar PV is increasingly competing head-to-head with conventional power sources, and doing so without financial support in a growing number of locations.

Offshore wind power and concentrating solar thermal power (CSP), although still at relatively early stages in deployment, both saw their costs fall between 2010 and 2017 to a global weighted average LCOE of USD 140 per MWh and USD 220 per MWh, respectively. These values are still relatively high, but the cost reduction potential for these technologies is strong.

The years 2016 and 2017 saw record low auction prices for solar PV in Abu Dhabi and Dubai in the United Arab Emirates, as well as in Chile, Mexico, Peru and Saudi Arabia. Similarly, very low auction results for onshore wind power in countries such as Brazil, Canada, Germany, India, Mexico and Morocco have made onshore wind power one of the most competitive sources of new generating capacity in those locations. For CSP and offshore wind power, 2016 and 2017 were breakthrough years: auction results for projects that will be commissioned in 2020 and beyond signal a step-change, with the costs of electricity under these contracts being significantly lower than the costs of projects commissioned in 2017.

The lowest auction prices for renewable power reflect a nearly constant set of key competitiveness factors. These include: a favourable regulatory and institutional framework; low offtake and country risks; a strong, local civil engineering base; favourable taxation regimes, low project development costs; and excellent renewable energy resources.

Projects contracted via competitive procurement in 2017 may represent a relatively small subset of renewable power capacity additions over the next few years, and trends in auction results may not be representative of LCOE trends at a project level. Nevertheless, based on the auction prices in 2017 and 2018, the outlook for solar and wind electricity prices to 2020 presages the lowest yet seen for these modular technologies, which can be deployed in every country of the world.

Source: IRENA. See endnote 200 for this section.

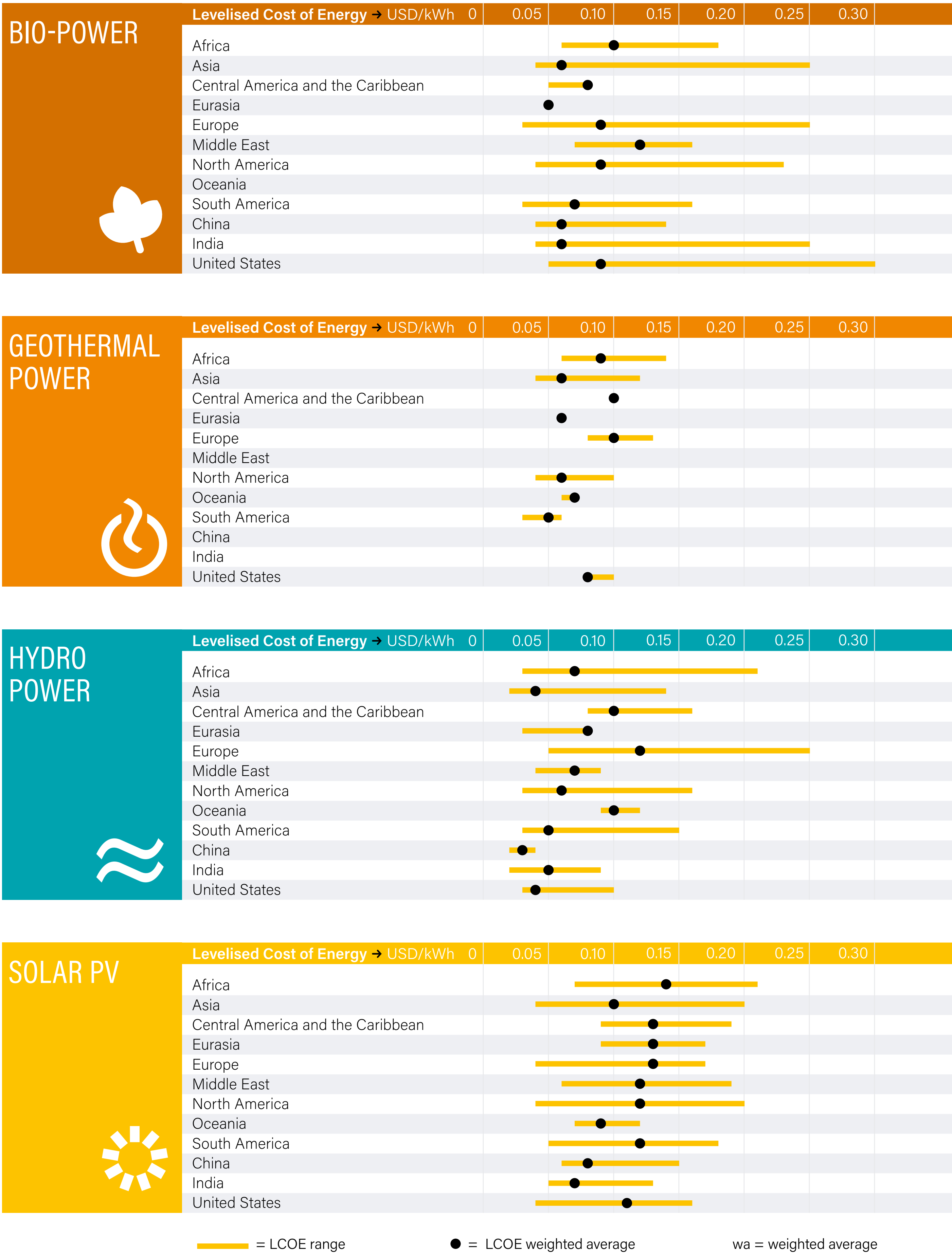
i This sidebar discusses utility-scale power generation costs and is based on data for 62 GW of renewable power generation capacity commissioned in that year.

ii 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.

iii In 2017, fossil fuel-fired power generation costs fell in the range USD 50 to USD 170 per MWh depending on the fuel and country, although higher values exist in countries reliant on diesel-fired electricity generation, notably island states.

iv The decline in module prices has accounted for about two-thirds of the cost reduction over this period, with balance-of-system cost reductions accounting for the rest.

TABLE 3. Status of Renewable Electricity Generating Technologies, Costs and Capacity Factors, 2017



Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	1,525	5,579	2,755		0.46	0.9	0.62
Asia	736	5,972	1,910		0.14	0.93	0.71
Central America and the Caribbean	1,450	2,295	1,696		0.27	0.8	0.6
Eurasia			1,344				0.83
Europe	507	7,957	3,462		0.18	0.98	0.84
Middle East	3,284	4,272	3,857		0.46	0.92	0.64
North America	510	7,375	3,718		0.16	0.96	0.84
Oceania							
South America	562	7,505	1,695		0.2	0.96	0.64
China	920	5,972	1,527		0.33	0.93	0.64
India	736	5,497	1,455		0.63	0.9	0.73
United States	1,668	10,240	4,400		0.93	0.96	0.94

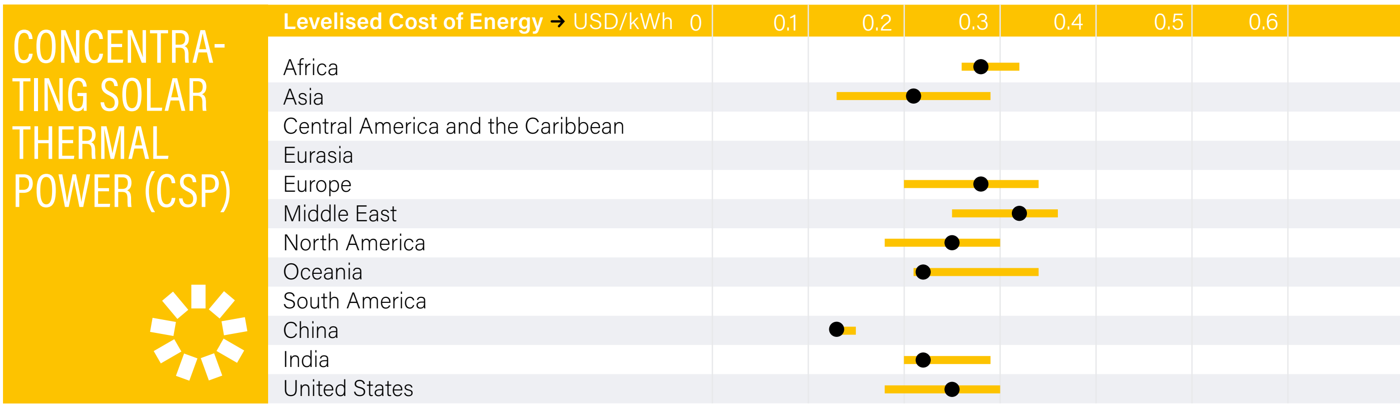
Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	3,745	7,689	5,101		0.8	0.92	0.87
Asia	1,867	8,736	3,055		0.41	0.9	0.85
Central America and the Caribbean			3,537				0.57
Eurasia			3,259				0.8
Europe	3,613	8,919	5,209		0.6	0.8	0.66
Middle East							
North America	2,029	6,720	3,422		0.8	0.924	0.87
Oceania	3,783	4,440	4,000		0.8	0.8	0.8
South America	4,348	4,348	4,348		0.8	0.95	0.83
China							
India							
United States	5,162	6,720	5,328		0.8	0.8	0.8

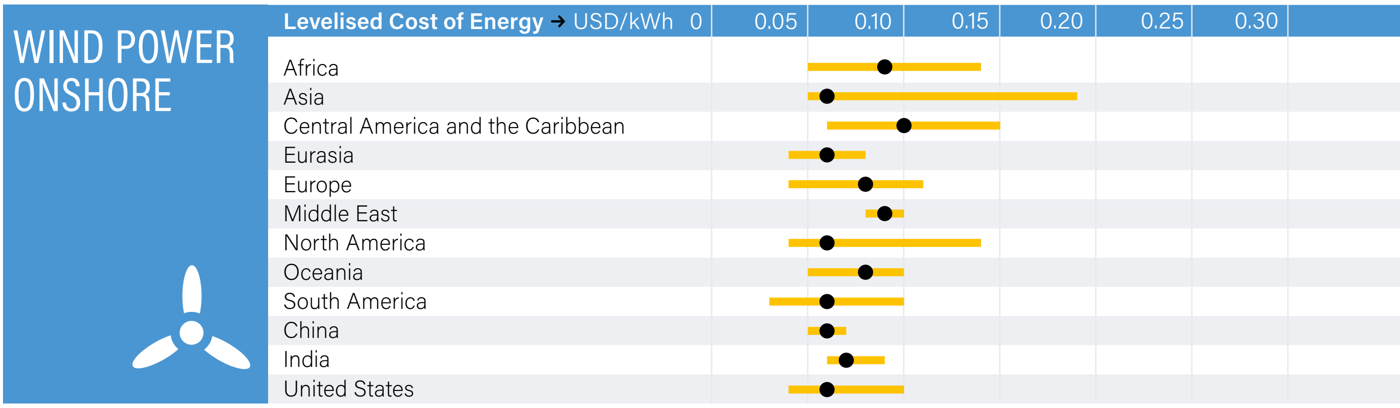
Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	532	6,730	2,114		0.3	0.86	0.59
Asia	483	5,666	1,316		0.16	0.82	0.46
Central America and the Caribbean	1,650	4,474	3,404		0.32	0.55	0.53
Eurasia	1,499	4,082	2,528		0.32	0.72	0.5
Europe	570	7,700	2,080		0.16	0.58	0.29
Middle East	1,475	1,971	1,657		0.31	0.53	0.34
North America	1,051	5,195	2,395		0.31	0.68	0.49
Oceania	3,727	3,729	3,729		0.31	0.5	0.45
South America	1,026	5,824	2,022		0.34	0.81	0.61
China	798	1,647	990		0.42	0.53	0.51
India	483	2,859	1,163		0.16	0.75	0.41
United States	1,051	4,228	1,351		0.31	0.5	0.37

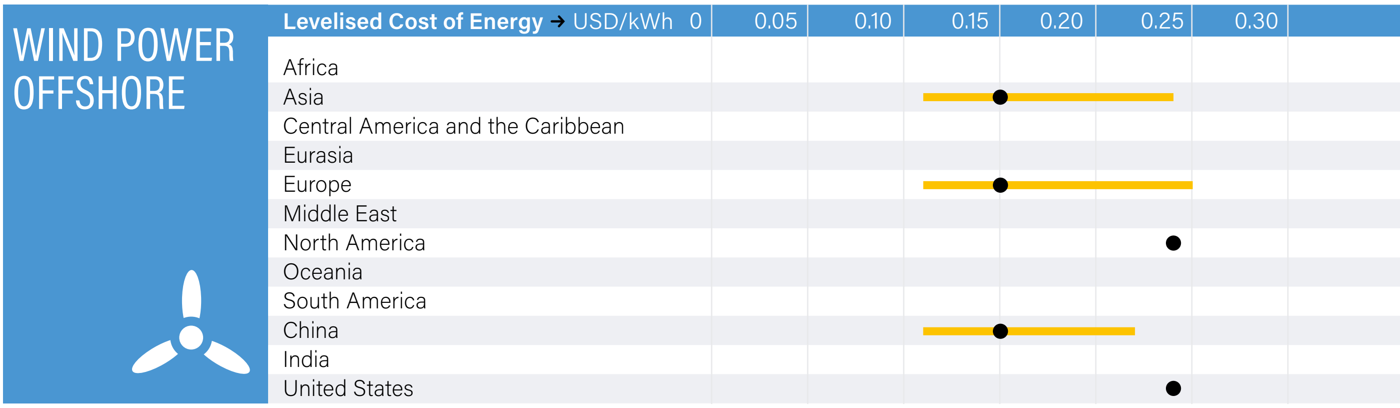
Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	805	4,735	2,172		0.14	0.28	0.18
Asia	832	4,212	1,248		0.1	0.23	0.17
Central America and the Caribbean	1,319	2,810	1,688		0.16	0.19	0.17
Eurasia	1,463	3,551	1,904		0.1	0.18	0.14
Europe	921	2,330	1,294		0.11	0.18	0.12
Middle East	1,201	3,850	2,487		0.18	0.35	0.22
North America	955	4,120	2,084		0.14	0.32	0.2
Oceania	1,550	2,535	1,924		0.2	0.26	0.22
South America	823	3,879	2,044		0.12	0.34	0.2
China	1,005	1,873	1,058		0.1	0.19	0.17
India	661	1,786	971		0.15	0.22	0.19
United States	850	2,215	1,869		0.14	0.32	0.2

Source: IRENA. See endnote 200 of Wind Power section in this chapter.

TABLE 3. Status of Renewable Electricity Generating Technologies, Costs and Capacity Factors, 2017 (continued)







= LCOE range ● = LCOE weighted average wa = weighted average

Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	6,850	11,300	7,841		0.36	0.53	0.39
Asia	3,053	7,475	4,110		0.21	0.54	0.28
Central America and the Caribbean							
Eurasia							
Europe	5,982	8,970	7,402		0.23	0.41	0.32
Middle East	6,220	6,680	6,373		0.24	0.39	0.29
North America	6,373	7,753	7,002		0.27	0.52	0.35
Oceania	6,672	6,673	6,673		0.11	0.23	0.12
South America							
China	2,550	3,450	3,223		0.28	0.29	0.28
India	3,053	7,475	4,228		0.21	0.54	0.28
United States	6,373	7,753	7,002		0.27	0.52	0.35

Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa	1,485	2,850	2,040		0.19	0.48	0.37
Asia	1,044	3,882	1,221		0.18	0.46	0.25
Central America and the Caribbean	1,981	3,265	2,184		0.24	0.54	0.33
Eurasia	1,032	2,002	1,605		0.24	0.49	0.37
Europe	1,151	3,702	1,868		0.14	0.51	0.29
Middle East	916	1,857	1,320		0.14	0.29	0.2
North America	1,270	3,001	1,718		0.22	0.51	0.4
Oceania	1,184	3,169	2,124		0.23	0.43	0.33
South America	972	2,909	1,829		0.26	0.55	0.4
China	989	1,414	1,197		0.23	0.29	0.25
India	850	1,282	1,097		0.19	0.33	0.24
United States	1,381	2,534	1,648		0.23	0.44	0.41

Total Investment Cost → USD/kW	min	max	wa	Capacity Factor →	min	max	wa
Africa							
Asia	1,890	5,055	3,260		0.23	0.29	0.28
Central America and the Caribbean							
Eurasia							
Europe	2,698	6,480	4,355		0.27	0.55	0.38
Middle East							
North America			9,667				0.48
Oceania							
South America							
China	1,890	4,258	3,249		0.23	0.29	0.28
India							
United States			9,667				0.48

Source: IRENA. See endnote 200 of Wind Power section in this chapter.

Note: All monetary values are expressed in USD2016. 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. 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. The data methodology and regional groupings are defined in IRENA, *Renewable Power Generation Costs in 2017* (Abu Dhabi: 2018), www.irena.org/costs.

04

DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

El Romero
Solar photovoltaic
power plant,
Atacama, Chile

As of 1 February 2018, Aguas Chañar, a water-cycle management company in Atacama, Chile, began using electricity from renewable sources under a long-term PPA with Acciona Energia of Spain. All the electricity supplied under the PPA comes from Acciona's 246 MW El Romero Solar power plant in the Atacama Desert and its 45 MW Punta Palmeras wind farm in the region of Coquimbo. The contract covers more than 70% of Aguas Chañar's electricity needs across several installations.

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 mini-grids[ii]) that generate and distribute energy independently of a centralised electricity grid. DREA systems provide a wide range of services – including lighting, operation of appliances, cooking, heating and cooling – in both urban and rural areas of the developing world. These systems represented about 6% of new electricity connections worldwide between 2012 and 2016, mainly in rural areas.[1] In some countries, DREA technologies play a key role in fulfilling the energy needs and enabling the livelihoods of millions of people living in rural and remote parts of the world.

In places where the electric grid does not reach or is unreliable[iii], DREA technologies provide cost-effective options for generating electrical and mechanical power, heating water and space, cooking and baking, and enabling various productive uses. For example, about 13% of the population of Bangladesh gained access to electricity through off-grid solar systems[iv], while 51% of the off-grid population of Kenya is served by DREA systems.[2] *(→ See Figure 38.)*

6%

of new electricity connections worldwide between 2012 and 2016 were provided by off-grid and mini-grid renewable energy systems

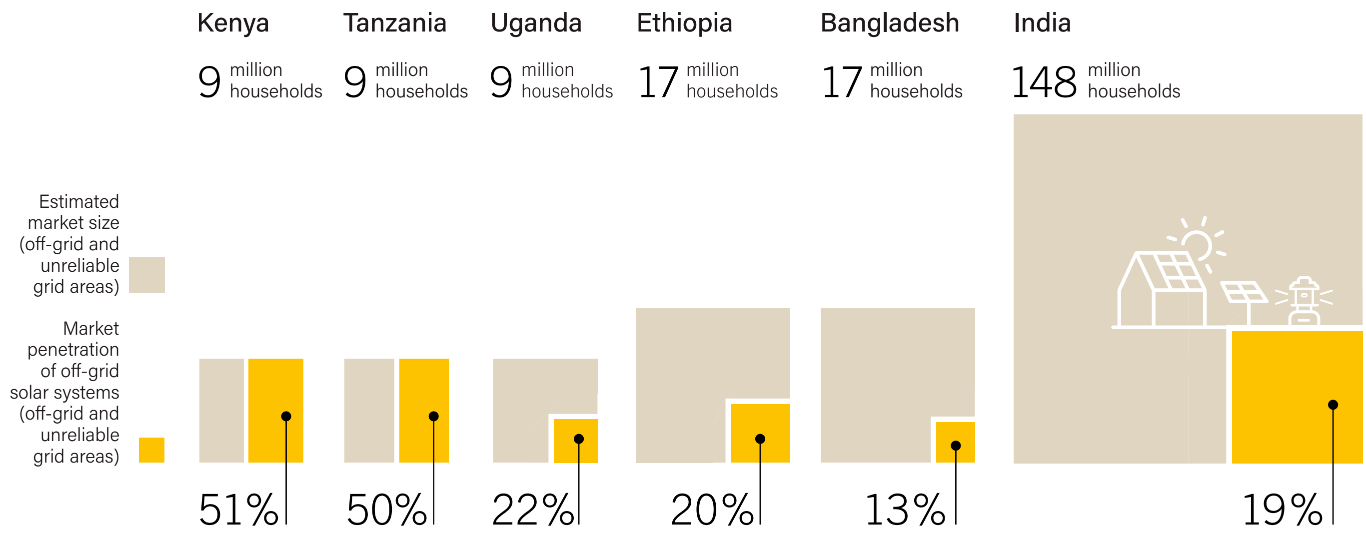
i See Sidebar 9 in GSR 2014 for more on the definition and conceptualisation of DREA. Note that the GSR has started using the acronym DREA to distinguish from distributed renewable energy that is not necessarily linked to providing energy access.

ii This chapter does not distinguish between mini- and micro-grids. For more details, see the glossary at the end of the report.

iii Unreliable is defined here as delivering electricity for less than 12 hours per day.

iv "Solar systems" throughout the chapter refers to solar PV systems, unless otherwise specified.

FIGURE 38. Market Size and Current Penetration of Off-Grid Solar Systems in Selected Countries, 2017



Source: 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 increasing reliability, short installation time, improved cost-benefit ratio and the emergence of financial schemes that reduce the upfront cost burden, DREA systems increasingly are being considered as either a complement to or, in some situations, a substitute for centralised power generation, with the added benefit of reducing dependence on fossil fuel imports.

In remote areas with low population densities, DREA systems can be the fastest and most cost-effective means for providing people with electricity, making these systems a compelling proposition for achieving energy access goals quickly.[3] In countries such as Kenya and Uganda, the number of off-grid systems deployed in 2016 outpaced the grid connections achieved by rural electrification agencies and national utility companies.[4]

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
- improved lighting quality for households
- increased school retention and improved grades for children
- increased income for small and medium-sized businesses and
- reduced negative impacts on forests.[5]

In 2017, an increasing number of national governments demonstrated their interest in DREA systems by enhancing the enabling environment[i].[6] In the off-grid solar market, sales of smaller devices (for example, solar lanterns) decreased in 2017.[7] At the same time, the market for larger systems continued to grow, building on the momentum of pay-as-you-go (PAYG)[ii] sales in the traditional East African markets and on a significant increase in sales in new West African markets, although these systems still supply a small proportion of overall off-grid solar customers.[8] Investments in off-grid solar companies decreased slightly despite an increase in the capital raised by PAYG companies.[9]

This chapter reviews the current status of and trends in DREA in developing and emerging countries and presents an overview of the major programmes and initiatives that were launched or were operational in 2017.

OVERVIEW OF ENERGY ACCESS

Approximately 1.06 billion people (about 14% of the global population) lived without electricity in 2016, about 125 million fewer people than in 2014.[10] The definition of electricity access may vary from country to country[iii], although efforts are ongoing to develop and harmonise statistical methodologies for the calculation of electrification rates.[11]

About 2.8 billion people (38% of the global population, and about 50% of the population in developing countries) live without clean cooking facilities[iv].[12] The vast majority of people without access to either electricity or clean cooking are in sub-Saharan Africa or the Asia-Pacific region, and most of them live in rural areas.[13] ***(→ See Reference Tables R22 and R23.)*** For example, 55% of people without electricity access live in sub-Saharan Africa and 41% live in developing Asia.[14] Furthermore, 67% of people without access to clean cooking facilities live in developing Asia and 30% live in sub-Saharan Africa.[15]

i For example, putting in place supporting legal and regulatory frameworks, appropriate financing mechanisms and sufficient overall investment, as well as strong partnerships between public and private actors.

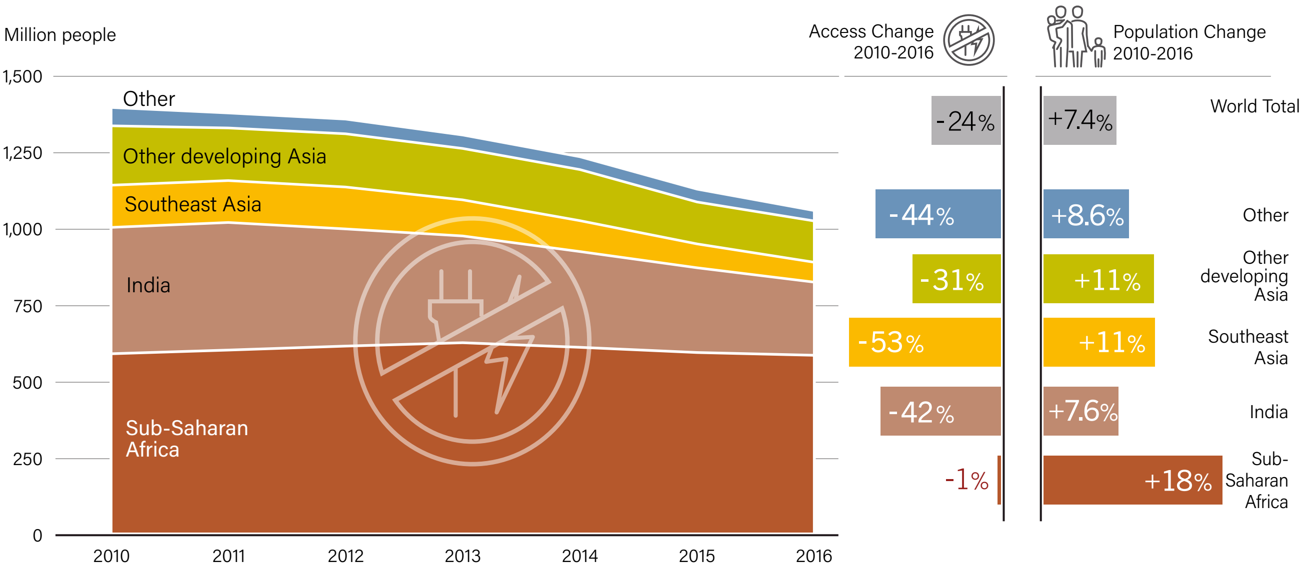
ii With the PAYG model, customers usually make a small deposit for the installation of the system and then pay regular instalments through mobile payment systems. PAYG has two main approaches: energy as a service approach whereby the customer pays for the electricity provided and does not own the system, and the lease-to-own model whereby the customer becomes the owner of the system after a period of time. The lease-to-own model is the most prominent one.

iii For example, in South Africa, a household is considered to have access to electricity if it is supplied with 50 kilowatt-hours (kWh) per month, while a village in India is considered electrified if electricity is provided to social institutions such as schools and health centres and to 10% of households.

iv This refers to the use of inefficient, unhealthy and unsafe open fires as well as rudimentary cook stoves running on solid fuels such as biomass, coal and animal waste for daily cooking needs.

In Africa, 588 million people (nearly 48% of the population) lack access to electricity, with the majority of those living in sub-Saharan Africa.[16] An estimated 26 million people in the region gained access to electricity annually between 2012 and 2016, with progress made in electricity access outpacing population growth between 2014 and 2016.[17] However, progress has been slow compared to other regions.[18] *(→ See Figure 39.)* Access also varies considerably, from close to 100% across North Africa to less than 15% in countries such as South Sudan (1%), the Central African Republic (3%), Chad (9%), Sierra Leone (9%) and Niger (11%).[19] ***(→ See Reference Table 22.)***

FIGURE 39. Population Without Access to Electricity, by Region or Country, 2010-2016



Source: See endnote 18 for this chapter.

In addition, as of the end of 2015, about 848 million people (72% of the population) in Africa lacked access to clean cooking facilities, with the vast majority (846 million) of them in sub-Saharan Africa.[20] In some 24 countries in the sub-Saharan region, more than 90% of the population still relied on traditional biomass[i], coal or kerosene for cooking purposes, including in Nigeria (171 million people; 94% of the population), Ethiopia (94 million people; 95% of the population) and the Democratic Republic of the Congo (75 million people; more than 95% of the population).[21] ***(→ See Reference Table R23.)***

In developing Asia, the number of people who lack access to electricity decreased from over 1 billion in 2000 to less than 0.44 billion in 2016, with significant progress particularly in Bangladesh, China, India and Indonesia.[22] In India, for example, the headline electrification rate improved from 43% in 2000 to 82% in 2016.[23] Despite progress, large numbers of people remain without access to modern energy. India is home to the highest number of people worldwide without reliable access to electricity (239 million, or 18% of the population).[24]

> **Electricity Access Rates**
> have improved across all regions, although sub-Saharan Africa is lagging behind

The number of people without electricity access in Bangladesh is approximately 41 million (25% of the population), in Pakistan 51 million (26%) and in Indonesia 23 million (9%).[25] ***(→ See Reference Table R22.)***

i Firewood, charcoal, dung or crop residues used in open fireplaces or unimproved cook stoves.

In addition, as of the end of 2015, about 1.9 billion people (49% of the population) living in developing Asia lacked access to clean cooking facilities.[26] The number of people relying on traditional biomass to meet their household cooking needs is more than 780 million (59%) in India, 307 million (33%) in China, 133 million (83%) in Bangladesh, 95 million (50%) in Pakistan and 67 million (32%) in Indonesia.[27] ***(→ See Reference Table R23.)***

Although 93% of the population in the Middle East region has access to electricity, in some individual countries high shares of the population still lack access to modern energy.[28] In Yemen, 48% of the population (14 million people) does not have access to electricity, and 39% of the population (11 million people) lacks access to modern cooking fuels and technologies.[29]

Similarly, in Latin America and the Caribbean as a whole, while 97% of inhabitants have access to electricity, several individual countries have high shares of people without access, including Haiti (67% of the population; 7 million people), Honduras (24%; 2 million) and Nicaragua (11%; 0.7 million).[30] About 59 million people in the region (12% of the population) do not have access to clean forms of cooking.[31]

In Haiti, 93% of the population is dependent on traditional cooking fuels and devices, while in Honduras and Nicaragua less than 50% of the population has access to clean cooking solutions.[32]

TECHNOLOGIES AND MARKETS

People in rural and remote regions generally acquire improved access to energy in three ways: through household-level use of isolated devices and systems that generate electricity and/or heat; through systems such as mini-grids that are village-wide or regional and that connect multiple users; and through grid extension, where the grid is extended beyond urban and peri-urban areas.

This section discusses developments in 2017 for distributed renewable energy and covers core technologies such as pico solar systems[i], plug-and-play[ii] and custom-made[iii] solar home systems (SHS), non-domestic off-grid power supply systems, mini-grids and clean cooking systems.

ACCESS TO ELECTRICITY

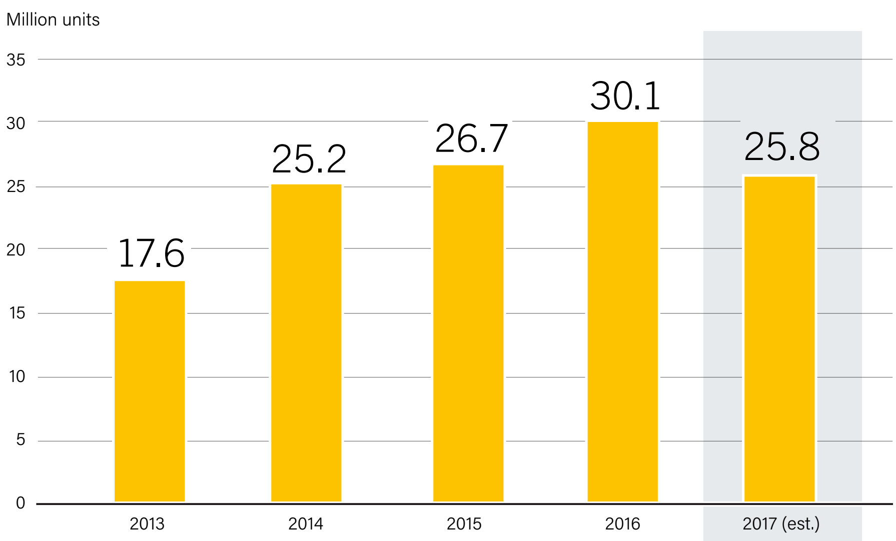
Off-grid solar systems such as solar lanterns and SHS experienced impressive growth between 2010 and 2017 (60% compound annual growth rate) and were notably the most significant technologies in the DREA sector in 2017 in terms of market development and technological and business model innovation.[33] Some 130 million quality-assured off-grid solar systems had been sold cumulatively by the end of 2017, providing electricity access to about 360 million people worldwide.[34] In 2017, an estimated 25.8 million off-grid solar systems were sold, a 14% decrease from sales reported in 2016.[35] *(→ See Figure 40.)* This contraction is attributed mainly to a decrease in sales of pico solar systems.[36] Pico solar systems still account for about 87% of the market, despite rising sales of plug-and-play SHS.[37]

i Pico systems are lanterns and simple multi-light systems (which may enable mobile charging), or units under 10 watts.

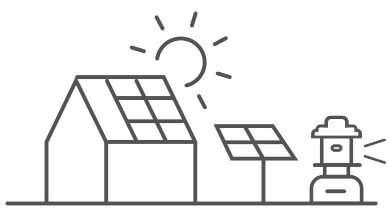
ii Plug-and-play systems are packaged solar home kits of 11 watts or more, typically powering several lights as well as energy-efficient appliances.

iii "Custom-made" systems (also referred to as "component" systems) are those in which components (such as the solar photovoltaic module, battery, lights, etc.) are compiled independently, and may be from different manufacturers. Systems may be assembled and distributed as part of national programmes or assembled in an entirely decentralised manner. Custom-made systems may offer price advantages but also may have lower quality and/or safety standards.

FIGURE 40. Annual Global Sales of Off-Grid Solar Systems, 2013-2017



Off-grid solar system sales saw a –14% change from 2016, due to a series of localised shocks and some market restructuring

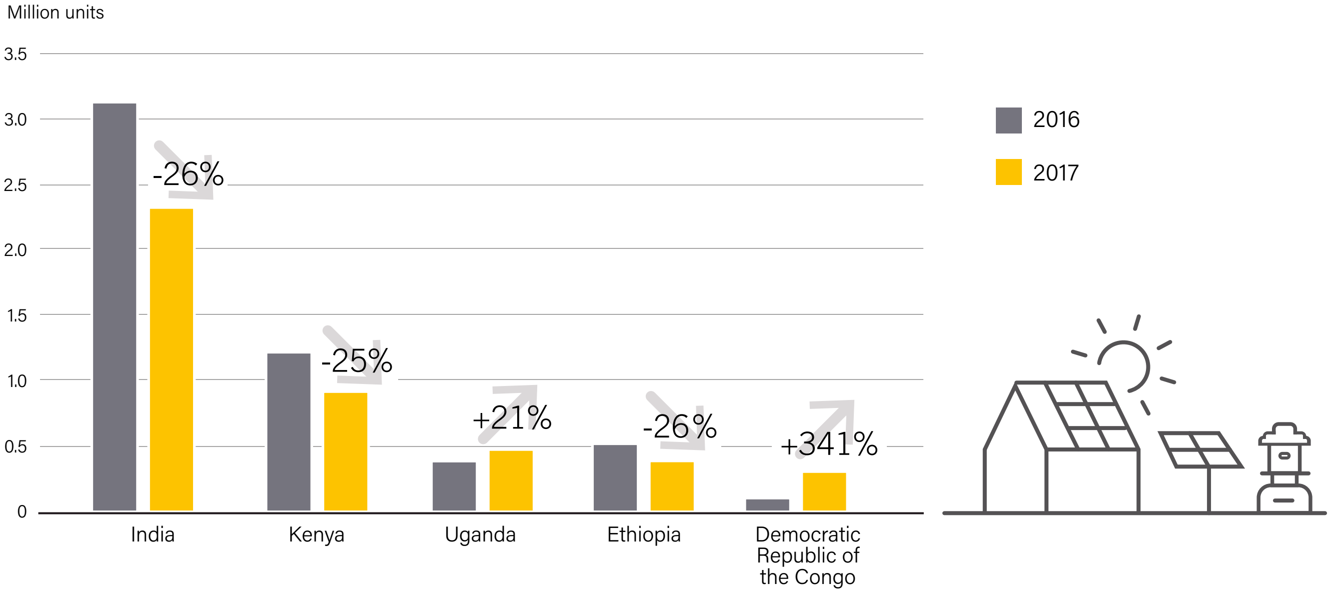


Source: See endnote 35 for this chapter.

Sales of off-grid solar systems decreased nearly 16% between 2016 and 2017 in both East Africa and South Asia, the two main regional markets that account for 66% of global sales.[38] In contrast, the market in Central Africa expanded by almost 173% in 2017 while markets in East Asia and the Pacific grew 41%.[39]

Across the top five markets, sales decreased in 2017 in Ethiopia, India and Kenya, whereas sales increased in the Democratic Republic of the Congo and Uganda.[40] *(→ See Figure 41.)* For example, Kenya, the largest market in sub-Saharan Africa, had a 24% decrease in reported sales in 2017 compared to 2016.[41] In contrast, the off-grid solar market in the Democratic Republic of the Congo and Uganda continued to grow, with sales in the Democratic Republic of the Congo reported to have more than tripled between 2016 and 2017.[42]

FIGURE 41. Number of Off-Grid Solar Systems Sold by GOGLA Affiliates in Top 5 Countries, 2016 and 2017



Note: Data reported here represent about 30% of all sales of off-grid solar PV products across these markets.

Source: See endnote 40 for this chapter.

Pico solar systems experienced a 15% drop in sales in 2017, with 22.3 million devices sold during the year.[43] This contraction in sales is attributed mainly to a series of localised shocks in the key markets of India, Kenya, Nigeria and Tanzania, as well as to structural market changes[i].[44]

In contrast, the market for plug-and-play SHS grew by about 28% in 2017, with estimated sales of 1.02 million.[45] Moreover, sales more than doubled in some regions between the second quarter of 2016 and the first quarter of 2017, albeit from a low base, with a 110% increase in South Asia and a 170% increase in West Africa.[46]

The share of custom-made SHS remains largely unstudied; however, new data suggest that these systems make up as much as 9% of the market for off-grid solar systems.[47] For example, a significant proportion of the 5.2 million SHS installed in Bangladesh by year-end 2017, with a total capacity of 218 megawatts (MW), consists of custom-made SHS distributed through a national programme.[48]

Many examples exist of DREA systems providing electricity access to social institutions. In 2017, projects deploying solar systems to multiple hospitals and clinics were implemented in Ghana, Malawi, Namibia, Pakistan, Uganda and Zimbabwe.[49] In 2016, Morocco embarked on an initiative to decrease the energy consumption of mosques, and several off-grid mosques were equipped with solar systems in 2017.[50] Also in 2017, an initiative aimed at improving school access to electricity deployed multiple systems in Zambia.[51]

i These changes include, for example, the exhaustion of relatively easier markets and the inability to penetrate untapped ones, and the market exit of some reporting companies due to increased competition with non-GOGLA affiliates.

In 2017, humanitarian efforts led to installations of DREA systems as part of reconstruction and stabilisation initiatives in Puerto Rico, the State of Palestine, South Sudan and Syria.[52] Under the initiative of the United Nations Refugee Agency (UNHCR), refugee camps in Jordan, Kenya, Lebanon and Rwanda were equipped with solar systems to improve camp power supply, provide light in schools and improve the lives of individual refugees.[53]

The mini-grid sector, although still considered a niche by many, has witnessed significant attention from governments and financiers. An increasing number of private mini-grid developers are actively testing a range of business models and helping to move the sector to maturity. The main drivers for the increased interest in mini-grids are the lower costs of solar photovoltaic (PV) technology, improved understanding by investors about potential returns, operational performance and costs, as well as government recognition that DREA systems can help achieve targets for energy access more rapidly than traditional grid extensions.[54]

Developments in the mini-grid sector targeting off-grid communities were driven by installations in East Africa and South Asia. A hotbed for business model innovation, India reported the largest number of mini-grid installations in the period 2016-2017, at 216 systems.[55] Mini-grid projects also were deployed in Bangladesh, Kenya, Liberia, Myanmar, Nigeria and Tanzania.[56]

According to one source, in 2017 an estimated 13 renewable energy-based large mini-grid projects (with installed capacity greater than 100 kW) were implemented in countries outside of the Organisation for Economic Co-operation and Development (OECD) and China, primarily in Africa and Southeast Asia, half of which were designed specifically to provide electricity access.[57] The pipeline for 2018 suggests that the market may more than double, with about 35 new mini-grid projects announced in 2017, although many smaller mini-grids are not included in these estimates.[58] *(→ See Figure 42.)*

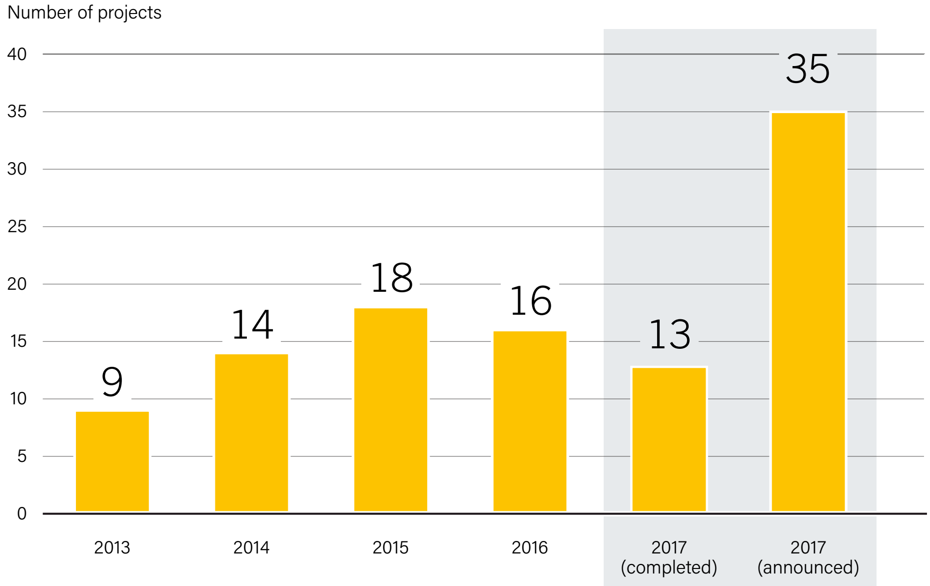
Solar PV is the technology of choice for most mini-grids under development in the last few years. Even in countries such as Indonesia and Myanmar, where hundreds of hydropower mini-grids have been serving rural customers for many years, solar PV systems are quickly starting to gain market share.[59] In countries such as Bangladesh, India and Rwanda, where many villages are relatively compact and densely populated, several companies are deploying direct current (DC) solar PV mini-grids that provide basic energy services.[60]

Biomass gasifiers traditionally have played an important role in the electrification of villages and in the provision of power to off-grid small and medium-sized enterprises in South and Southeast Asia. In recent years, interest from some Indian manufacturers to enter new markets has kick-started the deployment of gasifiers in sub-Saharan Africa as well, with installations of 5 gasifiers in Tanzania providing power to 1,000 customers.[61] A US-based manufacturer has installed two biomass gasifiers in Liberia since 2014.[62]

Hydropower-based mini-grids continue to be an important technology for the electrification of communities living in mountainous areas where the costs of expanding the grid are too high and the water resource is reliable. New installations in 2017 helped provide electricity access to communities in Afghanistan, Madagascar and Tajikistan.[63]

The rapid market growth of DREA technologies between 2010 and 2017 has been facilitated by several technological innovations. Key system components such as batteries, light-emitting diodes (LEDs), controllers and meters have experienced major cost reductions and efficiency improvements.[64] These developments have been complemented by the emergence and proliferation of solutions for remote monitoring, data analytics, and customer management and payments.[65] *(→ See also Digitalisation sidebar in Integration chapter.)* Adoption of these innovations by other DREA

FIGURE 42. Estimated Renewable Energy-based Large Mini-grid Projects (>100 kW) Installed Outside of the OECD and China, 2013-2017



In 2017, the number of annually installed smaller mini-grids is moving from tens to **HUNDREDS.**

Note: Data include only projects that have installed capacity greater than 100 kW and with at least two generation sources that have a local load and that are islandable. About half of these larger mini-grids are to improve energy access, with the rest for industrial/commercial use or to boost island supplies.

Source: Bloomberg New Energy Finance (BNEF). See endnote 58 for this chapter.

subsectors has the potential to unlock and accelerate new markets for DREA technologies and to increase customer choice.[66]

At the same time, several manufacturers have started marketing highly efficient low-voltage DC appliances such as televisions (TVs), fans, refrigerators and small machines designed specifically to be powered by off-grid solar systems.[67] By using high-efficiency products the energy system size can be reduced significantly so that consumers get the same or higher level of energy service at lower cost overall. For example, integrating super-efficient appliances on a mini-grid can reduce annual electricity expenditures by 60% compared to using conventional appliances, and the annualised cost of both appliances and their electricity use is reduced by 30%, despite higher upfront appliance costs.[68]

This technology evolution is increasingly transforming off-grid systems into viable propositions, as evidenced by the market entry of large energy companies.

ACCESS TO CLEAN COOKING FACILITIES

The market for clean cooking solutions continued to thrive in 2016, with clean[i] cook stoves making up 83% (30.8 million) of the 37 million cook stoves distributed.[69] The number of clean cook stoves distributed more than tripled in 2016 compared to 2015, highlighting the positive momentum in the sector.[70]

In 2016, building on the momentum of its Pradhan Mantri Ujjwala Yojana cooking gas programme, India became the main market for clean cook stoves, with 20.3 million distributed.[71] China continued to be a major market, with 6.2 million clean stoves distributed in 2016, while Bangladesh, Ghana and Kenya all matched or exceeded their 2015 numbers.[72] *(→ See Figure 43).*

In 2016, only an estimated 29% of the 30.8 million clean cook stoves distributed used renewable fuels, with most of those using wood or charcoal (25%)[ii], followed by biogas (3.5%).[73] *(→ See Figure 44.)* The majority of clean cook stoves (71%) use liquefied petroleum gas (LPG).[74]

Globally, a cumulative total of more than 50 million biogas cook stoves had been installed as of year-end 2016, with about

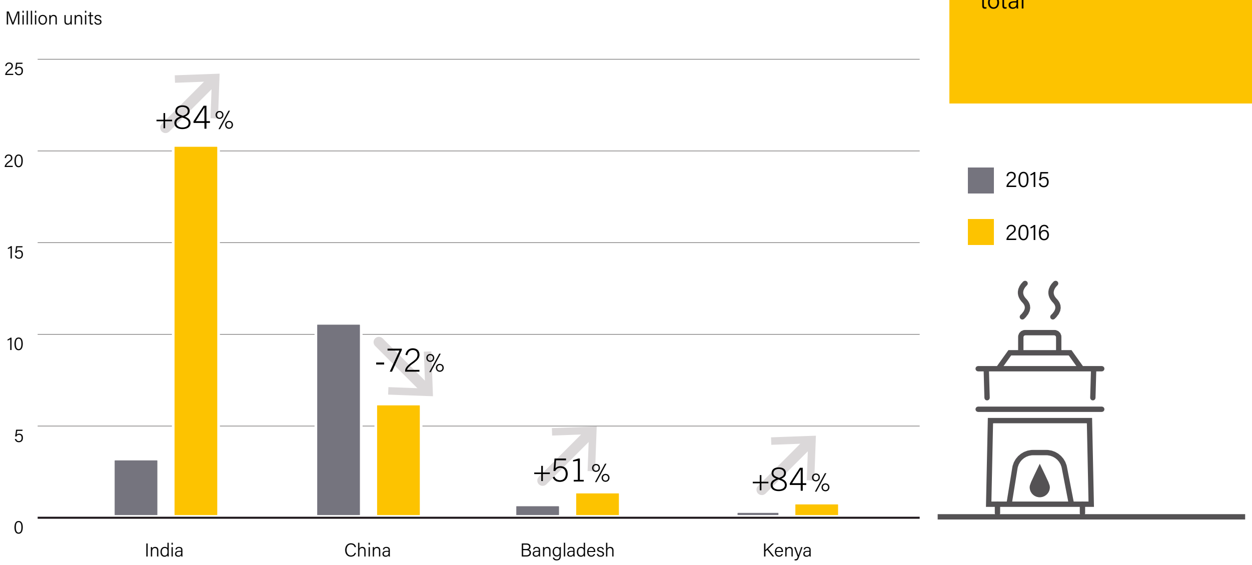
i "Clean" in this section refers to clean and/or efficient cook stoves as per the methodology of the Global Alliance for Clean Cookstoves: stoves and fuels that meet Tier 2 for efficiency are considered efficient, and those that meet Tier 3 for indoor emissions are considered clean for health, in accordance with the interim performance guidelines in the International Organization for Standardization International Workshop Agreement.

ii This includes pellets and gasifiers, both of which are wood-based.

20 million

clean cook stoves were distributed in India in 2016, two-thirds of the world total

FIGURE 43. Number of Clean Cook Stoves Distributed in Selected Countries, 2015 and 2016



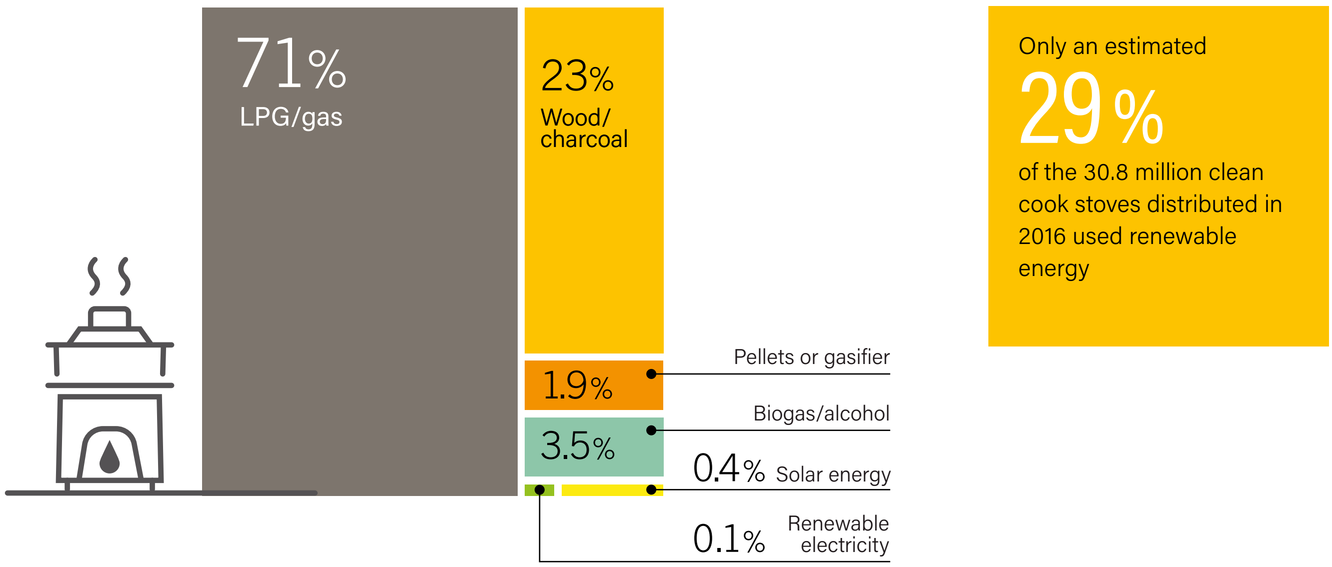
Note: Figure does not exclusively show renewable energy-based cook stoves. Figure includes cook stoves that were both sold (at market and subsidised prices) and given at no cost.

Source: See endnote 72 for this chapter.

126 million people using biogas for cooking, mainly in China (112 million) and India (10 million).[75] China accounted for 13 million cubic metres of biogas production from biogas digester installations for cooking in 2016, and India accounted for 2 million cubic metres.[76] The use of biogas for cooking continued to grow in South-Central and South-Eastern Asian countries such as Bangladesh, Cambodia, Indonesia and Nepal, and also in sub-Saharan Africa, namely in Ethiopia, Kenya and Tanzania.[77] (→ *See Figure 45.)* Through the Africa Biogas Partnership Programme, more than 58,000 biogas plants are estimated to have been installed in Burkina Faso, Ethiopia, Kenya, Tanzania and Uganda since 2009.[78]

As of the end of 2017, more than 3.1 million solar cookers were estimated to have been distributed worldwide, with 115,000 solar cookers deployed in 2016 to provide clean cooking facilities to households.[79]

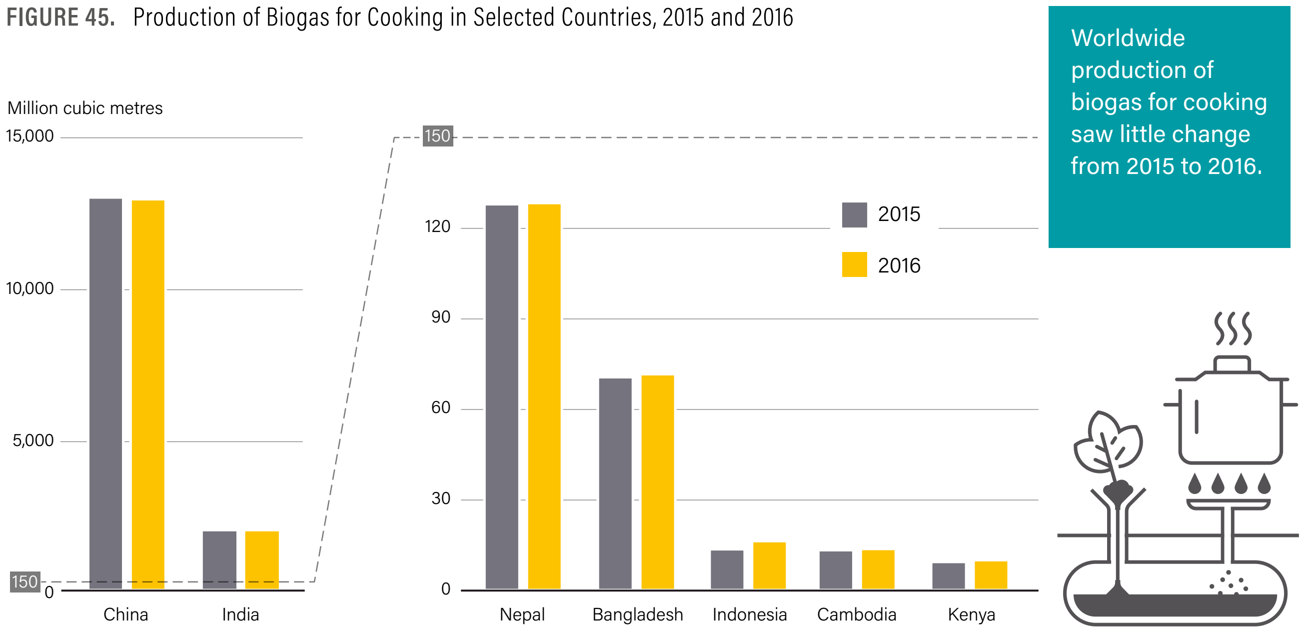
FIGURE 44. Approximate Proportion of Clean Cook Stoves by Energy Source, 2016



Note: LPG = liquefied petroleum gas

Source: See endnote 73 for this chapter.

FIGURE 45. Production of Biogas for Cooking in Selected Countries, 2015 and 2016



Source: See endnote 77 for this chapter.

INVESTMENT AND FINANCING

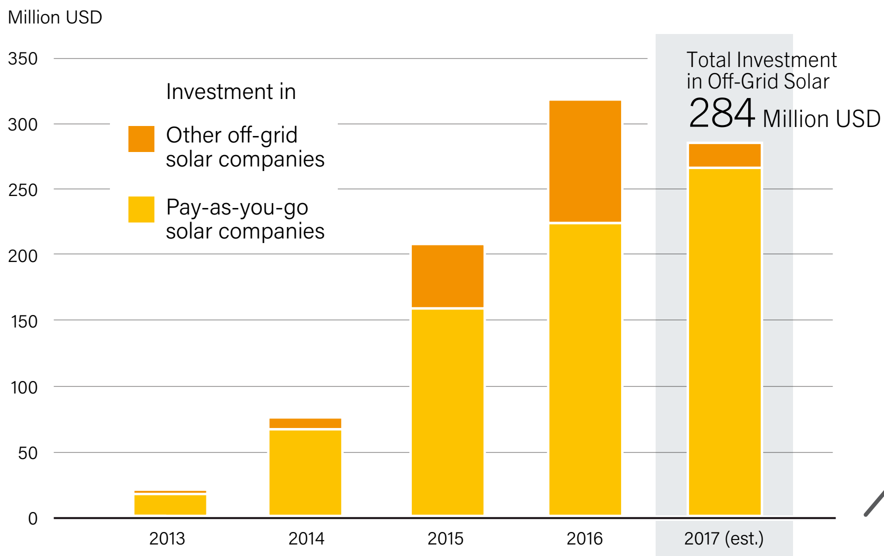
DREA systems attracted some USD 922 million in investment between 2012 and 2017, with a large portion of this for solar PV.[80] In 2017, off-grid solar companies raised USD 284 million, a decrease of 10% from the USD 317 million raised in 2016.[81] PAYG companies attracted nearly all of the investment.[82] *(→ See Figure 46 and Business Models section of this chapter.)* As of the end of 2017, the PAYG solar PV companies had raised an estimated USD 263 million, an increase of 18% from 2016.[83]

DREA companies attracted funding in 2017 from various sources, including development finance institutions (DFIs), impact investors, investment funds, foundations, commercial finance and crowdfunding platforms. Impact investors (USD 139 million) and DFIs (USD 71 million) accounted for nearly 75% of the financing secured by off-grid solar companies in 2017.[84] *(→ See International Initiatives and Programmes section in this chapter.)*

Off-grid solar companies operating in sub-Saharan Africa, primarily in East Africa, continued to be the main recipients of capital inflows in the sector. For example, the Kenyan solar energy company M-KOPA secured USD 80 million in 2017, the largest solar deal in Africa that year.[85] The German company Mobisol raised USD 25 million in 2017 to expand its operations in East Africa.[86] In 2017, off-grid solar projects accounted for 5 of the 11 largest solar investments on the African continent.[87]

Investments continued to flow to PAYG companies in Asia, although at a much slower pace than recorded in previous years. In 2017, Greenlight Planet raised USD 60 million in equity and debt financing to expand its activities in rural Africa and Asia, while India-based Mera Gao Power secured USD 2.5 million.[88] Off-grid solar companies in Latin America and the Caribbean raised about USD 12.5 million in investments in 2017, with Guatemala's Kingo announcing a USD 8 million investment to expand its activities in Central America.[89] The proportion of investment on a debt basis continues to grow, constituting 61% in 2017, up from 40% in 2015, with equity-based investments accounting for 36% and grant-based investments accounting for 3% in 2017.[90]

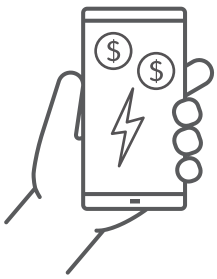
FIGURE 46. Global Investment in Off-Grid Solar PV Companies, 2013-2017



Investment in PAYG companies increased

1,400 %

during 2013-2017



Source: See endnote 82 for this chapter.

Note: Data for 2017 are estimated.

Mini-grids continued to attract financing in 2017, primarily through public funds or development banks. In 2017, Zambia-based Standard Microgrid announced that it had raised up to USD 3.5 million for the deployment of six solar PV mini-grids in the country.[91] PowerGen raised USD 4.5 million in view of providing electricity through mini-grids to some 50,000 people in the next two years in Kenya and Tanzania.[92] The government of Cameroon secured a loan of USD 123 million from the Bank of China for the extension of its rural electrification programme with solar PV mini-grids.[93]

Also in 2017, the government of Mozambique launched its USD 500 million electrification programme based on hydropower and solar PV mini-grids.[94] Indian mini-grid developer OMC Power announced an equity investment of about USD 9.3 million from Japan's Mitsui in a joint venture to install solar hybrid mini-grids in Africa.[95] The Microgrid Investment Accelerator, launched in 2017 by Facebook and Microsoft, aims to mobilise some USD 50 million between 2018 and 2020 to expand energy access in East Africa, India and Indonesia.[96]

In the clean cooking sector, Sustainable Energy for All (SEforALL) estimates that, on average, USD 32 million was invested annually in 2013-2014 in the 20 high-impact countries – an average of USD 26 million from international public funding and USD 6 million from private finance.[97] Nearly 78% of these investments (USD 24.8 million) targeted the sub-Saharan Africa region and in particular East African countries, while around USD 7.2 million was channelled to Asia (primarily India and Vietnam).[98]

After attracting an annual average of around USD 24 million in investment from 2012 to 2016, clean cooking companies recorded financing flows of only USD 18.1 million in 2017, highlighting the challenges impeding the growth of the sector[i],[99] Since 2014, debt and equity financing in the sector has increased considerably, making up nearly 70% of funds invested in the sector in 2017.[100] *(→ See Figure 47.)*

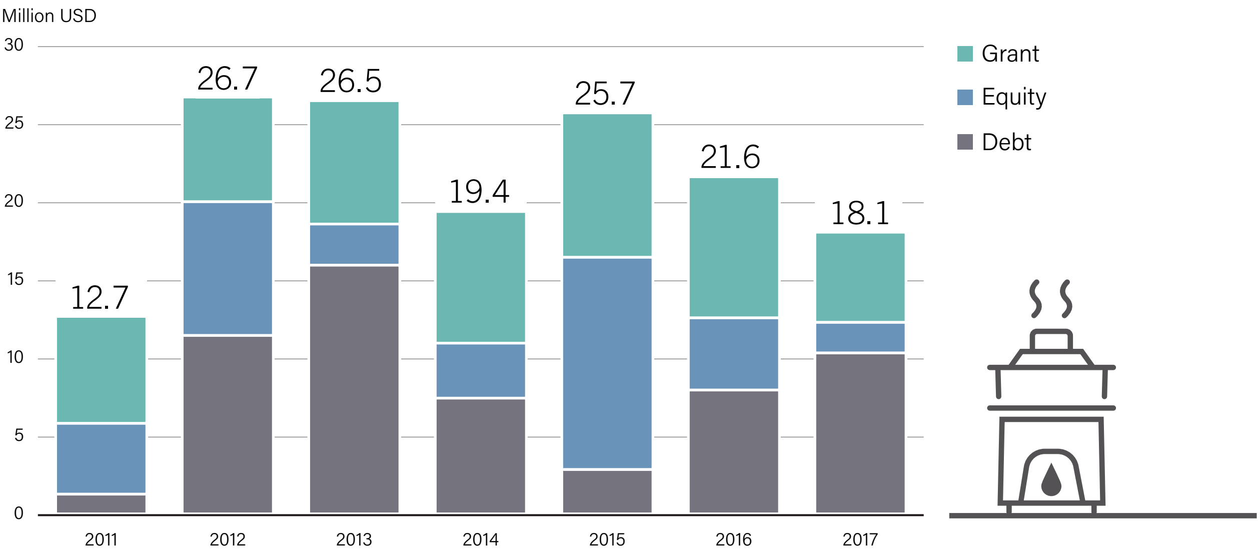
Less than half of the estimated annual investment required to achieve universal energy access by 2030 is being committed to fund energy access activities

For example, in 2017 Rwanda's Inyenyeri secured a loan of EUR 8 million (USD 9.6 million) from Athelia Climate Fund and the Dutch development bank FMO – as well as a grant of about EUR 3.75 million (USD 5.5 million) – to scale up its model to provide clean forced-draft gasifier stoves together with biomass pellets in Rwanda.[101] Also in 2017, ATEC Biodigesters (Australia) secured about USD 950,000 in the form of equity and results-based financing to expand its biogas and cook stove activities in Cambodia.[102] Although for LPG rather than for renewable cook stoves, at the end of 2017 Kenya's PayGo Energy had raised around USD 1.4 million as debt and equity financing to finance the development of clean cooking as a service solution that will allow for the purchase of small increments of LPG and therefore reduce the upfront affordability barrier.[103]

Alternative funding mechanisms such as crowdfunding continued to support the development of small DREA companies. For example, off-grid solar companies raised an estimated USD 2.7 million from crowdfunding platforms in 2017, more than double the amount raised in 2016.[104] In 2017, Namibian solar distributor Olusheno raised EUR 209,400 (USD 250,870) through crowdfunding to bring SHS to households in Namibia.[105]

i The sector currently is characterised by low margins, high transaction costs due to a fragmented and early-stage pipeline, and a lack of investor knowledge, among other issues that hinder investment flows.

FIGURE 47. Global Investment in Clean Cook Stove Companies, 2011-2017



Source: See endnote 100 for this chapter.

The non-profit organisation Energy 4 Impact rolled out a crowdfunding campaign to promote both clean cook stoves and solar lighting products among women entrepreneurs in East Africa.[106] Crowdfunding also helped finance mini-grid deployments in Nigeria and India.[107]

Climate finance is supporting the deployment of DREA systems as well. Sri Lanka secured support from the Global Environment Facility in 2017 for 1,000 biogas digesters as part of a Nationally Appropriate Mitigation Action (NAMA) project.[108] The Green Climate Fund (GCF) approved a USD 50 million project in Ethiopia in 2017 that includes the use of solar energy to power water pumps.[109] By the end of 2017, the GCF had approved two projects with a major focus on energy access, representing 4.7% of all funds allocated.[110]

However, despite the increasing capital flows in the DREA sector, the amount raised is far from the estimated annual investment of USD 45-56 billion required to achieve the objective of universal access to energy by 2030.[111] Less than half of this amount (an average of USD 19.4 billion for 2013 and 2014) is actually being committed to fund energy access activities; of this, only 0.1% (about USD 200 million per year) directly supports DREA-related activities.[112]

BUSINESS MODELS

About
80 %
of off-grid solar PV sales were PAYG in 2015-2017

In recent years, innovative business models have been used to scale up energy access delivery strategies. A shift has occurred from the donor/government-driven model to a private sector model, where private firms lease or sell an electricity generating system and supply energy to consumers who pay for the service provided.[113] These business models have enabled the commercialisation of affordable and reliable products, helped overcome market failures and increased the viability of providing services to the off-grid and poor populations that lack access to energy.

The success of these business models relies mainly on innovation in distribution and end-user financing.[114] Five distribution models are generally used by DREA companies: partnerships between companies and institutions; distributor-dealer channels; proprietary distribution; franchise models; and renting or leasing systems. To overcome the consumer financing hurdle, many DREA companies, mostly those involved in off-grid solar PV, are shifting from microfinance institution (MFI)-based product loans to the PAYG model of end-user financing in countries that have relatively high penetrations of mobile money and digital finance.[115]

From 2015 to 2017, PAYG systems made up about 80% of off-grid solar sales (mostly SHS), with estimated cumulative sales of 1.5 million systems and more than 30 companies deploying PAYG solar in Africa, Asia and Latin America.[116] East African markets made up almost 86% of PAYG cumulative sales between 2013 and 2017, with more than 500,000 units installed in Kenya alone, while a combined total of about 50,000 units had been installed in West Africa and South Asia as of 2016.[117]

As part of their revenue diversification strategy, more off-grid solar companies are starting to offer televisions as part of their solar package. In 2017, Simpa Networks launched India's first solar-powered satellite TV solution.[118] Similarly, d.light began commercialising a PAYG solar TV package in East Africa.[119] Also in 2017, UK-based Azuri Technologies partnered with Kenya's Mobicom to expand its solar TV systems offer.[120] By the end of 2017, M-KOPA announced that it had connected nearly 100,000 homes to solar TVs in East Africa since the launch of its solar-powered TV in 2016.[121]

Market-based approaches such as the PAYG model are yet to emerge as game changers for the clean cooking sector. As of the end of 2017, only an estimated 6-12% of improved cook stoves had been distributed through a non-subsidised market-based approach.[122] Companies such as Envirofit, BioLite and BURN Manufacturing are building partnerships with MFIs to sell their products through a partner with financial capacity, thereby circumventing the high upfront cost of clean cook stoves. BURN Manufacturing sold more than 300,000 clean cook stoves in Kenya between 2013 and mid-2017, helped by its partnerships with MFIs.[123]

Some companies in the clean cooking sector also are transforming their business models to provide clean cooking facilities on a PAYG basis, although most initiatives are focused on LPG rather than on renewable stoves. At the end of 2017, KopaGas, operating in Tanzania, was serving an estimated 15,000 customers monthly with its pay-per-use LPG.[124] Also in 2017, Envirofit experimented with its pay-as-you-cook model with the launch of its SmartGas LPG program.[125] Fenix International, a PAYG solar company, secured funding in 2017 to offer renewable clean cook stoves to its customers using a PAYG instalment method.[126]

Despite growing interest and several pilot projects, a business model has not yet been proven for renewable-based mini-grids.[127] Mini-grid models that have been developed in recent years are tailor-made to the site, the customer base, the ownership and the operation model, among other considerations.[128] In 2017, the US-based company Renewvia Energy and Nigeria's Community Energy Social Enterprises Limited and microfinance company Kilowatts partnered to power 10,000 Nigerian homes with solar mini-grids using a PAYG scheme.[129] Similarly, Powerhive received support from Power Africa's Development Innovation Ventures programme to develop its Productive Use Program based on renewable mini-grids that will provide customers in Kenya with low-cost appliance leases and business loans combined with enterprise development support.[130]

One growing trend in the DREA sector has been the establishment of partnerships between multinationals and local businesses and off-grid solar companies. Several notable partnerships were initiated in 2017. Africa's largest telecommunications company, MTN Group, expanded its partnerships with Mobisol and Fenix International.[131] Mobisol also partnered with solar distributors Baobab+ and SunTransfer to offer off-grid solar solutions through PAYG in Côte d'Ivoire and Ethiopia, respectively.[132] Following the agreement between Africa's Ignite Power and the government of Rwanda in 2016, UK-based BBOXX and the government of Togo signed an agreement to install about 300,000 SHS by 2022.[133] In 2017 the French energy giant ENGIE acquired Fenix International, a lease-to-own SHS provider.[134] The German energy utility E.ON is operating eight mini-grids in Tanzania.[135] In 2016, the French national utility EDF entered into a partnership with a company based in Myanmar aimed at developing mini-grids.[136] Similarly, Envirofit, a leading clean cook stove company, partnered with India's leader in technology and outsourcing, Infosys, to deliver 37,200 cook stoves in the state of Maharashtra.[137]

POLICY DEVELOPMENTS

Although much progress has been made in many regions of the world to increase energy access through the use of DREA systems, the lack of appropriate policy support and an enabling environment is often seen as one of the key challenges impeding growth of the sector.[138] For example, some 70% of Africa's least-electrified countries[i] have not yet established a proper enabling environment including the right policies, institutions, strategic planning, regulations and incentives to support energy access.[139]

Moreover, fewer than 50% of the 55 countries defined as access-deficit[ii] have implemented national programmes for the deployment of stand-alone solar systems.[140]

Policies supporting the growth of DREA systems can be classified in five broad categories:

- Reduce import duties and tariffs on renewable energy products
- Support the availability of local finance through loans, grants and microfinance
- Establish energy access targets and national commitments
- Establish rural electrification plans or programmes incorporating DREA
- Provide regulatory support such as established procedures for mini-grid operators or the adoption of quality standards for products and services.[141]

In 2017, several countries adopted policy measures to create the appropriate enabling environment for DREA deployment and increased rates of energy access.

To support the deployment of mini-grids, Nigeria approved comprehensive guidelines regulating the sector.[142] The guidelines provide clarity about key regulatory aspects important to developers, such as tariffs and grid integration. Other countries used government-backed energy funds to support the development of mini-grids. Along with Kenya and Tanzania, which have used government funds to deploy mini-grids for several years, the Mozambique Energy Fund announced in 2017 that it was providing substantial financing for the electrification of 322 villages in the country.[143]

While the policy framework for mini-grids seems to be improving in several countries, policy changes relating to import duties and value-added tax (VAT) for renewable energy technologies have negatively affected the sales of off-grid solar products.[144] However, in 2017 some countries such as Sierra Leone removed VAT and import duties on solar products.[145]

i Least-electrified countries are those with an access rate of less than 20%.

ii Access-deficit countries are those with less than 90% electrification or more than 1 million people without access.

INTERNATIONAL INITIATIVES AND PROGRAMMES

Numerous international actors and donors continued to be committed to deploying DREA systems in 2017. For example, in 2017 SEforALL launched a people-centred accelerator that aims to advance gender equality, social inclusion and women's empowerment in the sustainable energy sector.[146]

Power Africa continued to advance off-grid access through investments, technical assistance to rural electrification agencies and national utilities, and targeted support to the private sector.[147] By mid-2017, Power Africa reported that it had achieved 10.6 million connections towards its goal of 60 million connections by 2030, delivered mainly by pico solar systems and a small number of mini-grids.[148]

DFIs continued to be an important source of funding for DREA projects in 2017. The World Bank saw a record number of requests from partner governments for support of projects promoting energy access.[149] It approved USD 150 million for Kenya's Off-grid Solar Access Project for Underserved Counties, which aims to provide modern energy to an estimated 1.3 million people in the country.[150]

Niger also received USD 50 million from the World Bank to increase energy access in rural and peri-urban regions through stand-alone solar systems and solar hybrid mini-grids.[151] At the end of 2017, the World Bank was considering projects to construct mini-grids in Madagascar, Nigeria and Zambia, as well as a USD 200 million Regional Off Grid Electrification Project in the Economic Community of West African States and four Sahel countries.[152]

Similarly, the African Development Bank (AfDB) unveiled a USD 12 billion plan under its new electrification programme that aims to provide decentralised solar technologies to 75 million households and businesses between 2017 and 2022.[153] In 2017, the AfDB's Sustainable Energy Fund for Africa, which provides grants and technical assistance to governments, awarded USD 995,000 to the Republic of Gambia to facilitate private investments in green mini-grids, and USD 975,000 to Togo to enable the deployment of 300,000 solar kits over a five-year period.[154]

With the government of Japan, the AfDB also launched the Japan-Africa Energy Initiative that will support energy access activities in the region through USD 6 billion concessional and non-concessional finance.[155] The AfDB also successfully raised USD 90 million by issuing the first Light Up and Power Africa Bond, sold solely to Japan's Dai-ichi Life Insurance Company.[156] In addition, the AfDB together with the Nordic Development Fund launched the Facility for Energy Inclusion Off-Grid Energy Access Fund, a USD 55 million blended-finance debt fund.[157]

The Asian Development Bank approved sovereign financing for energy access and off-grid systems in Vanuatu and started the implementation of an off-grid market development project in Central Asia.[158] It also approved the third round of the Public-Private Infrastructure Development Facility in Bangladesh.[159]

The OPEC Fund for International Development (OFID) granted USD 800,000 to Tajikistan and the Kyrgyz Republic to facilitate access to sustainable energy for rural households primarily through solar PV.[160] In addition, OFID approved a grant of USD 1 million to Energy 4 Impact to drive the adoption of small-scale solar irrigation in Rwanda.[161]

> **Distributed renewable energy systems** are emerging as the least expensive and fastest option for providing energy access to many remote rural populations

In addition to multilateral funding, bilateral financing continued to flow in the sector. New Zealand granted USD 3.4 million to Vanuatu to provide modern energy to 8,400 households through SHS and mini-grids.[162] India announced that it would provide USD 66 million to finance a solar hybrid rural electrification project in Mauritania.[163]

Energising Development (EnDev) – an energy access partnership financed by seven donor countries[i] – continued to support energy access programmes in Africa, Asia and Latin America. In 2017, in collaboration with Barclays Bank Kenya, EnDev implemented a results-based financing (RBF) project to provide financial incentives to private project developers investing in solar PV hybrid mini-grids.[164] Similar RBF instruments were deployed for mini-grids and end-user appliances in Rwanda.[165]

The French Development Agency (AFD), through its subsidiary Proparco, secured EUR 24 million (USD 28.8 million) from the European Union's ElectriFI initiative to deploy its African Renewable Energy Scale-Up Facility.[166] This facility will use about half of the earmarked funds to provide technical assistance facilities to off-grid electricity providers, with the aim of providing energy to 1 million households on the continent.[167] Also in 2017, the Shell Foundation and Dutch development bank FMO announced a USD 50 million fund for energy access businesses in India and Africa.[168]

In the clean cooking sector, the Global Alliance for Clean Cookstoves provided support of up to USD 150,000 to six companies in 2017 to scale up investments in commercial clean cooking businesses.[169]

OUTLOOK

In 2017, off-grid distributed renewable systems attracted strong interest from governments and international organisations that are striving to improve energy access. The PAYG model for small solar systems, enabled by the emergence of mobile technology, has become one of the dominant business models. This, combined with the reduction in solar PV costs, has enabled the rapid spread of DREA into new markets, particularly in sub-Saharan Africa. DREA systems are emerging as the least expensive and fastest option for providing energy access to many remote rural populations. However, reaching energy access goals requires the necessary enabling environment in terms of legal and regulatory frameworks, appropriate financing mechanisms and sufficient overall investment, as well as strong partnerships between public and private actors.

i Australia, Germany, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom.

05

INVESTMENT FLOWS

Solar rooftop system at Jurong Port facility, City of Singapore, Singapore

The Jurong Port in Singapore completed a SGD 30 million (USD 22.4 million) installation of solar panels on its warehouse rooftop in 2016, making it the then-largest port-based solar PV facility in the world. The facility has a peak capacity of 9.5 MW and is estimated to generate more than 12 MWh of solar energy per year, providing more than 60% of the port's annual electricity needs.

INVESTMENT FLOWS

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 megawatts (MW)) totalled USD 279.8 billion in 2017, as estimated by Bloomberg New Energy Finance (BNEF)[i]. This represents an increase of 2% compared to the previous year, even as the costs of wind and solar power technologies fell further[ii]. Investment in renewable power and fuels has exceeded USD 200 billion annually since 2010. *(→ See Figure 48 and **Reference Table R26.**)* Investment in hydropower projects larger than 50 MW was an estimated additional USD 45 billion in 2017[iii].[1]

Global new investment in renewable power and fuels reached

279.8

billion USD

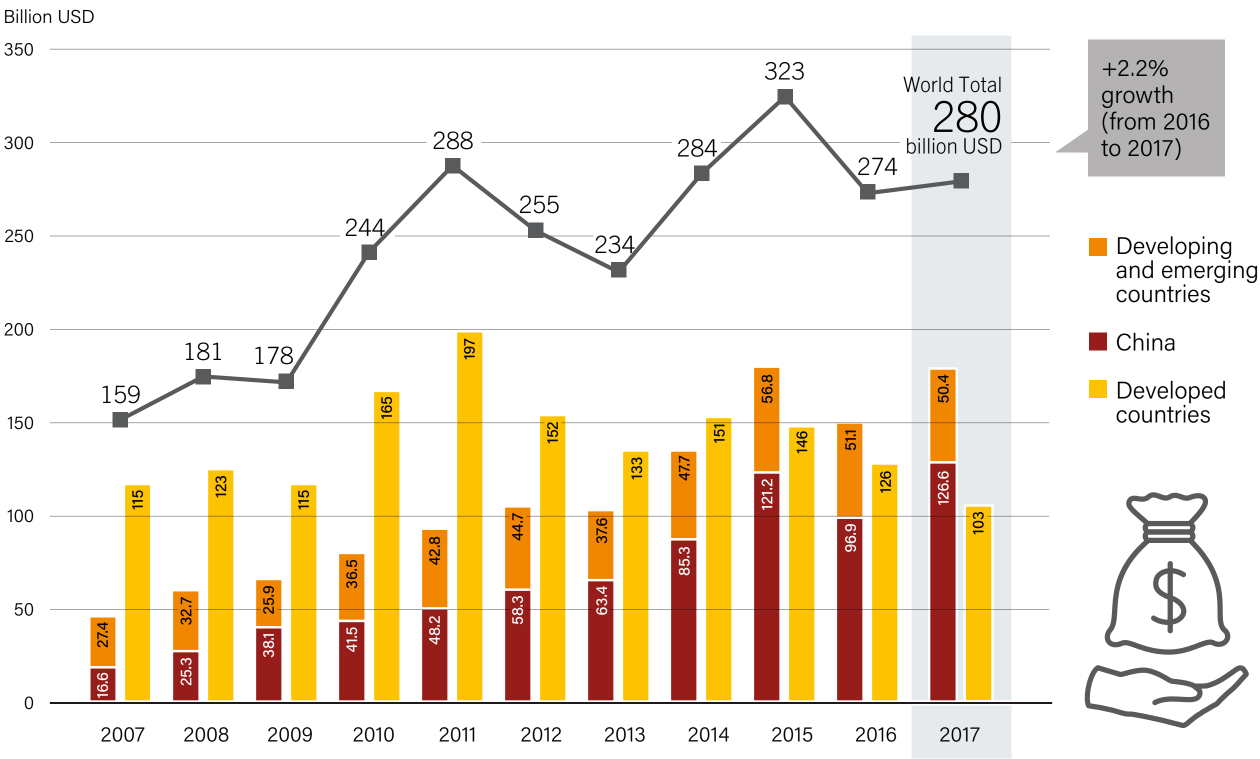
in 2017.

i This chapter is derived from United Nations Environment's ***Global Trends in Renewable Energy Investment 2018*** (Frankfurt: 2018), the sister publication to the GSR, prepared by the Frankfurt School–UNEP Collaborating Centre for Climate & Sustainable Energy Finance (FS-UNEP Centre) in co-operation with Bloomberg New Energy Finance (BNEF). Data are based on the output of the Desktop database of BNEF, unless otherwise noted, and reflect the timing of investment decisions. The following renewable energy projects are included: all biomass and waste-to-energy, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately and referred to as small-scale projects or small-scale distributed capacity; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more. For more information, please refer to the FS-UNEP Centre/BNEF *Global Trends Report*. Where totals do not add up, the difference is due to rounding.

ii 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 investment (monetary) do not necessarily reflect changes in capacity additions.

iii 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 48. Global New Investment in Renewable Power and Fuels in Developed, Emerging and Developing Countries, 2007-2017



Note: Figure does not include investment in hydropower projects larger than 50 MW. Investment totals have been rounded to nearest billion and are in current USD.

Source: BNEF.

These estimates do not include investment in renewable heating and cooling technologies, for which data are not collected comprehensively. The International Energy Agency[i] reports that global investment in solar thermal heating technologies increased steadily until 2013 but then fell each year through 2016 (latest data available).[2]

Investment in new renewable power capacity (including all hydropower) was three times the level of investment in fossil fuel generating capacity and more than double the investment in fossil fuel and nuclear capacity combined.

Investment in renewable energy continued to focus on solar power, particularly solar photovoltaics (PV), which increased its lead over wind power in 2017. Asset finance of utility-scale[ii] projects, such as wind farms and solar parks, dominated investment at USD 216.1 billion worldwide. Small-scale solar PV installations (less than 1 MW) accounted for USD 49.4 billion, representing an increase of 15%.

Renewable energy investment in developed countries[iii] as a group fell 19% in 2017. Investment decreased in the two developed-country front-runners, the United States and Japan, as well as in the leading European countries, Germany and the United Kingdom. Among developing and emerging countries, renewable energy investment increased 20%, to USD 177 billion.

China played a dominant role, investing USD 126.6 billion, its highest figure ever. Substantial increases in developing countries were witnessed in Mexico, Egypt, the United Arab Emirates and Argentina.

Developing countries extended their lead over developed countries in 2017, with

63 %

of global investment in renewable energy

i Methodologies for calculating investment in solar thermal heating and cooling technologies differ across institutions, and therefore data are not comparable.

ii "Utility-scale" in this chapter 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.

iii Developed-country volumes are based on OECD countries excluding Chile, Mexico and Turkey.

INVESTMENT BY ECONOMY

Developing and emerging economies overtook developed countries in renewable energy investment for the first time in 2015; they extended their lead in 2017, accounting for a record 63% of global investment in renewable energy, due largely to China. Developments in renewable energy investment varied by region[i], rising in China, Latin America (including Brazil) and the Middle East and Africa, and falling in Europe, the United States, Asia-Oceania (excluding China), Japan and India. *(→ See Figure 49.)*

Considering all financing of renewable energy (but excluding hydropower larger than 50 MW), China accounted for a record 45% of the global investment total, up from 35% in 2016. China was followed by Europe (15%), the United States (14%) and Asia-Oceania (excluding China and India; 11%). Smaller shares were seen in the Americas (excluding Brazil and the United States, 5%), India (4%), the Middle East and Africa (4%) and Brazil (2%).

The top 10 national investors consisted of four developing or emerging countries and six developed countries. In addition to China and the United States, top countries included Japan, India and Germany. The next five countries were Australia, the United Kingdom, Brazil, Mexico and Sweden.

China's investment in renewable power and fuels reached a record USD 126.6 billion in 2017, up 31% over 2016. Most of this total (USD 103.3 billion) was in asset finance, which increased 14% relative to 2016. In 2016, China invested roughly the same amount in solar and wind power; however, in 2017 the country experienced a boom in overall solar power investment, up 58% to USD 86.5 billion, whereas total investment in wind power declined by 6%.

Utility-scale solar power arrays of more than 1 MW accounted for most of China's solar power total, while the country's investment in small-scale solar PV project development increased nearly five-fold. By comparison, China's total investment in wind power was USD 36.1 billion; investment in onshore wind power was down 28%, while offshore wind power increased 180% to USD 10.8 billion. China also invested significant sums in large-scale hydropower[ii], commissioning 7.3 gigawatts (GW) in 2017, a large portion of which was projects larger than 50 MW.[3] *(→ See Hydropower section in Market and Industry chapter.)*

Investment in Europe totalled USD 40.9 billion in 2017, a significant drop (36%) from 2016. Asset finance accounted for 74% of the region's investment, at USD 30.4 billion, of which USD 26.7 billion was invested in wind power and USD 2.8 billion was invested in solar power. Small-scale distributed capacity in Europe fell sharply in 2017, to USD 6.6 billion, due in part to a significant reduction (by more than half) in the United Kingdom.

The United Kingdom – Europe's largest national investor in renewable energy in 2016 – saw total investment fall 65% to USD 7.6 billion. This decline reflected an end of subsidies for onshore wind and utility-scale solar power and a substantial gap in time between auctions for offshore wind power projects. Germany took over as the largest European investor at USD 10.4 billion, despite a 35% reduction from 2016. Germany's investment decline reflected investors' uncertainty as the country shifts away from feed-in tariffs to auctions for all technologies. Although Europe's two biggest markets saw reductions in 2017, investment increased in several other countries in the region, including Sweden (up 127% to USD 3.7 billion), the Netherlands (up 52% to USD 1.8 billion) and Greece (up 287% to USD 0.8 billion).

China accounted for a record **45%** of all financing in renewable energy

i Regions presented in this chapter reflect those presented in UN Environment's *Global Trends in Renewable Energy Investment 2017* (Frankfurt: 2017), and differ from the regional definitions across the rest of the GSR, which can be found at http://www.ren21.net/GSR-Regions.

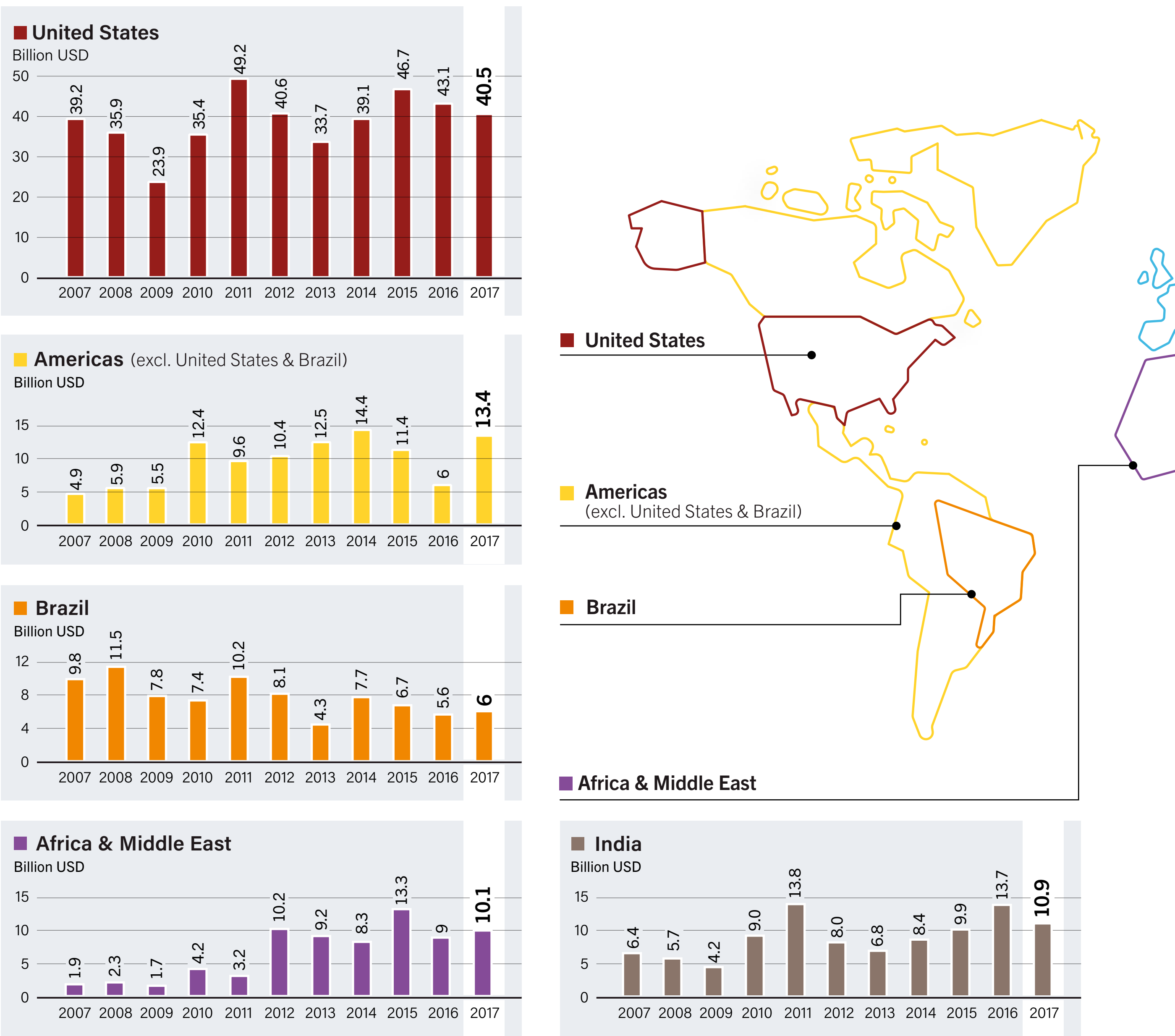
ii The Chinese government estimates that hydropower facilities of all sizes completed in 2017 represent an investment of CNY 61.8 billion (USD 9.8 billion), from China National Energy Administration, "National electric power industry statistics in 2017", 22 January 2018, http://www.nea.gov.cn/2018-01/22/c_136914154.htm (using Google Translate).

The United States remained the largest individual investor among developed economies, with a total of USD 40.5 billion in 2017, a decrease of 6% compared to 2016. Utility-scale asset finance remained stable, at USD 29.3 billion, with wind power accounting for the majority (67%). Although small distributed capacity (rooftop and other solar power systems of less than 1 MW) also attracted significant sums, the total of USD 8.9 billion was down 12% from 2016, due in part to a restructuring of the market. Investment in US public markets fell again in 2017, to USD 1.0 billion, from a high of USD 8.9 billion in 2015.

In Asia-Oceania (excluding China and India) investment fell 12% to USD 31.4 billion – the lowest amount since 2013, due largely to a decline in Japan. Japan's investment continued to fall in 2017, down 28% from 2016 to USD 13.4 billion. Investment was hampered by uncertainties related to grid connection and to a shift in policy from a generous feed-in tariff (FIT) to tendering for projects larger than 2 MW. Investment in both solar and wind power declined in 2017, whereas investment in biomass increased 120%, due in part to a shift towards biomass on the part of some solar power developers as well as to a looming FIT reduction.

Other markets in the region with decreases included Thailand (down 72% to USD 700 million), Chinese Taipei (down 10% to USD 600 million) and the Philippines (down 77% to USD 300 million). However, some countries saw noteworthy increases in investment, including Indonesia (up 67% to USD 1.0 billion) and Pakistan (up 42% to USD 700 million). The modest renewable energy investment figures in the region resulted largely from policy uncertainty, particularly in Indonesia, the Philippines, Thailand and Vietnam.

FIGURE 49. Global New Investment in Renewable Power and Fuels, by Country or Region, 2007-2017



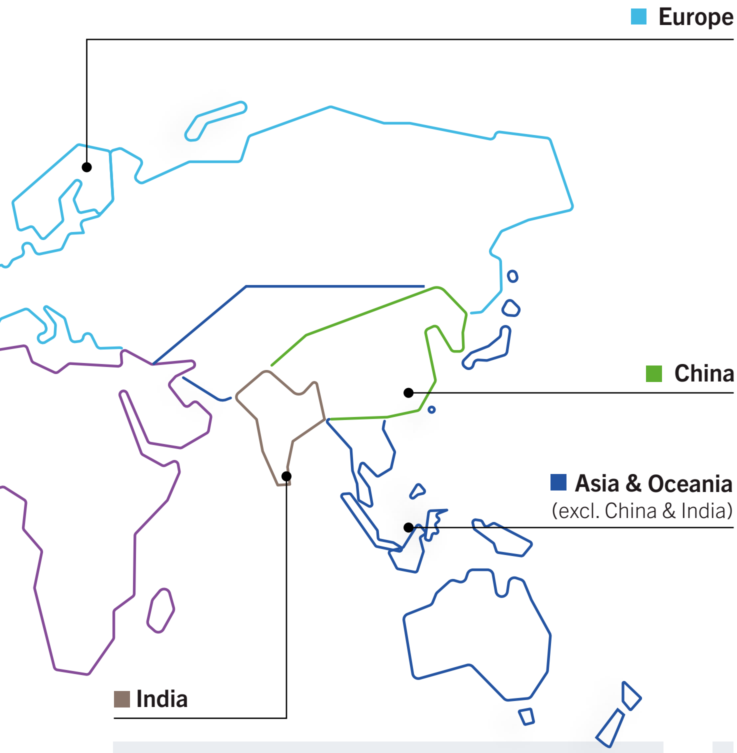
Note: Data are in current USD and include government and corporate R&D.
Source: BNEF.

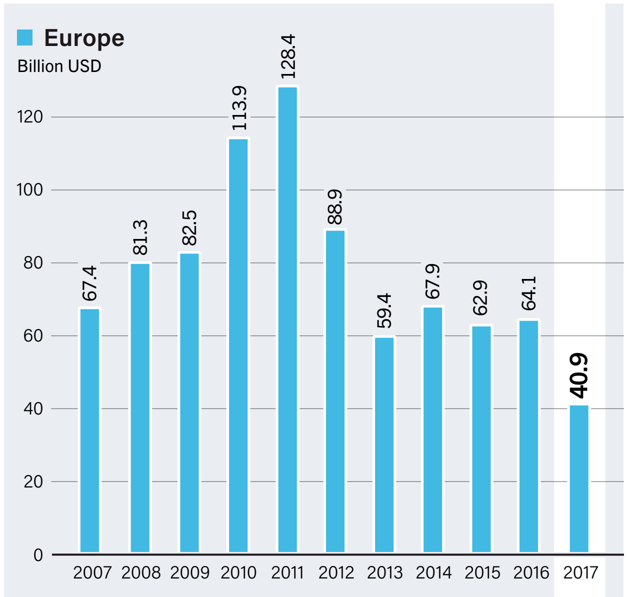
Investment in India declined 20% compared to 2016, to a total of USD 10.9 billion. Approximately USD 6.7 billion was invested in new solar power capacity (up 3%), and USD 4 billion was invested in wind power during 2017 (down 41%).

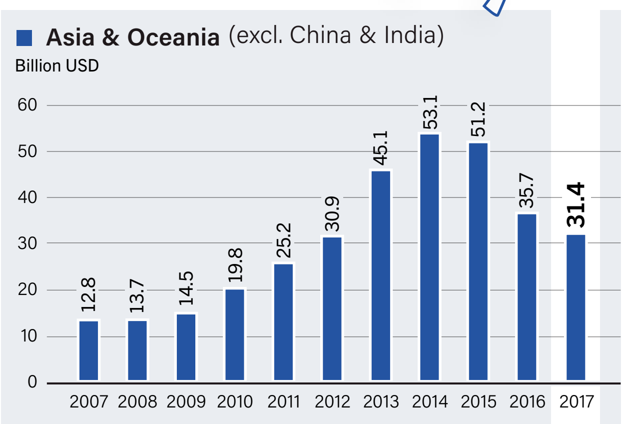
In the Americas (beyond Brazil and the United States) investment totalled USD 13.4 billion (up 124%). Investment in both Mexico and Argentina jumped roughly nine-fold, to USD 6 billion and USD 1.8 billion, respectively. Other countries in the region saw smaller increases. For example, investment was up in Chile (up 55% to USD 1.5 billion), Peru (up 66% to USD 300 million) and Costa Rica (up 31% to USD 300 million).

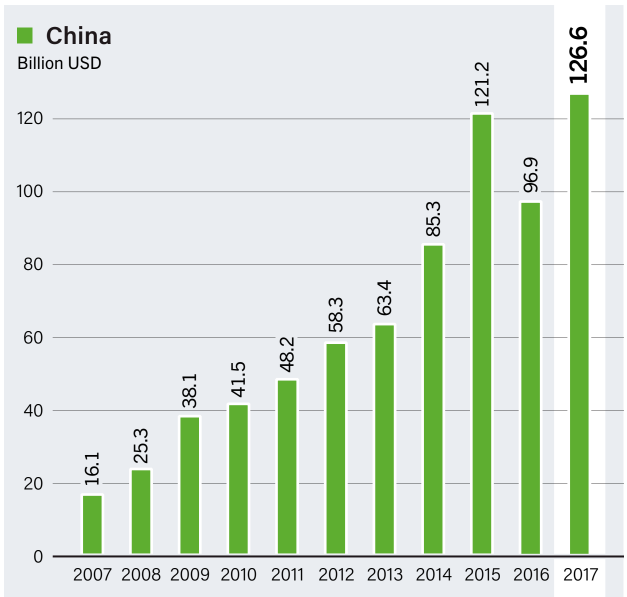
Brazil's total investment was USD 6 billion, an increase of 8% from 2016, but this was far below the peak total of USD 11.5 billion in 2008, when the global biofuels boom was still in full swing. Most of Brazil's 2017 investment was in wind power, at USD 3.6 billion (down 18% from 2016), and in solar power, which rose 204% to USD 1 billion.

Investment in the Middle East and Africa combined increased 11% in 2017, to USD 10.1 billion, with substantial increases in Egypt and the United Arab Emirates. Investment leapt nearly six-fold in Egypt, to USD 2.6 billion, and 29-fold in the United Arab Emirates, to USD 2.2 billion. In Jordan, investment rose 26% to a record USD 1.1 billion. At the same time, however, South Africa continued to experience a decline, with investment down to USD 102 million in 2017 from a high of USD 5.6 billion in 2012. Financing in Morocco also fell relative to 2016 (down 48% to USD 200 million).









INVESTMENT BY TECHNOLOGY

New investment in renewable energy in 2017 continued to be dominated by solar PV and wind power, accounting for roughly 57% and 38%, respectively. Solar power was the only technology to witness an increase in 2017, with new investment up 18% relative to 2016, to USD 161 billion.

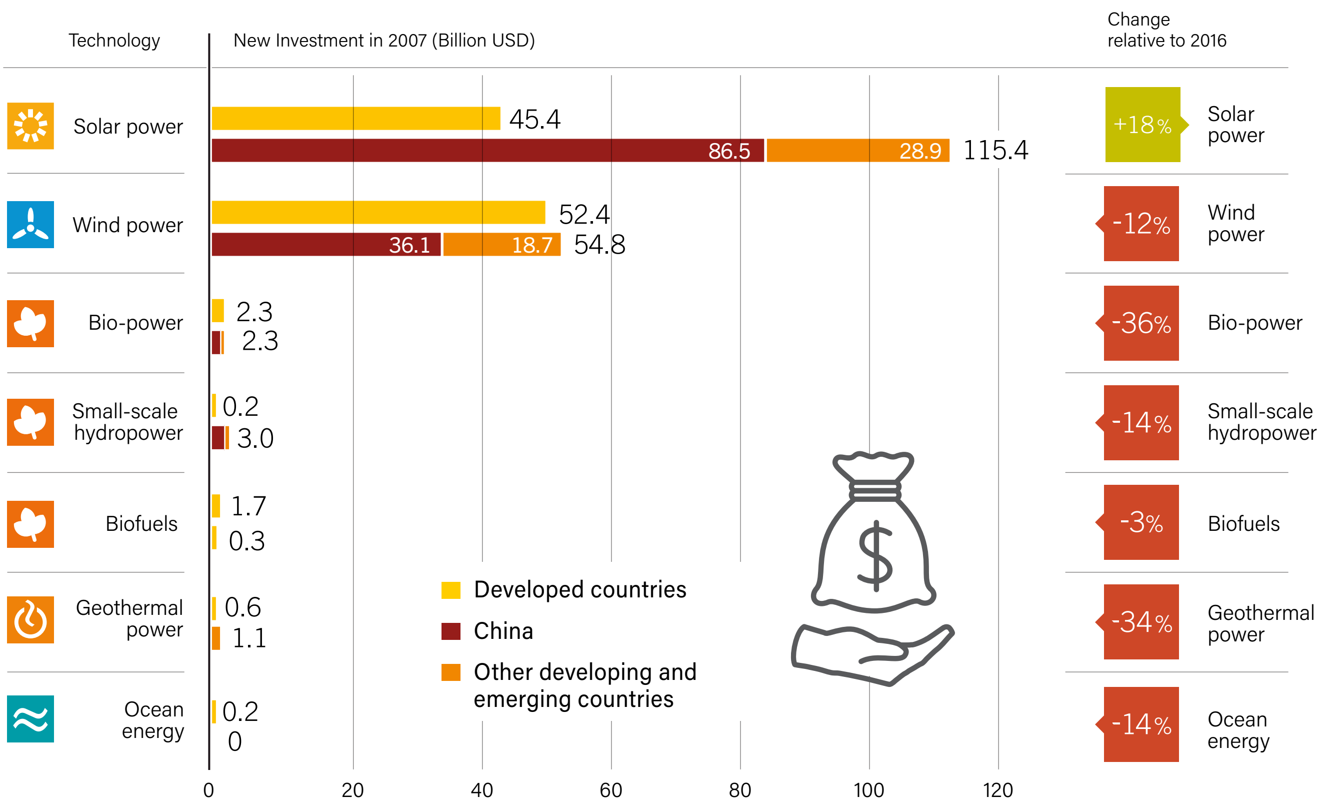
Investment in all other technologies was down in 2017. The most substantial declines in dollar value were seen in wind power (down 12% to USD 107 billion), in biomass/waste-to-energy[i] (down 36% to USD 4.7 billion) and in geothermal power (down 34% to USD 1.6 billion). Investment in biofuels declined 3% to USD 2.0 billion. *(→ See Figure 50.)*

In 2016, emerging and developing economies maintained a narrow lead in solar power investment and fell behind developed economies in wind power investment. In 2017, however, due primarily to China, these countries accounted for the bulk of solar power investment and recovered a small lead in wind power investment. Solar power investment declined 17% in developed countries (to USD 45.4 billion), while it increased 41% in developing countries (to USD 115.4 billion). Investment in wind power declined during 2017 in developed countries (down 19% to USD 52.4 billion) and in developing countries (down 4% to USD 54.8 billion).

Large-scale hydropower projects over 50 MW in size represented the third most important sector (after solar and wind power) for renewable energy investment in 2017. Translating hydropower capacity additions into asset finance dollars per year is not straightforward because the average project takes four years to build. Although BNEF does not track detailed statistics for large-scale hydropower projects, it estimates that asset financing for large-scale hydropower projects reaching financial go-ahead in 2017 totalled around USD 45 billion, up 108% from 2016.

i Includes all waste-to-power technologies but not waste-to-gas.

FIGURE 50. Global New Investment in Renewable Energy by Technology in Developed, Emerging and Developing Countries, 2017



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 BY TYPE

Global research and development[i] (R&D) spending rose 6% in 2017, to a record high of USD 9.9 billion, with the increase driven entirely by corporate R&D. Government R&D stayed flat relative to 2016, at USD 5.1 billion, while corporate R&D increased 12% to USD 4.8 billion. Europe was again the biggest regional investor in R&D and witnessed an 8% increase in 2017, to USD 2.7 billion. The United States out-spent China for the first time since 2011, increasing R&D investment 8% to 2.1 billion. China's investment remained steady at USD 2 billion.

Total R&D spending in 2017 was up for all sectors except ocean energy, which remained flat. R&D investment in solar power – the largest recipient of all such investment – increased 6% to USD 4.7 billion; wind power rose 6% to USD 1.9 billion (a new high); and biofuels increased 2% to USD 1.7 billion.

Asset finance of utility-scale projects again accounted for the vast majority of total investment in renewable energy. It totalled USD 216.1 billion during the year, an increase of just 0.2% relative to 2016, led by solar power projects in China, which totalled USD 64.9 billion.

Small-scale distributed capacity investment, or investment in solar PV systems of less than 1 MW, increased 15% to USD 49.4 billion. Small-scale investment in China jumped five-fold in 2017, to USD 19.6 billion, taking the global lead and accounting for almost 40% of the global total. Investment was down in this category in both the United States (-12%) and Japan (-38%) in 2017, to USD 8.9 billion and USD 5.4 billion, respectively.

Public market investment in renewable energy companies and funds fell 6% to USD 5.7 billion, the smallest amount seen since 2012. Funds raised by initial public offerings (IPOs) fell almost 50% to USD 1.4 billion. In the United States, investment via public markets in "yield companies" (yieldcos) extended its decline from a multibillion-dollar peak in 2015. Overall, solar power companies and related funds raised USD 2.5 billion (up USD 1 billion over 2016), while wind power companies raised USD 2.4 billion (down 44% compared to 2016).

Venture capital and private equity investment (VC/PE) in renewable energy decreased 33% in 2017, to USD 1.8 billion, continuing a downward trend as the sector matures and as R&D in wind and solar power moves increasingly into the hands of large manufacturers. As in previous years, solar power companies attracted the most VC/PE investment, with more than two-thirds of the total. VC/PE investment fell across all sectors, with solar power dropping 38% to USD 1.2 billion and wind power dropping 12% to USD 433 million. The United States remained the centre of worldwide VC/PE investment in renewables, representing 43% of the total, with USD 770 million (down 57% from 2016).

Solar power continues to dominate investment in renewable energy

Acquisition activity – which is not counted as part of the USD 278.9 billion in new investment – slipped 1% to USD 114 billion, after four years of growth. Both corporate mergers and acquisitions (M&A; the buying and selling of companies) and public market investor exits fell in 2017: M&A by more than half to USD 14.3 billion, and public market investor exits by more than 80% to USD 1.2 billion. Private equity buy-outs quintupled to USD 11.2 billion, a record high. Asset acquisitions and refinancing remained the largest single category of acquisition activity, with deals worth USD 87.2 billion, up 14% from 2016. Within this category, Europe overtook the United States to lead, increasing its activity 26% to USD 37.2 billion. Activity increased in the United States (up 4% to USD 30.8 billion) but decreased in China (down 40% to USD 3.8 billion). In other regions, substantial growth was seen in asset acquisitions and refinancing. For example, activity in Brazil doubled to USD 6.1 billion, and activity in India quadrupled to USD 1.3 billion, starting from a low base.

i See Sidebar 5 in GSR 2013 for an explanation of investment terms used in this chapter.

Global research and development	Asset finance	Small-scale distributed capacity investment	Public market investment	Venture capital and private equity	Acquisition activity
9.9 billion USD	216 billion USD	49.4 billion USD	5.7 billion USD	1.8 billion USD	114 billion USD

RENEWABLE ENERGY INVESTMENT IN PERSPECTIVE

In 2017, renewable power technologies continued to attract far more investment dollars than did fossil fuel or nuclear power generating plants. An estimated USD 310 billion was committed to constructing new renewable power plants (including USD 265 billion[i] without large-scale hydropower, plus an estimated USD 45 billion for hydropower projects larger than 50 MW). This compares to approximately USD 103 billion committed to fossil fuel-fired generating capacity and USD 42 billion for nuclear power capacity. Overall, renewable energy accounted for about 68% of the total amount committed to new power-generating capacity in 2017. *(→ See Figure 51.)*

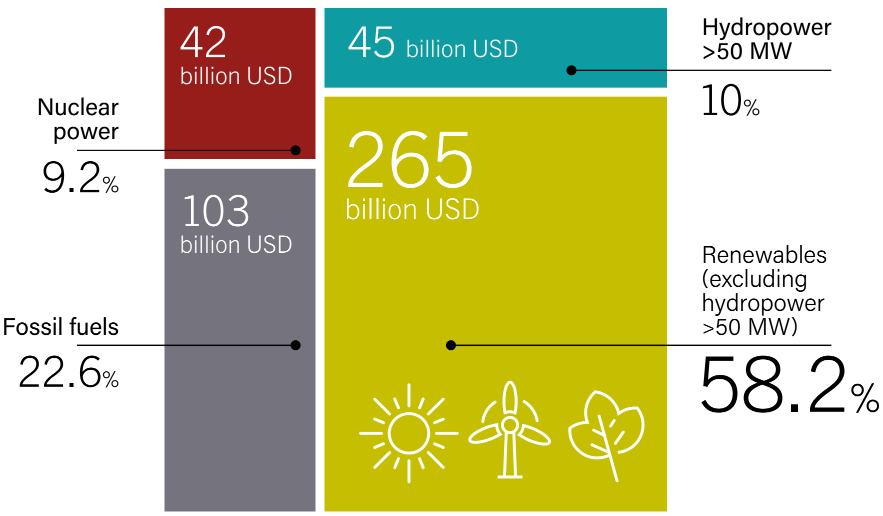
Investment in new renewable power capacity in 2017 was more than

twice

that in fossil fuels and nuclear combined

i This number is for renewable power asset finance and small-scale projects. It differs from the overall total for renewable energy investment (USD 278.9 billion) provided elsewhere in this chapter because it excludes biofuels and some types of non-capacity investment, such as equity-raising on public markets and development R&D.

FIGURE 51. Global Investment in New Power Capacity, by Type (Renewables, Fossil Fuels and Nuclear Power), 2017



Source: BNEF.

Note: Renewable investment data in figure exclude biofuels and some types of non-capacity investment. The bulk of the USD 45 billion in asset finance recorded for hydropower larger than 50 MW in 2017 (USD 28 billion) represents a single 16 GW project in China, to be completed by 2022.

SOURCES OF INVESTMENT

Most renewable energy projects are financed either on-balance-sheet by a utility, by an independent power producer or other investor, or by non-recourse project finance that is largely made up of debt from banks. Generally, non-recourse debt finance for projects takes the form of bank loans. In 2017, on-balance-sheet financing by utilities and energy companies was up 2% from 2016, to USD 121.5 billion, and non-recourse project finance decreased 4%, to USD 91.2 billion.

In 2017, global issuance of green bonds[i] jumped 67% to a record USD 163.1 billion. The strong growth in green bonds was related to a leap in the volume of asset-backed securities issued (mostly linked to residential solar PV systems in the United States), to growth in green bond issuance by sovereign governments, including those of France, Fiji and Nigeria, and to a jump in issuance by non-financial corporations.

In addition to commercial banks and bond issues, the other major source of debt for renewable power assets is borrowing directly from the world's large array of national and multilateral development banks. Aggregate figures for development bank lending to renewables in 2017 were not yet available at the time of publication. Among those that had published data in early 2018, the European Investment Bank provided finance for renewables totalling EUR 4.7 billion (USD 5.6 billion) in 2017, up from EUR 3.9 billion in 2016.

Institutional investors such as insurance companies and pension funds tend to be more risk-averse and therefore are interested in the predictable cash flows of a project already in operation. Nonetheless, in Europe, direct investment by institutional investors in renewable energy hit a record in 2017, totalling USD 9.9 billion, up 42% from 2016.

Renewables made up

68.2 %

of global investment in new power capacity

i Green bonds include qualifying debt securities issued by development banks, central and local governments, commercial banks, public sector agencies and corporations, asset-backed securities and green mortgage-backed securities, and project bonds.

06

ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

BMW wind power project and battery storage farm, Leipzig, Germany

In 2017, BMW launched a 15 MW battery storage farm with 700 second-life i3 electric vehicle batteries to store electricity from its 10 MW wind power facility. The four wind turbines produce around 26 GWh annually to power machines that make electric vehicles, including the model i3, at the BMW factory in Leipzig, Germany. Linking wind power with old electric vehicle batteries will enable the company to reduce its demand for electricity at peak times while more effectively integrating renewable energy into the power grid during off-peak periods.

ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

The increased deployment of renewable energy is driving a transformation of energy systems.[1] This is occurring mostly in the electricity sector, where many countries have seen significant growth in deployment driven by the rapid decline in solar photovoltaic (PV) and wind power costs, and several frontrunners are reaching relatively high shares of variable renewable energy (VRE) in their electricity mix.[2] However, the vast majority of countries are in the early stages of developing renewable electricity portfolios. In addition, while modern renewables contribute to heating and cooling[i] and the transport sector, growth has been relatively limited.[3] Whatever the rate of renewable energy uptake in various sectors, challenges related to its integration into existing energy systems remain.[4]

Energy systems integration, as defined here, is the significant elimination of technical, physical, organisational and legal impediments to high penetration of renewable energy (in particular VRE) in energy systems – including in power grids, district thermal systems and transport fuelling systems. Such integration encompasses changes and optimisation in the planning, design and implementation of energy-related supply- and demand-side technologies, infrastructure, markets and regulatory frameworks to facilitate much greater use of renewable energy sources across all end-use sectors while establishing, maintaining or improving sustainable, secure, adequate, reliable and affordable energy services.

i "Heating and cooling" in this chapter refers to thermal applications including climate control/space heating, heat for industrial use, cooking, agricultural drying, etc.

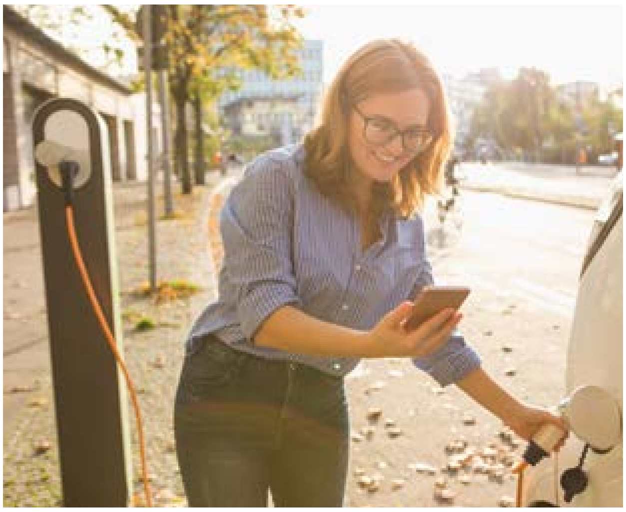
CHALLENGES OF ENERGY SYSTEMS INTEGRATION

The challenges of systems integration vary by local, national, and regional needs and conditions, but all pertain to the question of how renewable energy markets can continue to expand in an orderly manner.

Variable renewable electricity. High penetrations of variable renewable electricity can be impeded by physical, technical, regulatory and market constraints that are specific to the resource, but also by the characteristics and conditions of the wider energy system, including a relative lack of flexibility in the operation of system resources, whether on the supply or demand side.[5] This lack of system flexibility, combined with transmission bottlenecks and inadequate system information, can force uneconomical curtailment of VRE and raise overall system costs, as well as impede the advancement of renewables.[6]

In systems that rely predominantly on thermal generation, efforts to maintain system reliability traditionally have focused on the challenges and solutions associated with relatively few large, centralised dispatchable generators designed for continuous operation, with relatively long start and stop times.[7] A system with high proportions of wind and solar energy, however, requires somewhat different strategies, especially greater flexibility of both generation and demand over varying time frames.[8] The system may need market, regulatory or technical changes to enable VRE and associated technologies to provide ancillary services to maintain security of supply. Additional storage or interconnection among grid systems (where technically possible) may be required at some stages of development to avoid energy shortfalls, although current studies have indicated that such requirements arise at relatively high levels of penetration.[9]

Sector coupling and expanded markets for renewable electricity. Sector coupling refers to the integration of energy supply and demand across electricity, thermal and transport applications, which may occur via co-production, combined use, conversion or substitution. The coupling of the electricity sector with efficient transport and heating and cooling in buildings and industry can assist in integrating rising shares of VRE and reduce its curtailment; it also can open pathways for renewable electricity into new end-use markets, provided that the additional demand is aligned with system requirements and does not instead increase system stress.[10]



In 2017, at least 10 countries generated more than

15%

of their electricity from solar PV and wind power

The basic technologies required for sector coupling are in place. For example, heat pumps are a mature technology that allows efficient penetration of electricity into thermal markets.[11] Surplus[i] VRE generation can be used to produce thermal energy in individual buildings, for district heating and cooling (DHC) systems and for industrial purposes.[12] Electric vehicle (EV) markets are expanding rapidly, although from a small base. The challenge lies in co-ordinating the two objectives – expanded renewable energy markets and effective VRE integration – which requires timely information flow and the appropriate market design and technologies for optimal management of demand and supply.[13] (→ *See, for example, Electric Vehicles section in this chapter.)*

Renewable thermal energy. DHC systems offer a ready pathway to use renewable thermal energy (such as solar, geothermal and biomass), as well as renewable electricity, as a substitute for fossil fuel sources, enabling the aggregation of multiple and diverse consumer needs at a scale that can be more flexible and more economically efficient than are individual household or building systems.[14]

Challenges for incorporating renewable heating and cooling into thermal energy systems, including DHC systems, include: potentially high initial costs for new networks; high return temperatures in established DHC systems; lack of data on both available renewable resources and local thermal energy demand; lack of available space within urban environments for new geothermal, solar and biomass installations; lack of temporal correlation between resource availability and demand in the case of solar heat; and high biomass fuel cost and logistical challenges related to biomass fuel supply and plant siting.[15] Some of these challenges are mitigated by the relative demand density in cities; fuel substitution and conversion at existing thermal plants; seasonal thermal storage; and diversification of supply and demand, such as a combination of flexible biomass and binary geothermal plants for co-generation of heat and power.[16]

Renewable gases and liquid fuels. Liquid renewable fuels can serve road transport, aviation and marine applications. Properties of some biofuels, such as sugar-derived ethanol or biodiesel (fatty acid methyl ester), are similar enough to their fossil counterparts to allow blending.[17] Generally, blending levels and the integration of renewable fuels are subject to technological compatibility (e.g., fossil fuel-based infrastructure) and often to policy-influenced market shares (e.g., blending mandates), among others. Some biofuels may be used unblended: for example, ethanol can be used in road vehicles with some modification ("flex-fuel vehicles"), and

i Surplus here refers to electricity from variable renewable energy sources that exceeds instantaneous demand.

ii Drop-in biofuels are liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure.

"drop-in biofuels"[ii] – such as biojet and advanced biodiesel – are being developed for use in jet and diesel applications. *(→ See Bioenergy section in Market and Industry chapter.)*

Biomethane and hydrogen produced with renewable energy may be injected into natural gas distribution grids and subsequently used for thermal, electricity or transport applications. Blend levels for hydrogen are limited by end-use constraints, pipeline infrastructure and existing natural gas composition, and vary by location, but blending of 5-20% by volume is considered feasible without requiring significant modifications to existing pipeline infrastructure and end-use appliances.[18]

Integration challenges facing biogas include the costs of upgrading the biogas to meet the quality standards in place for natural gas grids, and the complications in distributing hydrogen because of its low volumetric density and purity requirements for transport applications.[19] The development of a lower-cost pathway for hydrogen made from renewable energy (and derived ammonia) is attracting interest for use in the chemical industry and in fuel cell vehicles.[20]

Distributed renewable electricity production. Transmission and distribution networks may benefit from distributed generation, especially when located within transmission-constrained areas. However, the proliferation of distributed energy resources, particularly solar PV, has changed network operational and planning requirements. High penetrations of distributed generation cause bi-directional flows of energy, which may require changes to infrastructure and system operations.[21] The adequacy of simple volumetric tariff structures to charge for network services is already challenged by the growth in appliances with high intermittent demand, such as air conditioners, and is further stressed by behind-the-meter generation.[22]

This chapter examines efforts to integrate variable renewable electricity into existing energy systems and to steer the evolution of energy systems to better accommodate renewable energy. It also reviews the status of some technologies that enable renewable energy integration.

INTEGRATING VARIABLE RENEWABLE ELECTRICITY

The primary role of electric power systems is to ensure that enough electricity is available at all times to meet demand safely, reliably and at a reasonable cost. To accomplish this objective, electricity system operators and regulators have always needed to plan ahead, arranging for system resources that can meet expected demand at all times and for the system to be resilient enough to withstand sudden changes in conditions.[23]

Integrating high penetrations of VRE may create challenges for system balancing (over periods of seconds, minutes, days and even seasons) as well as for power quality and equipment reliability.[24] The challenges vary depending on the specific characteristics of a given electricity system.[25]

However, the need to prepare for VRE integration is sometimes overshadowed by misconceptions that misrepresent or overstate the scale of challenges, especially at the early stages of VRE deployment.[26] Integrating relatively low[i] shares of VRE can be managed with modest adjustments, such as improved resource forecasting, improved grid codes (interconnection standards), better real-time information flow on VRE output, and sensible planning of geographical dispersion and balancing of wind and solar power installations (which often have complementary generation profiles).[27] At relatively high levels of VRE deployment, additional measures are needed, including designing methods to achieve greater flexibility from existing and new system resources to balance supply and demand and to maintain grid voltage and frequency stability.[28]

In 2017, at least 10 countries generated more than 15% of their electricity with solar PV and wind power.[29] *(→ See Figure 8 in Global Overview chapter.)* In Denmark, wind power accounted for a record 50.2% of annual electricity generation.[30] Several countries met far higher shares of their electricity demand with non-variable renewables, including hydropower, biomass and geothermal, as well as concentrating solar thermal power (CSP) with storage.

i VRE shares in the single-digit percentages would be presumed to be relatively low. However, what constitutes high penetration in the context of integration challenges is highly location- and system-specific. *(→ See Feature chapter in GSR 2017.)*

Some countries and regions are managing very high short-term shares of VRE in the generation mix. On 28 October 2017, wind power generated a record 24.6% of the European Union's (EU's) electricity demand, meeting 109% of demand in Denmark followed by 61% in Germany and 44% in Portugal.[31] In South Australia, during the 2016-2017 financial year, wind power met over 78% of demand for 5% of the time (and 143% of demand for one five-minute period), and solar PV met more than 30% of demand for 10% of the time.[32] In the US state of Texas, for a short period in late 2017, wind power met over 54% of demand for the main grid operator.[33] And for a brief period in May 2017, solar PV in the United Kingdom generated enough electricity to meet almost one-quarter of the country's demand.[34]

To date, most flexibility in power systems has been provided by transmission interconnections with neighbouring systems and by flexible generation capacity (particularly hydropower and natural gas-fired power plants). However, these traditional flexible assets are not keeping up with fast-growing VRE. In 2016, an estimated 130 gigawatts (GW) of new flexible and utility-scale storage capacity came online, the lowest level in more than a decade; meanwhile, capacity from solar PV and wind power has risen rapidly in recent years, with more than 130 GW added in 2016 alone.[35]

Rising penetration of solar and wind power has led to their curtailment in some countries, due to structural, regulatory or operational constraints. In China, for example, approximately 56.2 terawatt-hours (TWh) of solar PV and wind generation was curtailed in 2016 due to several factors, including lack of transmission capacity to transport electricity to high-demand centres, excess power supply and regulations granting priority to electricity from coal.[36] The share of wind generation in China subject to curtailment declined from 17% in 2016 to 12% in 2017 (41.9 TWh), and preliminary data indicate that curtailment of solar PV output declined also, to about 6-7%.[37] Germany is experiencing congestion on its grids due to rising VRE output and increased trade with its neighbours; this is limiting the flow of wind power from turbines in the north to high-demand regions in the south, leading to curtailment.[38] About 3.7 TWh of renewable electricity (mostly wind power), or about 2.3% of annual renewable generation, was curtailed in Germany during 2016.[39]

Raising and lowering of output from wind and solar power is typically **faster and more accurate** than for coal and nuclear power plants

Many options are available for ensuring reliability while integrating high proportions of VRE. These involve a combination of: 1) making VRE more suitable for the broader energy system, and 2) making the entire energy system (predominantly, but not limited to, the power sector) more suitable for VRE.[40] The first category of options includes improved resource forecasting, combining different types of variable resources with appropriate geographical distribution, and operational and technology improvements. The second involves measures to improve the flexibility and resilience of energy systems. These include improving energy system operations and performance through changes in market design and regulatory frameworks; improved planning and deployment of grid infrastructure, flexible generation, and information and control technology; energy storage; demand-response capability; and coupling of the electricity, thermal and transport sectors.[41] *(→ See Feature chapter, and Table 4 in GSR 2017.)*

The challenges associated with integrating high shares of VRE – and the mix of solutions selected – vary from place to place and depend on the flexibility of existing energy systems. Effective integration of VRE calls for holistic approaches to infrastructure planning, systems operations techniques, markets and rate regulations.[42]

Denmark's success in integrating and balancing VRE, for example, can be attributed in large part to the flexibility of the system. This flexibility is due to several factors including the unusual ability to vary the output of coal-fired power plants over a wide range[i]; day-ahead weather forecasting and real-time updates that enable quick responses to changes in VRE output; transmission planning in parallel with new generating capacity; the coupling of electricity with heat supply, including significant capacity of biomass combined heat and power; and the use of domestic balancing markets and interconnection with neighbouring grids to freely buy and sell power to balance solar and wind energy output.[43]

i Coal-fired power plants typically have a minimum load of 40-50% of their capacity and have long lead times and high costs for starting, with even a hot start taking 1-3 hours (see endnote 43).

MAKING VARIABLE RENEWABLE ENERGY EASIER TO INTEGRATE

Despite a pervasive misconception that the growing use of VRE resources must result in unacceptable cost and reliability penalties, VRE systems can be deployed without prohibitive additional expenditures and without the need for significant additional reserve capacity or storage.[44] Further, state-of-the-art solar and wind energy generators can provide a variety of relevant system services to stabilise the power grid.[45] Utility-scale solar PV plants, for example, can provide reactive power as well as voltage and frequency support.[46] Wind turbines can provide grid services such as voltage control and frequency regulation, as well as ride-through[i] when other plants fail.[47] Market reforms under way in Europe and elsewhere are enabling VRE to play a wider role in supporting the grid.[48] *(→ See Policy Landscape chapter.)*

VRE resource forecasting predicts the output of solar and wind power plants over different time frames, helping planners and system operators to cost-effectively schedule dispatchable power plants and spinning reserves.[49] Tools for wind and solar forecasting continue to advance, driven in large part by rising shares of VRE generation in grid systems.[50] Increasingly, on-site forecasting of wind and solar resources is a requirement of feed-in tariff rules and power purchase agreements (PPAs), as well as being important for optimising plant operations and performance.[51]

Day-ahead forecasting of wind power can be well over 90% accurate on average and more than 97% accurate less than one hour ahead.[52] In 2017, Texas grid operator ERCOT planned to launch intra-hour wind forecasting based on improved modelling to help manage plant variability and optimise generation assets. This approach will provide ERCOT with forecasts for the next two hours at five-minute intervals, which align with the system dispatch intervals.[53]

Solar PV plant operators continued to adopt a variety of satellite, cloud imaging and infrared technologies to improve short-term forecasting and increase revenues.[54] Public and private efforts to improve solar forecasting tools advanced during 2017.[55] In general, innovations in weather forecasting, image processing, satellite technology and digitalisation are providing more accurate solar forecasting data, helping to increase plant revenue and minimise balancing costs for plant and transmission system operators.[56]

Also important for renewable energy integration, particularly for high shares of VRE, are recent developments in software controls and power electronics that are enabling wind plants to supply the inertia currently provided by large spinning turbines (found in thermal and hydropower plants) to help stabilise grid electricity. This ability to provide "synthetic inertia" – responding to rapid changes in frequency by delivering a power boost, generally after a large power plant has gone offline – is helping to overcome some of the integration challenges facing VRE.[57]

Wind turbine manufacturers have continued to improve their synthetic inertia technology and are testing second-generation systems.[58] Hydro-Québec TransÉnergie was the first grid operator to mandate (in 2005) that new wind farms had synthetic inertia capability, and such requirements appear to be spreading.[59] Grid operators in Brazil, in the Canadian province of Ontario and in the US state of Texas have adopted mandates, and Europe's first harmonised grid code, which entered into force during 2017, opens the door for such requirements.[60]

Studies have shown that wind and solar power, utilising suitable inverter technology, can provide fast frequency response, voltage control as well as ramping control (regulation and dispatchable load following), much like conventional generators.[61] Coal-fired and nuclear power plants have minimum load levels below which they cannot reduce power (which can be 40% or more of a coal plant's maximum capacity), and nuclear plants typically offer limited load-following (ramping) capability; in contrast, wind and solar power facilities can be very flexible in this regard, subject to the instantaneous availability of the wind and solar resources.[62] Also, ramping of output from wind and solar power is typically faster and more accurate than for coal and nuclear power plants.[63]

Testing of a 300 megawatt (MW) solar PV farm in California during 2016 demonstrated the potential for solar power plants to provide grid frequency regulation, voltage stability and reactive power control, as well as to perform other valuable tasks for grid balancing. The plant can be operated at less than full capacity in order to shift output up or down as wholesale market prices change, and, on demand, it can contribute to frequency regulation more quickly than can natural gas-fired power plants.[64] Whether it is worthwhile to operate in this way depends on the revenues available in ancillary services markets and their ability to compensate for lost electricity sales.[65]

Solar (both PV and CSP) and wind power also are aiding integration by including storage capacity at installations and by incorporating storage into wind turbine design. *(→ See Energy Storage section in this chapter, and Market and Industry chapter.)* Improvements in low-wind turbine technologies are broadening their operating range and reducing variability in output, while wind turbines offshore are providing more consistent output.[66] Integrated systems planning is informing the integration and deployment of renewable energy technology, reflected in the regional distribution of VRE plants in large markets, co-locating of wind and solar power projects and east-west orientation of solar PV panels.[67]

i "Ride-through" is the capability of electric generators to continue operating during short periods when there is a drop in voltage, and thereby to "ride through" the dip.

MAKING ENERGY SYSTEMS MORE SUITABLE FOR VARIABLE RENEWABLE ENERGY

To ease the integration of VRE into power systems, governments around the world are undertaking planning studies and enacting policies that address system needs with increased VRE. So far, most policy developments related to integration appear to have occurred in Australia, China, Europe, India and North America. Policies include electricity regulations to improve the speed of system response (e.g., day-ahead scheduling, faster ramping of thermal power plants, shorter time scales for dispatch) as well as policies to advance the development and deployment of energy storage technologies and to enable sector coupling and general grid modernisation.[68] *(→ See Policy Landscape chapter.)* In addition, studies have been undertaken in several countries – including Australia, Canada, China and the United States – and in Europe (particularly in Germany) to assess the needs of systems that have high VRE penetration.[69]

In addition to policies and regulations, major transmission infrastructure projects to improve VRE integration were under way during 2017 in a number of countries, including China, India and Jordan.[70] China, for example, had plans to build 16 new ultra-high-voltage direct current lines, in addition to 8 already completed, in part to connect its high wind and solar power regions to demand centres.[71] China also has planned significant expansion of its pumped storage capability to complement variable solar and wind power generation – much of which is located far from load centres – and to thereby manage the load on the transmission system and reduce the investment needed in new transmission capacity.[72]

In 2017, Chile completed work on a 600-kilometre-long transmission line to connect the country's two largest power grids. Although the project originally was conceived to move fossil electricity to the primary load in central Chile, interconnection of the systems enables solar PV plants in the sunny north, which have faced high levels of grid congestion and low prices in the spot market, to export their generation and increase their margins.[73] Also in 2017, the US state of Missouri saw final approval of a new transmission line to help integrate more wind power to meet state renewable energy goals and reduce electricity rates.[74]

The EU is providing funding to help build four major transmission lines across Europe that will support the integration of VRE, particularly wind power. These include projects in Germany and Romania, as well as the Biscay Gulf France-Spain interconnection and the Viking Link interconnector between Denmark and the United Kingdom.[75] In 2017, Denmark approved the Viking Link, which reportedly will be the world's longest electricity cable, and the country is engaged in two other projects to link its electricity grid with its neighbours to sell surplus wind power into a larger market and have access to a larger supply when VRE output is not sufficient.[76] The United Kingdom saw the first power flow through the Western Link between Scotland and Wales, which aims to ease transmission bottlenecks and reduce constraints on generation from wind farms in Scotland.[77]

Increasingly, electric utilities and systems operators are adjusting their operations, adding energy storage and digitising systems to help integrate VRE, some in response to government initiatives but others of their own accord.[78]

In Europe and the western United States, grid operators are expanding their balancing areas. By linking markets (physically through transmission infrastructure, and operationally through trade, for example), VRE production can be spread more widely, increasing its value and enabling surpluses in one area to be used in another area or be stored (e.g., Denmark's wind energy stored in Norway's hydropower reservoirs).[79] In 2017, power exchanges and transmission system operators from 12 European countries were building a single intra-day market solution based on a common communication and control system, with the first of three phases expected to begin operation in early 2018. Experience in Europe has shown that expanding the balancing area enables system operators to hold less balancing power in reserve, such that balancing costs are declining even as the shares of VRE increase.[80]

In the United States, to maximise the use of renewable output and to avoid curtailment, California's Independent System Operator has partnered with other utilities in the region to pool resources to balance demand every five minutes, maximising the use of the least-expensive energy available (which often is VRE); in 2017, the regional market used an estimated 161 gigawatt-hours (GWh) of renewable energy that otherwise would have been curtailed.[81] Despite the potential benefits of expanding balancing areas, regulatory and other barriers to implementation remain in Europe, the United States and elsewhere.[82]

Enabling technologies can help to accommodate higher shares of VRE by contributing to

more flexible and integrated systems

Demand-side management – the modification of consumer demand through energy efficiency measures, education and financial incentives – has been in use for decades to reduce energy consumption during peak times. Increasingly, utilities and grid operators are using this tool to increase demand-side flexibility to help balance variable generation from wind and solar power.[83] The Australian Energy Regulator introduced a Demand Management Incentive Scheme in December 2017.[84] *(→ See Policy Landscape chapter.)* In the United States, the Michigan Public Service Commission issued a report calling for a new regulatory framework to do the same.[85] Arizona Public Service proposed adopting reverse demand response (load shifting) – ramping up dispatchable load from large customers (greater than 30 kilowatts) – to manage surplus electricity supply from VRE.[86]

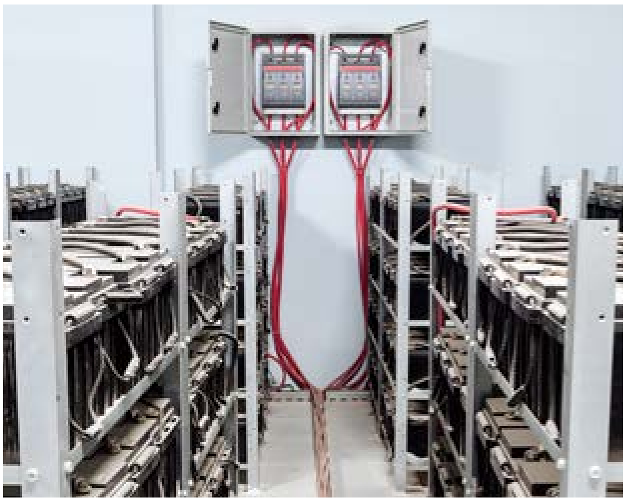
Utilities in Australia, Europe, North America and elsewhere deployed large battery storage systems in 2017 to support electric grids and help integrate VRE.[87] *(→ See Energy Storage section in this chapter.)* Some utilities also are connecting distributed storage-plus-solar using digital systems. For example, in early 2017 Melbourne-based utility AGL Energy launched the first phase of what it called the world's largest residential virtual power plant. The project aggregates residential battery and solar PV systems through a cloud-connected intelligent control system that enables the utility to discharge the batteries at a time of greatest benefit for customers and the community, and to enable high penetration of VRE in the South Australian grid, while ensuring grid stability.[88] Several utilities in Europe and the United States have partnered with storage, solar and other technology companies to pilot similar concepts.[89]

Continuing advances in "smart" technologies – the digitalisation of grid and ultra-high-speed telecommunications networks (along with improvements in cybersecurity) – enable remotely controlled devices, battery systems and other components to better manage supply and demand.[90] *(→ See Sidebar 3.)* An increasing number of utilities rely on wireless communication with smart appliances, such as thermostats, to reduce consumer demand when needed.[91] In 2017, Enel (Italy) announced plans to invest EUR 4.7 billion (USD 5.6 billion) over a three-year period to digitise its operations, processes and asset base and to improve connectivity in order to aid the integration of VRE and the transition to low-carbon energy.[92]

In several US states, utilities are focusing attention on smart inverters to determine how they can help enhance grid reliability. In Hawaii, utilities are working with inverter manufacturers to improve grid stability; in Arizona, pilot projects are using smart inverters to operate a "fleet" of rooftop solar PV systems as a traditional power plant; in California, utilities are focusing on communication standards to develop a common language between smart inverters and the grid to optimise what the utility asks of distributed energy resources (inverters, solar panels, batteries); and in Illinois, utilities are exploring the potential for smart inverters to strengthen grid reliability and integrate more VRE.[93]

In 2017, European utility TenneT (Netherlands/Germany), renewable project developer Vandebron (Netherlands), and the companies sonnen (Germany) and IBM (United States) launched two utility-scale pilot projects that aim to more cost-effectively and efficiently integrate VRE into the grid. The pilot projects use blockchain[i] technology to create a network of distributed residential solar PV-linked battery systems in Germany to reduce bottlenecks in the grid and reduce wind curtailment, and to use EV batteries in the Netherlands to balance grid supply and demand. With these projects, TenneT reportedly became the first transmission system operator to use a blockchain database to manage the networking of battery storage systems and electricity grids. The blockchain framework is said to ensure transparency and verifiability of transactions among market participants.[94]

Market, regulatory and technical change are all part of the energy sector transformation that is under way. The rest of this chapter discusses some of the technologies that aid in the integration of renewable energy.



i Blockchain remains at an early stage of development with most projects in the pilot stage. Significant technological, regulatory, and other challenges and uncertainties remain, including the potential for blockchain to be very energy-intensive, from World Energy Council, *The Developing Role of Blockchain – White Paper,* Executive Summary (London: November 2017), pp. 2, 7, https://www.worldenergy.org/wp-content/uploads/2017/11/WP_Blockchain_Exec-Summary_final.pdf.

SIDEBAR 3. Digitalisation of Energy Systems

The use of information and communication technologies (ICT) across sectors has been boosted by the declining costs of sensors and data storage, by faster and cheaper data transmission and by advances in artificial intelligence. Digital technologies have been used in the energy sector for decades, but in recent years their application has expanded rapidly. The ongoing digital transformation of energy has the potential to bring more efficiency, flexibility and co-ordination to the management of energy end-use sectors and across the entire system, with the added benefit of advancing the integration and further deployment of renewable energy.

Digitalisation is rapidly and fundamentally changing the way in which energy is produced and consumed. On the supply side, the use of sensors and analytics is helping to reduce operation and maintenance costs and plant outages, and is improving power plant and network efficiencies. On the demand side, vehicles are becoming smarter and more connected, energy efficiency in buildings is increasing, and process controls, smart sensors and data analytics are contributing to cost-effective energy savings in industry.

Digitalisation has further potential to transform energy systems by integrating energy sectors across supply and demand (sector coupling) and by improving overall system flexibility. The electricity sector is expected to be central to this transformation, by facilitating: the integration of VRE; efficient demand response for energy balancing and security; time-managed charging of EVs; and the efficient deployment of distributed energy resources such as rooftop solar PV systems.

With more than 50 million kilometres of power lines deployed worldwide (enough to cover the distance to Mars), the electricity grid is one of the most complex infrastructures in existence. Traditionally, electricity flows in the grid have been managed in a unidirectional manner, with electricity generated in large-scale production plants and with limited participation from the demand side. Digitalisation is helping to change this paradigm. In 2016, investment in smart and digital technologies grew to reach over 10% of the estimated USD 300 billion spent in retrofitting, upgrading and expanding grids.

New digitally enabled business models are set to reshape the experience of energy consumers as digitalisation redefines their interaction with energy suppliers. Some of these models enable peer-to-peer trading, and others are based on aggregation platforms that allow for higher degrees of customer participation in ancillary services.

Traditional utilities, network operators and third parties are developing joint platforms for decentralised energy that include installing rooftop solar PV and batteries behind the meter and operating them as "virtual power plants". The number of projects that are testing blockchain[i] in the energy sector has increased rapidly since 2015. Many of these projects focus on customer markets and enabling micro-trading among solar power prosumers. Peer-to-peer trading or virtual marketplaces are already being tested in several pilot projects at varying scales in Australia, Denmark, France, Japan, the Republic of Korea and the United States. In the United States, for example, New York's LO3 Energy is using blockchain and a micro grid to enable a Brooklyn community to buy and sell locally generated renewable electricity peer-to-peer within a small neighbourhood.

As energy systems become increasingly digitalised, a series of risks come to the forefront, including the security, privacy and ownership of the vast volume of data generated. Numerous questions remain to be addressed, including: Which data will be critical and prioritised, and for which stakeholders or sectors? Who should own data from meters and sensors, and who should have access to these data? How best to reconcile such risks and concerns against the presumed benefits of facilitating new business models and solutions that require the development of these new data sources?

A smarter, digitalised energy system is emerging; however, maximising its potential, accelerating the transition and mitigating the risks of the transition require increased awareness and action across a range of sectors and stakeholders. Smarter energy systems depend on the deployment of new infrastructure across end-use sectors, across distribution grids (electric, gas and thermal) and on the centralised supply side. In parallel, smarter energy systems require interconnection via high-speed communications networks that use standardised protocols to effectively integrate ICT with the world's energy systems.

Finally, some cultural and institutional challenges to the transition may arise as traditional utilities, regulators and consumers strive to stay abreast of new ICT. Policies will play a key role in steering developments towards a more secure, sustainable and smarter energy future.

Source: IEA. See endnote 90 for this chapter.

i Blockchain is a decentralised data structure in which a digital record of events (such as a transaction, or the generation of a unit of solar electricity) is collected and linked by cryptography into a time-stamped "block" together with other events. This block is then stored collectively as a "chain" on distributed computers. Any participant in a blockchain can read it or add new data.

TECHNOLOGIES FOR SYSTEMS INTEGRATION

So-called enabling technologies help to integrate VRE into the electricity sector and facilitate the coupling of renewable power with the thermal and transport sectors. They include energy storage (both electrical and thermal) as well as digital communication and control technologies for optimising distributed renewable energy for least-cost resource allocation, load balancing and ancillary services.

Such technologies have been advancing in parallel with renewables, in part to increase the efficiency and reliability of energy systems. But they also can help to accommodate higher shares of renewable energy by contributing to more flexible and integrated energy systems, provided that the policy and regulatory environment enables this to occur and provides incentives where needed. This section discusses three types of enabling technologies that can aid in integration: energy storage, heat pumps and electric vehicles.

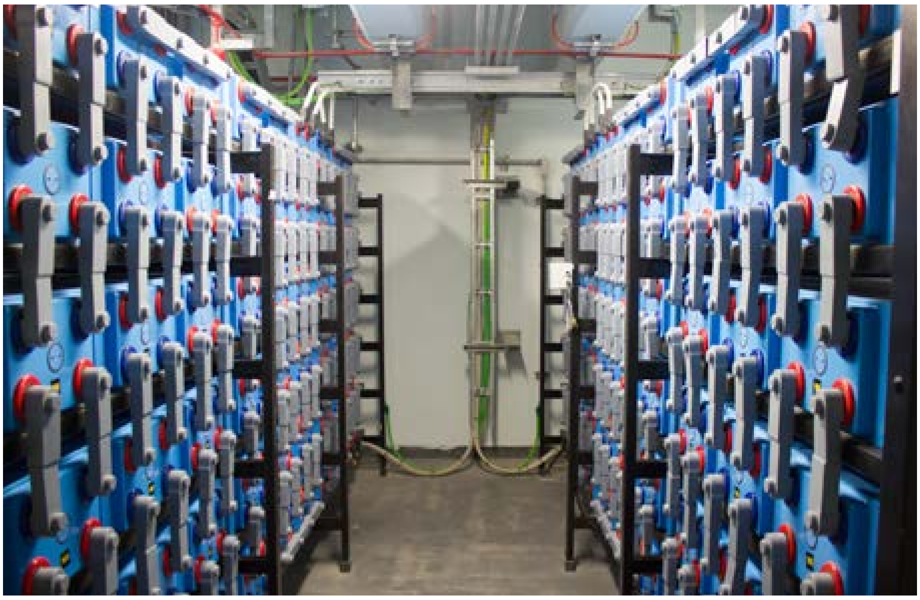
Energy storage. Utility-scale electricity storage can advance integration in several ways: it smooths fluctuating output from wind and solar power, and it enables the shifting of supply to better align with demand, thereby reducing the incidence of curtailment. Customer (behind-the-meter) electricity storage, installed alongside VRE systems, helps to integrate distributed resources by storing electricity that is produced when it is not needed and releasing it when demand is higher; this storage also can provide ancillary services (as does utility-scale storage) if markets and controls are set up properly.[95]

Thermal energy storage allows a temporal shift of renewable electricity or thermal energy supply to meet demand for heating and cooling (or for conversion back to electricity) when needed, and can allow (surplus) renewable electricity to serve thermal loads.[96] Power-to-gas (P2G) technologies enable temporal (seasonal), spatial and sectoral shifts, with the potential use of hydrogen fuel (and derived ammonia) in transport and industry, including fertiliser production, and regional trade in renewable energy. Pumped storage (hydropower) is well established and is the most significant source of electricity storage globally, but other storage technologies are becoming cost-effective in some applications.

Heat pumps. Heat pumps use energy from an external source (generally grid electricity) to efficiently provide heating or cooling services[i]. When used with appropriate control measures and thermal storage (e.g., thermal mass, hot water tanks, chilled water), heat pumps can help to balance the electrical system by shifting load away from peak periods, and also to reduce curtailment of VRE by using (surplus) solar and wind power to meet heating and cooling demand. Heat pumps that are connected to district heating systems also can increase flexibility by using thermal storage capacities.[97]

Electric vehicles. EVs can be a source of both demand- and supply-side flexibility.[98] On the demand side, EVs enable the use of renewable electricity in the transport sector. EVs draw significant amounts of power, but, as with heat pumps, battery charging or hydrogen production can be interrupted when it is not a priority.[99] While uncontrolled EV charging could exacerbate load peaks, charging that is managed to coincide with renewable power generation could help integrate larger shares of VRE. Through vehicle-to-grid[ii] (V2G) technology and infrastructure, EVs also have the potential to support grid stability by serving as electricity storage capacity.

These enabling technologies are advancing where there are supportive policies and market structures, including effective price signals. *(→ See Policy Landscape chapter.)*



Digitalisation

is rapidly and fundamentally changing the way in which energy is produced and consumed

i When used in heating mode, some of the output of heat pumps (or all, if operated with 100% renewable electricity) can be renewable energy.

ii V2G is a system in which EVs – 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 their rate of charging.

ENERGY STORAGE

For many decades, energy storage has been used for a variety of purposes, including to support the overall reliability of the electricity grid, to help defer or avoid investments in other infrastructure, to provide back-up energy during power outages or at times of system stress, to allow energy infrastructure to be more resilient, to support off-grid systems and facilitate energy access for underserved populations, and to store thermal energy for later use. Increasingly, energy storage is being used in conjunction with renewable energy technologies.[100]

Pumped storage[i] has provided the majority of electric storage capacity to date. It can be deployed at a large scale, and it is the oldest and generally least costly energy storage technology per unit of electricity (although limited by geography).[101] Hydropower facilities that incorporate reservoirs (without pumping capability) have always provided significant flexibility to the power grid by modulating output in line with fluctuations in demand and other generation. When output is reduced to accommodate surplus VRE, a hydropower reservoir functions as virtual storage, as natural water flows into the reservoir raise its energy potential in proportion to reduced output.[102]

Operations of some pumped storage facilities are changing dramatically to accommodate growing shares of VRE generation, as is the case in Scotland, where pumped storage plants have gone from 4 cycles to over 60 cycles per day to complement variability in wind power generation.[103] A growing number of pumped storage facilities are incorporating variable speed turbine technology to improve their ability to modulate operation for greater flexibility and VRE integration, including one project that came online in 2017 in Portugal.[104] *(→ See Hydropower section in Market and Industry chapter.)*

While pumped storage is the most mature and widely deployed electricity storage technology, other storage technologies have seen significant developmental gains in recent years.[105] Other electricity storage technologies include batteries (electro-chemical) as well as flywheels and compressed air (both electro-mechanical). Thermal energy storage (e.g., molten salt, ice storage) holds heating or cooling for later use (hours, days or months) and can serve both thermal applications and electricity by conversion, such as in CSP plants.[106] Electricity also can be converted, using an electrolyser, into gaseous energy carriers (P2G) that can be stored for later use in the power, heat and transport sectors, or for industrial processes. Different storage technologies can complement each other. For example, battery storage can provide instantaneous power close to load centres, but typically only for an hour or two, while pumped storage, where available, provides greater power output and long discharge times (up to eight hours).[107]

ENERGY STORAGE MARKETS

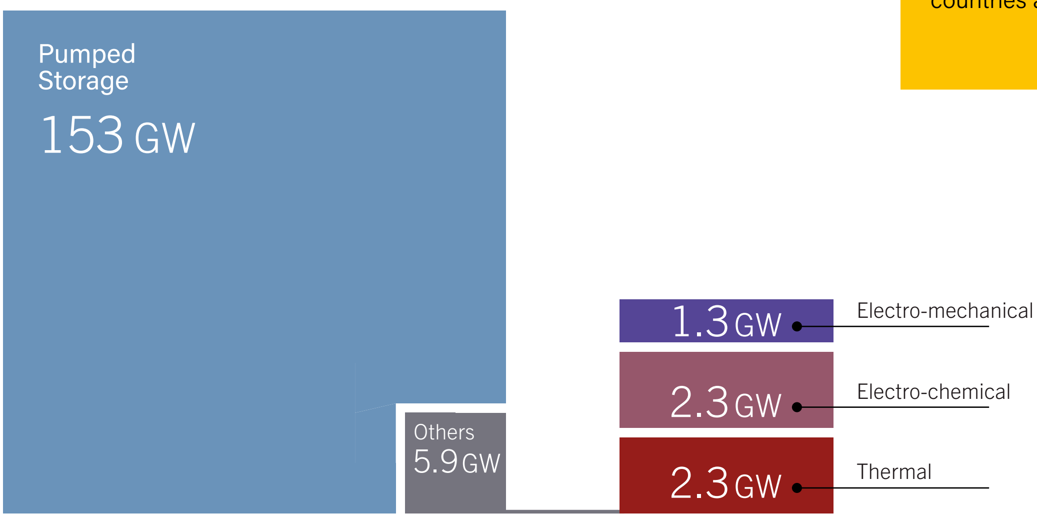
The markets for energy storage continued to expand in 2017. Data are limited for energy storage in all sectors and particularly for the transport and thermal sectors. Global stationary and grid-connected energy storage capacity totalled an estimated 159 GW, with pumped storage accounting for the vast majority.[108] Pumped storage is followed distantly by thermal storage (about 82% of which is molten salt storage at CSP plants), then by battery (electro-chemical) and electro-mechanical storage.[109] *(→ See Figure 52.)*

During 2017, more than 3 GW of pumped storage capacity was commissioned, for a year-end total of approximately 153 GW.[110] *(→ See Hydropower section in Market and Industry chapter.)*

i Pumped storage involves pumping water to a higher elevation to store its potential kinetic energy until the energy is needed. Pumped hydropower can be implemented in a stand-alone (closed-loop) application or as part of a conventional reservoir hydropower facility (open loop). Without pumping capability, a conventional reservoir hydropower facility can serve as storage only in the context of deferred generation, meaning that generation can be held off to accommodate other generation (such as solar PV and wind power), but excess grid electricity cannot be captured for storage.

More than 75% of stationary grid-connected storage capacity was operating in
only 10
countries as of 2017

FIGURE 52. Global Utility-Scale Energy Storage Capacity, by Technology, 2017



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 source data.

Source: See endnote 109 for this chapter.

About 0.5 GW of non-pumped utility-scale energy storage capacity became operational, for year-end capacity of an estimated 5.9 GW.[111] Large-scale battery installations amounted to less than 0.4 GW in 2017, for a total of around 2.3 GW.[112] This includes mostly large grid-connected installations (utility-scale and utility-owned installations) but excludes most small behind-the-meter installations. By one account, a combined 1.2 GW of utility-scale and behind-the-meter battery storage was added in 2017, with another 3.3 GW of utility-scale projects announced during the year.[113] Lithium-ion batteries continued to comprise the majority of new battery capacity installed.

More than 75% of stationary grid-connected storage capacity (including pumped storage) was operating in only 10 countries as of 2017, and nearly 50% was in just 3 countries (China, Japan and the United States).[114] The countries adding pumped storage in 2017 were China, Portugal and Switzerland.[115] In terms of non-pumped energy storage capacity, the US market led installations in 2017, with an estimated 431 megawatt-hours (MWh), but Australia took the lead in power capacity, with an estimated 246 MW added during the year.[116]

Electric utilities are increasingly deploying energy storage systems, and particularly batteries, to defer transmission upgrades, shift loads, mitigate local reliability issues, achieve greater operational flexibility and improve their ability to handle rising shares of VRE.[117] Battery storage can provide many grid services, including balancing short-term fluctuations in load or supply (such as when clouds temporarily shade a solar PV plant), fast frequency response and voltage regulation. Utilities have begun moving beyond pilot and research and development (R&D) battery storage projects, and the scale and speed of installation picked up significantly in 2017, with several large facilities coming online or announced.[118]

To date, most utility-scale battery capacity has been installed in developed economies and in energy markets with favourable regulatory frameworks.[119] Germany and the United States remain two of the leading markets for utility-scale battery storage, driven by regulations, falling costs and innovative technologies and business models.[120] In the United States, large utilities and regulators have begun to include energy storage in their long-term planning processes to support grid flexibility to accommodate rising shares of VRE, and some utilities acquired solar power combined with electricity storage through PPAs in 2017.[121] Australia's Hornsdale Power Reserve, which is located alongside a wind farm and was installed in record time, eclipsed California's Escondido system (30 MW/120 MWh) during the year to become the world's largest battery storage plant (100 MW/129 MWh).[122]

Stationary electrical storage capacity is growing rapidly in China as well, where it is seen as an important tool for reducing solar and wind power curtailment, and new markets are emerging in Europe, particularly in Italy and the United Kingdom, where energy storage is seen as a means to improve grid stability as VRE penetrations rise.[123] Large-scale renewable energy projects are increasingly being installed in combination with battery systems in order to increase the value of the electricity generated.[124]

Residential and commercial (behind-the-meter) electricity storage capacity also grew rapidly in 2017, primarily in places with supporting regulatory structures or with excellent solar resources, high grid electricity prices and relatively low remuneration for solar generation fed into the grid.[125] In Germany, driven by the desire to increase self-consumption of solar generation, about half of the residential solar PV systems installed in 2017 were combined with storage capacity; a significant share of residential storage systems in Germany provided frequency regulation services to the grid in 2017.[126] By the end of 2017, Germany had nearly 80,000 behind-the-meter installations, mainly in the residential sector.[127]

Australia installed an estimated 20,800 battery storage systems in 2017, tripling the number of systems added in 2016.[128] Most of these were sold in combination with rooftop solar PV, driven by rising retail rates and by the desire to maximise solar power self-consumption.[129] In Japan, an estimated 25,000 battery systems were installed, with the market for solar PV-plus-storage continuing to expand.[130] And in the US state of California, 90% of residential storage systems and 60% of commercial systems installed under the state's Self-Generation Incentive Program were paired with renewables.[131] Also in 2017, the newly established Energy Alliance Italia announced an agreement to install 20,000 battery systems over two years to create Italy's largest virtual power plant powered by solar PV.[132]

Other markets include large corporations with high targets for renewable power and resource extraction industries that are replacing diesel generators in remote regions with solar-plus-storage systems.[133] Electricity storage also is being used increasingly in mini-/micro grids and off-grid to provide energy access with renewable energy, particularly solar power, as well as for islands and other isolated grids that rely on diesel generators.[134] *(→ See Distributed Renewables chapter.)*

Thermal energy storage is playing an increasingly important role as well. Thermal storage systems[i] capture heat – generated with electricity or from thermal energy sources (such as biomass, solar thermal and geothermal resources) – for later use.[135] Depending on the storage technology used, stored thermal energy can be converted into electricity or used directly for heating and cooling. Likewise, surplus solar PV and wind power can be stored as, for example, hot or chilled water (or ice).[136] Solar heat systems generally include thermal storage to deal with variability of the solar resource.[137] Although thermal energy storage has been used successfully for decades, and issues of technological effectiveness are largely settled, the market for thermal storage applications remains small.[138]

Emerging technologies, such as those that convert surplus electricity to hydrogen or other gases, are in early stages of commercialisation and have not yet seen large deployment. However, progress continued in 2017 in P2G applications. Hydrogen offers the potential for short- and long-term energy storage and can be fed into existing natural gas grids. P2G applications can allow for load balancing over the course of a day, week or even season.[139] Interest is growing in the use of renewable hydrogen in micro-grids as well as in vehicles, including forklifts and long-haul trucks.[140] *(→ See Electric Vehicles section in this chapter.)*

i The most common type of system relies on a liquid or solid medium (sensible heat storage) – including water, sand, rocks and molten salt, from IRENA, *Electricity Storage and Renewables: Costs and Market to 2030* (Abu Dhabi: October 2017), p. 31, http://www.irena.org/DocumentDownloads/Publications/IRENA_Electricity_Storage_Costs_2017.pdf. Other forms of thermal storage include latent heat storage, which relies on a medium changing states (e.g., from solid to liquid), and thermo-chemical storage, which uses chemical reactions to store energy. Latent and thermo-chemical storage options offer higher energy densities, but they are more costly than sensible heat storage, from Abby L. Harvey, "The latest in thermal energy storage", ***Power Magazine***, 1 July 2017, http://www.powermag.com/the-latest-in-thermal-energy-storage/?printmode=1.

ENERGY STORAGE INDUSTRY

The year 2017 was characterised by continued technology advances and falling costs, the diversification of renewable energy and other companies into the storage industry to capture rapidly growing markets, and increasing linkages with VRE.[141]

Battery storage prices continued to decline, particularly for lithium-ion batteries.[142] Despite rapid growth in lithium-ion batteries, there is no clear prevailing storage technology due to the diverse range of storage needs (electric versus thermal, as well as response time, discharge time, output capacity, scale, efficiency, etc.).[143] Numerous options are under development to meet this variety of needs and to reduce unit costs and address concerns about the sustainability of materials use.[144]

Global battery manufacturing capacity surpassed 100 gigawatt-hours (GWh) in 2016 and continued to expand in 2017.[145] Battery manufacturing occurs largely in Asia, and the region's lead is expected to continue with several new facilities under construction during 2017 in China, India and elsewhere to manufacture batteries for EVs and for stationary systems to help integrate VRE.[146]

Also in 2017, several renewable technology companies formed partnerships (as did several electric utilities) with storage firms to advance storage technologies, gain a foothold in the industry or develop hybrid renewable energy storage products.[147]

A few companies are engaged in producing and installing systems that "store" electricity in the form of thermal energy. US-based Axiom Exergy, CALMAC and Ice Energy all use a similar technology to create ice, which is used when needed to cool building spaces or to preserve food supplies.[148] In 2017, Ice Energy expanded its offerings for residential applications.[149]

In addition, R&D continued on new materials and technologies for thermal storage of solar and wind power.[150] Siemens Gamesa (Spain) announced plans to construct its first full-scale wind-heat storage project that will convert electricity to heat for storage of surplus wind generation in rock fill, for later conversion to electricity via a steam turbine.[151] Wind turbine manufacturer Goldwind (China) partnered with SaltX Technology (Sweden) to develop and commercialise a large-scale power-to-heat solution (storing thermal energy in salt), starting with a demonstration plant in Beijing.[152]

Most P2G projects to date have been pilot systems, but a shift towards commercial projects is occurring along with increasing interest among a wide range of actors, including renewable energy developers, electric utilities and other companies traditionally focused on the oil and gas industry that see opportunities to make additional revenue by providing grid balancing services and helping to integrate VRE.[153] In 2017, Shell (Netherlands) and ITM Power (United Kingdom) announced plans for a 10 MW proton exchange membrane electrolyser at a crude oil refinery in Germany; Shell noted that, in addition to producing hydrogen, the technology could help integrate VRE into Germany's energy mix.[154]

Also in 2017, a Japanese partnership involving several corporations, municipal governments and one prefectural government was using hydrogen produced from wind power to supply fuel cell forklifts.[155] Nel ASA (Norway) entered into an agreement with H2V PRODUCT (France) to supply renewable hydrogen for injection into France's natural gas pipelines, and was awarded a contract to produce renewable hydrogen in Iceland.[156] And in December, auto manufacturer Toyota (Japan) announced plans to build the world's first megawatt-scale 100% renewable power and hydrogen generation station at the Port of Long Beach, California.[157]

2017 saw continued **advances and falling costs** for energy storage technologies

Hydrogen-related R&D also continued, with wind turbine manufacturer Lagerwey and hydrogen supplier HYGRO (both Netherlands) partnering to develop a 4.8 MW wind turbine that incorporates electrolysis technology, enabling it to produce hydrogen directly and feed it into a gas network. The initial turbine, to be installed by early 2019, will be used to provide hydrogen for fuel cell-powered trucks.[158]

HEAT PUMPS

Heat pumps are used primarily for space heating and cooling of buildings (with individual units and district systems), as well as for industrial heat applications. They provide efficient heating, cooling, humidity control and hot water for residential, commercial and industrial applications.

Depending on its inherent efficiency and operating conditions, a heat pump has the potential to deliver significantly more energy from the air, ground, water bodies and sources of waste heat than is used to drive it. The most efficient electrically driven heat pumps available in early 2018, operating under optimal conditions (a modest "lift" in temperature from source to sink), can deliver three to five units of energy for every one unit of energy consumed.[159] That incremental energy delivered is considered the renewable portion of the heat pump output (on a final energy basis)[i]. When the input energy is 100% renewable, so is the output of the heat pump.

i The total share of renewable energy delivered by a heat pump on a primary energy basis depends on the efficiency of the heat pump and on its operating conditions, as well as on the composition of the energy used to drive the heat pump. A heat pump operating at a performance factor of four, driven by electricity from a thermal plant at 40% efficiency, provides about 1.6 units of final energy for every 1 unit of primary energy consumed (4/(1/0.4) = 1.6).

HEAT PUMP MARKETS

Markets for heat pumps expanded around the world during 2017. Primary policy drivers for increased deployment of heat pumps include air pollution mitigation (particularly in China) and, in Europe, the opportunities to increase the use of renewable electricity (specifically VRE) for heating and cooling and to expand capacity for demand response.[160]

The scale of the global heat pump market is difficult to assess due to the lack of data[i] and to inconsistencies among existing datasets. It is estimated that air-source heat pumps make up the largest share of the global market, followed by ground-source heat pumps. As of 2014 (latest data available), the global stock of ground-source heat pumps represented 50.3 gigawatts-thermal (GW_{th}) of capacity, producing approximately 327 petajoules (91 TWh) of output.[161] Based on historical growth rates, global ground-source heat pump capacity may have reached 65 GW_{th} in 2017.[162]

The largest markets for heat pumps are China, the United States and Europe as a whole, where (in order of scale) France, Italy, Spain, Sweden and Germany were the most significant national markets in 2017.[163] Japan and the Republic of Korea also have significant heat pump markets.[164] In 2016 (latest data available), heat pumps for water heating achieved a 10% share of Japan's household water heater market.[165]

China's market for air-source heat pumps in 2016 was dominated by cooling applications (50 million units), with about 1.5 million units primarily serving space heating and hot water needs.[166] China's national heat pump market has expanded steadily in recent years, with sales increasing at an annual average rate exceeding 16% between 2013 and 2016, and continuing to grow in 2017.[167] Counting only air-source heat pump systems used specifically for low-temperature space heating, the number of units sold increased more than 30-fold from 2014 to 2016.[168]

Europe's combined heat pump market (air- and ground-source) grew by an estimated 10% in 2017, a slightly slower growth than was seen in 2016.[169] An estimated 1.1 million units were added, accounting for nearly 20% of the overall boiler market, for a total of 10.6 million units in use by the end of 2017.[170] The European market is rather concentrated, with the top seven countries accounting for more than 75% of the region's sales in 2017.[171]

On a per household basis, as of 2016, Norway was in the lead, followed by Estonia, Finland and Sweden.[172] Finland, a country with about 5.5 million people, is home to an estimated 0.8 million heat pumps.[173] Around 75% of single-family home builders in Finland choose heat pumps; in addition, heat pumps are being used increasingly in district heat systems combined with bioenergy and with solar thermal technologies.[174]

In the United States, heat pump sales dropped off considerably following the housing market collapse (which began in 2006), but the heat pump market has since recovered, with heat pumps accounting for a growing share of US shipments for space heating and cooling (to 24% in 2016), and sales reaching an estimated 2.4 million units in 2016 (latest data available).[175]

HEAT PUMP INDUSTRY

The heat pump industry is characterised by a large number of relatively small entities, although consolidation continued in 2017. Manufacturers have pursued acquisitions mainly to gain access to markets and to increase market share, as well as to access know-how and to complement existing product portfolios.

In recent years, the global industry has grown in scale and scope as major manufacturers from Europe, China and the United States have extended their areas of activity both geographically and sectorally (integrating heating, cooling and ventilation as well as, increasingly, dehumidification). A typical example is the acquisition of air conditioning and ventilation companies by boiler manufacturers, and vice versa.

US and Chinese companies have acquired companies in Europe, and European companies have invested in the United States and Asia.[176] Among the notable developments in 2017, Swedish heat pump maker NIBE completed several acquisitions of companies from around the world.[177]

Other notable trends in the industry include the integration of heat pump technologies and solar PV to increase on-site or local consumption of distributed renewable generation.[178] In addition, in some instances heat pumps are being configured to provide demand-response services to "smart" electric grids to take advantage of their inherent operational flexibility.[179]

ELECTRIC VEHICLES

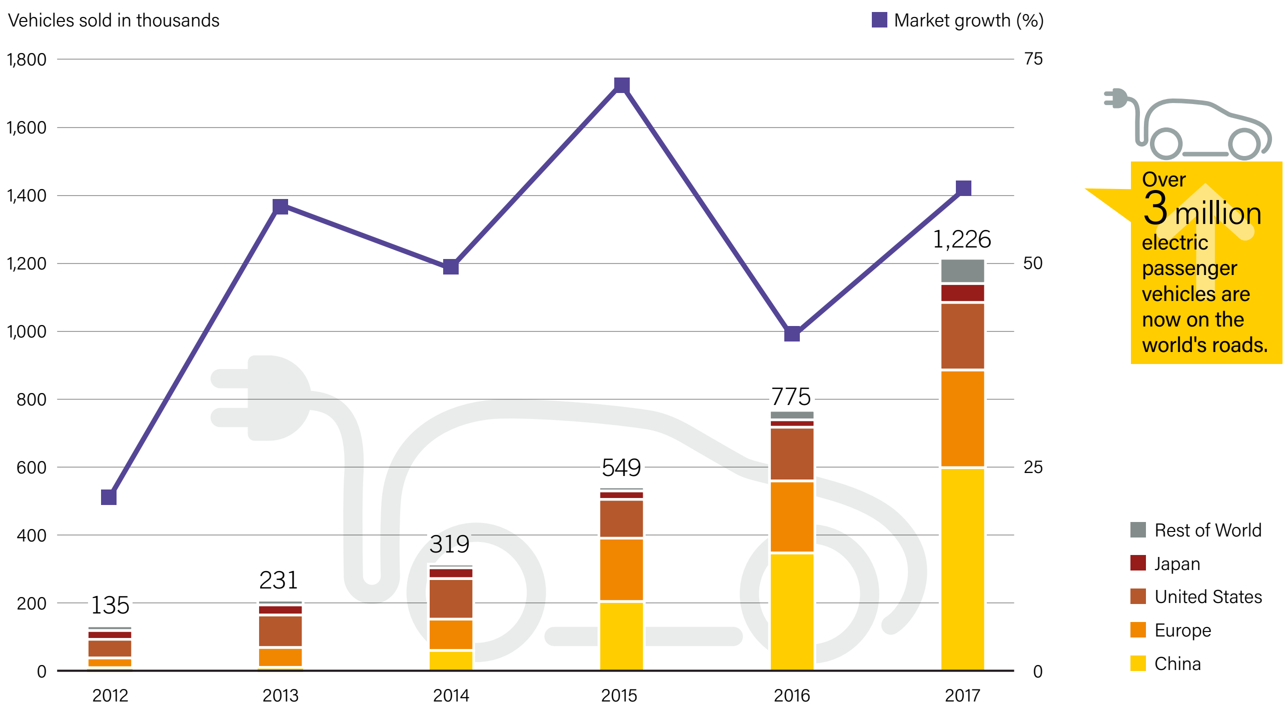
Electric vehicles encompass any road-, rail-, sea- and air-based transport vehicles that use electric drive and can take an electric charge from an external source, or from hydrogen in the case of fuel cell EVs. Some EV technologies are hybridised with fossil fuel engines (for example, plug-in hybrid EVs, or PHEVs), while others use only electric power via a battery (battery EVs). A third variant uses fuel cells to convert hydrogen into electricity. In 2017, an estimated 26% of the electricity consumed by EVs came from renewable sources, roughly in proportion to the renewable share of electricity generation.[180] A growing number of national and sub-national governments have established targets for EVs or announced plans to phase out sales of vehicles with internal combustion engines. *(→ See Policy Landscape chapter.)*

ELECTRIC VEHICLE MARKETS

Electrification of the transport sector expanded significantly during 2017, enabling greater integration of renewable energy in the form of electricity for trains, light rail and trams as well as for two-, three- and four-wheeled EVs and heavy-duty vehicles. In 2017, global sales of electric passenger cars (including PHEVs) reached an estimated 1.2 million units, up about 58% over 2016, and more than 3 million of the vehicles were traveling the world's roads by year's end.[181] *(→ See Figure 53.)*

i Part of the 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 thus heat pumps are counted as heating equipment, with cooling and dehumidification considered welcome byproducts, from European Heat Pump Association, personal communications with REN21, November 2016-March 2017.

FIGURE 53. Global Passenger Electric Vehicle Market (including PHEVs), 2012-2017



Source: See endnote 181 for this chapter.

Despite rapid growth, the EV passenger car market (including PHEVs) remains small, reaching only a 1.3% share of global passenger vehicle sales in 2017.[182] By year's end, EVs accounted for only a tiny portion of the total global passenger light-duty vehicle fleet. The market also is highly concentrated.[183] China, Europe and the United States together accounted for 94% of the total global market.[184] China alone accounted for about 49% of global unit sales.[185]

Norway remained well ahead of all other countries in market penetration, with EVs representing 32% of annual vehicle sales through most of 2017.[186] Both Norway and Iceland (which also has a growing share of EVs) derive virtually 100% of their electricity from renewable sources ***(→ see Reference Table POLR1)***, and EV charging has become a strong driver for new solar PV systems in Norway (although hydropower accounts for the vast majority of electricity generation and EV charging).[187]

Electric passenger car numbers are eclipsed by two- and three-wheeled EVs. More than 200 million were on the world's roads in 2016, and over 30 million are added each year.[188] The majority of these are in China, although the market in India is also large, and sales are increasing elsewhere in Asia as well as in Europe and the United States.[189]

EVs also come in the form of trains, trams, buses and other vehicles, including some marine vessels. By the end of 2017, around 386,000 electric buses were on the world's roads, with about 99% of these in China.[190] However, interest in electric buses is on the rise in other countries, with new orders from several cities in Australia, Europe, the US state of California and elsewhere around the world.[191] Electric trains on the Dutch railway network, which carries about 600,000 passengers daily, began relying entirely on wind power at the beginning of 2017.[192]

The use of electricity for marine transport also advanced in 2017. China saw the launch of the world's first all-electric cargo ship; ironically, the ship will be used primarily to carry coal up the Pearl River for electricity generation, but the technology also is expected to be used in passenger or engineering ships.[193] In Sweden, two large ferries that carry more than 7.3 million passengers and 1.8 million vehicles annually were converted from diesel to electricity.[194]

In late 2017, a coalition of global corporations from China, Europe and the United States launched EV100, a campaign to accelerate the uptake of EVs and associated infrastructure; membership reached 16 corporations by year's end.[195] Members aim to use their buying power and influence on employees and customers to increase demand and make EVs more affordable around the world.[196] Although the target is not directly linked to charging with renewable electricity, several members also have committed to going "100% renewable" through the RE100 campaign.[197]

In the United States, the governors of seven western states agreed in 2017 to develop a unified regional EV plan for a network of charging stations along 5,000 miles (more than 8,000 kilometres) of highways throughout the region. They agreed to advance opportunities to incorporate charging stations into planning processes, including building codes, metering policies and renewable energy projects.[198] The state of Nevada's participation in such initiatives has been driven in part by a desire to replace fuel imports with local renewable electricity.[199]

EVs

can provide grid services through demand response and smart charging

Rising numbers of EVs present both opportunities and challenges. The impacts of charging depend on when it occurs, the number of vehicles charging at a given time and where those vehicles are located on the grid. Without smart energy management, a large number of EVs all charging concurrently could cause spikes in electricity demand, affecting grid stability, efficiency and operating costs.[200] To address these concerns, several countries, municipalities, EV manufacturers and electric utilities continued to experiment with "smart" charging during 2017.[201] Smart charging enables EV power demand to follow wind and solar power output, which can help to smooth load profiles; it also provides a market for VRE electricity, thus avoiding curtailment.[202] A number of pilots have demonstrated that EVs can support the grid through demand response and smart charging.[203]

Several parties also are experimenting with vehicle-to-grid technologies, which could enable utilities to manage EV charging while allowing vehicle batteries to store grid electricity for re-injection as needed.[204] A one-year trial in Denmark, which concluded in 2017, demonstrated that utilities can use the batteries of parked EVs to help balance supply and demand on the grid, by storing electricity and delivering it back to the grid when needed, while also providing vehicle owners with a new revenue source.[205] V2G technologies remain in their infancy, but evidence suggests that they are moving beyond the pilot stage.[206] Challenges remain, including that the battery is the most costly part of an EV, and owners might not be willing to relinquish control of this resource, at least not without appropriate electricity rate structures and other incentives.[207]

Hydrogen vehicles offer the benefits of long range and rapid fuelling relative to battery EVs, but their commercial success so far has been more limited.[208] Challenges for successful competition of hydrogen vehicles include needed improvements in the durability and efficiency of fuel cells as well as innovative service models.[209] By the end of 2016, nearly 3,000 commercial fuel cell EVs had been sold or leased, and more than 14,000 hydrogen fuel cell forklifts were in operation worldwide.[210] More than 90 hydrogen fuelling stations opened during 2016, with most of these in Japan (45) and California (20).[211]

ELECTRIC VEHICLE INDUSTRY

Automakers are spending billions of dollars on EVs in response to government policies and the realisation that prices of EVs are dropping faster than expected.[212] Research, development and demonstration and increased production together have helped drive down battery costs and improve energy density.[213] In turn, the falling costs and rising density of batteries are helping to increase vehicle range and reduce vehicle costs.[214]

China leads in the potential production volume of EVs, followed distantly by the United States, and is also the leading manufacturer of battery cells for EVs in terms of production volume.[215] In 2017, several major auto manufacturers around the world made new pledges or announced plans to produce and sell a large variety of battery EVs, PHEVs and some hydrogen fuel cell vehicles.[216] In addition, companies in Asia, Europe and North America continued to develop electric buses, forklifts and long-distance electric trucks, as well as electric two- and three-wheel vehicles and marine transport vessels.[217]

The private sector and governments, often in partnership, continued to expand EV charging infrastructure.[218] As of mid-2017, an estimated 400,000 public charge points were in operation worldwide.[219] The global number of public charging stations doubled from late 2015 to late 2017.[220] In some instances, such as in Vancouver, Canada, publicly supported expansion is linked directly to advancing renewable energy goals.[221]

Electric utilities are playing a significant role in expanding EV charging points.[222] In Germany, for example, power companies account for about 35% of public charging stations, and in China, two utilities together have opened more than 27,000 charging stations.[223] In 2017, the largest investor-owned electric utilities in California proposed investing over USD 1 billion to accelerate electrification of the state's transport sector. Proposed projects focus on developing charging infrastructure and on advancing V2G integration through dynamic pricing, the use of storage in EV batteries and VRE power.[224] Although they are not necessarily driven by VRE integration, utilities in many countries are increasingly interested in the potential linkages between VRE and EVs.[225]

Vehicle manufacturers and others are working to advance the synergies between VRE and EVs by, for example: testing the potential of V2G for demand response; offering V2G services or free solar PV installations to their customers; manufacturing and co-marketing EVs, solar panels and storage systems; and developing networks of solar-powered charging stations.[226] In addition, an increasing number of companies have worked to integrate renewable technology directly into a range of vehicles. In 2017, for example, German start-up Sono Motors unveiled a battery EV that is powered partly by onboard solar cells; Dutch start-up Lightyear launched a solar-powered family car; Panasonic (Japan) started producing solar PV modules for use atop Toyota's latest Prius; and a Nigerian company started selling solar-powered tricycles.[227]

07

ENERGY EFFICIENCY

Solar thermal plant (bottom left) and a spent grain fermentation tank for biogas (centre) at Göss brewery of HEINEKEN in Leoben, Austria.

Already a leading brewery in terms of energy and water efficiency, HEINEKEN's Göss brewery became the world's first large-scale brewery to operate entirely on renewable energy and waste heat in 2016. All of the facility's electricity demand is met by hydropower, and its heat requirement is met by various sources to produce 1.4 million bottles of beer daily. An on-site solar thermal plant occupies about 1,500 m^2, contributing 3-5% of the brewery's heat demand. Another 50% of heat demand is met with waste heat from the facility itself and from a neighbouring sawmill, and the rest is provided by biogas from an anaerobic digestion plant. The company emphasised the importance of risk mitigation, efficiency and commercial opportunity in the investment, in addition to helping HEINEKEN achieve its commitment to a 70% renewable energy share in production by 2030.

ENERGY EFFICIENCY

OVERVIEW

Energy efficiency is the measure of energy services delivered relative to energy input. Energy efficiency is gained when more energy services are delivered for the same energy input, or the same amount of services are delivered for less energy input.[1] This can be achieved by reducing energy losses that occur during the conversion of primary source fuels, during energy transmission and distribution, and in final energy use[i], as well as by implementing other measures that reduce energy demand without diminishing the energy services delivered.

The advantages of energy efficiency are well reported, with positive impacts on society, the environment, health and well-being, and the economy.[2] Energy-efficient technologies and solutions can offer one of the most cost-effective ways of reducing energy costs, improving energy security, reducing local air pollution and mitigating climate change.[3]

Improvements and investments in energy efficiency can occur anywhere along the chain of energy production and use. Policy and regulatory drivers are instrumental to energy efficiency improvements, including building codes and energy performance standards. *(→ See Buildings section in Policy Landscape chapter.)*

Although most energy efficiency measures are not directly connected with the renewable energy sector, technical and economic synergies exist between efficiency improvements and renewable energy. Energy efficiency can support increased renewable energy deployment, and vice versa.

Synergies exist between energy efficiency and renewable energy; **energy efficiency** can support increased renewable energy deployment, and vice versa

Reducing overall energy consumption through efficiency improvements means that any given amount of renewables can meet a larger share of overall energy use. For example, efficient building envelopes (i.e., improving the air-tightness of buildings) reduce energy demand for heating or cooling, making it easier and less costly to meet the remaining demand with renewable energy. Also, technologies that improve final energy efficiency in end-use sectors, such as electric vehicles (EVs) and heat pumps, may aid in the effective integration of variable renewable energy sources. *(→ See Integration chapter.)* Furthermore, in areas with low energy access, energy-efficient appliances combined with renewable energy are improving access to electricity for off-grid households.[4] *(→ See Distributed Energy chapter, and Sidebar 3 in GSR 2017.)*

Renewable energy deployment can increase energy efficiency in energy production and distribution. For example, non-thermal renewable energy production reduces primary energy use and conversion losses when displacing thermal generation and may lessen transmission and distribution losses in some instances.

i See Glossary.

Despite these synergies, renewable energy and energy efficiency generally have been considered to be two distinct policy areas.[5] As the deployment scales of efficiency measures and renewable energy technologies grow, policies designed in isolation are more likely to result in inefficient outcomes.[6] Examples include duplication or gaps in policy formulation.[7] As such, much global potential remains for more integrated policy and planning that considers demand and supply together.[8]

Dialogue at the international level has begun to recognise the importance of integrating energy efficiency and renewable energy, with international organisations, global campaigns and a host of other actors increasingly raising awareness and encouraging policy makers to consider the two in concert.[9] Some policies have emerged in recent years that attempt to link renewables and energy efficiency. For example, an agreement was reached in late 2017 on updates to the European Union's (EU's) Energy Performance of Buildings Directive, designed to quicken the rate at which cost-effective renovations of existing buildings occur and to unlock public and private sector capital for energy efficiency and renewable energy in buildings.[10] Meanwhile, India has incorporated joint consideration of on-site renewable energy and energy efficiency in its building code.[11] *(→ See Buildings section in Policy Landscape chapter, and Energy Efficiency chapter in GSR 2017.)*

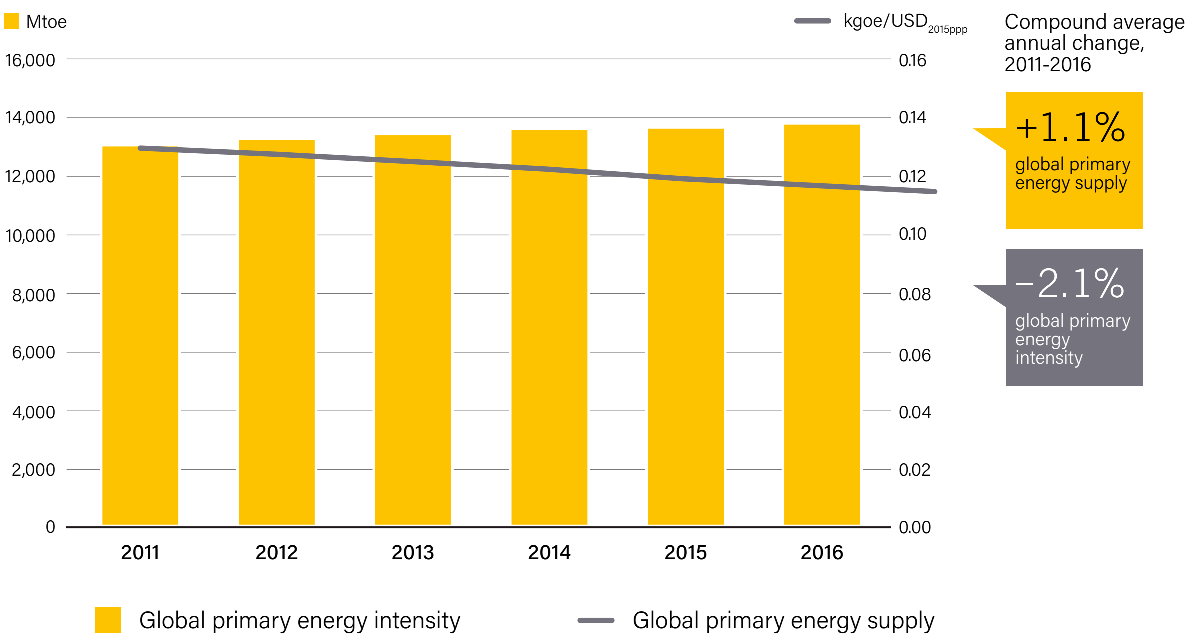
Because of the lack of precise indicators of energy efficiency, primary energy intensity[i] often is used to identify and monitor trends in energy efficiency across economies. Globally, the average decrease in primary energy intensity between 2011 and 2016 was appreciably greater than during the three preceding decades.[12]

Between 2011 and 2016, primary energy intensity decreased by about 10%, an average annual contraction of 2.1%.[13] This greatly moderated the growth in primary energy consumption, which grew by 5.7% over the same period (average annual growth of 1.1%).[14] *(→ See Figure 54.)* In 2016, global gross domestic product (GDP) grew 3%, whereas energy demand increased only 1.1%.[15] However, countries outside of the Organisation for Economic Co-operation and Development (OECD) continue to see growing energy use with growing GDP, while OECD countries, as a whole, do not.[16]

> The global economy grew nearly
> **3 times faster**
> than global energy demand during 2011-2016, in part because of energy efficiency improvements

i Defined as the ratio of gross inland consumption of energy per unit of GDP. Due to limits on data availability, primary energy intensities are used for overall energy intensity comparisons, while final energy intensities are used for sectoral comparisons.

FIGURE 54. Global Primary Energy Intensity and Total Primary Energy Supply, 2011-2016



Note: Dollars are at constant purchasing power parities.
Mtoe = megatonnes of oil equivalent;
kgoe = kilograms of oil equivalent.

Source: See endnote 14 for this chapter.

The decline in energy demand per unit of economic output has been made possible by a combination of supply- and demand-side focused policies and mechanisms as well as structural changes. These include:

- the expansion, strengthening and long-lasting impact of energy efficiency standards for appliances, buildings and industries;
- improved fuel efficiency standards and, more recently, the growing deployment of EVs – especially when supplied by renewable energy sources;
- fuel switching to less carbon-intensive alternatives, including renewables (for example, China's 13th Five-Year Plan aims to lower the share of coal in the primary energy supply from 62% to 58% by 2020);
- structural changes in industry, including a transition towards less energy-intensive and more service-oriented industries.[17]

At the regional level, annual changes in energy intensities vary widely. Asia and Oceania experienced the largest reductions in energy intensity between 2011 and 2016, with average annual declines of 3.3% and 2.5%, respectively.[18] Latin America's energy intensity remained flat over this period, while the Middle East was the only region that saw an overall increase, albeit ending the period with a decline of 3.1% in 2016.[19] (→ *See Figure 55.)*

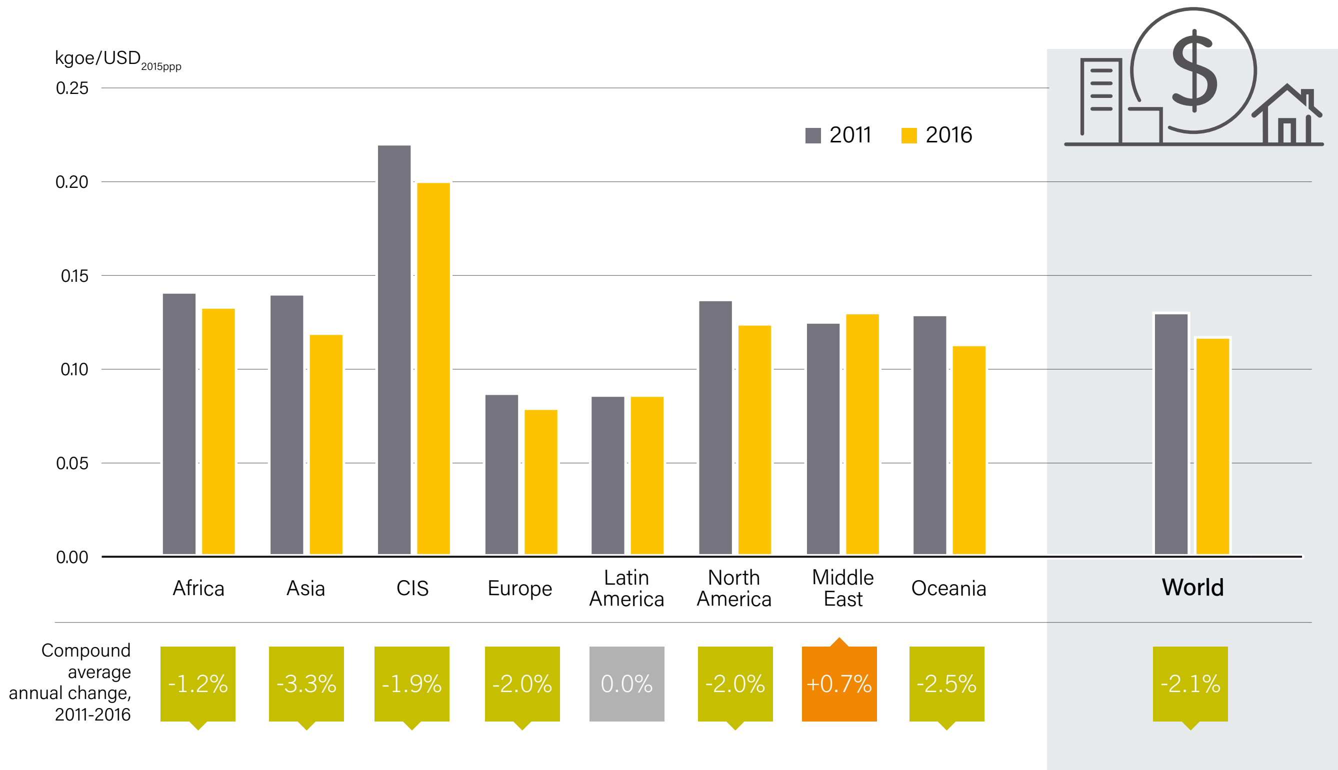
At least 25 countries[i] appear to have reached their peak energy demand and have since maintained lower demand, despite continued economic growth.[20] Germany's primary energy demand was more than 10% lower in 2016 than at its peak in 1979.[21] Total energy demand across all OECD countries peaked in 2007.[22]

Most energy efficiency advances occur in the context of various end-uses of energy, as well as in the generation of electricity for various (final) energy applications. In 2016, an estimated 38% of primary energy supply was allocated to electricity generation.[23] Total final consumption of energy (TFC)[ii] includes electricity, final

i Countries that have achieved peak energy demand, in chronological order from 1979 to 2016, are: Germany, the Czech Republic, Hungary, Poland, Denmark, the United Kingdom, Japan, Finland, France, Sweden, Italy, Portugal, Luxembourg, Switzerland, Greece, Spain, Slovenia, Ireland, the United States, the Netherlands, Belgium, Norway, Austria, Israel and Chile.

ii Total final consumption includes energy demand in all end-use sectors, which include industry, transport, buildings (including residential and services) 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. IEA, *Energy Efficiency Market Report 2016* (Paris: 2016), p. 18, https://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016_WEB.PDF.

FIGURE 55. Primary Energy Intensity of Gross Domestic Product, Selected Regions and World, 2011 and 2016



Note: Dollars are at constant purchasing power parities. CIS = Commonwealth of Independent States.

Source: See endnote 19 for this chapter.

uses of fuels and other sources of heat, and various non-energy uses. The buildings sector consumed 32% of TFC, industry 30% (excluding non-energy uses) and transport 29%, with the remainder consumed in other sectors and for non-energy applications, which comprise mainly industrial uses such as petrochemical manufacturing.[24]

Electricity makes up a portion of final energy use in all end-use sectors, and energy efficiency in power generation must be gauged in terms of its primary energy use. By contrast, the efficiency of end-use sectors is better measured in the context of final energy use. The following sections examine primary energy efficiency in electricity generation, followed by the efficiency of final energy use in the buildings, industry and transport sectors.

ELECTRICITY GENERATION

Improvements in the efficiency of electricity generation, as well as the adoption of non-thermal renewable energy sources, have helped to greatly reduce primary energy intensity. Between 2011 and 2016, the overall average efficiency of power generation increased from 41% to 43.1%, an annual rate of improvement of 1%.[25]

Primary energy efficiency in electricity generation can be improved through upgrades to more efficient technology (e.g., replacing open-cycle gas turbines with combined-cycle generators); through fuel switching (e.g., substituting non-thermal renewables for fossil fuel generation); through the use of co-generation, which maximises the utilisation of energy input; and by reducing transmission and distribution grid losses through improved grid infrastructure and management.

Between 2011 and 2016, the efficiency of electricity generation improved in all regions except Africa and Latin America, where it fell by 2.7% and 3.7%, respectively.[26] However, changes in efficiency can be driven by complex and sometimes unpredictable factors, such as Brazil's loss of hydropower output in recent years due to persistent droughts in parts of the country.[27] In other regions of the world, the efficiency of electricity generation improved, which may have been helped by rising shares of non-thermal renewable electricity, such as solar photovoltaics and wind power.[28]

BUILDINGS

The buildings sector accounts for nearly one-third of global final energy consumption, including the use of traditional biomass.[29] Residential buildings consume about three-quarters of this energy, while the rest is used in commercial facilities (services).[30] In 2016, electricity comprised an estimated 31% of building energy use, the rest being mostly various heat demands.[31] Efficiency of energy use in buildings is affected by building envelopes, design and orientation, as well as by the efficiency of energy-consuming devices, including climate-control systems, lighting, appliances and office equipment.

The overall energy intensity of the buildings sector (measured as final energy use per unit of floor area) declined at an average annual rate of 1.3% from 2010 to 2014, due primarily to the continued adoption and enforcement of building energy codes and efficiency standards.[32] However, declining energy use per unit area has not been enough to offset the growth in floor area (average annual growth of 3%) and the rising demand for various energy services in buildings.[33]

Globally, energy demand from lighting, appliances and other electrical equipment within buildings grew at an average annual rate of 1% between 2010 and 2016.[34] In non-OECD countries, the rate of demand growth has been double the global average.[35] The faster demand growth in developing countries is explained by improved access to electricity, increasing household wealth, and greater demand for energy services and thermal comfort within buildings. Overall, despite efficiency gains for appliances, global energy demand from major appliances grew by 50% between 1990 and 2016.[36]

Space heating and hot water demand grew at a slower pace (average annual growth of 0.5% since 2010), due in part to a shift away from the use of traditional biomass in developing countries and to the expanded use of condensing boilers and heat pumps in many developed economies.[37]

Energy efficiency gains between 2000 and 2016 were strongest in the residential end-use sector, especially for International Energy Agency (IEA) member countries, which saw efficiency improvements of 22% overall in the sector during this period.[38] For these countries, population growth had an incremental effect on energy use of 10%, and structural effects (such as increased floor area and higher levels of appliance ownership)

Buildings consume about **half** of all electricity; about 27% serves residential buildings and over 22% serves commercial and public buildings

provided a marginal boost of 9%.[39] However, efficiency enhancements offset those increments, resulting in a 7% net reduction in final energy use in the residential sector.[40]

An important factor in this net reduction was improved space heating, notably in Europe. Between 2000 and 2016, energy use per square metre of floor space decreased by 45% in Germany and 36% in France.[41] Conversely, in some emerging economies, energy efficiency gains have not been large enough to offset the incremental rise in energy demand from population growth and structural effects.[42]

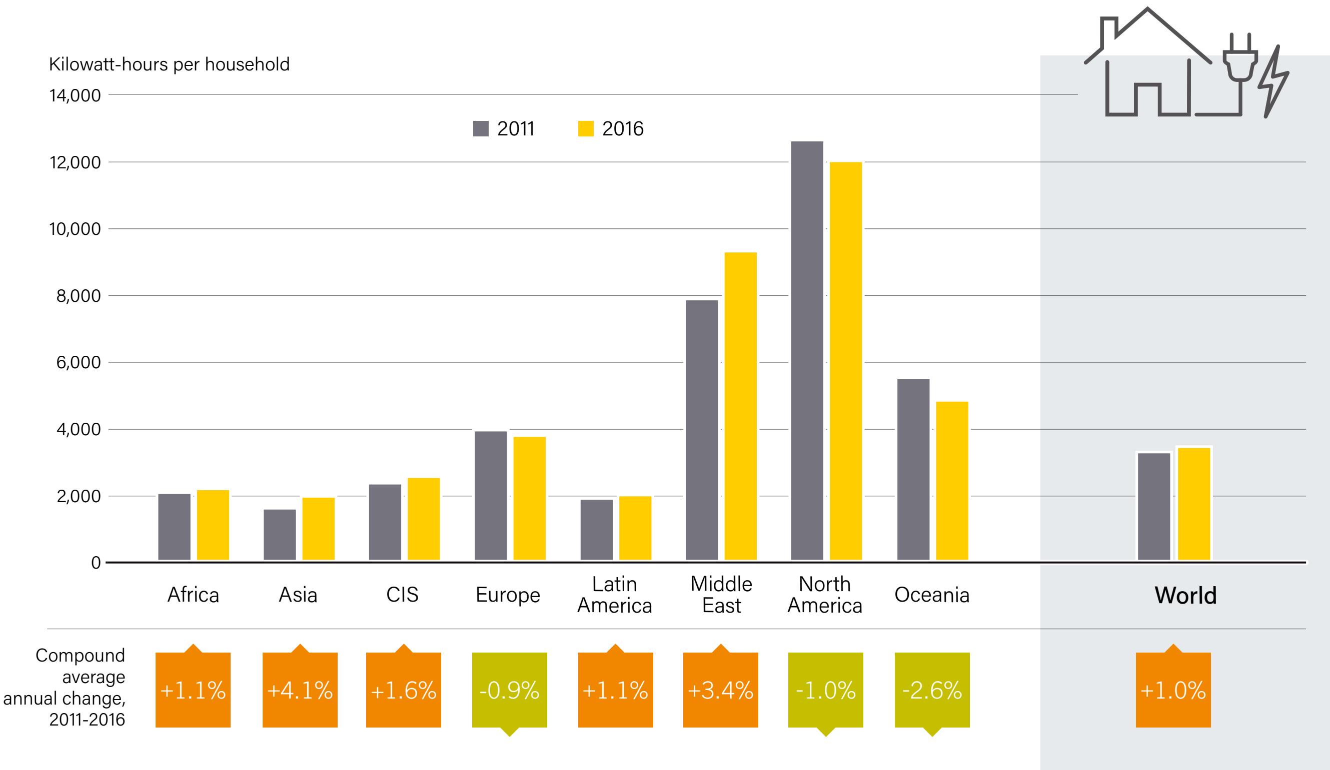
The buildings sector accounts for around half of world electricity consumption, with the residential sector consuming 27% of all electricity.[43] While global average electricity consumption per household grew nearly 1% annually between 2011 and 2016, the fastest growth was observed in Asia (average annual growth of 4.1%), followed by the Middle East (3.4%).[44] Oceania showed the greatest rate of decline (average annual contraction of 2.6%), followed by North America, with an average annual decline of 1%.[45] *(→ See Figure 56.)*

Energy efficiency in the service (commercial) sector can be indicated by the ratio of electricity consumption to value-added in commercial activity (in constant purchasing power parity, PPP).

Between 2011 and 2016, the electricity intensity of the service sector declined in every region except the Middle East (average annual growth of 3.1%) and Latin America (2.1%).[46] Overall, the energy intensity of the service sector globally declined at an average annual rate of 0.8%.[47]

As with other sectors, the energy intensity of services is the product of several factors. These include structural changes both within the sector (e.g., between more energy-intensive sub-sectors, such as hospitals, and less energy-intensive ones, such as warehouses) and across the economy; the growth of building size relative to sector GDP; and the uptake of more efficient technologies.[48]

FIGURE 56. Average Electricity Consumption per Electrified Household, Selected Regions and World, 2011 and 2016



Note: CIS = Commonwealth of Independent States

Source: See endnote 45 for this chapter.

INDUSTRY

The industrial sector accounts for nearly 30% (excluding non-energy uses) of TFC.[49] Including non-energy uses in industry, the total share of TFC is about 37%.[50] Key factors determining industry energy intensity have included higher equipment utilisation rates (driven by periods of stronger economic activity), structural change (such as growth in less energy-intensive sub-sectors or a shift away from energy-intensive industries) and the deployment of more efficient manufacturing equipment.[51]

The ratio of industry TFC to industry value-added (in PPP) is an indicator of the overall energy intensity of the sector. To compare overall industry energy intensity in different countries, the average energy intensity across all industry sectors is used. However, intensities vary widely across industry sectors. For example, across IEA member countries, the energy requirements for basic metals manufacturing are an order of magnitude larger than the requirements of the service industry, per unit of economic output. The manufacture of basic metals (among the most energy-intensive industries) requires around 25 megajoules (MJ) per USD_{PPP}, whereas the service industry requires less than 2 MJ per USD_{PPP}.[52]

Between 2000 and 2016, reductions in the energy intensity of industries worldwide ranged from 20% in the non-metallic minerals industry (mainly cement manufacturing), to 14% in the pulp and paper industry, to 8% in the food, beverage and tobacco sector.[53] In both IEA member countries and across major emerging economies, value-added in industry grew faster than energy consumption, resulting in a decline in the energy intensity of industry.[54] Nonetheless, between 2010 and 2016, global energy use in industry grew at an average annual rate of 1.5%.[55]

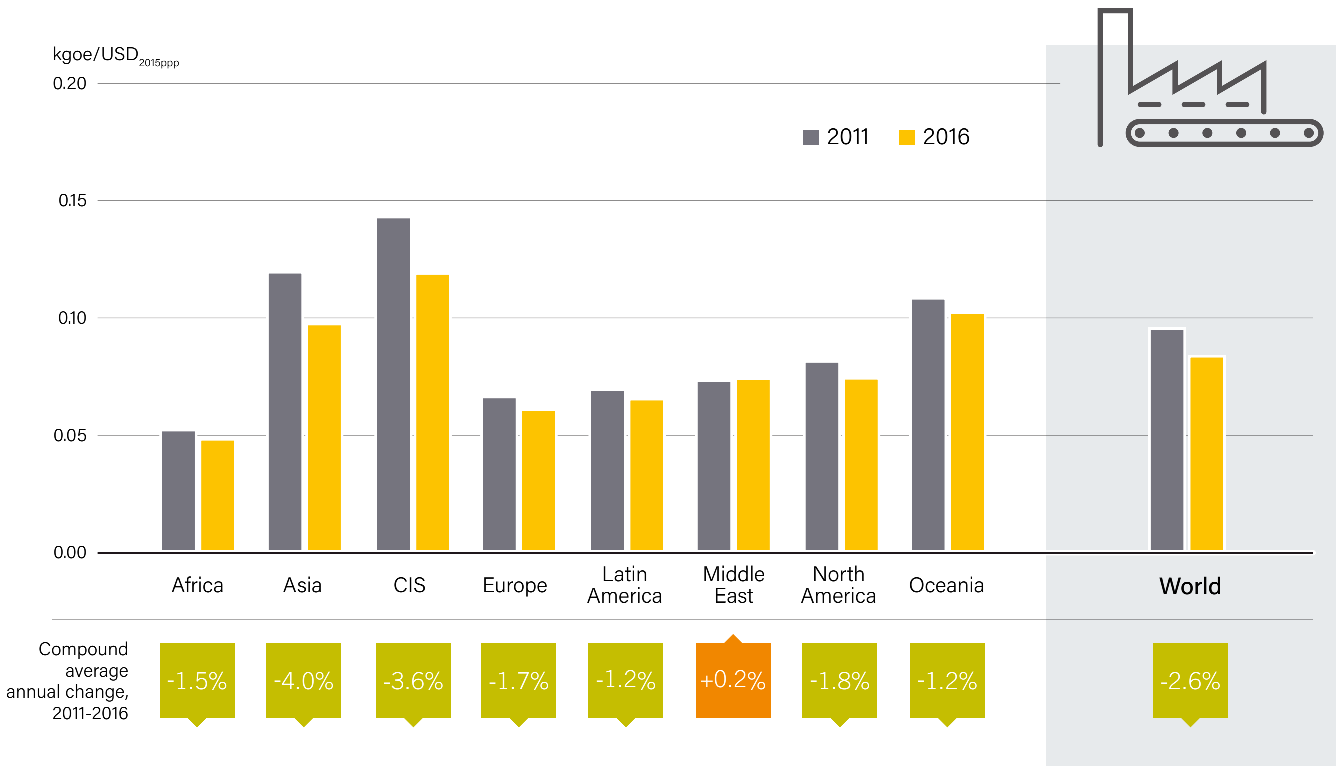
The global average energy intensity of industry contracted between 2011 and 2016, at an average annual rate of

2.6%

The global average energy intensity of industry contracted between 2011 and 2016, at an average annual rate of 2.6%.[56] The regions with the most marked decreases in energy intensity were Asia (average annual decline of 4%) and the Commonwealth of Independent States (3.6%).[57] Only the Middle East did not show notable improvement in energy intensity for the period.[58] *(→ See Figure 57.)*

At a global level, industrial efficiency drivers have varied among the different industry sectors. However, rising energy costs can trigger the implementation of energy efficiency measures (predominantly technical and logistical improvements) in the sector as a whole.[59] Higher energy overheads put pressure on companies to optimise their processes and also can be a driver for structural changes.

FIGURE 57. Average Energy Intensity of Industry, Selected Regions and World, 2011 and 2016



Note: Dollars are at constant purchasing power parities. CIS = Commonwealth of Independent States.

Source: See endnote 58 for this chapter.

Policies have played an important role in driving energy efficiency improvements in the industrial sector. Industrial Energy Performance Standards, for example, set minimum allowable energy efficiency values for existing and newly constructed plants, taking into account different types of raw materials, fuels and capacities. Such standards set mandatory benchmarks for companies and have been developed for a variety of industry processes and materials.[60]

TRANSPORT

The transport sector was responsible for an estimated 29% of global final energy use in 2016.[61] Renewable energy, in the form of biofuels, supplied only 2.9% of the energy used in transport, and electricity provided another 1.4% (however, only about 26% of the electricity consumed by EVs is renewable).[62] Road transport accounted for 75% of global transport energy use in 2015, followed by aviation (11%), marine transport (just over 9%), rail transport (2%) and pipeline and other transport.[63]

The energy intensity of the transport sector[i] is affected by efficiency improvements within transport modes (rail, road, aviation and shipping) and by shifts between transport modes (for example, from private car use to public transport, or from road freight to rail).

Between 2000 and 2016, the fuel efficiency of passenger vehicles (fuel use per vehicle kilometre, excluding aviation) improved by 7% in IEA member countries, driven by both technology advancement and transport policies (this does not include conversion losses in the fuel supply chain).[64] However, a reduction in the number of passengers per vehicle and other incremental effects resulted in a net 4% increase in transport energy use.[65]

By contrast, major emerging economies saw net passenger transport energy use triple between 2000 and 2016 due to demand growth, lower vehicle occupancy rates and a shift between transport modes.[66] This was despite a 15% efficiency improvement in passenger transport, linked to policy and technology.[67] Constantly improving fuel efficiency standards represented a significant contribution to energy efficiency improvements in passenger transport between 2000 and 2016 for IEA countries.[68]

The story is similar for freight transport, but here the relative impact of energy efficiency was even smaller than for passenger transport. In IEA member countries, efficiency gains of 5% were insufficient to overcome growth in the sector, resulting in a net increase in energy use of 9%.[69] In major emerging economies, demand growth and a shift towards the use of heavy-duty trucks raised energy demand in the sector by more than 250%[70], with no improvement in energy efficiency.

Increasing numbers of EVs and plug-in hybrid vehicles will contribute to improvements in fuel economy on a final energy basis. *(→ See Electric Vehicles section in Integration chapter.)*

29%

of global final energy use in 2016 was used for transport, with road transport accounting for a full 75% of global transport energy use

i This is defined as energy use in transport per unit of GDP. A more direct indicator of transport efficiency might be defined in terms of energy use per passenger-kilometre and energy per cargo-tonne-kilometre, but aggregated global data across all transport segments are not available.

08

CORPORATE SOURCING OF RENEWABLE ENERGY

Solar arrays on the roof of Apple headquarters, Cupertino, California, United States

Apple's new headquarters, opened in 2017, relies on a mini-grid with a 17 MW rooftop solar array and a 4 MW biogas-powered fuel cell system with battery storage.
The on-site generation system is estimated to provide 75% of power requirements during working hours for 12,000 Apple employees. The remaining electricity supply comes from a 130 MW solar project built by Monterey County and First Solar. Since April 2018, Apple's global facilities across 43 countries have been powered with 100% renewable energy. Twenty-three of Apple's suppliers also have committed to using 100% renewable energy for manufacturing the company's products.

FEATURE:
CORPORATE SOURCING OF RENEWABLE ENERGY

Scaling up renewable energy is crucial for limiting the rise in global average temperature to well below 2 degrees Celsius above pre-industrial levels, in line with the Paris Agreement. To increase renewables on such a scale, annual investment in the renewable energy sector through 2050 would need to be roughly triple that of 2017.[1] The bulk of the needed investment is expected to come from private finance.[2]

Corporate entities[i] account for around two-thirds of the world's final energy consumption and will continue to account for more than half by 2050, as estimated by the International Renewable Energy Agency's REmade Index under the Clean Energy Ministerial's Corporate Sourcing of Renewables campaign[ii]. As companies' demand for renewable energy increases, they have the potential to play an important role in driving investment in renewables and in helping to meet the global climate target.[3]

Since the mid-2000s, more and more companies in a variety of industries across different sectors have committed to ambitious renewable energy targets and have begun to source renewables to run their operations. As of early 2017, 48% of the US-based Fortune 500 companies and 63% of the Fortune 100 companies had at least one climate or clean energy target, and 10% of the Fortune 500 companies had set a specific renewable energy target.[4] By early 2018, more than 130 leading global corporations with operations across 122 countries had joined the RE100 initiative, a network of corporations committed to using 100% renewable energy.[5]

Corporate entities account for around **two-thirds** of the world's final energy consumption

Although US and European markets continue to account for the bulk of corporate renewable energy sourcing, this practice is now spreading to regions around the world; countries such as Burkina Faso, Chile, China, Egypt, Ghana, India, Japan, Mexico, Namibia, Thailand and others have experienced growth in corporate sourcing.[6]

Initially, many companies considered the adoption of renewable energy solutions to be mainly an act of corporate social responsibility. Meeting internal environmental and social objectives such as greenhouse gas emission reduction targets, and addressing the growing demand for corporate sustainability from investors and consumers, continue to be key drivers for corporate sourcing.[7] In recent years, however, significant reductions in renewable energy costs, as well as maturing market and policy environments, have made renewables cost-competitive and attractive sources of energy in their own right.[8] For corporations, the economic benefits of sourcing renewables

i Corporate entities in this chapter refers to companies, both publicly and privately owned.

ii This chapter is based in part on International Renewable Energy Agency (IRENA), "Corporate Sourcing of Renewables: Market and Industry Trends (REmade Index 2018)" (Abu Dhabi: May 2018), http://www.irena.org/publications. The REmade Index was developed under the Clean Energy Ministerial's Corporate Sourcing of Renewables campaign, for which IRENA is the operating agent, with support from an international network of non-state renewable energy actors including industry associations, private sector entities, and civil society and research organisations. See endnote 3 for this chapter.

may also include long-term price stability, security of supply, reduction of energy-related expenses and the possibility of new business opportunities.[9]

From a developer's perspective, having in place a long-term power purchase agreement (PPA) with a large, creditworthy corporate end-user has become a way to address off-taker[i] risk and decrease overall financing costs.[10] Other drivers for developers to sell directly to corporations may relate to the advantages of diversifying customer portfolios and revenue streams.

For governments, some of the drivers to encourage and facilitate corporate sourcing of renewable energy include compliance with national and international climate targets, job creation and economic growth through new investment, as well as other socio-economic benefits.

Although many companies are sourcing renewables to meet their thermal and transport energy needs, comprehensive global tracking of sourcing activity in these areas is still lacking or incomplete, and more efforts will need to be undertaken globally to assess this trend. This chapter focuses primarily on corporate sourcing of renewable electricity.

As of end-2017, corporate entities worldwide had actively sourced 465 TWh of renewable electricity.[11] The additionality[ii] of some corporate sourcing options and initiatives is difficult to measure and is not a given. Yet renewables projects with corporate off-takers or direct investors generally begin to generate renewable energy more rapidly than otherwise would be the case.[12]

HOW COMPANIES SOURCE RENEWABLE ELECTRICITY

As of end-2017, corporate entities worldwide had actively sourced

465 TWh

of renewable electricity

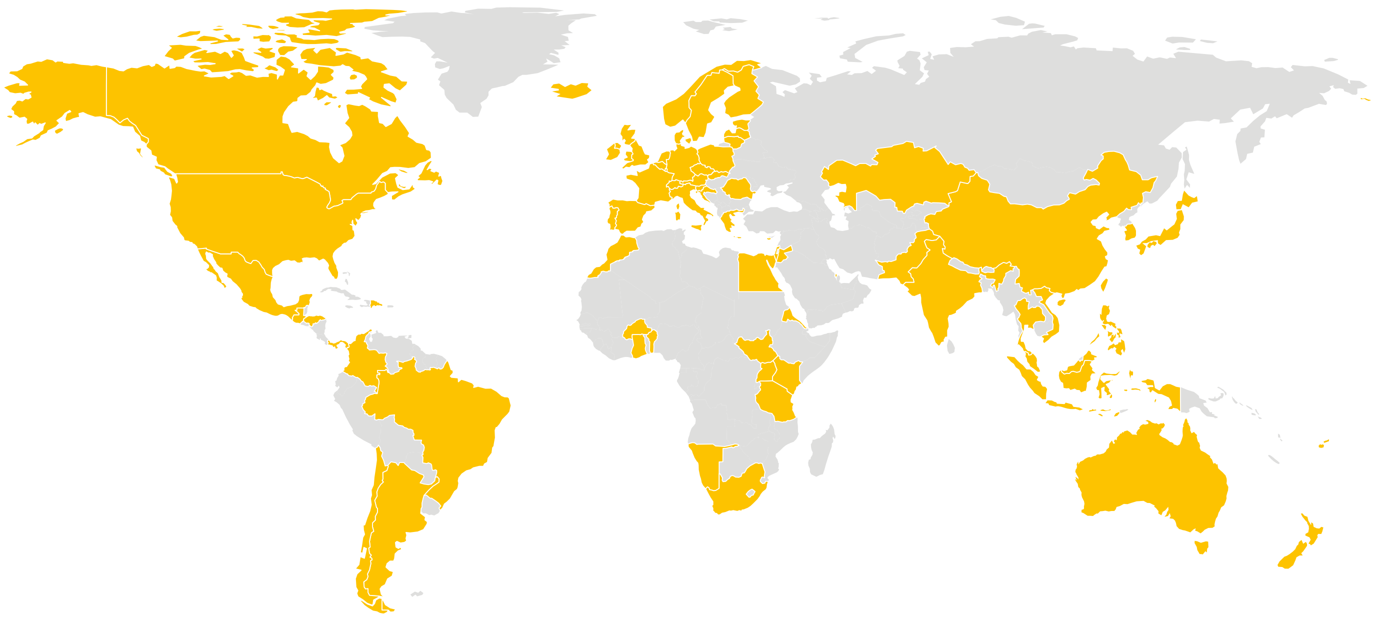
As of 2017, corporations sourced renewable electricity in 75 countries through corporate PPAs, utility green procurement programmes and unbundled[iii] renewable electricity certificates/guarantees of origin (RECs/GOs).[13] The majority of such activities took place in the United States, followed by Europe.[14] In addition, corporations in a large number of countries worldwide have invested directly in on-site and off-site renewable energy systems for their own consumption.[15] *(→ See Figure 58.)*

i Off-taker refers to the purchaser of the energy from a renewable energy project or installation (e.g., a utility company) following an off-take agreement. Off-taker risk is the risk of non-payment or delayed payment of the agreed tariff by the off-taker. (See Glossary.)

ii Additionality here refers to the net incremental capacity deployed or renewable energy generated as a direct result of corporate sourcing, beyond what would occur in its absence.

iii An "unbundled" electricity certificate is one that is traded separately from the electricity itself.

FIGURE 58. Countries Where Corporations Have Sourced Renewable Electricity, up to End-2017



Corporate sourcing in 2017 or prior

No corporate sourcing or no data

Note: Figure shows countries where corporate sourcing has taken place either through PPAs, utility green procurement programmes and/or the purchase of unbundled renewable electricity certificates. Direct investment in production for self-consumption is not included. Please see disclaimer on page 7 of this report for details on designations and presentation of material in this map.

Source: IRENA. See endnote 15 for this chapter.

CORPORATE PPAS

When sourcing renewable energy through a PPA, the corporation enters into a long-term contract with an independent power producer (IPP) or a utility and commits to purchasing a specific amount of renewable electricity, or the output from a specific asset, at an agreed price. The typical duration of a PPA for a newly built project is 10 years or longer, although the period varies across industry sectors and jurisdictions. "Virtual" PPAs[i] have become the norm in most larger PPA markets because they are more flexible in their structure and do not require the developer and the off-taker to be connected to the same network provider.[16]

Corporate PPAs started to become popular in the mid-2000s and have since emerged as an attractive option for companies to source renewable electricity while locking in a long-term, cost-competitive price. In 2017, a record level of corporate PPAs was reached with 5.4 GW of new capacity contracted, up 27% from the 2016 level.[17] The global cumulative renewable PPA capacity reached an estimated 19 GW in 2017, with about 60% of this capacity signed solely in the United States.[18] Around 20% of the cumulative corporate PPA capacity has been signed in Europe, with the Netherlands, Norway, Sweden and the United Kingdom dominating this market.[19] The remaining capacity is spread out, with India and Mexico leading the corporate PPA markets in their respective regions.[20]

The bulk of the global contracted PPA capacity has been wind energy and solar photovoltaics (PV), with some examples of hydropower and bioenergy plants.[21]

Given the complex contractual arrangements associated with corporate PPAs – and the desire by developers to seek credit-worthy off-takers – most of the deals have been contracted by large multinational corporations. Typically, the PPAs have been signed directly between a corporation and an IPP. However, another option for multiple corporate actors (including municipalities, local governments and universities, among others) is to form a consortium to aggregate their electricity demand under a single PPA deal. One of the most well-known consortium PPAs was signed in 2016 when three Dutch companies (AkzoNobel, DSM and Philips), along with Google (United States), jointly negotiated a PPA that enabled the construction of the 102 megawatt (MW) Krammer Wind Park in the Netherlands.[22]

UTILITY GREEN PROCUREMENT

In the case of utility green procurement, the corporation purchases renewable energy either through green premium products or through a tailored renewable energy contract, such as a green tariff, offered by a utility. Green premium products, which typically target residential or small-scale commercial utility customers, enable buyers to conveniently purchase renewable energy directly from the utility without a long-term commitment, but also without the prospect for price savings.

As of early 2018, most large utilities in Europe offered some sort of green premium product supported by the European Guarantee of Origin scheme, which certifies that the electricity was produced from renewable energy sources. Elsewhere, many utilities have similarly expanded their product portfolios to meet the growing corporate demand for renewable energy. To certify and communicate various sustainability aspects of their green premium products, some utilities use consumer labels – such as EKOenergy, Green-e and Gold Power – in addition to electricity attribute certificate schemes.

So-called green tariff programmes are utility options that allow for savings on electricity bills, developed in response to the growing demand for renewable energy from large-scale corporate customers. Green tariff programmes, where available, enable consumers to purchase renewable electricity from a specific asset through a longer-term utility contract. In the United States, utilities in 13 states and the District of Columbia were offering green tariff programmes as of late 2017.[23] Through these programmes, deals totalling more than 950 MW were contracted over the 2013-2017 period; the information technology (IT) sector alone contracted 560 MW of these deals in 2017.[24] An additional 465 MW of contracted capacity was under negotiation as of end-2017.[25]

In Europe, green tariffs have been used in various ways. For example, the Dutch national rail company Nederlandse Spoorwegen (NS) issued a tender in 2015 for a long-term green tariff contract, accepting bids for electricity only from new renewable energy installations. The utility that won the bid agreed to supply NS with renewable electricity from new wind farms under a 10-year contract.[26]

Data disclosed by more than 2,400 companies show that corporations voluntarily sourced an estimated 275 terawatt-hours (TWh) of renewable electricity through various types of utility programmes in 2016.[27]

DIRECT INVESTMENT FOR SELF-CONSUMPTION

In the case of direct investment for self-consumption (also known as auto-consumption), the corporation invests in and owns a renewable energy asset (on-site or off-site) primarily to generate electricity to power its own operations.

The market for direct investment for self-consumption is driven predominantly by companies that install relatively small-scale, on-site rooftop solar PV systems and by large industrial players with biomass waste streams that are used to produce energy. The latter may include breweries or pulp and paper industries investing in biomass-based combined heat and power plants to run their operations.

In addition, a few large companies have made direct investments in large-scale solar and wind power assets for their own use. For example, in early 2018, Argentinian aluminium producer Aluar placed a 50 MW order for the second phase of its wind park, doubling the company's wind power capacity for its own use. *(→ see page 46 in this report)*

In total, corporations actively consumed an estimated 465 TWh[ii] of renewable electricity by the end of 2017.[28]

i A "virtual" PPA is 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.

ii Given the different characteristics and geographical spread of direct investments, tracking the development of corporate renewable energy investment for self-consumption remains difficult, and these figures should be considered indicative.

UNBUNDLED RENEWABLE ELECTRICITY CERTIFICATES/ GUARANTEES OF ORIGIN

Unbundled RECs or GOs remain the most popular approach to corporate sourcing. They are purchased separately from the actual electricity sourcing as a mechanism to offset conventional electricity consumption. Each certificate purchased and cancelled or retired (meaning that the certificate is taken out of the market) is equivalent to the use of 1 megawatt-hour (MWh) of renewable electricity. Whether or not a corporation can purchase certificates directly varies from market to market. Currently, unbundled certificates can be purchased in the European Union (EU) as well as in China, India, Singapore and the United States, among other countries.[29]

Although certificates provide a convenient way to source renewables, questions have arisen with regard to their additionality. In some cases, there are concerns about the effectiveness and transparency of certificate tracking. As other cost-competitive options for purchasing renewable energy have become available in markets around the world, many large corporations that initially reached their renewables targets by buying RECs/GOs are now considering sourcing options that allow them to play a more active role in adding new renewable energy capacity to the grid.[30]

Corporations sourced renewable electricity in **75 countries** in 2017

Data collected from RE100 member companies show that, traditionally, one of the more popular approaches to sourcing renewables has been via certificate purchasing. However, the share of renewable electricity consumed by RE100 members through certificate purchasing declined from 60% in 2015 to only 40% percent in 2016.[31]

MAIN INDUSTRIES SOURCING RENEWABLE ELECTRICITY

The IT sector continues to purchase by far the largest amounts of renewable energy, mainly through wind energy PPAs. The three largest corporate buyers in all sectors at the end of 2017 were US-based Google, Amazon Web Services and Microsoft, all of which source renewables around the world.[32] Google announced in late 2017 that it had signed a corporate PPA for 536 MW of wind power, bringing its total contracted capacity of wind and solar power to more than 3.1 GW, equivalent to the total renewable energy capacity installed in Ireland.[33]

Amazon Web Services reached a total of 1.2 GW contracted by year's end, followed by Microsoft (759 MW) and US-based Apple (749 MW) and Facebook (736 MW).[34] The cost of energy to run data centres and cloud computing services represents a large share of expenses for companies in the IT sector, so the ability to lock in a long-term electricity price through a renewable energy PPA provides a clear business case for companies seeking to hedge against electricity price volatility while also meeting their greenhouse gas emission reduction targets.

Heavy industry, which has a tradition of either owning energy-generating assets or holding bilateral contracts with generators, also has experienced significant growth in its sourcing of renewables in recent years. Several major companies involved in energy-intensive manufacturing have signed long-term renewable energy PPAs; in 2017, among the largest industry off-takers were aluminium manufacturer Norsk Hydro (Norway), cement maker and building company Cemex (Mexico) and automobile manufacturer General Motors (United States). Norsk Hydro contracted 483 MW of wind energy PPAs in 2017, out of a total of 744 MW of such PPAs signed by the company since early 2016.[35] Cemex, which had contracted more than 500 MW of PPAs to power its operations in 2009, has since become a renewable energy project developer supporting other corporations in their sourcing of renewables.[36] General Motors contracted 200 MW of wind energy PPAs in 2017 to power its manufacturing facilities.[37]

Signing a long-term renewable energy PPA not only reduces the energy supply risks and price volatility associated with fossil fuels, but can help corporations comply with environmental regulations, such as carbon pricing, that are relevant for heavy industry in a growing number of markets. Furthermore, renewable energy has been shown to be a cost-competitive way to meet the energy needs of mining companies, where on-site renewable power and heat installations provide reliable energy in remote, off-grid locations.[38]

POLICY FRAMEWORKS TO ENABLE CORPORATE SOURCING OF RENEWABLES

The options available for corporations to source renewable energy depend greatly on the markets and policy frameworks in which they operate, as well as on the nature of their operations and internal capacity. As with any form of renewable energy deployment, corporate sourcing of renewables can reach its full potential when it has government backing through the establishment of long-term, stable and predictable policy frameworks. Although some corporate sourcing options, such as corporate PPAs, thrive in less-regulated markets, an enabling policy framework can advance most corporate sourcing options, whether in vertically integrated or liberalised energy markets.

Barriers to corporate sourcing of renewable energy include a lack of clarity around, or absence of: a credible renewable energy attribute and certificate tracking scheme; grid access rules; third-party sales/access; renewable energy procurement options; and/or net metering possibilities. Several policy measures have addressed these barriers successfully.[39] *(→ See Table 4.)*

Regardless of the corporate sourcing option used, a transparent and credible attribute mechanism (for example, GOs in Europe and RECs in Australia, China, India, Mexico and the United States) can guarantee that a specific amount of energy originates from a certain source. More importantly, an attribute certificate scheme supported by a transparent tracking mechanism can ensure that certificates are being cancelled or retired properly and that there is only one final claim of usage.

Renewable energy attribute certificate tracking schemes can support the direct trade of unbundled certificates by corporations,

TABLE 4. Overview of Policy Measures That Support Various Corporate Sourcing Options

Corporate Sourcing Option	Policy Measures	Examples of Countries Using These Policies Nationally or Sub-nationally
Corporate PPAs	▪ Allow third-party sales (bilateral trade/sales) directly between corporate buyers and IPPs ▪ Provide clear and transparent grid-access rules and "wheeling" arrangements that permit both on-site and off-site PPAs ▪ Provide transparent and credible tracking of renewable energy attribute certificates	Argentina, Brazil, Chile, Mexico, Netherlands, Norway, Sweden, United Kingdom, United States
Utility green procurement	▪ Support market-based renewable energy pricing ▪ Support tailored long-term renewable energy contracts for large-scale corporations (e.g., the creation of green tariff programmes) ▪ Provide transparent and credible tracking of renewable energy attribute certificates	Netherlands, United States
Direct investment for self-consumption	▪ Provide clear and stable mechanism for on-site and off-site systems to feed excess electricity to the grid (e.g., net metering scheme) – preferably with priority dispatch for renewable energy ▪ Provide a wheeling mechanism that allows for the transport of electricity from off-site generation to the place of consumption ▪ Provide transparent and credible tracking of renewable energy attribute certificates	China, India, Japan, United Kingdom
Unbundled renewable electricity certificates (RECs/GOs)	▪ Provide transparent and credible tracking of renewable energy attribute certificates ▪ Allow for corporations to buy electricity certificates directly	GOs in Europe; RECs in Australia, China, India, Mexico, United States

Note: "Wheeling" refers to the transfer of electric energy through transmission and distribution lines from one utility's service area to another's.

Source: IRENA. See endnote 39 for this chapter.

as well as the corporate PPA market, utility green procurement and direct investment for self-consumption. For corporations to make a renewable energy claim, they need clear ownership of the renewable energy attribute certificates that are generated under each contract arrangement or under particular policy incentive programmes, such as feed-in tariffs.[40]

An independent issuing body – ranging from a government agency to a private actor, depending on the market – generally is responsible for issuing, tracking and verifying credible attribute certificates. As of end-2017, certificate markets were in place mainly in North America and Europe; however, some countries in Asia and Latin America have established or are considering establishing electricity certificate schemes.[41] For example, China launched a national REC market in July 2017, following policy reforms in its power sector, and Clean Energy Certificates are to be traded in Mexico from 2018 onwards.[42]

CAPACITY BUILDING THROUGH KNOWLEDGE SHARING

For most corporations, electricity generation and/or complex power sourcing options are not part of their core business. Signing a long-term PPA or investing directly in a renewable energy system requires expertise that many companies do not have. In response to rising corporate interest in renewable energy sourcing, several initiatives have been established to recognise and further support the development and pursuit of ambitious renewable energy goals through various sourcing options.

The RE100 campaign, under The Climate Group and CDP, gathers some of the world's most influential businesses that are committed to sourcing 100% renewable electricity. Through events and webinars, the initiative seeks to support members in reaching their targets and going beyond them by also engaging their supply chains.[43]

Another successful initiative is the Renewable Energy Buyers Alliance, which brings together buyers, suppliers and policy makers to identify and remove barriers related to purchasing renewable energy. First established in the United States by Business for Social Responsibility, the Rocky Mountain Institute, the World Resources Institute and the World Wildlife Fund, the network is now active in Australia, China, India, Mexico and Vietnam.[44] A similar network, the RE-Source Platform, focuses on the European market (at both the EU and national levels) and was launched in 2017 by SolarPower Europe, WindEurope, RE100 and the World Business Council for Sustainable Development.[45]

To scale up corporate sourcing efforts globally, the Corporate Sourcing of Renewables campaign was launched in May 2016 at the Seventh Clean Energy Ministerial (CEM).[46] The campaign is a collaborative effort among CEM countries and several global organisations and initiatives to enable knowledge exchange and to incentivise new corporate renewable energy commitments and implementation.[47]

TABLE R1. Global Renewable Energy Capacity and Biofuel Production, 2017

	Added During 2017	Existing at End-2017
Power Capacity (GW)		
Bio-power	8.1	122
Geothermal power	0.7	12.8
Hydropower	19	1,114
Ocean power	~0	0.5
Solar PV	98	402
Concentrating solar thermal power (CSP)	0.1	4.9
Wind power	52	539
Thermal Capacity (GW_{th})		
Modern bio-heat	3	314
Geothermal direct use[1]	1.4	25
Solar collectors for water heating[2]	35	472
Transport Fuels Production (billion litres per year)		
Ethanol	2.9	106
FAME Biodiesel	0.1	31
HVO	0.6	6.5

[1] Data do not include heat pumps.

[2] Data do not include air 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 first decimal point; 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 2016 capacity data (particularly for bio-power and hydropower). Solar PV data are provided in direct current (DC); for hydropower, the GSR strives to exclude pure pumped storage capacity from hydropower capacity data. For more precise data, see Reference Tables R15-R21, Market and Industry chapter and related endnotes. FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil

Source: See endnote 1 for this section.

TABLE R2. Renewable Power Capacity, World and Top Regions/Countries[1], 2017

Technology	World Total	BRICS[2]	EU-28	China	United States	Germany	India	Japan	United Kingdom
		GW				GW			
Bio-power	122	40	40	14.9	16.7	8	9.5	3.6	6
Geothermal power	12.8	0.1	0.8	~0	2.5	~0	0	0.5	0
Hydropower	1,114	507	124	313	80	5.6	45	23	1.9
Ocean power	0.5	~0	0.2	~0	~0	0	0	0	~0
Solar PV[3]	402	152	108	131	51	42	18.3	49	12.7
Concentrating solar thermal power (CSP)	4.9	0.5	2.3	~0	1.7	~0	0.2	0	0
Wind power	539	236	169	188	89	56	33	3.4	18.9
Total renewable power capacity (including hydropower)	**2,195**	**936**	**443**	**647**	**241**	**112**	**106**	**79**	**39**
Total renewable power capacity (not including hydropower)	**1,081**	**429**	**320**	**334**	**161**	**107**	**61**	**57**	**38**
Per capita capacity (kilowatts per inhabitant, not including hydropower)	0.1	0.1	0.6	0.2	0.5	1.3	0.05	0.4	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, Germany, India 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 Methodological Notes for more information.

Note: Global total reflects additional countries not shown. Numbers are based on the best data available at the time of production. To account for uncertainties and inconsistencies in available data, numbers are rounded to the nearest 1 GW, with the exception of the following: capacity totals below 20 GW and per capita totals are rounded to the nearest decimal point (except for India, which is rounded to the nearest 0.01 kW). 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 Market and Industry chapter 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, Share of Primary or Final Energy and Progress, End-2015

Note: Text in **bold** indicates new/revised in 2017, 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%	→ 20% by 2020
Afghanistan			18%	→ 10% (no date given)
Albania	34.4%	→ 18% by 2020[1]	39%	→ 38% by 2020
Algeria			0.1%	→ 37% by 2030 [40% by 2030]
Armenia	12.4%	→ 21% by 2020 → 26% by 2025	15.8%	
Austria[2]	30.1% (2016)		34%	→ 45% by 2020
Azerbaijan	1.8%		2.3%	
Bangladesh	24.8%		34.8%	→ 10% by 2020[1]
Belarus	5.5%		6.8%	→ 32% by 2020
Belgium	6.7% (2016)	→ 9.7% by 2020	9%	→ 13% by 2020
Wallonia				→ *20% by 2020*
Benin	59.6%		50.9%	→ 25% by 2025[1]
Bosnia and Herzegovina	24.9%		40.8%	→ 40% by 2020
Brazil	40.3%		43.8%	→ 45% by 2030
Bulgaria	10.7%		17.7%	→ 16% by 2020
Burundi			96%	→ 2.1% by 2020[1]
China[3]	8.4%	→ 15% by 2020 → 20% by 2030	12.4%	
Côte d'Ivoire	3% (2016)	→ 15% by 2020 → 20% by 2030	64.5%	
Croatia	23.3%		33%	→ 20% by 2020
Cyprus	7.3%		9.9%	→ 13% by 2020
Czech Republic[2]	10.5% (2016)		15%	→ 13.5% by 2020
Denmark	30% (2016)		33%	→ 35% by 2020 → 100% by 2050
Djibouti		→ 17% by 2035	15.4%	
Egypt	3.8%	→ 14% by 2020	5.7%	
Estonia	17.6% (2016)		27.5%	→ 25% by 2020
Fiji			31.3%	→ 23% by 2030
Finland	31.2% (2016)		43.2%	→ 38% by 2020[1] → 40% by 2025[1]
France	9.6% (2016)		14%	→ 23% by 2020 → 32% by 2030
Gabon	76.7%		82%	→ 80% by 2020
Germany[2]	12.7% (2016)		14%	→ 18% by 2020 → 30% by 2030 → 45% by 2040 → 60% by 2050
Ghana	42.5%		41.4%	→ Increase by 10% by 2030 (base year 2010)
Greece[2]	12.1% (2016)		17%	→ 20% by 2020
Grenada		→ 20% by 2020	10.9%	
Guatemala	63%		63.7%	→ 80% by 2026

TABLE R3. Renewable Energy Targets, Share of Primary or Final Energy and Progress, End-2015 (continued)

Note: Text in **bold** indicates new/revised in 2017, 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
Guinea			76.3%	→ 30% by 2030
Guyana			25.3%	→ 20% by 2025
Hungary[2]	11.5% (2016)		16%	→ 14.65% by 2020
Iceland	89.5% (2016)		77%	→ 64% by 2020
Indonesia	6% (2016)	**→ 23% by 2025** **→ 31% by 2050**	36.9%	
Ireland	7.9% (2016)		9.1%	→ 16% by 2020
Israel	2.4% (2016)		3.7%	→ 13% by 2025 → 17% by 2030 [10% by 2020]
Italy	17.4% (2016)		17%	→ 17% by 2020
Jamaica	18.6%		16.8%	→ 20% by 2030
Japan	4.8% (2016)	→ 14% by 2030	6.3%	
Jordan	2.1%	→ 10% by 2020	2.8%	→ 11% by 2025
Korea, Republic of	1.7% (2016)	→ 6.1% by 2020 → 11% by 2030	2.7%	
Kosovo[4]			20.5%	→ 25% by 2020
Lao PDR			59.3%	→ 30% by 2025[1]
Latvia	39.1% (2016)		38%	→ 40% by 2020
Lebanon			3.7%	→ 15% by 2030 [12% by 2020]
Liberia	5% (2016)	→ 30% by 2030		→ 10% by 2030
Libya		→ 10% by 2020	2%	
Lithuania	19.6%	→ 20% by 2025	29%	→ 23% by 2020
Luxembourg	5.6% (2016)		9%	→ 11% by 2020
Macedonia, FYR	15.7%		24%	→ 28% by 2020
Madagascar			70.2%	→ 54% by 2020[1]
Malawi		→ 7% by 2020	83.7%	
Mali		→ 15% by 2020	61.5%	
Malta	3.2%		5%	→ 10% by 2020
Mauritania		→ 20% by 2020	32.2%	
Moldova	10.3%	→ 20% by 2020	14.3%	→ 17% by 2020
Mongolia	3.2%	→ 20–25% by 2020	3.4%	
Montenegro	30.6%		43%	→ 33% by 2020[1]
Nepal	84.1%	→ 10% by 2030[1]	85.3%	
Netherlands[2]	4.9% (2016)		6%	→ 14% by 2020
Niger	74.7%	→ 10% by 2020[1]	78.9%	
Norway	49.2% (2016)		58%	→ 67.5% by 2020
Palau		→ 20% by 2020	0%	
Palestine, State of				→ 25% by 2020
Panama	21.1%	→ 30% by 2050	21.2%	
Poland	8.5% (2016)	→ 12% by 2020	12%	→ 15.5% by 2020
Portugal	24.3% (2016)		27%	→ 40% by 2030 → 31% by 2020
Romania	18.7%		24%	→ 24% by 2020

TABLE R3. Renewable Energy Targets, Share of Primary or Final Energy and Progress, End-2015 (continued)

Note: Text in **bold** indicates new/revised in 2017, 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
Samoa		→ 20% by 2030	34.3%	
Serbia	13.1%		21.2%	→ 27% by 2020
Slovak Republic	9.7% (2016)		13%	→ 14% by 2020
Slovenia	16.8% (2016)		21%	→ 25% by 2020
Spain[2]	14.6% (2016)		16%	→ 20.8% by 2020
St. Lucia		→ 20% by 2020	2.1%	
Sweden[2]	37% (2016)	→ 100% by 2040	53%	→ 50% by 2020
Switzerland	22.3% (2016)	→ 24% by 2020	25.3%	
Syria	0.4%	→ 4.3% by 2030	0.5%	
Thailand	19.2%		22.9%	→ 30% by 2036 → 25% by 2021
Togo	78.9%		71.3%	→ 4% (no date)[1]
Ukraine	3%	→ 18% by 2030	4.1%	→ 11% by 2020 → **25% by 2035**
United Arab Emirates	0.2%		0.1%	→ 24% by 2021
United Kingdom	8.2%		8.7%	→ 15% by 2020
Uzbekistan	2.4%		3%	→ 16% by 2030 → 19% by 2050
Vanuatu			36.1%	→ 65% by 2020
Vietnam	27.6%	→ 5% by 2020 → 8% by 2025 → 11% by 2050	35%	

[1] Targets may exclude large-scale hydropower and/or traditional biomass. The definition of large-scale hydropower 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: Historical targets have been added as they are identified by REN21. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable energy for the country. Some countries shown have other types of targets (see Reference Tables R4-R10).

Source: See endnote 3 for this section.

TABLE R4. Renewable Energy Targets, Technology-Specific Share of Primary or Final Energy

Country	Technology	Target
Indonesia	Hydropower, solar PV, wind power	1.4% share in primary energy (combined) by 2025
	Biofuels	10.2% biofuel share of primary energy by 2025
Spain	Bioenergy from solid biomass, biogas and organic MSW[1]	5.8% of final energy by 2020
	Liquid biofuels	2.7% of final energy by 2020
	Hydropower	2.9% of final energy by 2020

[1] It is not always possible to determine whether data for municipal solid waste (MSW) include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

Source: See endnote 4 for this section.

TABLE R5. Renewable Heating and Cooling Targets and Progress, End-2016

Country	Progress 2016	Target
Austria	33%	32.6% by 2020
Belgium	8.1%	11.9% by 2020
Bhutan		Solar thermal: 3 MW equivalent by 2025
Bulgaria	30%	24% renewables in total heating and cooling by 2020
China	462.9 million m^2	Solar thermal: 800 million m^2 by 2020
Croatia	38%	19.6% by 2020
Cyprus	23%	23.5% by 2020
Czech Republic	20%	14.1% by 2020
Denmark	42%	39.8% by 2020
Estonia	51%	38% by 2020
Finland	54%	47% by 2020
France	21%	38% by 2030
Germany	13%	14% by 2020
Greece	25%	20% by 2020
Hungary	21%	18.9% by 2020
India	6.7 GW_{th}	Solar water heating: 5.6 GW_{th} (8 million m^2) of new capacity to be added 2012-2017; achieve 14 GW_{th} (20 million m^2) by 2022
Ireland	6.8%	15% by 2020
Italy	19% (2015)	17.1% by 2020
	6,320 ktoe (2015)	Bioenergy: 5,670 ktoe for heating and cooling by 2020
	207 ktoe	Geothermal: 300 ktoe for heating and cooling by 2020
	231.3 ktoe	Solar water and space heating: 1,586 ktoe by 2020
Jordan	0.882 GW_{th} (2015)	Solar water heating: systems for 30% of households by 2020
Kenya		Solar water heating: 60% of annual demand for buildings that use over 100 litres of hot water per day (no date)
Kosovo[1]		45.65% by 2020
Latvia	52%	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	47%	39% by 2020
Luxembourg	7.3%	8.5% renewables in gross final consumption in heating and cooling by 2020
Macedonia, FYR	32%	11% by 2020
Malawi		Solar water heating: produce 2,000 solar water heaters; increase total installed to 20,000 by 2030
Malta	15%	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
Montenegro	69%	38.2% by 2020
Morocco	0.316 GW_{th} (2015)	Solar water heating: 1.2 GW_{th} (1.7 million m^2) by 2020
Mozambique	0.001 GW_{th} (2015)	Solar water and space heating: 100,000 systems installed in rural areas (no date)
Netherlands	5.5%	8.7% by 2020
Poland	15%	17% by 2020
Portugal	35%	30.6% by 2020
Romania	27%	22% by 2020

TABLE R5. Renewable Heating and Cooling Targets and Progress, End-2016 (continued)

Country	Progress 2016	Target
Serbia	24%	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	9.9%	14.6% by 2020
Slovenia	34%	30.8% by 2020
Spain	17% (2015)	18.9% by 2020
		Bioenergy: 4,653 ktoe by 2020
	8.2 ktoe	Geothermal: 9.5 ktoe by 2020
	352.9 ktoe (2015)	Heat pumps: 50.8 ktoe by 2020
	224 ktoe	Solar water and space heating: 644 ktoe 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	Solar water heating: 300,000 systems in operation and 100 ktoe by 2022
Uganda		Solar water heating: 21 MW_{th} (30,000 m^2) by 2017
Ukraine		12.4% by 2020
United Kingdom	7%	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. 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 heat for the country. Table R5 includes targets established under EU National Renewable Energy Action Plans. 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.

Source: See endnote 5 for this section.

TABLE R6. Renewable Transport Targets and Progress, End-2016

Note: Text in **bold** indicates new/revised in 2017, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Share	Target
EU-28	7.1%	10% of EU-wide transport final energy demand by 2020
Albania	0%	→ 10% by 2020
Austria	11%	→ 11.4% by 2020
Belgium	5.9%	→ 10% by 2020
Wallonia		→ *10.14% by 2020*
Bulgaria	7.3%	→ 11% by 2020
Croatia	1.3%	→ 10% by 2020
Cyprus	2.7%	→ 10% by 2020
Czech Republic	6.4%	→ 10.8% by 2020
Denmark	6.8%	→ 10% by 2020
Estonia	0.4%	→ 10% by 2020
Finland	8%	→ 30% biofuel blending and 40% renewable transport fuel use by 2030
France	8.9%	→ 15% by 2020
Germany	5.2%	→ 10% by 2020
Greece	1.4%	→ 10.1% by 2020
Hungary	7.4%	→ 10% by 2020
Iceland	7.2%	→ 10% by 2020
Ireland	5.0%	→ 10% by 2020
Italy	7.2%	→ 10.1% (2,899 ktoe) by 2020
Latvia	2.8%	→ 10% by 2020
Liberia		→ 5% palm oil blends in transport fuel by 2030
Lithuania	3.6%	→ 10% by 2020
Luxembourg	5.9%	→ 10% by 2020
Malta	5.4%	→ 10.7% by 2020
Macedonia, FYR	0.1%	→ 2% by 2020
Moldova		→ 20% by 2020
Montenegro	1.1%	→ 10.2% by 2020
Netherlands	4.6%	→ 10% by 2020
Norway	17%	→ 20% by 2020
Poland	3.9%	→ 20% by 2020
Portugal	7.5%	→ 10% by 2020
Qatar		→ 10% by 2020
Romania	6.2%	→ 10% by 2020
Serbia	1.2%	→ 10% by 2020
Slovak Republic	7.5%	→ 10% by 2020
Slovenia	1.6%	→ 10.5% by 2020
Spain	5.3%	→ 11.3% from biodiesel by 2020 → 2,313 ktoe ethanol/ bio-ETBE[1] by 2020 → 4.7 GWh per year electricity in transport by 2020 (501 ktoe from renewable sources by 2020)
Sri Lanka		→ 20% from biofuels by 2020
Sweden	30%	→ 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
Uganda		→ 2,200 million litres per year biofuels consumption by 2017
Ukraine		→ 10% by 2020
United Kingdom	4.9%	→ 10.3% by 2020
Vietnam		→ 5% of transport petroleum energy demand by 2025

[1] ETBE is a form of biofuel produced from ethanol and isobutylene.

Note: Targets refer to share of renewable transport in total energy supply unless otherwise noted. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2017. 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.

Source: See endnote 6 for this section.

TABLE R7. Renewable Transport Mandates at the National/State/Provincial Levels, End-2017

Note: Text in **bold** indicates new/revised in 2017, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Biofuel Blend Mandates			Other Transport Mandates
	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Biofuel Mandate by Future Year	
Angola		10%		
Argentina	10%	**12%** [10%]		
Australia				
New South Wales	*2%*	*7%*		
Queensland	*0.5%*	***3%***	*E4 by July 2018 and B0.5*	
Belgium	4%	4%		
Brazil	**8%**	27%	**B9 by 2018 and B10 by 2019 (updated to B10 by early 2018)**	
Canada	2%	5%		
Alberta	*2%*	*5%*		
British Columbia	*4%*	*5%*		
Manitoba	*2%*	*8.5%*		
Ontario	*4%*	*5%*		
Saskatchewan	*2%*	*7.5%*		
China[1]		10%		
Taipei	1%			
Colombia	10%	8%		
Costa Rica	20%	7%		
Denmark			**0.9% advanced biofuels from waste materials by 2020**	
Ecuador	5%	10%		
Ethiopia		10%		
France				**Sales of all diesel and petrol cars and vans banned by 2040**
Guatemala		5%		
India	15%	22.5%		
Indonesia	20%	3%		
Italy			0.6% advanced biofuels blend by 2018; 1% by 2022	
Jamaica		10%		
Korea, Republic of	2.5%		B3 by 2018	
Malawi		10%		
Malaysia	10%	10%		
Mexico[2]		**10%** [5.8%]		
Mozambique		15%	E20 from 2021	
New Zealand	7%			**Maximum methanol blend of 3%**
Norway	3.5%		E20 by 2020	
Panama		10%		30% of new vehicle purchases for public fleets to be flex-fuel (no date)
Paraguay	1%	25%		
Peru	2%	7.8%		
Philippines	2%	10%		

TABLE R7. Renewable Transport Mandates at the National/State/Provincial Levels, End-2017 (continued)

Note: Text in **bold** indicates new/revised in 2017, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Biofuel Blend Mandates			Other Transport Mandates
	Existing Biodiesel Blend Mandate (% Biodiesel)	Existing Ethanol Blend Mandate (% Ethanol)	Biofuel Mandate by Future Year	
Romania		**8%** [4.5]		
Slovenia				**100% of heavy-duty trucks to run on biodiesel and 12% of vans and trucks to be electric by 2030**
South Africa	5%	2%		
Sudan		5%		
Thailand	7%	5%		
Turkey		2%		
Ukraine		7%		
United Kingdom				**Sales of all diesel and petrol cars and vans banned by 2040**
Scotland				***Sales of all diesel and petrol cars and vans banned by 2040***
United States				Renewable Fuel Standard (RFS) 2018 standards: 68.6 billion litres total renewable fuels, including 1.1 million 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%*	*10%*	***B20 as of May 2019***	
New Mexico	*5%*			
Oregon	*5%*	*10%*		
Pennsylvania			*E10 one year after 1.3 billion litres (350 million gallons) produced; B5 one year after 379 million litres (100 million gallons) produced, B10 one year after 757 million litres (200 millon gallons) produced, and B20 one year after 1.5 billion litres (400 million gallons) 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		**10%** [5%]		

[1] E10 mandates exist in nine Chinese provinces, including Anhui, Heilongjian, Henan, Jilin and Liaoning.
[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. Chile has targets of E5 and B5 but has no current blending mandate. The Dominican Republic has targets of B2 and E15 for 2015 but has no current blending mandate. Fiji approved voluntary B5 and E10 blending in 2011 with a mandate expected. The Kenyan city of Kisumu has an E10 mandate. Table R7 lists only transport mandates; transport and biofuel targets can be found in Table R6.

Source: See endnote 7 for this section.

TABLE R8. Renewable Power Targets, Share of Electricity Generation and Progress, End-2016

Note: Text in **bold** indicates new/revised in 2017, 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	Current Share	Target
EU-28	29.6%	
Afghanistan[1]		→ 100% by 2050
Algeria		→ 27% by 2030
Antigua and Barbuda		→ 5% by 2015 → 10% by 2020 → 15% by 2030
Argentina		→ 8% by 2018 → 9% by 2019 → 16% by 2021 → 18% by 2023 → 20% by 2025
Armenia	12%	→ 40% by 2025
Aruba		→ 100% by 2020
Australia		→ 23% by 2020
South Australia		*→ 50% by 2020*
Tasmania		*→ 100% by 2020*
Victoria		*→ 20% by 2020* *→ 40% by 2025*
Austria	73%	→ 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	16%	→ 20.9% by 2020
Belize	91%	→ 85% by 2017
Bhutan[1]		→ 100% by 2050
Bolivia		→ 79% by 2030
Brazil[2]		→ 23% by 2030
Brunei Darussalam		→ 10% by 2035
Bulgaria	19%	→ 20.6% by 2020
Burkina Faso[1]		→ 50% by 2025 → 100% by 2050
Cabo Verde		**→ 100% by 2025** → [100% by 2035] → [50% by 2020]
Cambodia[1]		→ 25% by 2035 → 100% by 2050
Cameroon		→ 25% by 2035
Canada[3]		→ No national target
Alberta		*→ 30% by 2030*
British Columbia		*→ 93% (no date given)*
New Brunswick		*→ 40% by 2020*
Nova Scotia		*→ 25% by 2015* *→ 40% by 2020*
Saskatchewan		*→ 50% by 2030*
Chile	16.0%	→ 20% by 2025
China		→ 27% by 2020
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[1]		→ 100% by 2050
Congo, Republic of		→ 85% by 2025
Costa Rica	98%	→ 100% by 2030
Côte d'Ivoire		→ 42% by 2020
Croatia	47%	→ 39% by 2020
Cuba	4%	→ 24% by 2030
Cyprus	8.6%	→ 16% by 2020
Czech Republic	13.6%	→ 14.3% by 2020
Denmark[4]	54%	→ 50% by 2020 → 100% by 2050
Djibouti		→ 35% by 2035
Dominica		→ 100% (no date)
Dominican Republic[1]	12%	→ 25% by 2025 → 100% by 2050
Ecuador		→ 90% by 2017 → [85% by 2017]
Egypt		→ 20% by 2022 → [20% by 2020]
Eritrea		→ 70% by 2030 → [50% (no date)]
Estonia	16%	→ 17.6% by 2020
Ethiopia[1]		→ 100% by 2050
Fiji		→ 100% by 2030
Finland	33%	→ 33% by 2020
France	19%	→ 40% by 2030 → 27% by 2020
Gabon		→ 80% by 2025 → 70% by 2020
Gambia[1]		→ 35% by 2020 → 100% by 2050
Germany	32%	→ 40–45% by 2025 → 55–60% by 2035 → 80% by 2050
Ghana[1]		→ 10% by 2020 → 100% by 2050
Greece	24%	→ 40% by 2020
Grenada[1]		→ 100% by 2050
Guatemala[1]	59%	→ 80% by 2030 → 100% by 2050
Guinea-Bissau		→ 2% by 2015
Guyana		→ 90% (no date)
Haiti[1]		→ 47% by 2030 → 100% by 2050
Honduras[1]	50%	→ 60% by 2022 → 80% by 2038 → 100% by 2050
Hungary	7.2%	→ 10.9% by 2020
India[5]		→ 40% by 2030
Indonesia		→ 26% by 2025
Iraq		→ 10% by 2030
Ireland	27%	→ 42.5% by 2020
Israel		→ 17% by 2030 → 10% by 2020
Italy	34%	→ 26% by 2020
Jamaica		→ 20% by 2030

■ TABLE R8. Renewable Power Targets, Share of Electricity Generation and Progress, End-2016 (continued)

Note: Text in **bold** indicates new/revised in 2017, 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	Current Share	Target
Japan		→ 22–24% by 2030
Jordan		→ 15% by 2015
Kazakhstan		→ 3% by 2020 → 50% by 2030
Kenya[1]		→ 100% by 2050
Kiribati[1]		→ 3% by 2020 → 100% by 2050
Korea, Republic of		→ 5% by 2018 → 6% by 2019 → 7% by 2020 → **20% by 2030**
Kuwait		→ 10% (no date)
Latvia	51%	→ 60% by 2020
Lebanon[1]		→ 12% by 2020 → 100% by 2050
Liberia		→ 30% by 2021
Libya		→ 7% by 2020 → 10% by 2025
Lithuania	17%	→ 21% by 2020
Luxembourg	6.7%	→ 11.8% by 2020
Macedonia, FYR	24%	→ 24.7% by 2020
Madagascar[1]		→ 79% (no date) → 100% by 2050
Malawi[1]		→ 100% by 2050
Malaysia		→ 9% by 2020 → 11% by 2030 → 15% by 2050
Maldives[1]		→ 16% by 2017 → 100% by 2050
Mali[6]		→ 10% by 2015 → 25% by 2033
Malta	5.6%	→ 3.8% by 2020
Marshall Islands[1]		→ 20% by 2020 → 100% by 2050
Mauritius		→ 35% by 2025
Mexico		→ 35% by 2024 → 37.7% by 2030 → 50% by 2050
Moldova		→ 10% by 2020
Montenegro	51%	→ 51.4% by 2020
Mongolia[1]		→ 20% by 2020 → 30% by 2030 → 100% by 2050
Morocco[1]		→ 52% by 2030 → [52% by 2039] → 100% by 2050
Namibia		→ 70% by 2030
Nepal[1]		→ 100% by 2050
Netherlands	13%	→ 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		→ 60% by 2025
Philippines[1]		→ 40% by 2020 → 100% by 2050
Poland	13%	→ 19.3% by 2020
Portugal	54%	→ 60% by 2020
Qatar		→ 2% by 2020 → 20% by 2030
Romania	43%	→ 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]		→ 20% by 2017 → 100% by 2050
Serbia	29%	→ 37% by 2020
Seychelles		→ 5% by 2020 → 15% by 2030
Sierra Leone		→ 33% by 2020 → 36% by 2030
Singapore		→ 8% (no date)
Slovak Republic	23%	→ 24% by 2020
Slovenia	32%	→ 39.3% by 2020
Solomon Islands		→ 100% by 2030
South Africa		→ 9% by 2030
South Sudan[1]		→ 100% by 2050
Spain	37%	→ 38.1% 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%	→ 62.9% by 2020
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
Tunisia[1]		→ 30% by 2030 → 100% by 2050

TABLE R8. Renewable Power Targets, Share of Electricity Generation and Progress, End-2016 (continued)

Note: Text in **bold** indicates new/revised in 2017, 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	Current Share	Target
Turkey		→ 30% by 2023
Tuvalu		→ 100% by 2020
Uganda		→ 61% by 2017
Ukraine		→ 11% by 2020 → 20% by 2030 → **25% by 2035**
United Arab Emirates		→ No national target
Abu Dhabi		→ *7% by 2020*
Dubai		→ *7% by 2020* → *15% by 2030*
United Kingdom	25%	→ No national target
Scotland		→ *100% by 2020*
United States[10]		→ No national target
Arizona		→ *15% by 2025*
California		→ *33% by 2020* → *50% by 2030*
Colorado		→ *30% by 2020 (IOUs)*
Connecticut		→ *27% by 2020*
Delaware		→ *25% by 2026*
Hawaii		→ *100% by 2045* → *25% by 2020* → *40% by 2030*
Illinois		→ *25% by 2026*
Maine		→ *40% by 2017*
Maine		→ *40% by 2017*
Maryland		→ *25% by 2020 [20% by 2020]*
Massachusetts		→ *15% by 2020 and an additional 1% each year thereafter*
Michigan		→ *15% by 2021 [10% by 2015]*
Minnesota		→ *26.5% by 2025 (IOUs)*[11] → *31.5% by 2020 (Xcel) [25% by 2025 (other utilities)]*
Missouri		→ *15% by 2021*
Nevada		→ *25% by 2025*

Country	Current Share	Target
New Hampshire		→ *24.8% by 2025*
New Jersey		→ *20.38% by 2020 and 4.1% solar by 2027*
New Mexico		→ *20% by 2020 (IOUs)*[11] → *10% by 2020 (co-ops)*[12]
New York		→ *50% by 2030*
North Carolina		→ *12.5% by 2021 (IOUs)* → *10% by 2018 (co-ops)*[12]
Ohio		→ *12.5% by 2026 [25% by 2024]*
Oregon		→ *50% by 2040 [25% by 2025 (utilities with 3% or more of state's load); 10% by 2025 (utilities with 1.5-3% of state's load); 5% by 2025 (utilities with less than 1.5% of state's load)]*
Pennsylvania		→ *18% by 2021*
Rhode Island		→ *38.5% by 2035 [16% by 2019]*
Vermont		→ *55% by 2017, increasing by 4% every three years until reaching 75% by 2032*
Washington		→ *15% by 2020*
District of Columbia		→ *50% by 2032*
Puerto Rico		→ *20% by 2035*
U.S. Virgin Islands		→ *30% by 2025*
Uzbekistan	**12.6%**	→ **19.7% by 2025**
Vanuatu		→ *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 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. A number of state/provincial and local jurisdictions have additional targets not listed here. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2017. 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 8 for this section.

TABLE R9. Renewable Power Targets, Technology-Specific Share of Electricity Generation

Note: Text in **bold** indicates new/revised in 2017 and brackets '[]' indicate previous targets where new targets were enacted.

Country	Technology	Target
Benin	Electricity (off-grid and rural)	50% by 2025
Denmark	Wind power	50% by 2020
Djibouti	Solar PV (off-grid and rural)	30% by 2017
Dominican Republic	Distributed power	20% by 2016
Egypt	Wind power	12% and 7.2 GW 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]		
Andhra Pradesh	*Solar power*	*0.25% by 2016–17*
Bihar	*Solar power*	*1.25% by 2016–17; 1.5% by 2017–18; 1.75% by 2018–19; 2% by 2019–20; 2.5% by 2020–21; 3% by 2012–22*
Delhi	*Solar power*	*0.35% by 2016–17*
Himachal Pradesh	*Solar power*	*0.25% by 2016–17; 0.5% by 2017–18; 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*
West Bengal	*Solar power*	*0.5% by 2016–17; 0.6% by 2017–18*
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
Latvia	Bio-power from solid biomass	8% by 2016
Lesotho	Electricity	35% of off-grid and rural electrification by 2020
Micronesia	Electricity	10% in urban centres and 50% in rural areas by 2020
Trinidad and Tobago	Electricity	5% of peak demand (or 60 MW) by 2020

[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 state/provincial and local jurisdictions have additional targets not listed here. Some countries shown have other types of targets ***(→ Tables R3, R4, R5, R6, R8, R10)***. See Policy Landscape chapter and Table R14 for more information about sub-national and municipal-level targets, and see Tables R22 and R24 for information on electricity access. Existing shares are indicative and may need adjusting if more accurate national statistical data are published.

Source: See endnote 9 for this section.

TABLE R10. Renewable Power Targets for Specific Amount of Installed Capacity or Generation

Note: Text in **bold** indicates new/revised in 2017, 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
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
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 renewable energy capacity 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	19.3 GW by 2021
	Hydropower (small-scale)	7.8 GW by 2021
	Wind power	19.5 GW by 2021
Bulgaria	Hydropower	Three 174 MW plants commissioned by 2017-2018
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*
Prince Edward Island	*Wind power*	*30 MW increase by 2030 (base year 2011)*

TABLE R10. Renewable Power Targets for Specific Amount of Installed Capacity or Generation (continued)

Note: Text in **bold** indicates new/revised in 2017, 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
China	Electricity	680 GW non-fossil fuel generation capacity by 2020
	Hydropower	340 GW by 2020
	Solar power	110 GW by 2020
	Wind power	210 GW by 2020
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*
Cuba	Electricity	2.1 GW biomass, wind, solar and hydropower capacity by 2030
Egypt	Hydropower	2.8 GW by 2020
	Solar PV	300 MW small-scale (<500 kW) solar PV systems installed 2015-2017; 2 GW medium and large-size solar PV (max. 50 MW) installed 2015-2017 [220 MW by 2020; 700 MW by 2027]
	CSP	1.1 GW by 2020; 2.8 GW by 2030
	Wind power	2 GW installed 2015-2017 7.2 GW by 2020
Ethiopia	Bio-power from bagasse	103.5 MW (no date)
	Geothermal power	450 MW by 2018; 1 GW by 2030
	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	25.8-26.05 GW by 2030
	Solar	10.2 GW by 2018 18.2-20.2 GW by 2023
	Wind power (onshore)	15 GW by 2018; 21.8-26 GW by 2023
	Wind power (offshore)	0.5 GW by 2018; 3 GW by 2023
Germany	Biomass	100 MW added per year
	Solar PV	2.5 GW added per year
	Wind power (onshore)	2.5 GW added per year
	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
Andhra Pradesh	*Solar PV*	*5,000 MW added 2015-2020*
Jharkhand	*Solar PV*	*2,650 MW installed by 2019-2020*

■ TABLE R10. Renewable Power Targets for Specific Amount of Installed Capacity or Generation (continued)

Note: Text in **bold** indicates new/revised in 2017, 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
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
Iraq	Solar PV	240 MW by 2016
	CSP	80 MW by 2016
	Wind power	80 MW by 2016
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	23 GW by 2017
	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 (2.9% of total generation) by 2015; 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	900 MW by 2016; 1.5 GW by 2019; 16,619 GWh per year by 2030
	Wind power (offshore)	2.5 GW by 2019
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 R10. Renewable Power Targets for Specific Amount of Installed Capacity or Generation (continued)

Note: Text in **bold** indicates new/revised in 2017, 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
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) 11% by 2020; 14% by 2030; 36% by 2050
	Solar power	1 GW capacity 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)
Nigeria	Bio-power	400 MW by 2025
	Hydropower (small-scale)[3]	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)	1 GW by 2020
Portugal	Electricity	15.8 GW by 2020
	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
	Concentrated solar photovoltaics (CPV)	50 MW by 2020
	Wind power (onshore)	5.3 GW by 2020
	Wind power (offshore)	27 MW by 2020

■ TABLE R10. Renewable Power Targets for Specific Amount of Installed Capacity or Generation (continued)

Note: Text in **bold** indicates new/revised in 2017, 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
Russian Federation[4]	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***
Rwanda	Electricity (off-grid)	5 MW by 2017
	Biogas power	300 MW by 2017
	Geothermal power	310 MW by 2017
	Hydropower	340 MW by 2017
Saudi Arabia	Electricity	9.5 GW by 2023; 54 GW by 2040
	Geothermal, bio-power (waste-to-energy)[5], wind power	13 GW combined by 2040
	Solar PV and CSP	41 GW by 2040 (25 GW CSP, 16 GW PV)
Serbia	Solar PV	150 MW by 2017
	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
Spain	Bio-power from solid biomass	1.4 GW by 2020
	Bio-power from organic MSW[5]	200 MW by 2020
	Bio-power from biogas	400 MW by 2020
	Geothermal power	50 MW by 2020
	Hydropower	13.9 GW by 2020
	Pumped storage[2]	8.8 GW by 2020
	Ocean power	100 MW by 2020
	Solar PV	7.3 GW by 2020
	CSP	4.8 GW by 2020
	Wind power (onshore)	35 GW by 2020
	Wind power (offshore)	750 MW by 2020
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
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

TABLE R10. Renewable Power Targets for Specific Amount of Installed Capacity or Generation (continued)

Note: Text in **bold** indicates new/revised in 2017, 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
Thailand	Bio-power from solid biomass	4.8 GW by 2021
	Bio-power from biogas	600 MW by 2021
	Bio-power from organic MSW[5]	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	1.7 GW by 2016; 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	1 GW (16% of capacity) by 2016; 4.6 GW (40% of capacity) by 2030
	Bio-power from solid biomass	40 MW by 2016; 300 MW by 2030
	Solar power	10 GW by 2030
	Wind power	16 GW by 2030
Turkey	Bio-power from solid biomass	1 GW by 2023
	Geothermal power	1 GW by 2023
	Hydropower	34 GW by 2023
	Solar PV	5 GW by 2023
	Wind power	20 GW by 2023
Uganda	Bio-power from organic MSW[5]	30 MW by 2017
	Geothermal power	45 MW by 2017
	Hydropower (large-scale)	1.2 GW by 2017
	Hydropower (mini- and micro-scale)	85 MW by 2017
	Solar PV (solar home systems)	700 kW by 2017
United Kingdom	Wind power (offshore)	39 GW by 2030
United States		No national target
Iowa	*Electricity*	*105 MW generating capacity for IOUs[6]*
Massachusetts	*Wind power (offshore)*	*1.6 GW by 2027*
Texas	*Electricity*	*5,880 MW*
Uzbekistan	**Solar PV**	**60.7 MW installed by 2018; 157.7 by 2019; 382.5 by 2020; 601.9 by 2021; 1.24 GW by 2025**
	Wind power	**102 MW installed by 2021; 302 MW installed by 2025**
Venezuela	Electricity	613 MW new capacity installed 2013-2019, including:
	Wind power	500 MW new capacity installed 2013-2019
Vietnam	Hydropower	21.6 GW by 2020; 24.6 GW by 2025; 27.8 GW by 2030
	Solar power	850 MW by 2020; 4 GW by 2025; 12 GW by 2030
	Wind power	800 MW by 2020; 2 GW by 2025; 6 GW by 2030
Yemen	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] Nigeria's target excludes hydropower plants >30 MW.
[4] The Russian Federation's targets exclude hydropower plants >25 MW.
[5] 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.
[6] 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, R4, R5, R6, R8, R9, R14).

Source: See endnote 10 for this section.

TABLE R11. Renewable Heating and Cooling Policies, 2017

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			
Italy		R/C/P			
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		
Tunisia	R/C		R/C		
United Kingdom					R/C/P
Ukraine			R		
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 11 for this section.

TABLE R12. Feed-in Electricity Policies, Cumulative Number of Countries/States/Provinces and 2017 Revisions

Note: Text in **bold** indicates new/revised in 2017, and text with a ~~strikethrough~~ indicates discontinuation.

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); Taipei (China); 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); 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)**
Total Existing[3]	**113**	

2017 FIT Policy Adjustments	
Canada – Ontario	*Awarded FIT support to solar PV (totalling 147.9 MW), biogas (1.6 MW) and landfill gas projects (0.5 MW)*
China	Regional reductions of 12–15% for solar PV FIT; Class 1 resources reduced to CNY 0.55 per kWh; Class 2 reduced to CNY 0.65 per kWh; Class 3 reduced to CNY 0.75 per kWh; solar distributed generation FIT reduced CNY 0.05 per kWh to CNY 0.37 per kWh
China – Taipei	*Solar PV rates reduced 12.8-13.5%; wind FIT reduced 0.7-4.6%; geothermal FIT increased 5%*
Germany	FIT eligibility expanded to include landlord and tenant electricity supply; onshore wind FIT reduced 2.4% to EUR 74.93 per MWh
India – Karnataka	*Reduced from INR 4.5 per kWh to INR 3.74 per kWh*
Luxembourg	FIT eligibility expanded to offer 15-year solar PV FIT to projects greater than 30 kW
United States – Massachusetts	*Launched SMART programme*
Vietnam	Launched solar PV FIT providing guaranteed 20-year tariffs of USD 0.091 per kWh
Zambia	Launched REFIT programme

[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. There is no national level FIT within the United States.
[3] "Total existing" excludes nine countries that are known to have subsequently discontinued policies either for all projects or new projects (Brazil, Republic of Korea, Mauritius, Norway, South Africa, Spain, Sweden, Uruguay and the United States) and adds nine countries (Andorra, Honduras, Maldives, Panama, Peru, Poland, 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 12 for this section.

TABLE R13. Renewable Power Tenders at the National/State/Provincial Levels, 2017

Country	Technology	Description
Argentina	Wind power	940.8 MW awarded
	Bio-power	143.2 MW awarded
	Bio-power (MSW)[1]	13.1 MW awarded
	Bio-power (biogas)	76.5 MW awarded
	Small-scale hydropower	20.8 MW awarded
	Solar power	781.8 MW awarded
Armenia	Geothermal power	30 MW offered
	Solar PV	55 MW offered
Bolivia	Solar PV	50 MW offered
Botswana	Solar PV	100 MW offered
Chile	Renewable energy	12 TWh offered
El Salvador	Solar PV	120 MW awarded
Ethiopia[2]	Solar PV	100 MW awarded; 250 MW launched
France	Solar power	Annual target increased from 1.45 GW to 2.45 GW; 500 MW awarded
	Wind power (offshore)	3 GW through June 2020
	Wind and solar power	200 MW awarded
	Self-consumption	51 MW awarded
Germany	Wind power	2,800 MW yearly (2017-2019); 2,900 MW yearly after 2019
India	Solar PV	241 MW offered for development across states of Gujarat, Uttar Pradesh and Rajasthan
	Wind power (onshore)	2 GW awarded
Israel	Solar PV	Expected 100-250 MW awarded in 2017; 1 GW through 2018
Japan	Solar PV	140 MW awarded
Madagascar	Solar PV	25 MW offered
Malaysia	Solar PV	563 MW awarded
Mexico	Solar power	1,323 MW awarded
	Wind power	689 MW awarded
Netherlands	Wind power (offshore)	700 MW offered
Oman	Solar PV	500 MW offered
Poland	Renewable energy	4.725 TWh awarded
Russian Federation	Hydropower (small scale)	49.8 MW awarded
	Solar PV	520 MW awarded
	Wind power	1.7 GW awarded
Saudi Arabia	Wind power	400 MW request for qualification
	Solar PV	300 MW offered
Senegal	Solar PV	100 MW offered
Spain	Solar PV	3.9 GW awarded
	Wind power (onshore)	4.1 GW awarded
Sri Lanka	Solar PV	10 MW offered
Turkey	Wind power (onshore)	1 GW awarded
Zambia	Solar PV	100 MW offered

State/Provincial Renewable Energy Auctions Held in 2017

Country	State/Province	Technology	Description
Australia	Victoria	Renewable energy	650 MW offered
	Queensland	Renewable energy	400 MW offered
		Energy storage[3]	100 MW offered
Canada	Alberta	Renewable energy	600 MW awarded
India	Tamil Nadu	Wind power	200 MW offered
United States	Massachusetts	Wind power (offshore)	400 MW offered

[1] 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.
[2] 100 MW of capacity was awarded under a tender launched in May 2016.
[3] Energy storage is not an energy source but is included here because it can play an important role as balancing power, in particular for variable renewable resources.

Note: Table R13 provides an overview of identified renewable energy tenders in 2017 and likely does not constitute a comprehensive picture of all capacity offered through tenders during the year.

Source: See endnote 13 for this section.

TABLE R14. Renewable Energy Targets, Selected City and Local Examples

Note: Text in **bold** indicates new/revised in 2017, and brackets '[]' indicate previous targets where new targets were enacted.

Targets for 100% of Total Energy or Electricity from Renewables

	Target date for 100% total energy	Target date for 100% electricity
Abita Springs, Louisiana, United States		**2030**
Australian Capital Territory, Australia		2020
Breckenridge, Colorado, United States		**2035**
Burlington, Vermont, United States		Achieved in 2014
Byron Shire County, Australia	2025	
Coffs Harbour, Australia		2030
Copenhagen, Denmark	2050	
Fayetteville, Arkansas, United States		**2050**
Frankfurt, Germany	2050	
Frederikshavn, Denmark	2030	
Fukushima Prefecture, Japan	2040	
Greensburg, Kansas, United States		Achieved in 2015
Groningen, The Netherlands		2035
Hamburg, Germany	2050	
Inje County, Republic of Korea		2045
Jeju Self Governing Province, Republic of Korea		2030
Lancaster, California, United States		2020
Madison, Wisconsin, United States		**[no date given]**
Malmö, Sweden	2030	
Minneapolis, Minnesota, United States		**2030**
Munich, Germany		2025
Nederland, Colorado, United States		**2025**
Orlando, Florida, United States		**2050**
Osnabrück, Germany		2030
Oxford County, Australia	2050	
Palo Alto, California, United States		[no date given]
Park City, Utah, United States		2032
Pittsburgh, Pennsylania, United States		**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
Seattle, Washington, United States		[no date given]
Skellefteå, Sweden		2020
Sønderborg, Denmark	2029	
St. Louis, Missouri, United States		**2035**
St. Petersburg, Florida, United States		**[no date given]**
The Hague, The Netherlands	2040	
Uralla, Australia	[no date given]	
City of Vancouver, Canada	2050	
Växjö, Sweden	2030	

TABLE R14. Renewable Energy Targets, Selected City and Local Examples (continued)

Note: Text in **bold** indicates new/revised in 2017, and brackets '[]' indicate previous targets where new targets were enacted.

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
Buffalo City, South Africa	→ 10% by 2018
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
Howrah, India	→ 10% by 2018
Nagano Prefecture, Japan	→ 70% by 2050
Oaxaca, Mexico	→ 5% by 2017
Paris, France	→ 25% by 2020
Skellefteå, Sweden	→ Net exporter of biomass, hydro or wind energy by 2020
City of Sydney, Australia	→ 50% of electricity, heating and cooling by 2030 (does not include transport)

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
Boulder, Colorado, United States	→ 20% by 2020
Canberra, Australian Capital Territory, Australia	→ 90% by 2020
Cape Town, South Africa	→ 20% 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

TABLE R14. Renewable Energy Targets, Selected City and Local Examples (continued)

Note: Text in **bold** indicates new/revised in 2017, and brackets '[]' indicate previous targets where new targets were enacted.

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

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
Cockburn, Australia	→ 20% of final energy in city buildings by 2020
Fayetteville, Arkansas, United States	→ **All government operations with 100% clean energy 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% of municipal operations powered by renewable energy 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**
City of Sydney, Australia	→ 100% of electricity in buildings; 20% for street lamps

TABLE R14. Renewable Energy Targets, Selected City and Local Examples (continued)

Note: Text in **bold** indicates new/revised in 2017, and brackets '[]' indicate previous targets where new targets were enacted.

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)
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)
Nantes, France	→ Extend district heating system to source heat from biomass boilers for half of city inhabitants by 2017
New York, New York, United States	→ Biofuel blend in heating oil equivalent to 2% by 2016, 5% by 2017, 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

Transport-Related Mandates and Targets	
Athens, Greece	→ **Ban petrol and diesel powered cars and vans by 2025**
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 2030**
San Francisco, California, United States	→ **50% renewable power by 2025 and 100% renewable power by 2045 for Bay Area Rapid Transit rail system**
Shenzhen, China	→ **100% electric public bus fleet (achieved in 2017)**

Note: Table R14 provides a sample of local renewable energy commitments worldwide. It does not aim to present a comprehensive picture of all municipal renewable energy goals. For example, in Germany more than 150 municipalities have a target to achieve 100% renewables in the energy system.

Source: See endnote 14 for this section.

TABLE R15. Biofuels Global Production, Top 15 Countries and EU-28, 2017

Country	Ethanol	Biodiesel (FAME)	Biodiesel (HVO)	Change relative to 2016
	Billion litres			
United States	60.0	6.0	1.7	1.7
Brazil	28.5	4.3		0.3
Germany	0.9	3.5		0.0
Argentina	1.1	3.3		0.5
China	3.3	1.0		0.2
France	1.0	2.3		-0.3
Thailand	1.5	1.4		0.5
Indonesia	0.1	2.5		-0.3
Canada	1.7	0.5		0.1
Netherlands	0.3	0.4	1.3	0.1
Spain	0.5	1.3		-0.2
Poland	0.2	1.0		0.0
Singapore	0.1	0.0	1.3	0.1
India	0.8	0.2		-0.2
Colombia	0.3	0.6		0.0
EU-28	**4.1**	**11.8**	**3.5**	**-0.3**
World Total	**105.5**	**30.7**	**6.5**	**3.5**

Source: See endnote 15 for this section.

TABLE R16. Geothermal Power Global Capacity and Additions, Top 10 Countries, 2017

Country	Added 2017	Total End-2017
	MW	GW
Top Countries by Additions		
Indonesia	275	1.8
Turkey	243	1.1
Chile	48	0.05
Iceland	45	0.7
Honduras	35	0.04
Mexico	25	0.9
United States	24	2.5
Japan	5	0.5
Portugal	4	0.03
Hungary	3	~0
Top Countries by Total Capacity		
United States	24	2.5
Philippines	–	1.9
Indonesia	275	1.8
Turkey	243	1.1
New Zealand	–	1.0
Mexico	25	0.9
Italy	–	0.8
Iceland	45	0.7
Kenya	–	0.7
Japan	5	0.5
World Total	**707**	**12.8**

Note: Capacity additions are rounded to the nearest 1 MW, and totals are rounded to the nearest 0.1 GW, with the exceptions of Chile, Honduras, Hungary and Portugal, which are rounded to the nearest 0.01 GW. Rounding is to account for uncertainties and inconsistencies in available data. Capacity amounts of < 5 MW are designated by "~0". For more information and statistics, see Geothermal Power and Heat section in Market and Industry chapter and related endnotes.

Source: See endnote 16 for this section.

TABLE R17. Hydropower Global Capacity and Additions, Top 10 Countries, 2017

Country	Added 2017	Total End-2017
	GW	
Top Countries by Additions		
China	7.3	313
Brazil	3.4	100
India	1.9	45
Angola	1.4	3
Turkey	0.6	28
Iran	0.5	11
Vietnam	0.4	17
Russian Federation	0.4	48
Sudan	0.3	3
Côte d'Ivoire	0.3	1
Top Countries by Total Capacity		
China	7.3	313
Brazil	3.4	100
Canada	0.1	81
United States	0.1	80
Russian Federation	0.4	48
India	1.9	45
Norway	0.0	30
Turkey	0.6	28
Japan	–	23
France	0.1	19
World Total	**19**	**1,114**

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. The GSR strives to exclude pure pumped storage capacity from hydropower capacity data; see Methodological Notes for details. For more information and statistics, see Hydropower section in Market and Industry chapter and related endnotes.

Source: See endnote 17 for this section.

TABLE R18. Solar PV Global Capacity and Additions, Top 10 Countries, 2007-2017

	Total End-2016	Added 2017	Total End-2017
		GW	
Top Countries by Additions			
China	78.1	53.1	131.1
United States	40.4	10.6	51.0
India	9.2	9.1	18.3
Japan[1]	42.0	7	49
Turkey	0.8	2.6	3.4
Germany	40.7	1.7	42.4
Australia	6.0	1.3	7.2
Republic of Korea	4.4	1.2	5.6
United Kingdom	11.8	0.9	12.7
Brazil	0.2	0.9	1.1
Top Countries by Total Capacity			
China	78.1	53.1	131.1
United States	40.4	10.6	51.0
Japan[1]	42.0	7	49
Germany	40.7	1.7	42.4
Italy	19.3	0.4	19.7
India	9.2	9.1	18.3
United Kingdom	11.8	0.9	12.7
France	7.2	0.9	8.0
Australia	6.0	1.3	7.2
Spain	5.5	0.1	5.6
World Total	**303**	**98**	**402**

[1] For Japan, estimates for 2017 additions and year-end capacity are available only to the nearest GW.

Note: Country data are rounded to the nearest 0.1 GW; 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 Canada, Chile, 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 18 for this section.

TABLE R19. Concentrating Solar Thermal Power (CSP) Global Capacity and Additions, 2017

Country	Total End-2016	Added 2017	Total End-2017
		MW	
Spain	2,304	0	2,304
United States	1,738	0	1,738
South Africa	200	100	300
India	225	0	225
Morocco	166	0	166
United Arab Emirates	100	0	100
Algeria	20	0	20
Egypt	20	0	20
Iran	17	0	17
China	20	0	20
World Total	**4,810**	**100**	**4,910**

Note: Table includes all countries with operating commercial CSP capacity at end-2017. 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), 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 19 for this section.

TABLE R20. Solar Water Heating Collectors and Total Capacity End-2016 and Newly Installed Capacity 2017, Top 20 Countries

	Total End-2016			Gross Additions 2017		
	GW_{th}			MW_{th}		
Country	**Glazed**	**Unglazed**	**Total**	**Glazed**	**Unglazed**	**Total**
China	324.5	0	324.5	26,082	0	26,082
Turkey	14.9	0	14.9	1,348	0	1,348
India	6.7	0	6.7	1,063	0	1,063
Brazil	6.2	3.3	9.6	442	443	884
United States	2.1	15.5	17.6	122	536	658
Germany	13.2	0.4	13.6	437	0	437
Australia	2.5	3.7	6.2	104	266	370
Israel	3.2	0	3.2	298	1	299
Mexico	1.6	0.7	2.4	193	80	274
Greece	3.1	0	3.1	221	0	221
Spain	2.6	0.1	2.7	138	3	141
Italy	3.1	0	3.1	136	0	136
South Africa	0.6	0.8	1.3	50	42	92
Poland	1.5	0	1.5	78	0	78
Taipei, China	1.2	0	1.2	68	0	68
Austria	3.4	0.3	3.6	71	0	71
Switzerland	1.0	0.1	1.1	42	4	45
Tunisia	0.6	0	0.6	44	0	44
Japan	2.5	0	2.5	43	0	43
France	1.5	0.1	1.6	34	0	34
Total 20 Top Countries	395.9	25.1	421.0	31,014	1,375	32,388
World Total	**428.2**	**27.8**	**455.9**	**33,398**	**1,529**	**34,927**

Note: Countries are ordered according to newly installed glazed collector capacity in 2017. Data are for glazed and unglazed water collectors excluding air collectors, which added 1,742,942 m^2 to the year-end world total for 2016, and excluding concentrating collectors with 183,052 m^2 additional aperture area in 2016. End-2016 data for individual countries, Total 20 Top Countries and World Total are rounded to nearest 0.1 GW_{th}; additions for individual countries, Total 20 Top Countries and World Total are rounded to 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 2016 is the most recent one for which firm global data on total capacity in operation are available. It is estimated, however, that 472 GW_{th} of solar thermal capacity (water and non-concentrating collectors only) was in operation worldwide by end-2017. For 2016 details and source information, see Solar Thermal Heating and Cooling section in Market and Industry chapter and related endnotes.

Source: See endnote 20 for this section.

TABLE R21. Wind Power Global Capacity and Additions, Top 10 Countries, 2017

Country	Total End-2016	Added 2017	Total End-2017
	GW		
Top Countries by Additions			
China[1]	149/168.7	15/19.7	164/188.4
United States	82.0	7.0	89.0
Germany[2]	50.0	6.1	56.1
United Kingdom	14.6	4.3	18.9
India	28.7	4.1	32.8
Brazil	10.7	2.0	12.8
France	12.1	1.7	13.8
Turkey	6.1	0.8	6.9
South Africa	1.5	0.6	2.1
Finland	1.5	0.5	2.1
Top Countries by Total Capacity			
China[1]	149/168.7	15/19.7	164/188.4
United States	82.0	7.0	89.0
Germany[2]	50.0	6.1	56.1
India	28.7	4.1	32.8
Spain	23.1	0.1	23.2
United Kingdom	14.6	4.3	18.9
France	12.1	1.7	13.8
Brazil	10.7	2.0	12.8
Canada	11.9	0.3	12.2
Italy	9.2	0.3	9.5
World Total	**487**	**52**	**539**

[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 figures for China. (See Wind Power section in Market and Industry chapter and related endnotes for more details.)

[2] For Germany, some onshore capacity was decommissioned in 2017; 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; 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 decommissioning of existing projects. Data reflect a variety of sources, some of which differ quite significantly, reflecting variations in accounting or methodology. For more information, see Wind Power section in Market and Industry chapter and related endnotes.

Source: See endnote 21 for this section.

TABLE R22. Electricity Access by Region and Country, 2016 and Targets

World/Region/Country	Electrification Rate in 2016	People Without Access to Electricity in 2016	Targets
	Share of population with access	Millions	Share of population with access
World[1]	**86%**	**1,060**	
All Developing Countries	**82%**	**1,060**	
Africa	**52%**	**588**	
North Africa	**100%**	**< 1**	
Sub-Saharan Africa	**43%**	**588**	
Developing Asia	**89%**	**439**	
Central and South America	**97%**	**17**	
Middle East	**93%**	**17**	
Africa			
Algeria	100%	0	
Angola	35%	17	→ 100% by 2030
Benin	32%	8	→ 5% by 2025 (urban) → 65% by 2025 (rural)
Botswana	55%	1	→ 100% by 2030
Burkina Faso	20%	15	→ 100 by 2025
Burundi	10%	10	→ 25% by 2025
Cabo Verde	97%	0.2	→ 100% by 2020
Cameroon	63%	9	
Central African Republic	3%	5	→ 50% by 2030
Chad	9%	13	
Comoros	71%	0.2	
Congo	43%	3	
Côte d'Ivoire	63%	9	→ 100% by 2025
Congo, Democratic Republic of	15%	68	→ 60% by 2025
Djibouti	42%	0.5	→ 100% by 2035
Egypt	100%	0	
Equatorial Guinea	68%	0.3	
Eritrea	33%	4	
Ethiopia	40%	61	→ 100% by 2030
Gabon	90%	0.2	
Gambia	48%	1	→ 100% by 2030
Ghana	84%	5	→ 100% by 2020
Guinea	20%	10	→ 100% by 2030
Guinea-Bissau	13%	2	→ 80% by 2030
Kenya	65%	17	→ 100% by 2022
Lesotho	34%	1	→ 40% by 2020
Liberia	12%	4	→ 100% by 2030
Libya	100%	0	
Madagascar	23%	19	
Malawi	11%	16	→ 30% by 2020
Mali	41%	11	→ 87% by 2030

■ TABLE R22. Electricity Access by Region and Country, 2016 and Targets (continued)

World/Region/Country	Electrification Rate in 2016	People Without Access to Electricity in 2016	Targets
	Share of population with access	Millions	Share of population with access
Africa (continued)			
Mauritania	31%	3	
Mauritius	100%	0	
Morocco	99%	0.4	
Mozambique	29%	21	→ 100% by 2025
Namibia	56%	1	
Niger	11%	18	→ 65% by 2030
Nigeria	61%	74	→ 75% by 2020 → 90% by 2030 → 100 by 2025
Rwanda	30%	8	→ 100% by 2030
São Tomé and Príncipe	59%	0.1	
Senegal	64%	6	→ 100% by 2025
Seychelles	99%	<1	
Sierra Leone	9%	6	→ 100% by 2025
Somalia	16%	9	
South Africa	86%	8	→ 100% by 2019
South Sudan	1%	13	
Sudan	46%	22	
Swaziland	84%	<1	→ 75% by 2018 → 85% by 2020 → 100% by 2025
Tanzania	30%	36	→ 75% by 2030
Togo	35%	5	→ 82% by 2030
Tunisia	100%	0	
Uganda	19%	33	→ 98% by 2030
Zambia	34%	11	→ 66% by 2030
Zimbabwe	34%	11	→ 66% by 2030 → 90% by 2030 (urban) → 51% by 2030 (rural)
Developing Asia			
Bangladesh	75%	41	→ 100% by 2021
Brunei	100%	0	
Cambodia	60%	6	→ 70% by 2030 (rural)
China	100%	0	
India	82%	239	→ 100% by 2019
Indonesia	91%	23	
Lao PDR	91%	<1	
Korea DPR	27%	19	→ 90% by 2017
Malaysia	99%	<1	
Mongolia	91%	0.3	
Myanmar	59%	22	→ 87% by 2030

TABLE R22. Electricity Access by Region and Country, 2016 and Targets (continued)

World/Region/Country	Electrification Rate in 2016	People Without Access to Electricity in 2016	Targets
	Share of population with access	Millions	Share of population with access
Developing Asia (continued)			
Nepal	77%	7	
Pakistan	74%	51	
Philippines	90%	11	
Singapore	100%	0	
Sri Lanka	100%	0	
Thailand	100%	0	
Vietnam	98%	2	
Central and South America			
Argentina	99.6%	<1	
Barbados	100%	0	
Bolivia	92%	< 1	→ 100% by 2025 (rural)
Brazil	99.6%	< 1	
Chile	100%	0	
Colombia	98%	1	
Costa Rica	99.2%	< 1	
Cuba	100%	0	
Dominican Republic	97%	0.3	
Ecuador	98%	0.5	→ 98.9% by 2022 (urban) → 96.3% by 2022 (rural)
El Salvador	96%	0.4	
Guatemala	94%	1	
Haiti	33%	7	→ 50% by 2020
Honduras	76%	2	
Jamaica	99.5%	0.2	
Mexico	100%	0	
Nicaragua	89%	<1	
Panama	96%	0.3	
Paraguay	99%	0.1	
Peru	95%	2	
Suriname	87%	0.1	
Trinidad and Tobago	99%	<1	
Uruguay	99.9%	<1	
Venezuela	99.5%	<1	

TABLE R22. Electricity Access by Region and Country, 2016 and Targets (continued)

World/Region/Country	Electrification Rate in 2016	People Without Access to Electricity in 2016	Targets
	Share of population with access	Millions	Share of population with access
Middle East			
Bahrain	100%	0	
Iran	99%	<1	
Iraq	99%	<1	
Jordan	100%	0	
Kuwait	100%	0	
Lebanon	100%	0	
Oman	99.6%	<1	
State of Palestine[2]	100%	0	
Qatar	99%	<1	
Saudi Arabia	99%	0.2	
Syria	96%	<1	
United Arab Emirates	100%	0	
Yemen	48%	14	
Oceania			
Federated States of Micronesia	75%	<1	→ 90% by 2020 (rural)[3]

[1] Includes countries in the OECD and economies in transition.

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

[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 DREA 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. Population Without Access to Clean Cooking, by Region and Country,, 2015

World/Region/Country	Population Without Access to Clean Cooking in 2015	Population Without Access to Clean Cooking in 2015	Targets
	Share of population	Millions	Share of population with access to clean cooking
World[1]	**38%**	**2,792**	
All Developing Countries	**49%**	**2,792**	
Africa	**71%**	**848**	
Sub-Saharan Africa	**84%**	**846**	
North Africa	**1%**	**2.1**	
Developing Asia	**49%**	**1,874**	
Central and South America	**12%**	**59**	
Middle East	**5%**	**12**	
Africa			
Algeria	0%	0	
Angola	61%	15	→ 100% by 2030
Benin	90%	10	
Botswana	43%	<1	
Burkina Faso	87%	16	→ 100% by 2030 (urban) → 65% by 2030 (rural)
Burundi	98%	11	
Cabo Verde	25%	0.2	→ 100% by 2020
Cameroon	77%	18	
Central African Republic	97%	5	
Chad	95%	13	
Comoros	93%	<1	
Congo	84%	4	
Côte d'Ivoire	77%	17	
Congo, Democratic Republic of	95%	75	
Djibouti	94%	<1	
Egypt	1%	<1	
Equatorial Guinea	77%	<1	
Eritrea	90%	5	
Ethiopia	95%	94	→ 100% by 2025
Gabon	15%	<1	
Gambia	90%	2	→ 100% by 2030
Ghana	71%	20	→ 100% by 2030
Guinea	98%	12	→ 50% by 2025
Guinea-Bissau	98%	2	→ 75% by 2030
Kenya	86%	40	→ 100% by 2022
Lesotho	63%	1	
Liberia	98%	5	→ 100% by 2030
Libya	0%	0	
Madagascar	98%	24	
Malawi	97%	17	
Mali	50%	9	→ 100% by 2030

TABLE R23. Population Without Access to Clean Cooking, by Region and Country, 2015 (continued)

World/Region/Country	Population Without Access to Clean Cooking in 2015	Population Without Access to Clean Cooking in 2015	Targets
	Share of population	Millions	Share of population with access to clean cooking
Africa (continued)			
Mauritania	66%	3	
Mauritius	2%	<1	
Morocco	3%	1.2	
Mozambique	95%	27	
Namibia	55%	1	
Niger	97%	19	→ 100% by 2030 (urban) → 60% by 2030 (rural)
Nigeria	94%	171	
Rwanda	98%	12	→ 100% by 2030
São Tomé and Príncipe	40%	<1	
Senegal	71%	11	
Seychelles	2%	<1	
Sierra Leone	98%	6	
Somalia	95%	11	
South Africa	18%	10	
South Sudan	98%	12	
Sudan	65%	26	
Swaziland	50%	<1	→ 100% by 2030
Tanzania	96%	51	→ 75% by 2030
Togo	91%	7	→ 80% by 2030
Tunisia	2%	<1	
Uganda	98%	38	→ 99% by 2030
Zambia	87%	14	
Zimbabwe	71%	11	
Developing Asia			
Bangladesh	83%	133	
Cambodia	83%	13	
China	33%	457	
India	64%	834	
Indonesia	32%	83	
Lao PDR	>95%	7	
Korea DPR	46%	12	
Malaysia	0%	0	
Mongolia	67%	2	
Myanmar	94%	51	
Nepal	70%	20	
Pakistan	50%	95	
Philippines	62%	62	
Singapore	0%	0	
Sri Lanka	83%	17	
Thailand	26%	18	
Vietnam	41%	37	

TABLE R23. Population Without Access to Clean Cooking, by Region and Country, 2015 (continued)

World/Region/Country	Population Without Access to Clean Cooking in 2015	Population Without Access to Clean Cooking in 2015	Targets
	Share of population	Millions	Share of population with access to clean cooking
Central and South America			
Argentina	0%	0	
Bolivia	17%	2	
Brazil	5%	10	
Chile	7%	1.3	
Colombia	13%	6.4	
Costa Rica	6%	<1	
Cuba	6%	<1	
Dominican Republic	12%	1	
Ecuador	6%	0.4	
El Salvador	20%	1.2	
Guatemala	30%	5	
Haiti	93%	9.9	
Honduras	53%	4.2	
Jamaica	13%	0.3	
Mexico	15%	19.1	
Nicaragua	52%	3.2	
Panama	14%	0.6	
Paraguay	41%	2.2	
Peru	32%	10.1	
Venezuela	2%	<1	
Middle East			
Bahrain	1%	<1	
Iran	1%	<1	
Iraq	1%	0.2	
Jordan	0%	0	
Kuwait	0%	0	
Lebanon	1%	<1	
Oman	2%	<1	
Yemen	39%	11	

[1] Includes countries in the OECD and economies in transition.

Disclaimer: The tracking of data related to energy access and DREA systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

Source: See endnote 23 for this section.

TABLE R24. Programmes Furthering Energy Access, Selected Examples

Name	Brief Description	Web Address
ACP-EU Energy Facility	A co-financing instrument that works to increase access to sustainable and affordable energy services in impoverished rural and peri-urban areas of African, Caribbean and Pacific (ACP) countries by involving local authorities and communities.	https://ec.europa.eu/europeaid/regions/african-caribbean-and-pacific-acp-region/acp-multi-country-cooperation/energy_en http://energyfacilitymonitoring.eu/
Africa-EU Renewable Energy Cooperation Programme (RECP)	A programme that contributes to the African EU Energy Partnership's political targets of increasing renewable energy use and bringing modern access to at least an additional 100 million people by 2020. It provides policy advice, private sector co-operation, project preparation support activities and capacity development.	http://www.euei-pdf.org/africa-eu-renewable-energy-cooperation-programme-recp
Asian Development Bank (ADB) – Energy for All Initiative	An initiative that strengthens the ADB's investments in energy access. Energy for All offers a suite of services to sustainable energy companies, depending on their level of maturity. Its intention is to build a dynamic ecosystem where technology innovation and application flow seamlessly across borders in Asia.	https://www.energyforall.asia/eforall_initiative/about_the_initiative
Central America Clean Cooking Initiative (CACCI)	An initiative that aims to help scale up clean cooking solutions in countries such as Guatemala, Honduras, Nicaragua and possibly El Salvador. Activities to be financed by the grant include development of a roadmap to achieve universal clean cooking access by 2030. The roadmap will build on the regional Sustainable Energy Strategy 2020.	https://www.esmap.org/node/4006
CleanStart	Developed by the UN Capital Development Fund and United Nations Development Programme to help poor households and micro-entrepreneurs access micro-financing for low-cost clean energy. By 2020, it 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.	http://www.uncdf.org/en/cleanstart
Electrification Financing Initiative (ElectriFI)	A flexible financial facility funded by the European Commission and managed by the Association of European Development Finance Institutions.	http://electrifi.eu/
Energising Development (EnDev)	A multilateral initiative supported by the governments of the Netherlands, Germany, Norway, Sweden, Switzerland and the United Kingdom. It operates in 25 countries in Asia, Africa and Latin America with the aim of facilitating sustainable access to modern energy services. By December 2016, EnDev had facilitated 17.3 million people, 19,400 social institutions and 38,600 small enterprises to gain sustainable access to modern energy services.	http://endev.info/
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/
Energy & Environment Partnership (EEP) Mekong	A programme that focuses on increasing and improving access of rural populations to sustainable and affordable energy services and products in five countries – Cambodia, Lao PDR, Myanmar, Thailand and Vietnam – in collaboration with government partners.	http://eepmekong.org/

■ TABLE R24. Programmes Furthering Energy Access, Selected Examples (continued)

Name	Brief Description	Web Address
Energy Access Ventures Fund	A private equity fund that invests in small and medium-sized enterprises 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
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, more than EUR 50 million has been allocated to projects focusing on energy access.	http://www.eu-africa-infrastructure-tf.net/about/index.htm
Global Alliance for Clean Cookstoves (GACC)	A public-private partnership created with the goal of enabling the adoption of 100 million clean and efficient cook stoves and fuels by 2020. GACC uses a market-based approach to bring together diverse groups of actors across government, development, non-governmental organisations (NGOs), academia and the private sector to save lives, improve livelihoods, empower women and protect the environment through initiatives designed to catalyse and champion the sector, mobilise resources, promote standards and testing, and co-ordinate sector knowledge and research.	http://www.cleancookstoves.org/the-alliance/
Global Lighting and Energy Access Partnership (Global LEAP)	An initiative of the Clean Energy Ministerial that includes more than 10 governments and development partners. It provides support for quality assurance frameworks and programmes that encourage market transformation towards super-efficient technologies for off-grid use, including the Global LEAP Awards for Outstanding Off-Grid Products.	http://globalleap.org/
Green Climate Fund (GCF)	A fund established by 194 countries party to the UN Framework Convention on Climate Change in 2010 that aims to mobilise funding at scale to invest in low-emission and climate-resilient development in developing countries. The fund is to mobilise USD 100 billion per year by 2020.	http://news.gcfund.org/https://www.greenclimate.fund/home
Green Mini-grids Helpdesk	A platform supported by the African Development Bank (AfDB) providing a complete information service for developers of green mini-grids in Africa. The resource was developed by Energy 4 Impact and Inensus.	http://greenminigrid.se4all-africa.org/
IDEAS – Energy Innovation Contest	A contest launched in 2009 that supports the implementation of innovative projects in the areas of renewable energy, energy efficiency and energy access in Latin America and the Caribbean by promoting innovative energy solutions that can be replicated and scaled up in the region.	http://www.iadb.org/en/topics/energy/ideas/ideas,3808.html
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. ADFD provides concessional loans of USD 5 million to USD 15 million to renewable energy projects in developing countries over seven funding rounds of approximately USD 50 million each. The Facility is running its fifth round and since 2012 has allocated USD 189 million to 19 renewable energy projects.	http://adfd.irena.org/

TABLE R24. Programmes Furthering Energy Access, Selected Examples (continued)

Name	Brief Description	Web Address
Lighting a Billion Lives	A global initiative launched in 2008, steered by The Energy and Resources Institute (TERI), to facilitate access to clean lighting and cooking solutions for energy-starved communities. The programme operates on an entrepreneurial model of energy service delivery to provide innovative, affordable and reliable off-grid solar solutions. As of March 2016, it had facilitated access to clean lighting and cooking solutions for more than 4.5 million people in India, sub-Saharan Africa and South Asia.	http://labl.teriin.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 of modern lighting options.	http://www.lightingasia.org/
OPEC Fund for International Development (OFID)	A development aid institution with a 40-year standing and a presence in over 130 countries. It works in co-operation with developing country partners and the international donor community to stimulate economic growth and alleviate poverty. Since 2008, the year that OFID launched its Energy for the Poor Initiative (EPI), energy poverty alleviation has been the primary strategic focus. In June 2012, the OFID Ministerial Council committed a minimum of USD 1 billion to bolster activities under the EPI, and in 2013 it turned this commitment from a one-time obligation to a revolving pledge.	http://www.ofid.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 over 40 investors and practitioners that have committed to invest 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
Readiness for Investment in Sustainable Energy (RISE)	A World Bank Group project providing indicators that compare the investment climate of countries across the three focus areas of the SEforALL initiative: energy access, energy efficiency and renewable energy.	http://rise.worldbank.org/
Renewable Energy and Energy Efficiency Partnership (REEEP)	A partnership that invests in clean energy markets in developing countries to reduce CO_2 emissions and build prosperity. Based on a strategic portfolio of high-impact projects, it works to generate energy access, improve lives and economic opportunities, build sustainable markets and combat climate change. REEEP has formed partnerships with more than 120 governments, banks, businesses, NGOs and inter-governmental organisations and has invested about USD 20 million (EUR 16.4 million) in more than 145 projects.	http://www.reeep.org/

■ TABLE R24. Programmes Furthering Energy Access, Selected Examples (continued)

Name	Brief Description	Web Address
Scaling Up Renewable Energy in Low Income Countries (SREP)	A Strategic Climate Fund programme that was established to expand renewable energy markets and scale up renewable energy deployment in the world's poorest countries. To date, USD 264 million has been approved for 23 projects and programmes. An additional USD 1.9 billion in co-financing is expected from other sources.	https://www.climateinvestmentfunds.org/cif/node/67
Small-Scale Sustainable Infrastructure Development Fund (S3IDF)	A fund that promotes a Social Merchant Bank approach to help local entrepreneurs create micro-enterprises that provide infrastructure services to the poor. As of early 2015, it had a portfolio of almost 200 small investments and associated enterprises in India, and an additional 100 projects in the pipeline.	http://s3idf.org/
SNV Netherlands Development Organisation – Biogas Practice	A multi-actor sector development approach that supports the preparation and implementation of national biogas programmes throughout the world. In co-operation with its partners, by end-2015 SNV had installed over 700,000 bio-digesters in Asia, Africa and Latin America, impacting 3.5 million people.	http://www.snv.org/sector/energy/topic/biogas
Sustainable Energy for All Initiative (SEforALL)	A global initiative of former UN Secretary-General Ban Ki-moon with three objectives for 2030: achieving universal access to electricity and clean cooking solutions; doubling the share of the world's energy supplied by renewable sources; and doubling the rate of improvement in energy efficiency.	http://www.se4all.org
Sustainable Energy Fund for Africa (SEFA)	A fund administered by the AfDB and anchored by a Danish government commitment of USD 57 million to support 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/
US Agency for International Development (USAID) Development Innovation Ventures (DIV)	A USAID 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

Source: See endnote 24 for this section.

TABLE R25. International Networks Furthering Energy Access, Selected Examples

Name	Brief Description	Web Address
Africa Mini-grid Developers Association (AMDA)	An association representing efforts by the mini-grid development industry to alleviate the problem of energy access with 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/
AKON Lighting Africa	An initiative launched in February 2014 that seeks to provide a concrete response at the grassroots level to Africa's energy crisis and to lay the foundations for future development. It aims to develop an innovative solar-powered solution that will provide African villages with access to a clean and affordable source of electricity.	http://akonlightingafrica.com/
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. It has more than 90 members along the whole value chain of off-grid technologies.	http://www.ruralelec.org/
Alliance of CSOs for Clean Energy Access (ACCESS)	A coalition consisting of a range of civil society organisations (CSOs), both international and national. ACCESS aims to strengthen the visibility and presence of CSOs working to deliver universal energy access, particularly within SEforALL, Sustainable Development Goal 7 implementation and other global energy initiatives. ACCESS is co-ordinated by the Catholic Agency for Overseas Development, ENERGIA, Greenpeace, HIVOS, the International Institute for Environment and Development, Practical Action, TERI, the World Resources Institute and WWF.	https://access-coalition.org/
Climate Technology Centre and Network (CTCN)	The operational arm of the UN Climate Change Technology Mechanism, hosted by UN Environment and the UN Industrial Development Organization. CTCN promotes the accelerated transfer of environmentally sound technologies for low-carbon and climate-resilient development at the request of developing countries. It 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 the Climate Technology Initiative (CTI) in co-operation with the UN Climate 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/
Consultative Group to Assist the Poor (CGAP)	A global partnership of 34 leading organisations, housed at the World Bank, that seeks to advance financial inclusion. It 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/

■ TABLE R25. International Networks Furthering Energy Access, Selected Examples (continued)

Name	Brief Description	Web Address
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 operating in over 170 countries representing small, medium-sized and large clean energy enterprises, civil society, government and academia. The 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, bilateral, multilateral and non-governmental development partners. The Partnership, led by the ADB, 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 over 125 members as the voice of the off-grid solar energy industry and promotes the solutions they offer. GOGLA was founded in 2012, borne out of the IFC/World Bank's Lighting Global programme.	https://www.gogla.org
Global Renewable Energy Islands Network (GREIN)	A network created to help islands accelerate their renewable energy uptake. It serves as a platform for pooling knowledge, sharing best practices and seeking innovative solutions for the accelerated update of clean and cost-effective renewable energy technologies in island states and territories.	http://grein.irena.org/
HEDON Household Energy Network	A network aimed at empowering practitioners to unlock barriers to household energy access by addressing knowledge gaps, facilitating partnerships and fostering information sharing.	http://www.hedon.info/tiki-index.php
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) hydropower 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. It is dedicated to promoting sustainable energy and social development and is funded by a mix of national governments, multilateral institutions and CSOs. INFORSE 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 R&D.	http://www.inforse.org/

■ TABLE R25. International Networks Furthering Energy Access, Selected Examples (continued)

Name	Brief Description	Web Address
International Solar Alliance (ISA)	A coalition of solar resource-rich countries that was conceived to address their special energy needs and to provide a platform to collaborate on addressing the identified gaps through a common, agreed approach. The 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
La Via Campesina (LVC)	Informally known as the "international peasants' movement", LVC is a group of about 150 organisational members that co-ordinate migrant workers, farmers, rural women and indigenous communities on rural development issues. The "sustainable agriculture", "water" and "women and human rights" programmes deal with various aspects of rural energy use, especially the connections between food security and biofuels.	http://viacampesina.org/
Power for All	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, bilateral, multilateral and non-governmental development partners. The Partnership, led by the ADB, 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
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.	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 co-ordinate investments to connect more households and businesses to electricity. It aims to incentivise technological innovation, fund early stage companies and support critical elements of the off-grid ecosystem. Founding partners are USAID, the UK Department for International Development and the Shell Foundation.	https://www.scalingoffgrid.org/
Wind Empowerment	A global association for the development of locally built small-scale wind turbines for sustainable rural electrification.	http://windempowerment.org/

Source: See endnote 25 for this section.

■ TABLE R26. Global Trends in Renewable Energy Investment, 2007-2017

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Billion USD										
New Investment by Stage											
Technology Research											
Government R&D	2.7	2.8	5.4	4.9	4.8	4.7	5.2	4.5	4.4	5.1	5.1
Corporate R&D	3.2	3.6	3.8	3.9	4.5	4.2	4.0	3.9	4.2	4.2	4.8
Development / Commercialisation											
Venture capital	2.1	3.3	1.6	2.7	2.7	2.6	1.1	1.1	1.5	1.0	1.0
Manufacturing											
Private equity expansion capital	3.5	6.9	3.2	5.5	2.4	1.7	1.4	1.7	1.8	1.7	0.8
Public markets	20.8	10.8	12.7	10.8	9.9	4.0	10.2	15.1	12.0	6.1	5.7
Projects											
Asset finance	115.1	135.6	120.4	155.2	190.1	169.4	159.3	201.3	252.4	215.6	216.1
(re-invested equity)	2.6	3.6	1.9	1.5	1.8	2.6	1.0	3.3	6.1	2.9	3.1
Small-scale distributed capacity	14.0	22.1	33.0	62.2	75.2	71.6	54.4	60.0	53.2	43.1	49.4
Total New Investment	**158.9**	**181.4**	**178.3**	**243.6**	**287.8**	**255.5**	**234.4**	**284.3**	**323.4**	**274.0**	**279.8**
Merger & Acquisition Transactions											
	59.1	61.3	65.1	60.0	74.0	66.9	68.1	88.1	98.4	115.5	114.0
Total Transactions	**218.0**	**242.7**	**243.3**	**303.6**	**361.8**	**322.4**	**302.5**	**372.3**	**421.8**	**389.5**	**393.8**
New Investment by Technology											
Solar power	38.7	61.5	64.0	103.3	158.1	140.5	119.9	145.3	179.3	136.5	160.8
Wind power	60.9	74.8	79.5	101.5	87.2	83.6	86.4	110.7	124.7	121.6	107.2
Biomass and waste-to-energy	22.9	17.5	15.1	16.9	20.2	15.8	14.0	12.7	9.4	7.3	4.7
Hydropower <50 MW	6.5	7.6	6.2	8.2	7.6	6.5	5.8	7.0	3.6	3.9	3.4
Biofuels	27.4	18.2	10.2	10.6	10.6	7.2	5.2	5.2	3.5	2.1	2.0
Geothermal	1.7	1.7	2.8	2.9	3.9	1.6	2.8	2.9	2.5	2.5	1.6
Ocean energy	0.8	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2
Total New Investment	**158.9**	**181.4**	**178.3**	**243.6**	**287.8**	**255.5**	**234.4**	**284.3**	**323.4**	**274.0**	**279.8**

Source: See endnote 26 for this section.

METHODOLOGICAL NOTES

This 2018 report is the 13th 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 2017 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.

NOTES ON ESTABLISHING RENEWABLE ENERGY SHARES OF TOTAL FINAL ENERGY CONSUMPTION (TFEC)

1. 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, are as follows: solar PV, ocean energy and wind power (8.5%); hydropower (9.6%); CSP (14.5%); and bio-power (15.5%). 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 2015 from IEA, *World Energy Statistics and Balances*, 2017 edition (Paris: 2017).

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*, 2017 edition (Paris: 2017).

2. Significant Downward Revisions in Data for Traditional Use of Biomass in China

The renewable energy share of total final energy consumption provided in this edition of the GSR has changed significantly relative to previous years due mainly to a downward revision of data for traditional uses of biomass in China (data from IEA, *World Energy Statistics and Balances 2017*). As a result, the renewable energy share of TFEC is lower than it was in GSR 2017, as seen in Figure 1.

NOTES ON RENEWABLE ENERGY CAPACITIES AND ENERGY OUTPUT

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 chapter on Market and Industry Trends 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 within the production time frame of the GSR.

i For information on renewable energy data and related challenges, see Sidebar 4 in GSR 2015 and Sidebar 1 in GSR 2014.

2. 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.

3. 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.)*

4. 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.

5. Solar PV Capacity Data[i]

The capacity of a solar PV panel is rated according to direct current (DC) output, which is 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% to as much as 50%. Most utility-scale plants built in 2017 have ratios in the range of 1.1 to 1.5[ii].

This report attempts to report all solar PV capacity data on the basis of DC output (where data are provided in AC, this is specified) for consistency across countries. Some countries (e.g., Canada, Chile, Japan since 2012 and Spain) 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.

6. 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.

7. 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 15 May 2018 for technology data, and by 1 May 2018 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 2017 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 Photovoltaic Systems Programme (IEA PVPS), *Snapshot of Global Photovoltaic Markets 2018* (Paris: April 2018), p. 11, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA_PVPS-A_Snapshot_of_Global_PV-1992-2017.pdf; IEA PVPS, *Trends in Photovoltaic Applications, 2016*: *Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), p. 7; 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.

ii IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, p. 11.

GLOSSARY

Absorption chillers. Chillers that use heat energy from any source (solar, biomass, waste heat, etc.) to drive air conditioning or refrigeration systems. The heat source replaces the electric power consumption of a mechanical compressor. Absorption chillers differ from conventional (vapour compression) cooling systems in two ways: 1) the absorption process is thermochemical in nature rather than mechanical, and 2) the substance that is circulated as a refrigerant is water rather than chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), also called Freon. The chillers generally are supplied with district heat, waste heat or heat from co-generation, and they can operate with heat from geothermal, solar or biomass resources.

Adsorption chillers. Chillers that use heat energy from any source to drive air conditioning or refrigeration systems. They differ from absorption chillers in that the adsorption process is based on the interaction between gases and solids. A solid material in the chiller's adsorption chamber releases refrigerant vapour when heated; subsequently, the vapour is cooled and liquefied, providing a cooling effect at the evaporator by absorbing external heat and turning back into a vapour, which is then re-adsorbed into the solid.

Auction. See Tendering.

Bagasse. The fibrous matter that remains after extraction of sugar from sugar cane.

Behind-the-meter system. Any generation capacity, storage or demand management device on the customer side of the interface with the distribution grid (i.e., the meter).

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 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 fear 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 typically 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 recorded and confirmed anonymously. Each transaction is collected and linked in a secure format (by cryptography) into a time-stamped "block"; this block is then stored collectively as a "chain" on distributed computers. Blockchain may be used in energy markets, including for micro-trading among solar power prosumers.

Building codes and standards. Rules specifying the minimum 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 concentrating solar power or 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.

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 feeds electricity to customers.

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.

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 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 intensity. Primary energy consumption per unit of economic output. 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.

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 electricity, district heating, mechanical energy, liquid hydrocarbons such as kerosene or fuel oil, and various gaseous fuels such as natural gas, biogas and hydrogen.

Final energy consumption. Energy that is supplied to the consumer for all final energy services such as cooling and lighting, building or industrial heating or mechanical work, including transport.

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.

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.

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 energy. Energy captured from ocean waves, tides, currents, salinity gradients and ocean temperature differences. Wave energy converters capture the energy of surface waves to generate electricity; tidal stream generators use kinetic energy of moving water to power turbines; and tidal barrages are essentially dams that cross tidal estuaries and capture energy as tides ebb and flow.

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. See Solar pico system.

Pico solar devices. 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.

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 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 five types of solar cookers: 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 power small electric devices and provide modest amounts of electricity to homes for lighting, communication and appliances, usually in rural or remote regions that are not connected to the electricity grid.

Solar photovoltaics (PV). A technology used for converting light 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. Monocrystalline modules typically are slightly more efficient but relatively more expensive than multi-crystalline silicon modules, although these differences have narrowed with advances in manufacturing and technology. Thin film solar PV materials can be applied as flexible films laid over existing surfaces or integrated with building components such as roof tiles. 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 pico system. A very small solar PV system – such as a solar lamp or an information and communication technology (ICT) appliance – with a power output of 1-10 watts that typically has a voltage of up to 12 volts.

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.

Subsidy. A government measure that artificially reduces the price that consumers pay for energy or that reduces the production cost.

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.

Tendering (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 power, 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 (MWth) 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
AFD	French Development Agency
AfDB	African Development Bank
AUD	Australian dollar
BECCU	Bioenergy with carbon capture and use
BNEF	Bloomberg New Energy Finance
BRICS	Brazil, Russian Federation, India, China and South Africa
CDM	Clean Development Mechanism
CEM	Clean Energy Ministerial
CHP	Combined heat and power
CNY	Chinese yuan
CO_2	Carbon dioxide
COP23	Conference of the Parties, 23rd meeting
CSP	Concentrating solar thermal power
DC	Direct current
DDU	Deep direct-use
DFI	Development finance institution
DHC	District heating and cooling
DMIS	Demand Management Incentive Scheme
DOE	US Department of Energy
DREA	Distributed renewables for energy access
EC	European Commission
ECOWAS	Economic Community of West African States
EGS	Enhanced (or engineered) geothermal systems
EJ	Exajoule
EMEC	European Marine Energy Centre
EnDev	Energising Development
EPA	US Environmental Protection Agency
ETS	Emissions Trading Scheme
EU	European Union (specifically the EU-28)
EV	Electric vehicle
FAME	Fatty acid methyl ester
FIT	Feed-in tariff
G20	Group of Twenty
GCF	Green Climate Fund
GDP	Gross domestic product
GO	Guarantee of origin
GSR	Global Status Report
GW/GWh	Gigawatt/gigawatt-hour
GW_{th}	Gigawatt-thermal
H_2S	Hydrogen sulphide
HEFA	Hydrotreated esters and fatty acids
HVO	Hydrotreated vegetable oil
ICT	Information and communication technologies
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
IPO	Initial public offering
IPP	Independent power producer
IRENA	International Renewable Energy Agency
IT	Information technology
ktoe	kilotonne of oil equivalent
kW/kWh	Kilowatt/kilowatt-hour
kW_{th}	kilowatt-thermal
LCOE	Levelised cost of energy (or electricity)
LED	Light-emitting diode
LPG	Liquefied petroleum gas
M&A	Mergers and acquisitions
m^2	Square metre
m^3	Cubic metre
MENA	Middle East and North Africa
MFI	Microfinance institution
MJ	megajoules
MSW	Municipal solid waste
Mtoe	Megatonne of oil equivalent
MW/MWh	Megawatt/megawatt-hour
MW_{th}	Megawatt-thermal
NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contribution
O&M	Operations and maintenance
OECD	Organisation for Economic Co-operation and Development
OFID	OPEC Fund for International Development
P2G	Power-to-gas
PAYG	Pay-as-you-go
PERC	Passivated Emitter Rear Cell
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
PKS	Palm kernel shells
PPA	Power purchase agreement
PPMC	Paris Process on Mobility and Climate
PPP	Purchasing power parity
PTO	Power take-off device
PUC	Public Utilities Commission
PV	Photovoltaic
R&D	Research and development
RBF	Results-based financing
REC	Renewable electricity certificate
RED	EU Renewable Energy Directive
RFS	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
SUM4ALL	Sustainability Mobility for All
TDA	Transport Decarbonisation Alliance
TES	Thermal energy storage
TFC	Total final consumption of energy
TFEC	Total final energy consumption
Toe	Tonne of oil equivalent
TW/TWh	Terawatt/terawatt-hour
UAE	United Arab Emirates
UN	United Nations
UNEP	United Nations Environment
UNHCR	United Nations Refugee Agency
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
Yieldco	Yield company

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: 32.7 MJ/l
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 1.3 litres of biodiesel 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.

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20 Ibid., all sources.

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188 Total capacity based on data provided throughout this report. See Market and Industry chapter, Reference Table R1 and related endnotes for details and sources. Share of generation based on the following: total global electricity generation in 2017 is estimated at 25,518 TWh, based on 24,765 TWh in 2016 from IEA, *World Energy Outlook 2017*, op. cit. note 18, and on estimated 3.04% growth in global electricity generation in 2017. Growth rate is based on the weighted average actual change in total generation for the following countries/regions (which together account for nearly two-thirds of global generation in 2016): United States (-1.52% net generation), EU (+2.88%), Russian Federation (+0.52%), India (+7.67%), China (+5.9%) and Brazil (+1.02%). Generation data for 2016 and 2017 by country or region from the following: EIA, *Electric Power Monthly with Data for December 2017* (Washington, DC: February 2018), Table 1.1; EC, Eurostat database, http://ec.europa.eu/eurostat, viewed May 2018; System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2017* (Moscow: 31 January 2018), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2018/ups_rep2017.pdf; Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly generation report", http://www.cea.nic.in/monthlyarchive.html, viewed April 2018; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2017 national economic and social development", press release (Beijing: 28 February 2018), http://www.stats.gov.cn/english/PressRelease/201802/t20180228_1585666.html (using Google Translate); National Electrical System Operator of Brazil (ONS), http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed April 2018. **Hydropower** generation in 2017 of 4,184 TWh from International Hydropower Association (IHA) personal communications with REN21, March-April 2018. **CSP** estimated at 11.9 TWh, based on preliminary data for Spain (5,375 GWh) from Red Eléctrica de España (REE), *The Spanish Electricity System – Preliminary Report 2017* (Madrid: 5 February 2018), with estimated data as of 13 December 2017, p. 4, http://www.ree.es/en/statistical-data-of-spanish-electrical-system/annual-report/spanish-electricity-system-preliminary-report-2017; US generation (3,269 GWh) from EIA, op. cit. this note, Table 1.18.B, and projected global generation in 2017 for rest of world (3,251 GWh) from IEA, *Renewables 2017*, op. cit. note 18. **Solar PV** worldwide production potential of 494 TWh, from Gaëtan Masson, Becquerel Institute and IEA PVPS, personal communication with REN21, 29 March 2018; and potential close to 500 TWh, from IEA PVPS, op. cit. note 184, pp. 4, 12-15. 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 2017. **Wind power** generation estimated at 1,430 TWh based on capacity at end-2017 from GWEC, op. cit. note 186, p. 17, and on weighted average capacity factors by region, and for both onshore and offshore wind power, from IRENA, personal communications with REN21, March-April 2018. (See Table 3 in this report.) **Geothermal power** generation of 87.7 TWh from IEA, *Renewables 2017*, op. cit. note 18. **Ocean energy** generation of 1.1 TWh from idem. **Bio-power** generation of 555 TWh from note 35 in Bioenergy section in Market and Industry chapter. **Figure 6** based on all sources in this note.

189 IRENA, *Renewable Power Generation Costs in 2017* (Abu Dhabi: 2018), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf.

190 Ibid., pp. 16, 23.

191 Ibid., p. 17.

192 Wind power from Steve Sawyer, GWEC, personal communication with REN21, 8 February 2018, and from GWEC, op. cit. note 186, p. 17. See also: Gillian Steward, "Alberta leads the pack with cheap wind power; more to come", Renewable Energy World, 21 February 2018, https://www.renewableenergyworld.com/articles/2018/02/alberta-leads-the-pack-with-cheap-wind-power-more-to-come.html; "Wind joins pricing race with solar", Bridge to India, 9 October 2017, http://www.bridgetoindia.com/wind-joins-pricing-race-solar/; FS-UNEP and BNEF, op. cit. note 31, pp. 11, 34, 40; FTI Consulting, "Vestas Holds the Top Spot in Global Wind Turbine Supplier Ranking in 2017", 26 February 2018, http://www.fticonsulting.com/about/newsroom/press-releases/vestas-holds-the-top-spot-in-global-wind-turbine-supplier-ranking-in-2017. Solar PV from, for example: FS-UNEP and BNEF, op. cit. note 31, pp. 11, 34; Emiliano Bellini, "Lowest solar bid in Argentina's latest RE auction reaches $40.4/MWh", *PV Magazine*, 24 November 2017, https://www.pv-magazine.com/2017/11/24/lowest-solar-bid-in-argentinas-latest-re-auction-reaches-40-4mwh/; Anindya Upadhyay and Rajesh Kumar Singh, "Cheaper solar in India prompts rethink for coal projects", *Bloomberg*, 1 June 2017, https://www.bloomberg.com/news/articles/2017-06-01/cheaper-solar-in-india-prompts-rethink-for-more-coal-projects; Tom Kenning, "Yet another India solar tariff record of 2.44 rupees in Rajasthan", PV-Tech, 12 May 2017, https://www.pv-tech.org/news/yet-another-india-solar-tariff-record-of-2.44-rupees-in-rajasthan; Anu Bhambhani, "World's lowest solar price offer in technical bid of 300 MW Sakaka PV project in Saudi Arabia offered at 1.79 US cents/kWh", *Taiyang News*, 5 October 2017, http://taiyangnews.info/markets/record-low-solar-bid/. See Solar PV and Wind Power sections of Market and Industry chapter for more information and sources.

193 See, for example, David Weston, "UK offshore falls to £57.50 in latest CfD round", *Windpower Offshore*, 11 September 2017, http://www.windpoweroffshore.com/article/1444146/uk-offshore-falls-5750-latest-cfd-round; FTI Consulting, op. cit. note 192; BMWi, "Windenergieanlagen auf See", https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Ausschreibungen/Offshore/offshore-node.html, viewed 17 April 2018; Tino Andresen, "Offshore wind farms offer subsidy-free power for first time", *Bloomberg*, 13 April 2017, https://www.bloomberg.com/news/articles/2017-04-13/germany-gets-bids-for-first-subsidy-free-offshore-wind-farms; David Weston, "Vattenfall bids in no-subsidy Dutch tender", *Windpower Offshore*, 15 December 2017, https://www.windpoweroffshore.com/article/1452992/vattenfall-bids-no-subsidy-duch-tender. For more information, see Wind Power section in Market and Industry chapter.

194 Solar or wind plus batteries is now competitive with gas peaking plants in Australia, India and the United States, from Giles Parkinson, "Solar, wind and batteries are killing market for new gas plants", RenewEconomy, 9 April 2018, https://reneweconomy.com.au/solar-wind-batteries-killing-market-new-gas-plants-57621/; Australia also from Reputex, "The Energy Trilemma – a cost curve for abatement & energy storage in Australia", 8 March 2018, http://www.reputex.com/research-insights/update-the-energy-trilemma-a-cost-curve-for-abatement-energy-storage-in-australia/. See also Colorado, from Martin Rosenberg, "Batteries out-distance gas-burning generators", *Energy Times*, 14 February 2018, http://www.theenergytimes.com/solar/batteries-out-distance-gas-burning-generators.

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196 European Wind Energy Association, *Design Options for Wind Energy Tenders* (Brussels: December 2015), p. 8, http://www.ewea.org/fileadmin/files/library/publications/position-papers/EWEA-Design-options-for-wind-energy-tenders.pdf.

197 Shota Furuya, Institute for Sustainable Energy Policies (ISEP), "The community power movement is on the rise in Japan", *The Beam*, 13 February 2017, https://medium.com/thebeammagazine/community-power-gears-up-global-renewable-energymovement-dccbc184fea6.

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199 Furuya, op. cit. note 197; Hironao Matsubara, ISEP, Tokyo, personal communication with REN21, 1 May 2018. Capacity of community solar PV projects increased from 45 MW in 2016 to 86 MW in 2017, from idem.

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Country data from the following sources: **China**: hydropower based on data from IHA and IRENA, personal communications with REN21, March-April 2018; wind power from China Wind Energy Association, "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, and from GWEC, op. cit. note 186, p. 17; solar PV from IEA PVPS, op. cit. note 184, pp. 4, 5, 10, 15, from NEA, "National power industry statistics list", 22 January 2018, http://www.nea.gov.cn/2018-01/22/c_136914154.htm (using Google Translate), and from NEA, "National Energy Administration press conference introduces related energy situation, etc", 24 January 2018, http://www.nea.gov.cn/2018-01/24/c_136921015.htm (using Google Translate); bio-power from NEA, idem; geothermal power from IRENA, personal communication with REN21, April 2018; CSP based on 10 MW Supcon project (operational as of 2013) and 10 MW SunCan project (operational as of 2016), both from NREL, "Concentrating solar power projects in China", http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=CN, updated 17 April 2017 (see CSP section in Market and Industry chapter for more details); ocean power from IRENA, "Renewable Electricity Capacity and Generation Statistics", op. cit. note 186. **United States**: hydropower and geothermal from EIA, op. cit. note 188, Tables 6.2.B and 6.3; US Federal Energy Regulatory Commission (FERC), "Energy Infrastructure Update for December 2017" (Washington, DC: December 2017), https://www.ferc.gov/legal/staff-reports/2017/dec-energy-infrastructure.pdf; wind power from American Wind Energy Association, *AWEA U.S. Wind Industry Annual Market Report Year Ending 2017* (Washington, DC: April 2018); solar PV from IEA PVPS, op. cit. note 184, pp. 4, 15, and from GTM Research and Solar Energy Industries Association, *U.S. Solar Market Insight: 2017 Year in Review, Executive Summary* (Boston: March 2018), p. 9, https://www.greentechmedia.com/research/subscription/u-s-solar-market-insight; bio-power from FERC, op. cit. this note; CSP from NREL, "Concentrating solar power projects in the United States", https://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=US, viewed April 2018; ocean power from IRENA, "Renewable Electricity Capacity and Generation Statistics", op. cit. note 186. **Brazil**: hydropower based on data from National Agency for Electrical Energy (ANEEL), "Resumo geral dos novos empreendimentos de geração", http://www.aneel.gov.br/acompanhamento-da-expansao-da-oferta-de-geracao-de-energia-eletrica, updated April 2018, and from ANEEL, "Informações gerenciais", http://www.aneel.gov.br/informacoes-gerenciais; wind power from GWEC, op. cit. note 186, p. 17, and from Associação Brasileira de Energia Eólica, "Brasil sobe mais uma posição no Ranking mundial de capacidade instalada de energia eólica", 15 February 2018, http://www.abeeolica.org.br/noticias/brasil-sobe-mais-uma-posicao-no-ranking-mundial-de-capacidade-instalada-de-energia-eolica/ (using Google Translate); solar PV from Becquerel Institute, personal communication with REN21, 29 March 2018; bio-power from IRENA, "Renewable Electricity Capacity and Generation Statistics", op. cit. note 186, p. 29. **Germany:** all from BMWi, *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) (Stand: Februar 2018)* (Berlin: March 2018), p. 7, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html; wind power also from WindEurope, *Wind in Power 2017: Annual Combined Onshore and Offshore Wind Statistics* (Brussels: February 2018), pp. 7, 9, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf. **India:** hydropower from Government of India, Ministry of Power, CEA, "Hydro reports", December 2017, http://www.cea.nic.in/monthlyarchive.html, and from Government of India, Ministry of Power, CEA, "Executive summary of the power sector (monthly)", http://www.cea.nic.in/monthlyarchive.html, viewed April 2018; wind power from Government of India, Ministry of Power, CEA, *All India Installed Capacity, Monthly Report January 2018* (New Delhi: 2018), table on "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; solar PV from IEA PVPS, op. cit. note 184, pp. 4, 10; bio-power from Government of India, Ministry of New and Renewable Energy, "Physical progress (achievements)", https://mnre.gov.in/physical-progress-achievements, viewed 30 January 2018; CSP from NREL, "Concentrating solar power projects in India", https://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=IN, viewed 5 May 2018.

201 China share and capacity data based on statistics and references provided elsewhere in this section. See also Market and Industry chapter and Reference Table R2.

202 Rankings for top countries for non-hydropower capacity based on sources provided for China, the United States, Germany and India in endnote 200, and from the following: **Japan:** hydropower based on data from Japan Agency for Natural Resource and Energy, Ministry of Trade and Energy, provided by Hironao Matsubara, ISEP, personal communication with REN21, 8 May 2018; wind power from GWEC, op. cit. note 186, p. 17; solar PV from Becquerel Institute, personal communication with REN21, 29 March 2018, and from IEA PVPS, op. cit. note 184, pp. 4, 10; bio-power from IEA, *Renewables 2017*, op. cit. note 18, Table 5, viewed 4 May 2018; geothermal based on data for end-2016 (522 MW, running capacity) from IEA Geothermal, *2016 Annual Report* (Taupo, New Zealand: October 2017), p. 66, http://iea-gia.org/publications-2/annual-reports/, and addition of 5 MW in 2017, from Alexander Richter, "Idemitsu Kosan starts operation of 5 MW Takigami geothermal plant, Japan", ThinkGeoEnergy, 7 March 2017, http://www.thinkgeoenergy.com/idemitsu-kosan-starts-operation-of-5-mw-takigami-geothermal-plant-japan. **United Kingdom**: hydropower, bio-power and ocean power from UK Department for Business, Energy & Industrial Strategy, "Energy Trends: renewables, Section 6", p. 69, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, updated 29 March 2018; wind power from WindEurope, op. cit. note 200, pp. 7, 9; solar PV from UK Department for Business, Energy & Industrial Strategy, "Solar Photovoltaics Deployment in the UK February 2018", updated 29 March 2018, Table 1, https://www.gov.uk/government/statistics/solar-photovoltaics-deployment, and from IEA PVPS, op. cit. note 184, pp. 4, 15. **Figure 7** based on sources in this note, on sources in endnote 200, and on global data available throughout this report, including Reference Tables R1 (and associated endnote) and R2, as well as on data for the following: **EU-28:** hydropower from the following: IRENA, personal communication with REN21, April 2018; IHA, personal communication with REN21, April 2018; IRENA, "Renewable Electricity Capacity and Generation Statistics", op. cit. note 186; BMWi, op. cit. note 200, p. 7; UK Department for Business, Energy & Industrial Strategy, "Energy Trends: renewables, Section 6", op. cit. this note, p. 69; and from IHA, *2018 Hydropower Status Report – Sector Trends and Insights* (London: May 2018), https://www.hydropower.org/sites/default/files/publications-docs/2018_hydropower_status_report_0.pdf. Wind power from WindEurope, op. cit. note 200, pp. 7, 9; solar PV from Becquerel Institute, personal communication with REN21, April 2018; bio-power based on data from BMWi, op. cit. note 200, p. 7, and from UK Department for Business, Energy & Industrial Strategy, op. cit this note, p. 69; bio-power data for other countries is based on forecast 2017 capacity figures from IEA, *Renewables 2017*, op. cit. note 18, Table 5. Geothermal based on data for Germany from BMWi, op. cit. note 200, p. 7. Italy from from IEA Geothermal, op. cit. this note, pp. 55, 66; Austria, France and Portugal from IRENA, "Renewable Electricity Capacity and Generation Statistics", op. cit. note 186. CSP based on REE, op. cit. note 200, p. 4, (beyond Spain,

projects are small-scale and/or pilots). Ocean power from IRENA, "Renewable Electricity Capacity and Generation Statistics", op. cit. note 186. **Russian Federation**: hydropower from System Operator of the Unified Energy System of Russia, op. cit. note 187; wind power from WindEurope, op. cit. note 200, pp. 7, 9; solar PV from Anton Usachev, Russian Solar Industry Association, personal communication with REN21, April 2018; bio-power from IEA, *Renewables 2017*, op. cit. note 18, Table 5; geothermal and ocean power from IRENA, "Renewable Electricity Capacity and Generation Statistics", op. cit. note 186. **South Africa**: hydropower from idem; wind power from GWEC, op. cit. note 186, p. 17; solar PV from IEA PVPS, op. cit. note 184, pp. 4, 15; bio-power from IEA, *Renewables 2017*, op. cit. note 18, Table 5; CSP from NREL, "Concentrating solar power projects in South Africa", https://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=ZA, viewed 5 May 2018.

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POLICY LANDSCAPE

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BIOENERGY

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36 **Figure 18** based on analysis conducted using historical REN21 data for years to 2015, and on analysis of national data from the following sources: United States from EIA, op. cit. note 35, Table 1.1a, corrected for difference between net and gross electricity generation; Germany from BMWi, op. cit. note 34, Table 3; United Kingdom from UK Department for Business, Energy & Industrial Strategy, op. cit. note 34, Table 6.1; China from NEA, op. cit. note 34. Data for other countries are based on forecast 2017 generation figures from IEA, *Renewables 2017*, op. cit. note 2.

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34 Second consecutive year based on solar PV being the largest source of new US generating capacity in 2016, from Mark Bolinger et al., *Utility-scale Solar 2016: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States* (Berkeley, CA: LBNL, September 2017), p. ii, https://emp.lbl.gov/sites/default/files/utility-scale-solar-2016-report.pdf. Leading source in 2017 based on US additions of 8,173 MW of solar PV capacity (utility-scale plus small-scale), 6,257 MW of wind power capacity, and 5,984.6 MW (net) of natural gas capacity, from EIA, op. cit. note 2, Table 6.1, https://www.eia.gov/electricity/monthly/archive/february2018.pdf. Note that EIA data are net additions and omit plants with a total generator nameplate capacity below 1 MW.

35 Data for top states from GTM Research and SEIA, op. cit. note 33, p. 9. California had 21,074 MW (about 40% of the country's total capacity) in operation at end-2017, from SEIA, op. cit. note 33.

36 Solar PV accounted for more than 10% of total electricity generation in California, Hawaii, Nevada, Vermont and Washington, DC during 2017, and for more than 5% in Arizona, Massachusetts and Utah, based on data from EIA, op. cit. note 2, Tables 1.17.B and 1.3.B.

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38 Based on 2017 data (including 6,234 MW_{dc} of utility-scale and 2,227 MW_{dc} of residential solar PV capacity installed), from GTM Research and SEIA, op. cit. note 33, pp. 5, 12, and on 2016 data (including 10,593 MW_{dc} of utility-scale installations and 2,583 MW_{dc} of residential installations), from GTM Research and SEIA, *U.S. Solar Market Insight: 2016 Year in Review, Executive Summary* (Boston: March 2017), pp. 10, 11, https://www.greentechmedia.com/research. The residential sector contracted due to weakness in California, which is home to almost half of US rooftop systems, and in major northeast markets, from GTM Research and SEIA, op. cit. note 33, p. 11.

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85 A solar thermal air conditioning system planned in Turpan with 40,000 m² of flat plate solar collectors working with lithium bromide absorption chillers cooling the demonstration building (mainly public buildings) with a floor space of 200,000 m², from Zheng Ruicheng, Institute of Built Environment and Energy Efficiency of the China Academy of Building Research, Beijing, China, personal communication with REN21, March 2018; 10,000 m² of collector area should heat and cool the Xiaoya office and industry complex in Jinan, the capitol of Shandong Province, from QingLong Zhang, Sanqiaoneng New Energy, Jinan, China, personal communication with REN21, March 2018.
86 Monitoring results were published for a 35 kW absorption chiller with 240 m² of flat plate collectors in a building containing offices and flats in Montpellier, southern France, that increased the annual solar fraction of the domestic hot water production to 70% and prevented the solar system from overheating in summer, from Bärbel Epp, "Solar cooling increases annual solar fraction", solarthermalworld, 24 February 2018, http://www.solarthermalworld.org/content/solar-cooling-increases-annual-solar-fraction.

87 Cheng, op. cit. note 16.

88 Bärbel Epp, "World's largest flat plate collector manufacturers in 2017", solarthermalworld, 19 March 2018, http://www.solarthermalworld.org/content/worlds-largest-flat-plate-collector-manufacturers-2017.

89 Bärbel Epp, "Austria: Haier now holds 51% stake in Greenonetec", solarthermalworld, 15 June 2017, http://www.solarthermalworld.org/content/austria-haier-now-holds-51-stake-greenonetec.

90 Epp, op. cit. note 12.

91 Zhang, op. cit. note 85.

92 Epp, op. cit. note 12; Cheng, op. cit. note 15.

93 Epp, op. cit. note 88.

94 Ibid.

95 Ibid.

96 Ibid.

97 Bärbel Epp, "Sonnenkraft, Holter and Tisun – the changing face of Austria's industry", solarthermalworld, 26 February 2018, http://www.solarthermalworld.org/content/sonnenkraft-holter-and-tisun-changing-face-austrias-industry.

98 Among the world's 20 largest flat plate collector manufacturers, 7 were very satisfied or satisfied with their sales levels in 2017, and only 4 were disappointed or very disappointed. The majority of these companies reached a sales volume as expected, as per the survey carried out by solrico, Germany in January and February 2018 of the 20 largest flat plate collector manufacturers worldwide related to collector area produced in 2017, from Epp, op. cit. note 88.

99 Epp, op. cit. note 88.

100 Costas Travasaros, Greek Solar Industry Association (EBHE), Piräus, Greece, personal communication with REN21, January 2017.

101 Ibid.

102 Alejandro Diego Rosell, "Spain's 2017 figures show increase in collector production despite declining market", solarthermalworld, 6 March 2018, http://www.solarthermalworld.org/content/spains-2017-figures-show-increase-collector-production-despite-declining-market.

103 With the revenue from this sale, Absolicon started automating and upgrading production at its headquarters in Härnösand, Sweden, from Joakim Byström, Absolicon Solar Collector, Härnösand, Sweden, personal communication with REN21, March and April 2018.

104 Eugene Gerden, "Moldova: Vacuum tube collector assembly line inaugurated", solarthermalworld, 22 September 2017, http://www.solarthermalworld.org/content/moldova-vacuum-tube-collector-assembly-line-inaugurated.

105 Bärbel Epp, "State-of-the-art collector production in Uzbekistan", solarthermalworld, 9 February 2018, http://www.solarthermalworld.org/content/state-art-collector-production-uzbekistan.

106 Epp, op. cit. note 88.

107 Ibid.

108 Two of three major thermal chiller system manufacturers and suppliers in Germany use not solar, but waste heat, as the driving source for the chillers, from Bärbel Epp, solrico, Germany, personal communication with REN21, March 2018; Romina Bayer, Invensor GmbH, Germany, personal communication with REN21, March 2018.

109 For 2017, Yazaki's European sales partner Maya (Italy) reported the construction of six new solar thermal cooling systems in Italy and three units in Spain; all were installed in commercial buildings for co-production of hot water and/or space heating, from Bärbel Epp, "Solar cooling demand on the rise in Italy, Spain and the Middle East", solarthermalworld, 27 April 2018, http://www.solarthermalworld.org/content/solar-cooling-demand-rise-italy-spain-and-middle-east.

WIND POWER

1 The wind industry added a gross of 52,492 MW for a total of 539,123 MW (net of decommissioning), about 3.8% below 2016 additions, from Global Wind Energy Council (GWEC), *Global Wind Report – Annual Market Update 2017* (Brussels: April 2018), p. 4, http://files.gwec.net/files/GWR2017.pdf; additions were up slightly relative to 2016, to 51,402 MW for a total of 539,291 MW, from World Wind Energy Association (WWEA), "Wind power capacity reaches 539 GW, 52,6 GW added in 2017", press release (Bonn: 12 February 2018), http://www.wwindea.org/2017-statistics/; 53,531 MW was added for a total of 540,997 MW, from FTI Consulting, *Global Wind Market Update – Demand & Supply 2017, Part Two – Demand Side Analysis* (London: April 2018), p. 47, https://fti-intelligencestore.com/index.php?route=download/main&download_id=160; and 51,644 MW was added (connected capacity) for a total of 539,256 GW, from EurObserv'ER, *Wind Energy Barometer* (Paris: February 2018), p. 3, https://www.eurobserv-er.org/wind-energy-barometer-2018/.

2 Increase and cumulative capacity based on data from all sources in endnote 1. **Figure 34** based on historical data from GWEC, op. cit. note 1, p. 20; data for 2017 from sources in this section. Note that annual additions reported in this section are generally gross additions; the net increase in total capacity can be lower, reflecting decommissioning. However, relatively few of the countries that installed wind power capacity during the year decommissioned previously existing capacity. Year-end totals account for decommissioned capacity.

3 Steve Sawyer, GWEC, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 6 March 2018, and GWEC, op. cit. note 1. China also from FTI Intelligence, "Preliminary turbine OEM rankings for 2017", 26 February 2018, https://fti-intelligencestore.com/index.php?route=download/main&download_id=157, and from "Vestas keeps lead in onshore wind, Siemens Gamesa narrows gap", Bloomberg New Energy Finance (BNEF), 26 February 2018, https://about.bnef.com/blog/vestas-keeps-lead-in-onshore-wind-siemens-gamesa-narrows-gap/. Records were set in Belgium, Croatia, France, Germany, Ireland and the United Kingdom in Europe, and in India, as well as in the offshore sector, from GWEC, op. cit. note 1.

4 Figure of 90 countries from Shruti Shukla, GWEC, personal communication with REN21, 13 April 2017, and confirmed with same source in March 2018. Figure of 30 countries from Jean-Daniel Pitteloud, WWEA, personal communication with REN21, 4 April 2018, and from GWEC, op. cit. note 1, p. 18.

5 GWEC, op. cit. note 1, p. 25.

6 Steve Sawyer, GWEC, personal communications with REN21, 24 January and 20 April 2018; WWEA, op. cit. note 1; Feng Zhao, FTI Consulting, Copenhagen, personal communication with REN21, 19 April 2018; WindEurope, Brussels, personal communication with REN21, 29 March 2018; EurObserv'ER, op. cit. note 1.

7 Sawyer, op. cit. note 3; Tom Randall, "Wind and solar are crushing fossil fuels", *Bloomberg*, 6 April 2017, https://www.bloomberg.com/news/articles/2016-04-06/wind-and-solar-are-crushing-fossil-fuels; "Wind power leading the charge to drive out fossils", GWEC, 15 June 2017, http://gwec.net/wind-power-leading-the-charge-to-drive-out-fossils/.

8 Steve Sawyer, GWEC, personal communication with REN21, 14 February 2018; Vestas, "Annual Report 2017 – Summary", https://www.vestas.com/en/investor/financial_reports/2017/q4#!intro, viewed 18 March 2018; Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance (FS-UNEP) and BNEF, *Global Trends in Renewable Energy Investment 2018* (Frankfurt: April 2018), p. 18, http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf.

9 Based on data from GWEC, op. cit. note 1, p. 17. GSR data 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.

10 GWEC, op. cit. note 1; WWEA, op. cit. note 1.

11 Based on data from GWEC, op. cit. note 1, and WindEurope, *Wind in Power 2017: Annual Combined Onshore and Offshore Wind Statistics* (Brussels: February 2018), p. 9, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf. **Figure 35** based on country-specific data and sources provided throughout this section (or see endnote for Reference Table R21).

12 Jean-Daniel Pitteloud, WWEA, personal communication with REN21, April 2018. Denmark had an estimated 960.3 watts (W) per 1,000 inhabitants, followed by Ireland (704.7 W), Sweden (672.4 W), Germany (671.5 W) and Portugal (515.3 W), from EurObserv'ER, op. cit. note 1, p. 13.

13 China added 19.66 GW in 2017 for a year-end total of 188.39 GW, from Chinese 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. CWEA data 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. China added 19.52 GW in 2017, from China Electricity Council (CEC), "CEC releases 2016-2018 annual electricity supply and demand situation analysis and forecast report'", 1 February 2018, http://www.cec.org.cn/guihuayutongji/gongzuodongtai/2018-02-01/177584.html (using Google Translate); China added 19,660 MW for a total of 188,392 MW, from GWEC, op. cit. note 1, p. 17; added 19,660 MW for a total of 188,390 MW, from FTI Consulting, op. cit. note 1, p. 51; and added 19,000 MW for a total of 187,730 MW, from WWEA, op. cit. note 1.

14 Steve Sawyer, GWEC, personal communication with REN21, 20 April 2018; Zhao, op. cit. note 6; EurObserv'ER, op. cit. note 1, pp. 4-5.

15 Based on additions of 15.03 GW for total of 164 GW in operation, from China National Energy Board, cited in China National Energy Administration (NEA), "Wind grid operation in 2017", 1 February 2018, http://www.nea.gov.cn/2018-02/01/c_136942234.htm (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 2017 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 Sawyer, op. cit. note 14. No Chinese statistics provide actual grid-connected capacity, and discrepancies among available statistics can be quite large. Data from CWEA do include some capacity that is not 100% grid-connected by year's end, but are believed to most closely reflect the status of the market in China, from Liming Qiao, GWEC, personal communication with REN21, 2 May 2018. About 12% of installed capacity (24 GW) was not connected at year's end, from FTI Consulting, op. cit. note 1, p. 22.

16 Locations of installations based on data 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); NEA, op. cit. note 15; China Energy Portal, "2016 wind power installations and production by province", 26 January 2017, https://chinaenergyportal.org/en/2016-wind-power-installations-production-province/; China Energy Portal, "2017 wind power installations and production by province", 1 February 2018, https://chinaenergyportal.org/en/2017-wind-power-installations-production-province/; GWEC, op. cit. note 1, p. 40. The restrictions were on Heilongjiang, Jilin and Gansu provinces, and on Inner Mongolia, Ningxia Hui and Xinjiang Uygar autonomous regions, from "New wind power projects banned in six regions due to wastage", *China Daily*, 23 February 2017, http://www.chinadaily.com.cn/business/2017-02/23/content_28316786.htm. Low wind-speed regions from FTI Consulting, op. cit. note 1, p. 20.

17 Top provinces from China Energy Portal, "2017 wind power installations...", op. cit. note 16; close to demand centres based on Yiyi Zhou and Sophie Lu, *China's Renewables Curtailment and Coal Assets Risk Map* (London: BNEF, 25 October 2017), p. 10, https://data.bloomberglp.com/bnef/sites/14/2017/10/Chinas-Renewable-Curtailment-and-Coal-Assets-Risk-Map-FINAL_2.pdf.

18 National curtailment data for 2017 from China National Energy

Board, op. cit. note 15. National curtailment was 49.7 TWh in 2016, from NEA and CEC, provided by Shi Pengfei, CWEA, personal communication with REN21, 21 March 2017, and from NEA, op. cit. note 16.

19 Concentrated from NEA, "National Energy Administration press conference introduces related energy situation, etc.", 24 January 2018, http://www.nea.gov.cn/2018-01/24/c_136921015.htm (using Google Translate). The highest rates of curtailment in 2017 were seen in Gansu (33%), Xinjiang (29%), Jilin (21%), Inner Mongolia (15%) and Heilongjiang (14%), from China National Energy Board, op. cit. note 15. National curtailment data for 2016 from NEA and CEC, provided by Shi, op. cit. note 18, and from NEA, op. cit. note 16. The highest rates of curtailment in 2016 were seen in Gansu (43%), Xinjiang (38%), Jilin (30%) and Inner Mongolia (21%), from NEA, op. cit. note 16. Policies 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, http://www.renewableenergyworld.com/articles/2017/12/china-s-xinjiang-region-cuts-wind-and-solar-curtailment-rate-by-almost-30-percent.html, and GWEC, op. cit. note 1, p. 40.

20 Share of output from China National Energy Board, op. cit. note 15. Wind generation was 305.7 TWh in 2017, from idem. This was up from 241 TWh and 4% of generation in 2016, from NEA, op. cit. note 16; 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).

21 India added approximately 4,147.56 MW of wind power capacity in 2017 for a year-end total of 32,848.46 MW, based on Government of India, Ministry of Power, Central Electricity Authority (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; Government of India, Ministry of Power, CEA, *All India Installed Capacity, Monthly Report January 2017* (New Delhi: 2017), Table: "All India installed capacity (in MW) of power stations (as on 31.01.2017) (Utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-01.pdf. India added 4,148 MW for a total of 32,848 MW, from GWEC, op. cit. note 1, p. 49; and added 4,148 MW for a total of 32,846 MW, from FTI Consulting, op. cit. note 1, p. 51.

22 FTI Consulting, op. cit. note 1, p. 20; "India wind power market report 2017 – research and markets", Business Wire, 12 December 2017, https://www.businesswire.com/news/home/20171212006200/en/India-Wind-Power-Market-Report-2017--.

23 "India wind power…", op. cit. note 22; Sushma U N, "After the storm of 2017, India's wind power sector is settling down", Quartz India, 6 April 2018, https://qz.com/1245556/indias-wind-power-sector-had-a-terrible-year-in-2017-can-it-turn-around/; Ann Josey et al., "India's electricity companies have surplus power – and that's a big challenge", Scroll.in, 30 May 2017, https://scroll.in/article/838000/indias-electricity-companies-have-surplus-power-and-thats-a-big-challenge; Government of India, Ministry of Power, "Power sector at a glance – All India: 3.0 power supply position", https://powermin.nic.in/en/content/power-sector-glance-all-india#, viewed 1 April 2018; Bhanvi Arora, "India's low tariffs hurt wind turbine makers", Renewable Energy World, 14 September 2017, http://www.renewableenergyworld.com/articles/2017/09/india-s-low-tariffs-hurt-wind-turbine-makers.html; Steve Sawyer, GWEC, personal communication with REN21, April 2018. By year's end, India had little need for new power capacity in the short-term: over the period 2009-2017, India's significant power supply deficits were dramatically reduced, from Bridge to India, "2017, a year of some 'highs' but many 'lows'", 20 December 2017, http://www.bridgetoindia.com/wp-content/uploads/2018/01/Weekly-2017-a-year-of-some-highs-but-many-lows.pdf.

24 Bridge to India, op. cit. note 23; Arora, op. cit. note 23; Sushma, op. cit. note 23.

25 Turkey added 1,387.75 MW in 2016 for a total of 6,106.05 MW, and added 766.05 MW in 2017 for a total of 6,872.1 MW, from Turkish Wind Energy Association, *Türkiye Rüzgar Enerjisi Istatistik Özet Raporu* (Ankara: January 2018), p. 4, http://www.tureb.com.tr/files/tureb_sayfa/duyurular/2018/02_subat/turkiye_ruzgar_enerjisi_istatistik_ozet_raporu.pdf; added 766 MW in 2017 for a total of 6,857 MW, from WindEurope, op. cit. note 11, p. 9; added 766 MW for a total of 6,871 MW, from FTI Consulting, op. cit. note 1, p. 50; added 900 MW for a total of 6,981 MW, from WWEA, op. cit. note 1.

26 "2,130 MW wind power plants to be established in 32 locations across Turkey", Daily Sabah, 25 December 2017, https://www.dailysabah.com/energy/2017/12/26/2130-mw-wind-power-plants-to-be-established-in-32-locations-across-turkey.

27 Pakistan added 199 MW for a total of 789 MW, Japan added 177 MW for a total of 3,400 MW, and the Republic of Korea added 106 MW for a total of 1,136 GW, from GWEC, op. cit. note 1, p. 17. In addition, Mongolia added 50 MW for a total of 100 MW, Vietnam added 38 MW for a total of 197 MW, Thailand added 24 MW for a total of 633 MW, Chinese Taipei added 10 MW for a total of 692 MW, and all Asia ended 2017 with approximately 235,599 MW (including Turkey), from idem. Pakistan added 200 MW for a total of 909 MW, Japan added 177 MW for a total of 3,395 MW, the Republic of Korea added 106 MW for a total of 1,112 MW, the Philippines added 40 MW for a total of 499 MW, Chinese Taipei added 13 MW for a total of 690 MW, and Thailand added 98 MW for a total of 679 MW, from FTI Consulting, op. cit. note 1, pp. 51, 54.

28 The EU installed 15,638 MW (14,998 MW_{net}), including 12,484 MW onshore and 3,154 MW offshore, for a year-end total of 168,729 MW (153 GW onshore and 15.8 GW offshore), based on data from WindEurope, op. cit. note 11, pp. 7, 9. The EU installed 14,750 MW, decommissioned 605 MW, and ended 2017 with a total of 168,993 MW, from EurObserv'ER, op. cit. note 1, p. 3.

29 Change in regulatory framework from WindEurope, op. cit. note 6; EurObserv'ER, op. cit. note 1, p. 2; "Europe powered by wind: Germany added 42% of EU's 2017 wind capacity", EU Bulletin, 15 February 2018, http://www.eubulletin.com/8183-europe-powered-by-wind-germany-added-42-of-eus-2017-wind-capacity.html; David Weston, "Race to beat auctions sees European capacity grow 20%", *Windpower Monthly*, 13 February 2018, https://www.windpowermonthly.com/article/1456946/race-beat-auctions-sees-european-capacity-grow-20. See also Craig Richard, "Danish installations surge ahead of support closure", *Windpower Monthly*, 15 March 2018, https://www.windpowermonthly.com/article/1459597/danish-installations-surge-ahead-support-closure. The EU installed 12,484 MW onshore and 3,154 MW offshore, from WindEurope, op. cit. note 11, pp. 7, 9. For more on the European Commission (EC) guidelines, see EC, "Communication from the Commission: Guidelines on State aid for environmental protection and energy 2014-2010", *Official Journal of the European Union*, 28 June 2014, Section 3.3, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014XC0628%2801%29.

30 WindEurope, op. cit. note 11, pp. 7, 9, 15; 12% in 2012 from WindEurope, op. cit. note 6.

31 WindEurope, op. cit. note 11, pp. 7, 9.

32 Estimated output in 2017 was 336 TWh and share of EU consumption was 11.6%, from WindEurope, op. cit. note 11, pp. 7, 21, 22; estimated output in 2016 was 300 TWh, from WindEurope, *Wind in Power – 2016 European Statistics* (Brussels: February 2017), p. 7.

33 WindEurope, op. cit. note 11, pp. 7, 9.

34 Ibid., p. 19. Ireland was followed by Germany and the United Kingdom.

35 Finland added 535 MW for a total of 2,071 MW, from WindEurope, op. cit. note 11, pp. 7, 9, 10, and from GWEC, op. cit. note 1, p. 17; last projects under FIT, and Finland added 516 MW for a total of 2,040 MW, all from FTI Consulting, op. cit. note 1, pp. 15, 50.

36 WindEurope, op. cit. note 11, pp. 7, 9. In 2016, 20 countries added capacity from idem, pp. 7, 9; also in 2016, six countries accounted for 79.2% of the region's installations in 2016, from WindEurope, op. cit. note 32, p. 10. Only 15 EU countries added capacity during 2017, from EurObserv'ER, op. cit. note 1, p. 7.

37 Germany added 5,333.53 MW onshore and 1,247 offshore for a gross total of 6,580.53 MW added, and a net total (considering 467.27 MW of decommissioned capacity onshore) of 6,113.26 MW added, all from WindEurope, personal communication with REN21, 30 April 2018; year-end total capacity of 56,132 MW, from WindEurope, op. cit. note 11, p. 9; year-end total offshore capacity of 5,355 MW, from WindEurope, *Offshore Wind in Europe – Key Trends and Statistics 2017* (Brussels: February 2018), p. 18, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2017.pdf; year-end onshore total capacity of 50,777 MW based on total capacity of 56,132 MW less offshore capacity of 5,355 MW. WindEurope

reports net capacity connected to the grid by 31 December 2017, from WindEurope, personal communication with REN21, 30 April 2018. Data from other sources vary considerably due to differences in methodology. For example, Germany's gross additions were 5,484 MW onshore and 1,275 MW offshore for a total of 6,762 MW, from Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) and Umwelt Bundesamt, *Erneuerbare Energien in Deutschland, Daten zur Entwicklung im Jahr 2017* (Dessau-Roßlau: March 2018), pp. 9-10, https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/180315_uba_hg_eeinzahlen_2018_bf.pdf; and net additions were 5,015 MW onshore and 1,275 MW offshore for a total of 6,290 MW added in 2017, and year-end cumulative of 50,469 MW onshore plus 5,407 MW offshore, for a combined total of 55,876 MW, all 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 2018)* (Berlin: March 2018), p. 7, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html. Germany added a net of 6,145.26 MW in 2017, based on net additions onshore of 4,866.26 MW (5,333.53 MW gross additions; 951.77 MW repowering; 467.27 MW dismantled), plus offshore additions of 1,250.3 MW, plus modifications to existing offshore turbines for additional capacity of 28.8 MW, for a cumulative year-end total of 56,163 MW (50,776.93 MW onshore and 5,387 MW offshore), from Deutsche Windguard, *Status of Offshore Wind Energy Development in Germany* (Varel: undated), http://www.windguard.com/year-2017.html, and from Deutsche Windguard, *Status of Land-based Wind Energy Development in Germany* (Varel: undated), http://www.windguard.com/year-2017.html.

38 WindEurope, op. cit. note 11, p. 18; EurObserv'ER, op. cit. note 1, p. 10. EC requirements from EC, op. cit. note 29.

39 Increase in capacity based on data for end-2016 and end-2017, from WindEurope, op. cit. note 11, p. 9; increase in generation based on data for 2016 (79.9 TWh) and 2017 (106.6 TWh generated), from BMWi, op. cit. note 37, pp. 6, 7, 42, 43. Better wind conditions from AGEE-Stat and Umwelt Bundesamt, op. cit. note 37, p. 9. Figure of 19% based on Germany's total net generation of 546.91 TWh and net wind power generation of 103.65 TWh, from Fraunhofer ISE, "Energy charts – annual electricity generation in Germany in 2017", https://www.energy-charts.de/energy.htm?source=all-sources&period=annual&year=2017, updated 12 March 2018.

40 The United Kingdom added 4,270 MW (2,590 MW onshore and 1,680 MW offshore) for a total of 18,872 MW, from WindEurope, op. cit. note 11, pp. 9, 11. The country added a net of 3,619 MW for a total of 19,837 MW, from UK Department for Business, Energy & Industrial Strategy, "Energy Trends: Renewables, Section 6", p. 69, updated 12 April 2018, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables; added 4,270 MW for a total of 18,456 MW, from FTI Consulting, op. cit. note 1, p. 50; added 3,340 MW for a total of 17,852 MW, from WWEA, op. cit. note 1.

41 WindEurope, op. cit. note 11, p. 18. Cancellation was one year earlier than expected, from FTI Consulting, op. cit. note 1, p. 15.

42 France added 1,694 MW for a total of 13,759 MW, from WindEurope, op. cit. note 11, p. 9; added 1,797 MW for a total of 13,559 MW, from Réseau de transport d'électricité (RTE), *Panorama de L'Électricité Renouvelable en 2017* (Paris: 2018), p. 13, http://www.rte-france.com/sites/default/files/panorama_enr_2017.pdf; added 1,694 MW for total of 13,624 MW, from FTI Consulting, op. cit. note 1, p. 50; added 1,695 MW for a total of 13,760, from WWEA, op. cit. note 1; and added 1,798 MW for a total of 13,559 MW, from EurObserv'ER, op. cit. note 1, p. 7. Record for second consecutive year from RTE, op. cit. this note.

43 Since 2013 from WindEurope, op. cit. note 6; FTI Consulting, op. cit. note 1, p. 15.

44 Largest in four years, from WindEurope, op. cit. note 6. Spain added 96 MW for a total of 23,170 MW, from WindEurope, op. cit. note 11, p. 9, and from EurObserv'ER, op. cit. note 1, p. 7; added 96 MW for a total of 23,131 MW, from FTI Consulting, op. cit. note 1, pp. 50, 59; added 6 MW for a total of 23,026 MW, from WWEA, op. cit. note 1. Spain held two auctions in 2017, with 4.1 GW going to onshore wind power and 3.9 GW to solar PV, from Pablo Del Río González, Instituto de Políticas y Bienes Públicos, Spain, personal communication with REN21, 8 April 2018.

45 FS-UNEP and BNEF, op. cit. note 8, p. 41. The commitment was to purchase most of the electricity from the 650 MW Markbygden Ett wind project over the 2021-2039 period, from idem.

46 Norway added 324 MW for a total of 1,162 MW, Ukraine added 68 MW for a total of 593 MW, and Serbia added 8 MW for a total of 18 MW, from WindEurope, op. cit. note 11, p. 9.

47 The 35 MW Russian wind farm is located near the city of Ulyanovsk, from "Russia's first commercial-scale wind farm has been commissioned", EV Wind, 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 1, p. 17. Russian tender from GWEC, op. cit. note 1, p. 12.

48 The United States added 7,017 MW in 2017, from American Wind Energy Association (AWEA), AWEA U.S. *Wind Industry Annual Market Report Year Ending 2017* (Washington, DC: April 2018); and added 8,203 MW in 2016, from AWEA, *AWEA U.S. Wind Industry Annual Market Report Year Ending 2016* (Washington, DC: April 2017). Down for second consecutive year from Jim Efstathiou with Brian Eckhouse, "The U.S. added wind power at a leisurely pace in 2017", *Bloomberg*, 30 January 2018, https://www.bloomberg.com/news/articles/2018-01-30/wind-additions-dip-in-2017-given-tax-credit-has-further-to-run.

49 AWEA, U.S. *Wind Industry Fourth Quarter 2017 Market Update* (Washington, DC: 25 January 2018), http://awea.files.cms-plus.com/FileDownloads/pdfs/4Q%202017%20AWEA%20Market%20Report%20Public%20Version.pdf; Efstathiou with Eckhouse, op. cit. note 48. For more on partial repowering see, for example, Eric Lantz et al., *Wind Power Project Repowering: Financial Feasibility, Decision Drivers, and Supply Chain Effects* (Golden, CO: US National Renewable Energy Laboratory, December 2013), p. v, https://www.nrel.gov/docs/fy14osti/60535.pdf; Kevin Randolph, "Repowering wind turbines becoming more common in US, EIA says", Daily Energy Insider, 7 November 2017, https://dailyenergyinsider.com/news/8892-repowering-wind-turbines-becoming-common-us-eia-says/.

50 Rankings based on data in this section. The United States added 7,017 MW for a total of 88,973 MW (accounting for decommissioning), from AWEA, *AWEA U.S. Wind Industry Annual Market Report Year Ending 2017*, op. cit. note 48, and added a net of 6,257 MW in 2017 for a total of 87,543.6 MW, from US Department of Energy (DOE), US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2017* (Washington, DC: February 2018), Table 6.1, https://www.eia.gov/electricity/monthly/archive/february2018.pdf; wind power generated 254.3 TWh of electricity in 2017, up 12% over 2016, from idem, Table 1.1.A and Table ES1.B. Note that EIA data do not include facilities smaller than 1 MW and do not include off-grid capacity.

51 Based on data from EIA, op. cit. note 50, Table 6.1.

52 Texas added 2,305 MW for a total of 22,637 MW, from AWEA, op. cit. note 49, pp. 6, 8. Ranking based on data and sources throughout this section. The states following Texas for capacity added were Oklahoma, Kansas, New Mexico and Iowa, from idem, p. 8.

53 Texas' share of electricity generation from wind power was 14.8% in 2017, based on net wind power generation at utility-scale facilities in all economic sectors and on total net power generation in Texas, from EIA, op. cit. note 50, Tables 1.3.B and 1.14.B.

54 Based on net generation from wind power at utility-scale facilities in all economic sectors in each state and nationally and total net generation in each state and nationally, from EIA, op. cit. note 50, Tables 1.3.B and 1.14.B. The top states for share of utility-scale generation from wind were Iowa (36.9%), Kansas (36%), Oklahoma (31.9%), South Dakota (30.1%) and North Dakota (26.8%), all from idem.

55 AWEA, op. cit. note 49; Chris Brown, "Major utilities buying more wind as economics drive US energy transformation", Renewable Energy World, 19 July 2017, http://www.renewableenergyworld.com/ugc/articles/2017/07/18/major-utilities-buying-more-wind-as-economics-drive-us-energy-transformation.html.

56 AWEA, op. cit. note 49.

57 Ibid., pp. 2-3. Announced corporate wind power deals (publicly announced contracted capacity of corporate PPAs as well as green power purchases, green tariffs and outright ownership) in the United States during 2017 totalled 2,281 MW, from Rocky Mountain Institute, Business Renewables Center, "State of the market – BRC member event" (April 2018), slides 2 and 13, http://www.prweb.com/releases/2018/04/prweb15421076.htm.

58 AWEA, op. cit. note 49, p. 9.

59 Canada added 341 MW for a total of 12,239 MW, from Canadian Wind Energy Association (CanWEA), "Installed capacity", https://canwea.ca/wind-energy/installed-capacity/, viewed 31 January 2018. In 2016, Canada added 702 MW, from idem, viewed 17 February 2017, and in 2015 the country added 1,506 MW, from CanWEA, "Wind energy continues rapid growth in Canada in 2015", press release (Ottawa: 12 January 2016), https://canwea.ca/news-release/2016/01/12/wind-energy-continues-rapid-growth-in-canada-in-2015/.

60 CanWEA, "Wind energy in Canada", https://canwea.ca/wp-content/uploads/2018/01/canwea-2017-wind-energy-in-canada.pdf, viewed 8 March 2018.

61 Ibid., viewed 8 March 2018. Prince Edward Island was followed by Nova Scotia (9%) and Alberta (8%), from idem.

62 Additions of 3,056 MW for a total of 21,896 MW in 2017 (including Mexico), from GWEC, op. cit. note 1, p. 17, and additions of 3,138 MW for a total of 22,009 MW, from FTI Consulting, op. cit. note 1, p. 53. Down from 2016 based on data for 2017 from idem, both sources, and on 2016 data from GWEC, *Global Wind Report – Annual Market Update 2016* (Brussels: April 2017), pp. 15, 18, http://www.gwec.net/strong-outlook-for-wind-power/.

63 Among the global top 10 and Brazil added 2,022 MW for a total of 12,763 MW, from GWEC, op. cit. note 1, p. 17; Brazil added 2.02 GW for a total of 12.76 GW, from Associação Brasileira de Energia Eólica (ABEEólica), "Brasil sobe mais uma posição no Ranking mundial de capacidade instalada de energia eólica", 15 February 2018, http://www.abeeolica.org.br/noticias/brasil-sobe-mais-uma-posicao-no-ranking-mundial-de-capacidade-instalada-de-energia-eolica/ (using Google Translate); added 2,022 MW for a total of 12,718 MW, from FTI Consulting, op. cit. note 1, p. 53; and added 1,963 MW for a total of 12,763 MW, from WWEA, op. cit. note 1.

64 Two-year lull from Camila Ramos, Clean Energy Latin America, São Paulo, personal communication with REN21, 6 March 2018. Brazil contracted 1.45 GW of wind power capacity in 2017, from idem. Cancellation from Luciano Costa, "Brazil wind, solar projects stall as power demand remains sluggish", *Reuters*, 3 July 2017, http://www.reuters.com/article/brazil-power-wind-solar-idUSL8N1JU52W, and from "Brazil cancels 25 wind, solar power projects at request of firms", *Reuters*, 28 August 2017, http://www.reuters.com/article/us-brazil-power-renewables/brazil-cancels-25-wind-solar-power-projects-at-request-of-firms-idUSKCN1B82G4.

65 Ramos, op. cit. note 64.

66 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 also from National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed March 2018.

67 Mexico added 478 MW for a total of 4,005 MW, Uruguay added 295 MW for a total of 1,505 MW, Chile added 116 MW for a total of 1,540 MW, and Costa Rica added 59 MW for a total of 378 MW, from GWEC, op. cit. note 1, p. 17. Mexico added 478 MW for a total of 4,027 MW, Uruguay added 295 MW for a total of 1,441 MW, Chile added 116 MW for a total of 1,639 MW, and Costa Rica added 59 MW for a total of 426 MW, from FTI Consulting, op. cit. note 1, p. 53.

68 Additions of 24 MW from GWEC, op. cit. note 1, p. 17, and from FTI Consulting, op. cit. note 1, p. 53; investments and project pipeline from Steve Sawyer, GWEC, personal communication with REN21, 20 September 2017.

69 Sawyer, op. cit. note 3; GWEC, op. cit. note 1, p. 17.

70 South Africa added 618 MW for a total of 2,085 MW, from GWEC, op. cit. note 1, p. 17; GWEC, "The great energy transition gathers momentum", press release (Brussels: 14 February 2018), https://gwec.net/the-great-energy-transition-gathers-momentum/. Added 621 MW for a total of 2,195 MW, from FTI Consulting, op. cit. note 1, p. 55. All of Africa added 940 MW (including 184 MW in Egypt and 135 MW in Morocco) for a total of 4,870 MW, from FTI Consulting, op. cit. note 1, p. 55.

71 GWEC, op. cit. note 70; Steve Sawyer, GWEC, personal communication with REN21, 14 February 2018. The Lake Turkana project was waiting to be commissioned and awaiting grid connection, from Shruti Shukla, GWEC, personal communication with REN21, 28 March 2018.

72 "Saudi Arabia issues REQ for 400MW wind power project", *Technical Review Middle East*, 17 July 2017, http://technicalreviewmiddleeast.com/power-a-water/renewables/saudi-arabia-issues-req-for-400mw-wind-power-project-in-al-jouf-region; "Saudi Arabia pre-qualifies 25 bidders for 400 MW wind power project", EV Wind, 29 August 2017, https://www.evwind.es/2017/08/29/saudi-arabia-pre-qualifies-25-bidders-for-400-mw-wind-power-project/60843; John Bambridge, "Liebherr crane erects first wind turbine in KSA", *Construction Week Online*, 30 March 2017, http://www.constructionweekonline.com/article-43720-liebherr-crane-erects-first-wind-turbine-in-ksa/. Iran brought a 30 MW wind power plant (Mapna-Kahak 3) into operation in February 2017 in Takestan, Qazvin Province, from Iran Ministry of Energy, Renewable Energy and Energy Efficiency Organization, "Statistics of RE power plants", 31 October 2017, http://www.satba.gov.ir/en/investmentpowerplants/statisticsofrepowerplants. In addition, the government of Khuzestan in Iran signed several agreements with European companies to increase investment in wind power in the province, from "Europeans set to build wind farms in Khuzestan", *Financial Tribune*, 2 October 2017, https://financialtribune.com/articles/energy/73335/europeans-set-to-build-wind-farms-in-khuzestan.

73 FTI Consulting, op. cit. note 1, p. 17. Jordan had 119 MW of capacity at year's end, from GWEC, op. cit. note 1, p. 17. The Middle East region added 22 MW in 2017 for a total of 328 MW, from FTI Consulting, op. cit. note 1, p. 55.

74 Australia added 245 MW for a total of 4,557 MW, from GWEC, op. cit. note 1, p. 17; added 651 MW for total of 4,976 MW, from FTI Consulting, op. cit. note 1, p. 54; and added 553 MW for a total of 4,879 MW, from WWEA, op. cit. note 1. Additional capacity from, for example, Sophie Vorrath, "Victoria set to host Australia's biggest wind farm – 800MW", RenewEconomy, 26 September 2017, http://reneweconomy.com.au/victoria-set-host-australias-biggest-wind-farm-800mw-40345/; Declan Gooch, "Australia's biggest wind turbine blades trucked 530km to far west NSW wind farm", *ABC News*, 6 December 2017, http://www.abc.net.au/news/2017-12-07/australias-biggest-wind-turbine-blades-trucked-silverton-nsw/9236010; David Porter, "Tilt Renewables begins to develop its energy pipeline", *Bay of Plenty Business News*, 31 January 2018, http://bopbusinessnews.co.nz/2018/01/31/tilt-renewables-begins-develop-energy-pipeline/.

75 Figure of 4,334 MW connected to grids in nine countries for world total of 18,814 MW, and onshore total based on global total wind capacity at end-2017, from GWEC, op. cit. note 1, pp. 54-55. World capacity increased 25.9% for a total of 18,228 MW, from EurObserv'ER, op. cit. note 1, p. 4; 4,358 MW was added (including 3,181 MW in Europe and 1,177 MW in Asia-Pacific), for a total of 18,391 MW, and globally 21 offshore turbines (totalling 35 MW) were decommissioned, from FTI Consulting, op. cit. note 1, p. 48; 11 offshore turbines were decommissioned in Europe, from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 11.

76 The United Kingdom added 1,679 MW, followed by Germany (1,247 MW), China (1,164 MW) and Belgium (165 MW); others that added capacity were Finland (60 MW), Japan (5 MW), the Republic of Korea (3 MW), Chinese Taipei (8 MW) and France (2 MW). Data for European countries from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 18; data for other countries from GWEC, op. cit. 1, p. 55. Germany added 1,275 MW based on 4,132 MW at end of 2016 and 5,407 MW at end of 2017, from BMWi, op. cit. note 37, p. 7; and China added 1.16 GW, from CWEA, op. cit. note 13.

77 A record 3,148 MW (net) was connected to the grid for a total of 15,780 MW, and 1,927 MW (82 turbines) was awaiting grid-connection at year's end, from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 7.

78 All from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 10. Finland added 60 MW, from idem and from GWEC, op. cit. note 1, p. 55, and added 42 MW from "Finns cut Tahkoluoto ribbon", reNEWS, 1 September 2017, http://renews.biz/108340/

finns-cut-tahkoluoto-ribbon/. France added its first offshore turbine, a 2 MW Floatgen demonstrator launched by Ideol (France), from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 10, and from Ideol, "Ideol has inaugurated Floatgen", press release (La Ciotat, France: 13 October 2017), http://ideol-offshore.com/en/actualites/ideol-has-inaugurated-floatgen. Denmark decommissioned the 5 MW Vindeby wind farm for a year-end total of 1,266 MW, from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 18. In addition, Portugal decommissioned a 2 MW demonstration project in 2017, from WindEurope, op. cit. note 6. Germany added 222 turbines offshore with a combined capacity of 1,250 MW; in addition, 152 existing turbines received upgrades, increasing their capacity by up to 29 MW, increasing total offshore capacity feeding the grid by 1,279 MW to 5,387.4 MW, or an increase in cumulative capacity of 31% over end-2016, all from Deutsche Windguard, *Status of Offshore...*, op. cit. note 37.

79 Statoil, "World class performance by world's first floating wind farm", press release (Stavanger, Norway: 15 February 2018), https://www.statoil.com/en/news/15feb2018-world-class-performance.html; EurObserv'ER, op. cit. note 1, p. 9.

80 China added 1,164 MW in 2017 for a year-end total of 2,788 MW, from GWEC, op. cit. note 1, p. 55; capacity under construction from FTI Consulting, op. cit. note 1, p. 32.

81 Lagging and challenges from Teis Jensen, "China to call on Denmark to help build offshore wind farm", *Reuters*, 4 September 2017, http://www.reuters.com/article/us-denmark-windpower-china/china-to-call-on-denmark-to-help-build-offshore-wind-farm-idUSKCN1BF1DX; regulatory barriers from Zhao, op. cit. note 6; regulatory and jurisdictional issues from Sawyer, op. cit. note 14; on track from GWEC, op. cit. note 1, p. 58. At least three provinces also have targets: Jiangsu (3.5 GW by 2020), Guangdong and Fujian (both 2 GW by 2020), from GWEC, "Latest update on China offshore wind", 2018, http://gwec.net/latest-update-on-china-offshore-wind/, viewed March 2018.

82 Additions from GWEC, op. cit. note 1, pp. 55, 57-60; Japan's first offshore tender from FTI Consulting, op. cit. note 1, p. 32. The auction followed the government's amendment of existing port and harbour law in 2016 in order to promote offshore development, from Ibid.

83 Figures of 14 projects, capacity and 10 states, all from AWEA, *AWEA U.S. Wind Industry Annual Market Report Year Ending 2017*, op. cit. note 48. Policies in five states (Connecticut, Massachusetts, New Jersey, New York and Rhode Island) from Val Stori, "The launch of a U.S. offshore wind industry", Clean Energy Group, 7 February 2018, https://www.cleanegroup.org/launch-u-s-offshore-wind-industry/. Massachusetts and New York are focusing on development of infrastructure, such as ports and transmission lines, from Iulia Gheorghiu, "East coast states take lead in offshore wind after Paris Accord", *Morning Consult*, 19 July 2017, https://morningconsult.com/2017/07/19/east-coast-states-take-lead-offshore-wind-paris-accord/. As of 2017, Massachusetts had a Renewable Portfolio Standard of 1.6 GW of offshore wind by 2027, from Jennifer Delony, "Bids are in for Massachusetts offshore wind procurement; storage included", Renewable Energy World, 20 December 2017, http://www.renewableenergyworld.com/articles/2017/12/bids-are-in-for-massachusetts-offshore-wind-procurement-storage-included.html; by early 2018, several other East Coast states had targets, from Greg Alvarez, "One month into 2018 offshore wind is all the rage", AWEA, 1 February 2018, http://www.aweablog.org/one-month-2018-offshore-wind-rage/. Other states exploring options for offshore wind power include California and Delaware, from Steve Hanley, "California & Delaware explore offshore wind power", CleanTechnica, 28 November 2017, https://cleantechnica.com/2017/11/28/california-delaware-explore-offshore-wind-power/; Gary Norton, "4 emerging trends in U.S. offshore wind technologies", US DOE, Office of Energy Efficiency & Renewable Energy (EERE), 9 August 2017, https://energy.gov/eere/articles/4-emerging-trends-us-offshore-wind-technologies.

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86 The United Kingdom had 6,835 MW, Germany had 5,355 MW, Denmark had 1,266 MW, and the Netherlands had 1,118 MW, from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 18; the United Kingdom had 6,836 MW, followed in Europe by Germany (5,355 MW), Denmark (1,271 MW) and the Netherlands (1,118 MW), and China had 2,788 MW, from GWEC, op. cit. note 1, pp. 56, 57. Note that Germany had a total of 5,407 MW offshore at the end of 2017, from BMWi, op. cit. note 37, p. 7.

87 Europe's total offshore capacity at year's end was 15,780 MW, from WindEurope, *Offshore Wind in Europe*, op. cit. note 37, p. 18. Europe was followed by Asia (2,998 MW) and the United States (30 MW), from GWEC, op. cit. note 1, p. 55. Europe's share in 2016 based on data from FTI Consulting, op. cit. note 1, p. 48. **Figure 36** based on data from 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, op. cit. note 62, p. 58; GWEC, op. cit. note 1, p. 55; 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*, op. cit. note 37, p. 6; AWEA, "First US offshore wind farm unlocks vast new ocean energy resource", press release (Block Island, RI: 12 December 2016), http://www.awea.org/MediaCenter/pressreleasev2.aspx?ItemNumber=9627.

88 See, for example, Energy4All Limited, "European co-operative growth", https://energy4all.co.uk/european-co-operative-growth/, viewed 28 April 2018; Energy4All Limited, "E4A co-ops", https://energy4all.co.uk/e4a-co-ops/, viewed 28 April 2018; Community Windpower website, http://www.communitywindpower.co.uk/, viewed 28 April 2018; Windustry, "Community wind", http://www.windustry.org/community-wind, viewed 28 April 2018; Simon Holmes à Court, "NSW's largest windfarm highlights power of community investment", *The Guardian* (UK), 19 January 2018, https://www.theguardian.com/commentisfree/2018/jan/20/nsws-largest-windfarm-highlights-power-of-community-investment.

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91 Craig Morris, "Share of German citizen renewable energy shrinking", Energy Transition, 7 February 2018, https://energytransition.org/2018/02/share-of-german-citizen-renewable-energy-shrinking/. Citizens (households and farms) accounted for 42.5% of investments in renewable energy through 2016, down from 27% through the end of 2012, from Trend Research, cited in Morris, op. cit. this note.

92 BMWi, "Akteursvielfalt/Bürgerenergie", https://www.erneuerbare-energien.de/EE/Navigation/DE/Recht-Politik/EEG-Ausschreibungen/Akteursvielfalt-Buergerenergie/akteursvielfalt-buergerenergie.htm, viewed 17 April 2018; FTI Consulting, op. cit. note 1, p. 15; WWEA and Landesverband Erneuerbare Energien Nordrhein-Westfalen, *Community Wind in North Rhine-Westphalia: Perspectives from State, Federal and Global Level, Status December 2017* (Bonn and Düsseldorf: January 2018), pp. iv, 15-16, 25, 40, http://www.wwindea.org/wp-content/uploads/2018/02/

CP_Study_English_reduced.pdf. Lower access barriers include no requirement for planning approval and a longer term for implementation, from BMWi, op. cit. this note. There were a number of community projects even though it seems that many of them were backed or sponsored by large corporations, from Sebastian Hermann, German Environment Agency, personal communication with REN21, April 2018.

93 WWEA, 2017 *Small Wind World Report Summary* (Bonn: June 2017), p. 5, http://www.wwindea.org/wp-content/uploads/filebase/small_wind_/SWWR2017-SUMMARY.pdf; Alice Orrell et al., *2016 Distributed Wind Market Report* (Richland, WA: Pacific Northwest National Laboratory, August 2017), p. i, https://energy.gov/sites/prod/files/2017/08/f35/2016-Distributed-Wind-Market-Report.pdf; WWEA, *Small Wind World Report 2016* (Bonn: March 2016), Summary, http://www.wwindea.org/small-wind-world-market-back-on-track-again/; RenewableUK, *Small and Medium Wind UK Market Report* (London: March 2015), https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/publications/reports/smallmediumwindukmarket.pdf; SWIP Project, "SWIP objectives and summary", http://swipproject.eu/?page_id=12146, viewed 11 March 2018; displace diesel from Navigant Research, "Small and medium wind power", http://www.navigantresearch.com/research/small-and-medium-wind-power, viewed 12 February 2014.

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95 Data for 2016 from WWEA, op. cit. note 94. Data for 2015 were preliminary, from WWEA, *2017 Small Wind World Report Summary*, op. cit. note 93. Global small wind capacity at end-2016 was estimated to be at least 1.4 GW, from Orrell et al., op. cit. note 93, p. i. This was up from an estimated 1.3 GW at the end of 2015, based on surveys of international government and industry publications, from Alice C. Orrell et al., *2015 Distributed Wind Market Report* (Richland, WA: Pacific Northwest National Laboratory, August 2016), p. ii, https://energy.gov/sites/prod/files/2016/08/f33/2015-Distributed-Wind-Market-Report-08162016_0.pdf, and from an estimated 810 MW at the end of 2014, 678 MW in 2012, and 755 MW in 2013, from Alice C. Orrell et al., *2014 Distributed Wind Market Report* (Washington, DC: US DOE, EERE), August 2015), pp. 15-16, https://energy.gov/eere/wind/downloads/2014-distributed-wind-market-report.

96 WWEA, op. cit. note 94.

97 Navigant Research, "Global annual installed capacity of small and medium wind turbines is expected to exceed 446 MW in 2026", press release (Boulder, CO: March 2017), https://www.navigantresearch.com/newsroom/global-annual-installed-capacity-of-small-and-medium-wind-turbines-is-expected-to-exceed-446-mw-in-2026; Orrell et al., op. cit. note 93, pp. 9-10; Michael Allen, "New blades and generators for more efficient small wind turbines", Phys Org, 17 January 2017, https://phys.org/news/2017-01-blades-efficient-small-turbines.html.

98 WWEA, op. cit. note 94.

99 United Kingdom and United States from Orrell et al., op. cit. note 93, pp. 7, 9-10, 14. In 2016, the United States deployed only 2.4 MW of small-scale wind turbines, but sales of turbines 10 kW and less increased relative to 2015, for total unit sales of 2,560 in 2016; this compares with 3.4 MW (1,695 units) in 2015, 3.7 MW (1,600 units) in 2014 and 5.6 MW (2,700 units) in 2013, from idem, pp. i, 7, 9.

100 Figure of 561 turbines (for total capacity of 551 MW), from FTI Consulting, *Global Wind Market Update – Demand & Supply 2017, Part One – Supply Side Analysis* (London: April 2018), p. 25, https://fti-intelligencestore.com/index.php?route=download/main&download_id=159; figure of 646.8 MW from GWEC, op. cit. note 1, p. 17. Estimate of 614 MW decommissioned worldwide during 2017 (605 MW in the EU, 7 MW in Japan, 2 MW elsewhere in Asia) from EurObserv'ER, op. cit. note 1, p. 3.

101 Germany dismantled 387 onshore turbines totalling 467 MW, Denmark dismantled 96 MW, followed by the Netherlands (68 MW), Latvia (3.7 MW), Finland (3 MW) and Belgium (1.7 MW), from WindEurope, op. cit. note 6; Japan decommissioned 7.3 MW and the Republic of Korea decommissioned 1.5 MW, from Sawyer, op. cit. note 14. Germany dismantled 387 units for a total of 482 MW, followed by Denmark (162 units, 91 MW), Japan (8 units, 5 MW), Finland (3 units, 3 MW) and Chinese Taipei (1 unit, 2 MW), from FTI Consulting, op. cit. note 100, p. 25. Germany decommissioned 371 onshore turbines, based on data from Bundesnetzagentur, "Veröffentlichung der Registerdaten (08/2014 bis 02/2018)", updated 31 March 2018, https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/ZahlenDatenInformationen/VOeFF_Registerdaten/2018_02_Veroeff_RegDaten.html?nn=654268, provided by Peter Bickel, Zentrum für Sonnenenergie und Wasserstoff-Forschung, personal communication with REN21, April 2018. Finland also from Craig Richard, "First Finnish repowering project complete", *Windpower Monthly*, 9 October 2017, https://www.windpowermonthly.com/article/1446814/first-finnish-repowering-project-complete. The United States decommissioned 33 turbines with a total of 43 MW of capacity, from AWEA, *AWEA U.S. Wind Industry Annual Market Report Year Ending 2017*, op. cit. note 48.

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125 Figure of 80% for 2017, from FTI Consulting, op. cit. note 100, pp. 6, 10, 11; figure of 75% in 2016 based on data from FTI Consulting, *Global Wind Market Update – Demand & Supply 2016, Part One – Supply Side Analysis* (London: 2017), p. 10, http://www.fti-intelligencestore.com/index.php?route=download/main&download_id=147. **Figure 37** based on data from FTI Consulting, op. cit. note 100, pp. 6, 10, 11. Data based on total sales of 52,150 MW, and considering only manufacturers that sell turbines of 200 kW and up. Data for Vestas include 50% of new installations from MHI Vestas, a joint venture between Vestas Wind Systems A/S and Mitsubishi Heavy Industries (MHI).

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16 **Table R16** from the following sources: data for **Italy, Japan and New Zealand** from IEA Geothermal, *2016 Annual Report* (Taupo, New Zealand: October 2017), http://iea-gia.org/wp-content/uploads/2018/01/Annual-Report-2016.pdf; **Chile** from Enel, "Enel and Enap inaugurate South America's first geothermal power plant Cerro Pabellón", press release (Rome and Santiago: 12 September 2017), https://www.enel.com/media/press/d/2017/09/enel-and-enap-inaugurate-south-americas-first-geothermal-power-plant-cerro-pabelln; **Iceland** based on capacity of 665 MW at end-2016 and addition of 45 MW in 2017, from Orkustofnun, *Energy Statistics in Iceland 2016* (Reykjavik: 2017), http://os.is/gogn/os-onnur-rit/Orkutolur-2016-enska.pdf; **Indonesia** based on data from Indonesian Ministry of Energy and Mineral Resources, "Statistik Ketenagalistrikan 2016", January 2016, https://www.esdm.go.id/assets/media/content/content-statistik-ketenagalistrikan-tahun-2016-1.pdf, and from idem, "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; **Mexico** from Luis C.A. Gutiérrez-Negrín, Mexican Geothermal Association, personal communication with REN21, March 2018; **Philippines** from Philippines Department of Energy, Electrical Power Industry Management Bureau, "Power Supply and Demand Highlights: January-June 2017", https://www.doe.gov.ph/electric-power/power-supply-and-demand-highlights-january-june-2017; **Turkey** from Turkish Electricity Transmission Company (TEİAŞ) website, http://www.teias.gov.tr, viewed April 2018; **United States** from EIA, *Electric Power Monthly*, February 2018, Tables 6.3 and 6.4, http://www.eia.gov/electricity/monthly, from Ormat, "24 MW Tungsten Mountain geothermal power plant in Nevada begins commercial operation", press release (Reno, NV: 21 December 2017), http://investor.ormat.com/file/Index?KeyFile=391543763, and from EIA, op. cit. this note, Tables 1.1, 1.1.A and 6.2. Capacity data for all other countries from IRENA, op. cit. note 1. See Geothermal Power and Heat section in Market and Industry chapter and related endnotes for additional statistics and details.

17 **Table R17** from the following sources: Global capacity estimates based on data from International Hydropower Association (IHA), personal communications with REN21, March-April 2018 and IHA, *Hydropower Status Report 2018* (London: May 2018), https://www.hydropower.org/publications/2018-hydropower-status-report. At end-2017, total installed capacity was 1,267 GW, less 153 GW of pumped storage. See Renewable Energy Policy Network for the 21st Century (REN21), *Renewables Global Status Report* (Paris: 2014-2017 editions). Country data from the following sources: **China:** total capacity, capacity growth, utilisation and investment from China NEA, summary of national electric industry statistics for 2017, http://www.nea.gov.cn/2018-01/22/c_136914154.htm; capacity additions in 2017 of 12.87 GW, including 2 GW of pumped storage, from China Electricity Council (CEC), annual report on national power system, 1 February 2018, http://www.cec.org.cn/hangyeguangjiao/meitijujiao2/2017-12-26/176468.html; pumped storage capacity of 28.49 GW as of 26 December 2017, from CEC, http://www.cec.org.cn/hangyeguangjiao/meitijujiao2/2017-12-26/176468.html; generation of 1,189.8 TWh and annual growth of 0.5% from National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2017 national economic and social development", press release (Beijing: 28 February 2018), http://www.stats.gov.cn/english/PressRelease/201802/t20180228_1585666.html; total capacity including pumped storage of 341.19 GW, pumped storage capacity of 28.49 GW and hydropower capacity of 312.7 GW; capacity additions (excluding pumped storage) of 7.3 GW; and pumped storage additions of 1.8 GW from IHA and IRENA, personal communications with REN21, March-April 2018. **Brazil:** 3,412 MW (3,115 MW large-scale hydro, 187 MW small-scale hydro and 110 MW very small-scale hydro) added in 2017, from National Agency for Electrical Energy (ANEEL), "Resumo geral dos novos empreendimentos de geração", http://www.aneel.gov.br/acompanhamento-da-expansao-da-oferta-de-geracao-de-energia-eletrica, updated April 2018, and from ANEEL, "Informações gerenciais", http://www.aneel.gov.br/informacoes-gerenciais; large-scale hydro capacity is listed as 94,662 MW at end-2017, small-scale (1-30 MW) hydro as 5,020 MW and very small-scale (less than 1 MW) hydro as 594 MW (compared to 484 MW in the previous year), for a total of 100,275 MW; generation of 401 TWh from National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.

org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed April 2018. **United States:** capacity from EIA, *Electric Power Monthly*, February 2018, Tables 6.2.B and 6.3, http://www.eia.gov/electricity/monthly; generation from idem, Table 1.1. **Canada:** data for 2016 only from Statistics Canada, "Table 127-0009 installed generating capacity, by class of electricity producer", https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002201, viewed March 2018; generation for 2016 only from idem, "Table 127-0007 electric power generation, by class of electricity producer, annual". **Russian Federation:** capacity and generation from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2017* (Moscow: 31 January 2018), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2018/ups_rep2017.pdf. **India:** installed capacity in 2017 (units larger than 25 MW) of 40,177.82 MW (plus 4,785.6 MW of pumped storage) from Government of India, Ministry of Power, Central Electricity Authority (CEA), "Hydro reports", December 2017, http://www.cea.nic.in/monthlyarchive.html; installed small-scale (<25 MW) hydro capacity of 4,418 MW, all capacity additions in 2017 of 1,908 MW, and generation for plants larger than 25 MW (127.9 TWh) from idem, "Executive summary of the power sector (monthly)", http://www.cea.nic.in/monthlyarchive.html, viewed April 2018; output from hydro plants smaller than 25 MW (7.9 TWh) from idem, "Renewable energy generation report", http://www.cea.nic.in/monthlyarchive.html, viewed April 2018. **Norway:** capacity and generation from Statistics Norway, https://www.ssb.no/statbank/list/elektrisitet, viewed March 2018, and from Norwegian Water Resources and Energy Directorate, https://www.nve.no/energiforsyning-og-konsesjon/energiforsyningsdata/ny-kraftproduksjon, viewed March 2018. See Hydropower section in Market and Industry chapter and related endnotes for additional statistics and details.

18 **Table R18** from the following sources: unless noted otherwise, data for end-2016 from IEA Photovoltaic Power Systems Programme (IEA PVPS), *Trends in Photovoltaic Applications, 2017: Survey Report of Selected IEA Countries Between 1992 and 2017* (Paris: 2017), pp. 7, 74, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_Trends_in_PV_Applications_2017_-_EXECUTIVE_SUMMARY.pdf, and from SolarPower Europe, *Global Market Outlook for Solar Power 2017-2021* (Brussels: 2017), http://www.solarpowereurope.org/reports/global-market-outlook-2017/; data for 2017 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018* (Paris: April 2018), pp. 3-6, 10, 15, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2017.pdf, and from sources provided below. This report aims to provide all solar PV data in direct current (DC) units. Note that some countries (e.g., Canada, Chile, Japan since 2012 and Spain) 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 2017 from China NEA, cited in "Energy Bureau conference information of 2017 renewable energy grid operation", 24 January 2018, http://shupeidian.bjx.com.cn/news/20180124/876448.shtml (using Google Translate); total from NEA, "National power industry statistics list", 22 January 2018, http://www.nea.gov.cn/2018-01/22/c_136914154.htm (using Google Translate). **United States:** Total at end-2016 from Becquerel Institute, Brussels, personal communication with REN21, April 2018, and from IEA PVPS, *Trends in Photovoltaic Applications, 2017*, op. cit. this note; additions and total in 2017 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, from US Solar Energy Industries Association (SEIA), "After back-to-back years of double-digit growth, U.S. solar passes 50 GW milestone", 15 March 2018, https://www.seia.org/blog/after-back-back-years-double-digit-growth-us-solar-passes-50-gw-milestone, and from GTM Research and SEIA, *U.S. Solar Market Insight: 2017 Year in Review, Executive Summary* (Boston: March 2018), p. 9, https://www.greentechmedia.com/research/subscription/u-s-solar-market-insight. **India:** Total at end-2016 from Becquerel Institute, op. cit. this note; additions and total in 2017 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, p. 10. **Japan:** Becquerel Institute, op. cit. this note, 29 March 2018; IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, p. 10. **Turkey:** Total at end-2016 from IEA PVPS, *Trends in Photovoltaic Applications, 2017*, op. cit. this note, p. 74; additions and total in 2017 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, p. 15. **Germany:** BMWi, op. cit. note 1, p. 7. **Australia:** Total at end-2016 from IEA PVPS, *Trends in Photovoltaic Applications, 2017*, op. cit. this note, p. 74; additions and total in 2017 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, p. 10, from Australian PV Institute, "Australian PV market since April 2001", figure "Australian PV installations since April 2001: total capacity (kW)", http://pv-map.apvi.org.au/analyses, viewed 12 April 2018, and from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, p. 10. **Republic of Korea:** Total at end-2016 from IEA PVPS, *Trends in Photovoltaic Applications*, op. cit. this note, p. 74; additions and total in 2017 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, p. 10. **United Kingdom:** UK Department for Business, Energy & Industrial Strategy, "Solar Photovoltaics Deployment in the UK February 2018", updated 29 March 2018, Table 1, https://www.gov.uk/government/statistics/solar-photovoltaics-deployment. **Brazil:** Total at end-2016 from Becquerel Institute, op. cit. this note; additions and total in 2017 from Becquerel Institute, op. cit. this note, 29 March and April 2018, and from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, pp. 3, 6. **Italy, France and Spain:** Total at year-end 2016 from IEA PVPS, *Trends in Photovoltaic Applications, 2017*, op. cit. this note, p. 74; additions and total in 2017 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018*, op. cit. this note, p. 15. See Solar PV section in Market and Industry chapter and related endnotes for additional statistics and details.

19 **Table R19** from the following sources:: New Energy Update, "CSP today global tracker", http://tracker.newenergyupdate.com/tracker/projects, viewed on numerous dates leading up to 27 April 2018; US National Renewable Energy Laboratory, "Concentrating solar power projects", https://www.nrel.gov/csp/solarpaces/, with the page and its subpages viewed on numerous dates leading up to 27 April 2018 (some subpages are referenced individually throughout this section); REN21, *Renewables 2017 Global Status Report* (Paris: 2016), pp. 72-74, 171, http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf; CSP World, "CSP world map", http://cspworld.org/cspworldmap, with the page and its subpages viewed on numerous dates leading up to 3 April 2018; IRENA, op. cit, note 1; Luis Crespo, European Solar Thermal Electricity Association, Brussels, personal communication with REN21, 20 April 2018. In some cases, information from the above sources was verified against additional country-specific sources, as cited in endnotes for CSP section in Market and Industry chapter. Global CSP data are based on commercial facilities only; demonstration or pilot facilities 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.

20 **Table R20** from the following sources: cumulative solar thermal capacity in operation nationally and globally at end-2016 from Monika Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communications with REN21, March-May 2018; Weiss and Spörk-Dür, op. cit. note 1. Gross additions on a national level from the following associations and experts: David Ferrari, Sustainability Victoria, Melbourne, Australia; Werner Weiss, AEE INTEC, Vienna, Austria; Marcelo Mesquita, ABRASOL, São Paulo, Brazil; Hongzhi Cheng, Shandong SunVision Management Consulting, Dezhou, China; Marco Tepper, BSW Solar, Berlin, Germany; Edwige Porcheyre, Uniclima, Paris, France; Costas Travasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; Jaideep Malaviya, Solar Thermal Federation of India, Pune, India; Eli Shilton, Elsol, Kohar-yair, Israel; Federico Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milan, Italy; Kumiko Saito, Solar System Development Association, Tokyo, Japan; 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; Kung-Ming Chung, Energy Research Center of the National Cheng Kung University, Tainan City, Chinese Taipei; 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, Ontario, CA, United States, all personal communications

with REN21, February-April 2017. The additions for Australia are preliminary, and the share of vacuum tube collectors within the new glazed collector area was assumed to be 10%, as in GSR 2016. China and world data reflect an assumption that systems have a lifetime of 10 years in China, 14 years in Turkey, 20 years in Germany and 25 years in all other countries. Total gross additions worldwide for 2017 are based on estimates from Spörk-Dür, op. cit. this note.

21 **Table R21** from the following sources: unless noted otherwise, data are from Global Wind Energy Council (GWEC), *Global Wind Report – Annual Market Update 2017* (Brussels: April 2018), p. 17, http://files.gwec.net/files/GWR2017.pdf, and European data also from WindEurope, *Wind in Power 2017: Annual Combined Onshore and Offshore Wind Statistics* (Brussels: February 2018), pp. 7, 9, https://windeurope.org/about-wind/statistics/european/wind-in-power-2017/. **China:** Official total at end-2016 from China National Energy Board, cited in NEA, "2016 wind power and grid operation", 26 January 2017, www.nea.gov.cn/2017-01/26/c_136014615.htm (using Google Translate); official additions and total in 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). Unofficial data for 2016 and 2017 are all from China Wind Energy Association, "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; from GWEC, op. cit. this note, p. 17; and from FTI Consulting, *Global Wind Market Update – Demand & Supply 2017, Part Two – Demand Side Analysis* (London: April 2018), p. 51, http://www.apren.pt/contents/publicationsothers/global-wind-market-update-2017--part-ii-abril-2018-fti-consulting.pdf. **United States:** Total at end-2016 from American Wind Energy Association (AWEA), *U.S. Wind Industry Fourth Quarter 2017 Market Report* (Washington, DC: 25 January 2018), p. 4, http://awea.files.cms-plus.com/FileDownloads/pdfs/4Q%202017%20AWEA%20Market%20Report%20Public%20Version.pdf; additions and total in 2017 from AWEA, *AWEA U.S. Wind Industry Annual Market Report Year Ending 2017* (Washington, DC: April 2018). **Germany:** WindEurope, *Wind in Power 2017*, op. cit. this note, p. 9; WindEurope, personal communication with REN21, 30 April 2018. See also BMWi, op. cit. note 1, p.7. **United Kingdom:** WindEurope, *Wind in Power 2017*, op. cit. this note; the United Kingdom added a net of 3,619 MW for a total of 19,837 MW, from UK Department for Business, Energy & Industrial Strategy, op. cit. note 1, p. 69, updated 12 April 2018. **India:** Total at end-2016 from GWEC, op. cit. this note, p. 17; additions and total in 2017 based on data 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, and from Government of India, Ministry of Power, CEA, *All India Installed Capacity, Monthly Report January 2017* (New Delhi: 2017), Table: "All India installed capacity (in MW) of power stations (as on 31.01.2017) (Utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-01.pdf. **Brazil:** Total at end-2016 from GWEC, op. cit. this note, p. 17; additions and total in 2017 from Associação Brasileira de Energia Eólica, "Brasil sobe mais uma posição no Ranking mundial de capacidade instalada de energia eólica", 15 February 2018, http://www.abeeolica.org.br/noticias/brasil-sobe-mais-uma-posicao-no-ranking-mundial-de-capacidade-instalada-de-energia-eolica/ (using Google Translate), and from GWEC, op. cit. this note, p. 17. **France:** WindEurope, *Wind in Power 2017*, op. cit. this note. France had 11,670 MW in operation as of 31 December 2016, from Réseau de transport d'électricité (RTE), *Bilan Électrique Français 2016: Synthèse presse* (Paris: 2016), p. 5, http://www.rte-france.com/sites/default/files/2016_bilan_electrique_synthese.pdf, and added 1,797 MW in 2017 for a year-end total of 13,559 MW, from RTE, *Panorama de L'Électricité Renouvelable en 2017* (Paris: 2018), p. 13, http://www.rte-france.com/sites/default/files/panorama_enr_2017.pdf. **Turkey:** Turkish Wind Energy Association, *Türkiye Rüzgar Enerjisi Istatistik Özet Raporu* (Ankara: January 2018), p. 4, http://www.tureb.com.tr/files/tureb_sayfa/duyurular/2018/02_subat/turkiye_ruzgar_enerjisi_istatistik_ozet_raporu.pdf; WindEurope, *Wind in Power 2017*, op. cit. this note. **South Africa:** GWEC, op. cit. this note, p. 17. **Finland and Spain:** WindEurope, *Wind in Power 2017*, op. cit. this note. **Canada:** End-2016 from Canadian Wind Energy Association (CanWEA), "Powering Canada's Future", December 2017, https://canwea.ca/wp-content/uploads/2018/02/Canada-Current-Installed-Capacity_e.pdf; 2017 from CanWEA, "Installed capacity", https://canwea.ca/wind-energy/installed-capacity/, viewed 31 January 2018. **Italy:** WindEurope, *Wind in Power 2017*, op. cit. this note; Italy added 252 MW in 2017 for a total of 9,485 MW, from FTI Consulting, op. cit. this note, p. 50. See Wind Power section in Market and Industry chapter and related endnotes for additional statistics and details.

22 **Table R22** from the following sources: IEA, World Energy Outlook 2017 Energy Access Database, http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/, viewed 26 April 2018; Sustainable Energy for All (SEforALL), Africa Hub Country Database, https://www.se4all-africa.org/se4all-in-africa/country-data/, viewed 30 April 2018; World Bank, Access to Electricity Database, https://data.worldbank.org/indicator/EG.ELC.ACCS.UR.ZS, viewed 30 April 2018; Power for All, "Energy Access Target Tracker", 2017, viewed 26 April 2018.

23 **Table R23** from the following sources: IEA, op. cit. note 22; targets from SE4ALL, op. cit. note 22, viewed 26 April 2018; Chile and Mexico from World Bank, Access to Clean Fuels and Technologies for Cooking Database, https://data.worldbank.org/indicator/EG.CFT.ACCS.ZS?locations=MX.

24 **Table R24** from submissions by report contributors and from various institutional reports and websites.

25 **Table R25** from Ibid.

26 **Table R26** from Frankfurt School-UNEP Centre for Climate & Sustainable Energy Finance and Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2018* (Frankfurt: April 2018), p. 12, http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf.

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