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RENEWABLES NOW

RENEWABLES 2022
GLOBAL STATUS REPORT

2022

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REN21 CROWD-SOURCED KNOWLEDGE AND DATA

The REN21 community is at the heart of REN21's data and reporting culture. Collectively, hundreds of experts make REN21 reports among the world's most comprehensive crowd-sourced and peer-reviewed publications on renewables. This unique reporting and verification process makes REN21 a globally recognised data and knowledge broker.

REN21 reports that carry the *REN21 Crowd-Sourced Knowledge and Data* stamp verify that this collaborative process was applied:

REN21 CROWD-SOURCED DATA AND KNOWLEDGE

- Developing **data collection** methods that build on a global multi-stakeholder community of experts from diverse sectors, enabling access to dispersed data and information that frequently are not consolidated and are difficult to collect.
- Consolidating **formal** (official) and **informal** (unofficial/unconventional) data gathered from a wide range of sources in a collaborative and transparent way e.g., by using extensive referencing.
- Complementing and validating data and information in an open **peer-review** process.
- Obtaining expert input on renewable energy trends through **interviews** and personal communication between the REN21 team and authors.
- Using validated data and information to provide fact-based evidence and to develop a supportive narrative to **shape the sectoral, regional or global debate** on the energy transition, monitor advancements and inform decision processes.
- Making data and information **openly available** and clearly documenting our sources so they can be used by people in their work to advocate for renewable energy.
- Using crowd-sourced data to develop a **shared language** and create an understanding as the foundation for collaboration.

Over **650 experts** contributed to GSR 2022, working alongside an international authoring team and the REN21 Secretariat.

More than **2,000 sources** have been used to write GSR 2022.

For more information, see the Methodological Notes section on data collection and validation.

REN21
RENEWABLES NOW

RENEWABLE ENERGY POLICY NETWORK
FOR THE 21st CENTURY

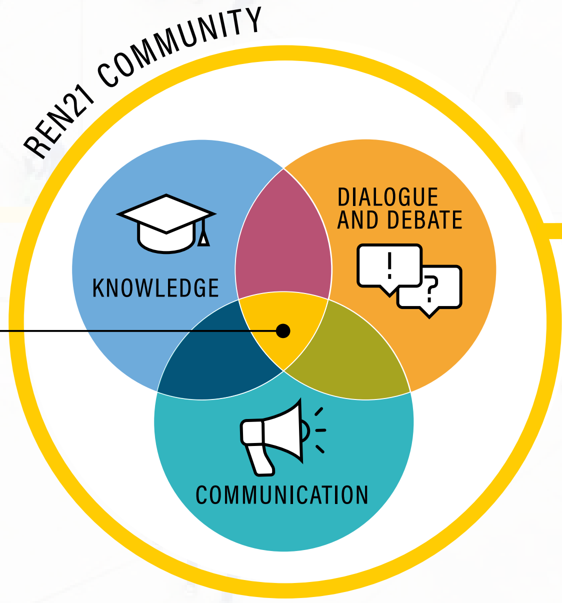
REN21 is the only global community of actors from science, governments, NGOs and industry **working collectively** to drive the rapid uptake of renewables – now!

REN21 works to build knowledge, shape dialogue and debate and communicate these results to **inform decision-makers** to strategically drive the deep transformations needed to make renewables the norm. We do this in close cooperation with the community, providing a platform for these stakeholders to engage and collaborate. REN21 also connects with non-energy players to grow the energy discourse, given the economic and social significance of energy.

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

Our more than **3,000 community members** guide our co-operative work. They reflect the vast array of backgrounds and perspectives in society. As REN21's eyes and ears, they collect information, share intelligence and make the renewable voice heard.

REN21 takes all this information to better understand the current thinking around renewables and change norms. **Our publications** are probably the world's most comprehensive crowdsourced reports on renewables. Each is a truly collaborative process of co-authoring, data collection and peer reviewing.



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Endnotes: see full version online at www.ren21.net/gsr

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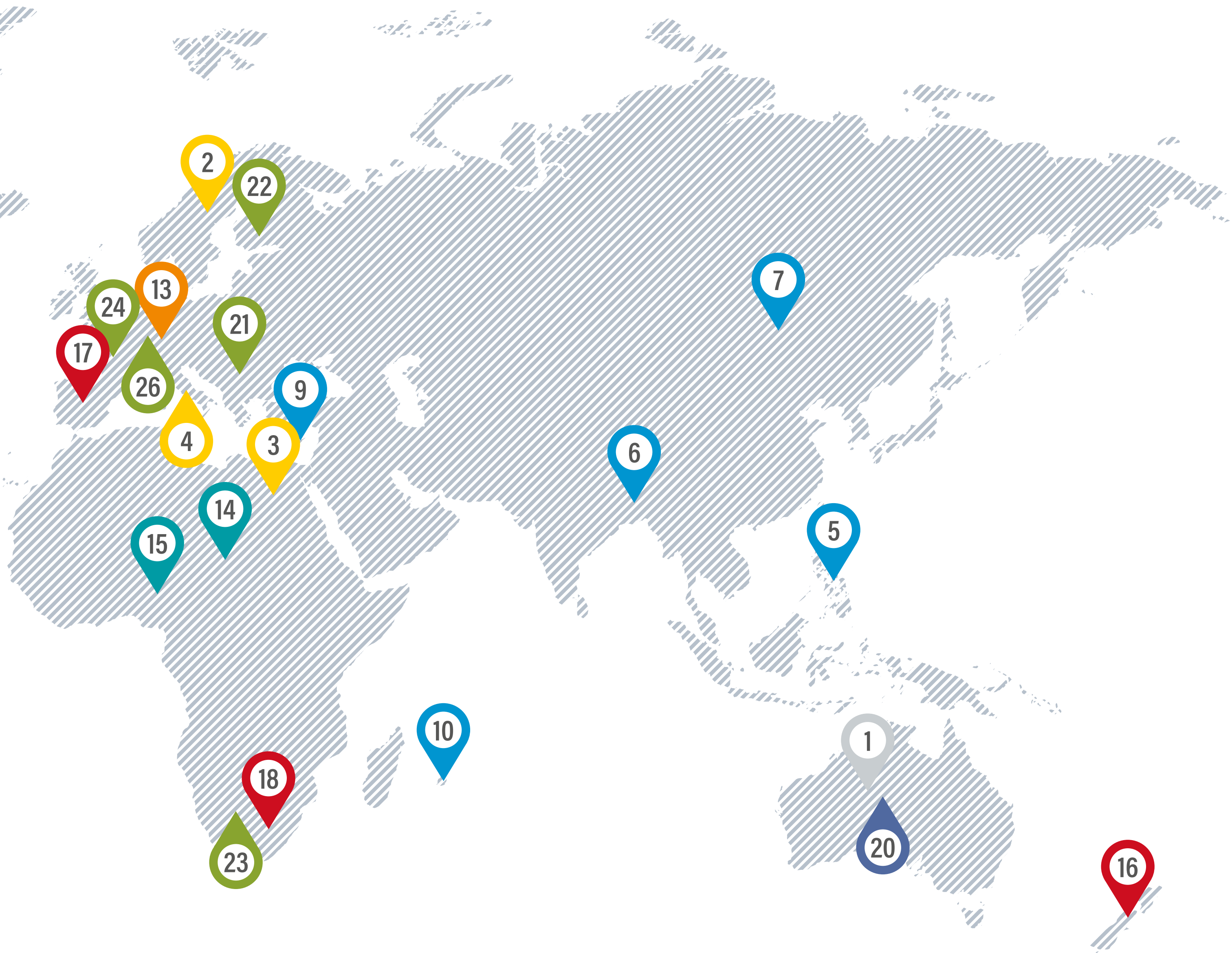
SNAPSHOTS. OVERVIEW

This report features a number of Snapshots (case studies) from around the world putting forward stories from 2021; where renewables have been deployed in different end-use sectors (buildings, transport, industry and agriculture) at the national and sub-national level. These stories showcase the context, drivers, challenges and achievements, as well as stakeholders involved and are portrayed through policy, markets investment, energy access, system integration and cities lenses.

Featuring

26 renewable energy success stories

across the globe.



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FOREWORD

In response to an unprecedented public health crisis, countries around the world had hoped to seize the post-COVID-19 opportunity for a green and equitable recovery. Unfortunately, and despite record growth in renewable energy deployment in 2021, this historic chance has been lost. As of mid-2022, the world was experiencing its biggest energy crisis on record. Although this crisis was exacerbated by the Russian Federation's February 2022 invasion of Ukraine, prices for fossil fuels – coal, oil and natural gas – were already spiking by late 2021, leading to the threat of energy poverty for billions of people.

Despite evidence that renewables are the most affordable energy source to both improve resilience and support decarbonisation, governments across the world continue to resort to fossil fuel subsidies to keep energy bills under control. This growing gap between countries' ambition and action on the ground is alarming and sends a clear warning that the global energy transition is not happening.

We now stand at a historic crossroads. Instead of continuing to support a fossil fuel-based energy order, which serves only some and triggers massive natural and economic disasters affecting all countries and citizens, we need to take bold action to phase out fossil fuels and accelerate the deployment of energy efficiency and renewables. Decision makers can no longer delay the structural reforms that are urgently needed not only to preserve the climate and the environment but also to reduce the vulnerability of our economies to geopolitical threats.

The *Renewables 2022 Global Status Report* documents the progress made in the renewable energy sector. It highlights the opportunities afforded by a renewable-based economy and society, including the ability to achieve more diversified and inclusive energy governance through localised energy generation and value chains. Countries with higher shares of renewables in their total energy consumption enjoy a greater level of energy independence and security.

The report also illustrates the power of a collective intelligence. This year, more than 650 experts have contributed data and information. I would like to thank all of them and extend particular thanks to the Research Direction Team of Duncan Gibb, Nathalie Ledanois, Lea Ranalder and Hend Yaqoob; Special Advisors Adam Brown and Janet L. Sawin (Sunna Research); the many authors; our editors, Lisa Mastny and Kelly Trumbull; our designers, Caren Weeks, Nicole Winter and Sebastian Ross; and all those who provided data and participated in the peer-review process.

I hope that you will find in this report the knowledge, data, perspective and inspiration to help and support you in your efforts to make renewable energy the undisputable backbone of our economies and societies.

Rana Adib
Executive Director, REN21

SNAPSHOT. SOUTH AUSTRALIA

Looking Beyond 100% Renewables

South Australia is by far the leader in Australia's energy transition. In just over 15 years, the state has transformed its energy system from heavy coal and natural gas reliance to zero coal and more than 60% renewable electricity, supported by battery storage as well as gas. In 2021, South Australia generated 63% of its electricity from wind and solar power, supported by 22 wind farms, 4 solar farms, 4 grid-scale batteries, 2 world-leading home battery schemes and more than 10 virtual power plants. During nearly half of the days of 2021, renewable energy resources met 100% of the state's operational demand, bringing South Australia well ahead of its target for 100% net renewables by 2030.

Following a call for expressions of interest by the South Australian government in early 2021, seven companies from Australia and across the globe were selected to invest and develop land around Port Bonython on the Eyre Peninsula for hydrogen export, specifically hydrogen produced using green methods (i.e., renewable hydrogen). The proposed projects, totalling more than AUD 13 billion (USD 9.4 billion) in investment, could generate up to 1.8 million tonnes of hydrogen by 2030, both for domestic use and for export.

South Australia has defined an energy export strategy aimed at generating 500% of its energy needs and making the excess available for global use by 2050. To encourage investment in energy exports, the state is investing more than half a billion Australian dollars over four years to accelerate new hydrogen projects and shipping infrastructure in Whyalla, the gateway to the Eyre Peninsula. Additional locations are being identified around the Spencer Gulf, including Port Bonython, Port Pirie and Cape Hardy. A memorandum of understanding has been established with the Port of Rotterdam in the Netherlands, and export markets in Asia (such as Japan) also are being explored. The renewable hydrogen strategy also aims to produce green steel and green ammonia for domestic industry use.

Source: See endnote 12 from the Global Overview chapter.

EXECUTIVE SUMMARY

01 GLOBAL OVERVIEW

Renewables experienced yet another year of record growth in power capacity, despite aftershocks from the pandemic and a rise in global commodity prices that upset renewable energy supply chains and delayed projects. The role of renewables in improving energy security and sovereignty by replacing fossil fuels became central to discussions, as energy prices increased sharply in late 2021 and as the Russian Federation's invasion of Ukraine unfolded in early 2022.

Investment in renewable power and fuels rose for the fourth consecutive year, reaching USD 366 billion, and a record increase in global electricity generation led to solar and wind power providing more than 10% of the world's electricity for the first time ever. Strong market rebounds for solar thermal and biofuels, following declines in 2020, improved the outlook for renewables in heating and transport. Strengthened political commitments and rapid growth in sales of heat pumps and electric vehicles also led to increased renewable electricity use in these sectors.

At the same time, diverse factors continued to slow the global shift to renewable-based energy systems. A rebound in worldwide energy demand, which increased an estimated 4% in 2021, was met largely with coal and natural gas and led to record carbon dioxide emissions (up 6%, adding more than 2 billion tonnes). Large sums also continued to be invested in and to subsidise fossil fuels, with the USD 5.9 trillion in subsidies spent in 2020 equivalent to roughly 7% of global gross domestic product.

Similar to past years, the highest share of renewable energy use (28%) was in the electricity sector; however, electrical end-uses accounted for only 17% of total final energy consumption (TFEC). The transport sector, meanwhile, accounted for an estimated 32% of TFEC and had the lowest share of renewables (3.7%). The remaining thermal energy uses, which include space and water heating, space cooling, and industrial process heat, represented more than half (51%) of TFEC; of this, renewables supplied 11.2%.

As of 2020, modern renewable energy accounted for an estimated 12.6% of TFEC, nearly one percentage point higher than in 2019, as the temporary reduction in energy demand during 2020 favoured higher shares of renewables, while the share of fossil fuels barely changed.

The slow progress in energy conservation, energy efficiency and renewables prevents the transition away from fossil fuels that is necessary to meet global energy demand and reduce greenhouse gas emissions. A structural shift in the energy system is increasingly urgent. An energy-efficient and renewable-based economy is a game changer for a more secure, resilient, low-cost – and sustainable – energy future.

POWER

The renewable power sector took a large step forward, driven by record expansion in solar photovoltaic (PV) and wind power.

Despite supply chain disruptions, shipping delays, and surging prices for wind and solar energy components, renewable power capacity additions grew 17% in 2021 to reach a new high of more than 314 gigawatts (GW) of added capacity. The total installed renewable power capacity grew 11% to reach around 3,146 GW, although this is far from the deployment needed to keep the world on track to reach net zero emissions by 2050.

During 2021, China became the first country to exceed 1 terawatt of installed renewable energy capacity. Its total installed capacity of renewables increased 136 GW during the year, accounting for around 43% of global additions, with China leading in all technologies except concentrating solar power (CSP). By year's end, at least 22 countries had more than 10 GW of non-hydropower renewable capacity, up from 9 countries in 2011. The share of renewables in net power additions continued to increase, reaching a record 84% of newly installed capacity.

Renewables generated 28.3% of global electricity in 2021, similar to 2020 levels (28.5%) and up from 20.4% in 2011. Despite the progress of renewables in the power sector, the surge in global energy demand was met mostly with fossil fuels.

BUILDINGS

Renewable energy represents 14.7% of final energy demand in buildings, supplied mostly by renewable electricity followed by modern bio-heat.

Energy demand in buildings has continued to increase – including the energy used to construct buildings as well as to operate them. Direct use of modern renewable energy supplies two-thirds of renewable heat in buildings, with the rest coming from indirect sources such as electricity and district heating. The use of renewable electricity to generate heat in buildings has grown 5.3% per year, with electricity's share of building heating rising from 2.0% in 2009 to 3.3% in 2019.

A significant share of global heating needs in buildings continues to be met though the traditional use of biomass in developing and emerging economies. However, this share fell from 30% in 2009 to an estimated 26% in 2020.

During 2021, government policy played an important role in growing the renewable energy use in buildings through pricing, financial support and regulatory policies. Even though policy developments indicate rising attention to the use of renewables in buildings, these measures often exist alongside incentives for fossil fuel appliances, potentially undermining the effectiveness of renewable energy policies.

For the first time, solar and wind power provided

more than 10% of the world's electricity.

INDUSTRY AND AGRICULTURE

The share of renewables in industry and agriculture increased 4 percentage points in a decade, driven mostly by the electrification of industrial processes.

Renewables represent 16.1% of the industry and agriculture sector's total final energy consumption; half of this renewable energy is used to produce heat (mainly from modern bioenergy, followed by small amounts of geothermal and solar thermal), and the other half is renewable electricity. The electrification of industrial processes has led to growing use of renewable electricity for industrial heating, which rose 80% during the decade. Renewable hydrogen demonstration and pilot projects have been deployed in hard-to-decarbonise sectors such as steel.

Direct renewable energy policies in industry remained limited in 2021 and were focused mainly on renewable heat applications. Governments have pledged to support steel and concrete decarbonisation and also have developed specific industry decarbonisation roadmaps that include the use of renewable energy and renewable hydrogen.

TRANSPORT

Transport remains the sector with the lowest share of renewable energy use, with the overwhelming contribution coming from biofuels.

Biofuels production bounced back in 2021 to surpass pre-pandemic levels for both ethanol and biodiesel. Electrification grew across nearly all transport modes through 2021. Some regions saw increased interest in hydrogen and synthetic fuels as transport fuel, with minimal investment in renewable hydrogen.

Much of the growth in electrification can be attributed to targets and policy support for electric vehicles, in addition to the rising economic competitiveness, technological advancement and model availability of these vehicles. In 2021, electric car sales totalled 6.6 million worldwide, more than doubling from 2020, while sales of other electric vehicles such as two- and three-wheelers and buses also saw significant increases.

Countries with targets for renewable energy in transport have failed to meet these targets in large part because they lack supportive policy frameworks that encourage an energy and transport transition, or because the frameworks that are in place are ineffective or not enforced.

Renewables shares in total final energy demand

remained low in the sectors.

02 POLICY LANDSCAPE

Policy support for renewables remained strong throughout 2021, particularly in the power sector.

By the end of 2021, nearly all countries worldwide had in place a renewable energy support policy, with most support continuing to occur in the power sector and fewer efforts to accelerate renewables in buildings, transport and industry. Electrification of end-uses such as heating and road transport has emerged as a focus for decision makers.

By year-end, nearly all countries had a **renewable energy policy in place**, mostly supporting the power sector.

CLIMATE CHANGE POLICY

Climate change policy commitments accelerated in 2021, especially as countries announced net zero pledges and targets in the lead-up to the United Nations climate talks in Glasgow, Scotland.

Rising interest in decarbonisation is an increasingly important driver of renewable energy support policies. By the end of 2021, at least 135 countries and the European Union (EU) had in place some form of net zero target.

The most common type of fossil fuel ban enacted at the national and state/provincial level was on coal. Expanded policy support for decarbonisation of the transport sector included announcements of bans on fossil fuels for road transport.

RENEWABLE ENERGY TARGETS

Targets for renewables increased in 2021, although most continued to be implemented exclusively in the power sector.

By the end of 2021, 169 countries had in place some type of target (either economy-wide or in specific sectors) at the national and/or state or provincial level to increase the uptake of renewables. As in previous years, the greatest number of targets were in the power sector. Many targets in the transport and heating and cooling sectors expired in 2020, and only a few countries passed new ones in 2021 to replace them.

ECONOMIC DEVELOPMENT AND RECOVERY

Increasingly, renewables have been included as core components of national economic development plans and strategies.

Concerns related to rising energy prices and the security of energy supply are increasing policy makers' interest in including renewables in economic development plans. Several countries have used post-COVID recovery plans as opportunities to support the shift to renewables and have enforced strategies to build the necessary workforce for the future and re-skill existing workers.

POWER

The number of countries with renewable power policies again increased in 2021, continuing a multi-year trend.

By year's end at least 135 countries had some form of renewable electricity target. As in prior years, auctions, tenders and other competitive pricing strategies continued to overtake administratively set pricing policies such as feed-in tariffs. For small-scale renewable generation, although no rooftop solar PV mandates for buildings exist at the national level, several states/provinces have implemented such policies (in particular for new buildings or during major house renovations).

HEATING AND COOLING IN BUILDINGS

Despite the enormous potential for renewable heating and cooling in buildings, policy developments remain scarce.

Globally, the supply of heat in buildings remains heavily dependent on fossil fuels. By the end of 2021, at least 29 countries had committed to renewable heating and cooling targets. Although this was up from only 19 targets in 2020, it too reflects the trend of numerous expired targets not being replaced. Financial incentives remained the most popular form of support to scale up renewable heating. During 2021, interest in electrification of heating gained increased attention, with several countries setting specific targets and support mechanisms for heat pump installations.

TRANSPORT

As in previous years, policies supporting renewables in transport were focused mainly on road transport, with rail, aviation and shipping receiving far less attention.

Although biofuel support policies have been the most common type of renewable energy policy in the transport sector for many years, the number of countries with biofuel mandates has remained unchanged for four years running. Meanwhile, policy focus has shifted towards the electrification of transport (particularly road transport), although most transport electrification policies are not linked explicitly with renewable power generation.

INDUSTRY AND AGRICULTURE

The industrial sector continued to receive far less policy attention than other end-use sectors.

Financial incentives remained the most common policy support for renewable heat in industry in 2021. Renewable hydrogen has emerged as a potential tool to support industrial decarbonisation. Although several countries announced hydrogen support policies in 2021, almost all hydrogen continues to be manufactured using fossil fuels. By the end of 2021, at least 38 countries and the EU had a hydrogen roadmap or strategy in place. Interest in using renewables in agriculture is increasing, in particular related to agrivoltaics.

03 MARKET AND INDUSTRY TRENDS

BIOENERGY

Modern bioenergy provided 5.3% of total global final energy demand in 2020, accounting for around 47% of all renewable energy in final energy consumption.

In 2020, modern bioenergy provided 14.7 exajoules (EJ) for heating, or 7.6% of global requirements; two-thirds of this was used in industry and agriculture and the rest in buildings. Industry use is concentrated in countries with large bio-based industries such as Brazil, China, the United States, and India, while use for buildings occurs mainly in Europe and North America. The use of bioenergy to fuel district heating systems has grown strongly.

Biofuels – mostly ethanol and biodiesel – provided around 3.5% of transport energy in 2020. In 2021, biofuel production levels returned to 2019 levels after falling in 2020 due to reductions in transport demand due to the COVID-19 pandemic. Nevertheless, production in 2021 was constrained by high feedstock costs. Production of ethanol, the most widely used biofuel, increased 26% between 2011 and 2021. Global biodiesel production doubled between 2011 and 2021, due mainly to higher production and use in Asia. Production of HVO (hydrotreated vegetable oil, also known as renewable diesel) rose 36% in 2021.

In the electricity sector, bioenergy's contribution rose 10% in 2021 and has increased 88% overall since 2011. China remained the largest generator of bioelectricity, with production rising by a factor of 4.5 since 2011. The next-largest producers are the United States, Brazil and Germany, although generation has not grown significantly in these three countries in recent years. In contrast, generation has increased strongly in some other Asian and European countries.

GEOTHERMAL

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

New geothermal power generating capacity of 0.3 GW came online in 2021, bringing the global total to around 14.5 GW. This was more than double the additions in 2020 but below the five-year average of 0.5 GW since 2016. Capacity was added in Chile, Chinese Taipei, Iceland, Indonesia, New Zealand, Turkey and the United States.

The most active geothermal power markets have been Turkey and Indonesia, whereas other historically significant markets (such as the Philippines) have seen little or no capacity additions in recent years. During 2016-2021, the top 10 markets by reported capacity additions (new plant installations) were Turkey (0.9 GW added), Indonesia (0.7 GW), Kenya (0.2 GW) and the United States (0.2 GW), followed by Iceland, Chile, Japan, New Zealand, Costa Rica and Mexico (all less than 0.1 GW). The leading market, Turkey, has decelerated notably in recent years, possibly due in part to declining government support (reduced feed-in tariffs).

Worldwide, the capacity for geothermal direct use – direct extraction of geothermal energy for thermal applications – totalled an estimated 35 GW_{th} in 2021. Geothermal energy use for thermal applications grew by an estimated 12.8 TWh in 2021 to total around 141 TWh (508 PJ), with China being the largest market by far. The top countries for geothermal direct use remained (in descending order) China, Turkey, Iceland and Japan.

Generation from renewables **grew more than 5%** although extreme weather events affected production.

HEAT PUMPS

In 2020, heat pumps met only around 7% of the global heating demand in residential buildings, as fossil fuel-powered heaters and water heaters still comprised around half of the heating equipment sold.

However, this trend is changing as heat pumps become more common in new buildings. Globally, air-source heat pumps continued to dominate the market in 2021, with the top regions being China, Japan, Europe and North America.

Sales of air-source heat pumps in China peaked in 2017, whereas in Japan these units have been a common offering for more than 20 years, and sales are relatively stable. US heat pump sales have risen steadily and more rapidly than other heating alternatives in the country. In Europe, heat pump sales experienced double-digit growth in 2021; the top three European markets were France, Italy, and Germany, with the latter experiencing 28% growth for the year.

Various factors, such as technological maturity and the ability to provide additional flexibility in the electricity network or heating system, have led governments to integrate heat pumps into their climate action plans as a key means for decarbonising heating in buildings. Updates of building codes and regulations together with purchase subsidies (grants, loans or tax credits) can help counterbalance the upfront costs of heat pumps, particularly during building renovations; in new buildings, meanwhile, heat pumps can be an affordable solution. In 2021 both Ireland and Germany introduced a strengthened carbon price to balance the price of electricity relative to fossil gas, while also funding grant programmes for heat pumps.

HYDROPOWER

The global hydropower market progressed in line with long-term trends in 2021, with new capacity additions of at least 26 GW, raising the total global installed hydropower capacity to around 1,197 GW.

China maintained the lead in capacity additions in 2021, followed by Canada, India, Nepal, Lao PDR, Turkey, Indonesia, Norway, Zambia and Kazakhstan.

Despite these continuing additions, global generation from hydropower fell an estimated 3.5% in 2021 to 4,218 TWh. This is explained by changes in hydrological conditions, specifically the significant and sustained droughts that have affected the major producers in the Americas and many parts of Asia. Climate-induced changes in operating conditions, such as the loss of Himalayan glacial icecaps, appear to be causing long-term change in output.

Large hydropower producers that saw the most significant declines in generation in 2021 were Turkey (-28.7%), Brazil (-9.1%) and the United States (-8.8%). Other major markets that showed more modest annual contractions (but in some instances larger multi-year declines) included India (-2.2%), Canada (-1.5%) and China (-1.1%).

Global pumped storage capacity grew around 1.9% (3 GW) during the year, with most new installations in China.

OCEAN POWER

The resource potential of ocean energy is enormous but remains largely untapped, and ocean power represents the smallest portion of the renewable energy market.

Following significant delays to planned deployments, the industry rebounded in 2021 as supply chains recovered from disruptions caused by the COVID-19 pandemic. Around 4.6 MW of capacity was added during the year, bringing the total operating installed capacity to 524 MW. While the focus remains on small-scale (less than 1 MW) demonstration and pilot projects, the industry is progressing towards semi-permanent installations and arrays of devices.

Development activity is concentrated mainly in Europe, particularly Scotland, but policy support and deployments have increased steadily in China, the United States and Canada. Financial and other support from governments is critical for leveraging private finance and supporting commercialisation of ocean power technologies.

SOLAR PV

Solar PV maintained its record-breaking streak, adding 175 GW of new capacity in 2021 to reach a cumulative total of around 942 GW.

Global capacity additions of centralised utility-scale solar PV increased around 20%, with 100 GW of new installations, driven by the economic competitiveness of solar power and the attractiveness of power purchase agreements. Utility-scale PV accounted for the majority of new installations in the United States, India, Spain and France.

Distributed solar PV installations rose around 25%, adding 75 GW, driven by surging electricity prices that pushed entities to rely on self-consumption and to reduce their dependency on the distribution grid, where possible. Self-consumption from distributed systems played a crucial role in China, Australia, Germany and Brazil.

After many years of declines, PV module costs jumped an estimated 57% in 2021 as the cost of raw materials increased sharply. Factors contributing to rising module costs included a polysilicon shortage and a rise in the cost of shipping containers from China, the world's dominant module producer. Supply chain disruptions in 2021 highlighted the importance of domestic production of PV modules, with the United States extending its import tariff and India setting unprecedently high solar import duties.

CONCENTRATING SOLAR THERMAL POWER (CSP)

Global CSP market growth declined in 2021 despite reductions in the technology cost.

The CSP market contracted to a total cumulative capacity of 6 GW, as the launch of the 110 MW Cerro Dominador plant in Chile was offset by the decommissioning of nearly 300 MW of old CSP plants in the United States. The decline of CSP in the past decade has resulted from competition with solar PV, policy changes and project failures in the historically dominant markets of Spain and the United States.

In 2021, more than 1 GW of combined CSP capacity was under construction in Chile, China, the United Arab Emirates and South Africa. Most of this is based on parabolic trough technology and is being built in parallel with thermal energy storage (TES). By year's end, 23 GWh of TES in conjunction with CSP plants was operating across five continents, representing 40% of the global energy storage capacity outside of pumped hydropower.

Renewables represented
84% of newly installed capacities.

SOLAR THERMAL HEATING AND COOLING

The global solar thermal market grew 3% in 2021, to 25.6 GW_{th}, bringing the total global capacity to around 524 GW_{th}. China again led in new installations, followed by India, Turkey, Brazil and the United States.

Annual sales of solar thermal units grew at double-digit rates in several large markets, including Brazil, France, Greece, India, Italy, Morocco, Poland, Portugal and the United States. Demand was up due to increased activities in the construction sector in many countries, additional support schemes as part of national economic recovery policies, and rising fossil fuel and electricity prices globally. Large collector manufacturers benefited more than small manufacturers from the growing market and continued to consolidate their market positions. The 20 largest flat plate collector manufacturers increased production 15%. Chinese large collector manufacturers continued to expand their portfolios into renewable heating more broadly, with half of them offering stand-alone heat pumps and solar heat pump solutions.

Industrial companies around the world are turning increasingly to a zero carbon heat supply. At least 71 solar industrial heat (SHIP) solutions, totalling 36 MW_{th}, started operation globally in 2021, an increase of 8% to bring the total to around 975 SHIP plants. Another 44 MW_{th} of SHIP capacity was under construction by year's end, including the largest SHIP system in Europe (15 MW_{th}), which will provide process heat for a whey powder factory in France.

Due to growing interest in the electrification of heating, demand for PV-thermal (PV-T) or hybrid collectors increased again in 2021. Thirty manufacturers reported sales of PV-T capacity of at least 88 MW_{th} during the year, up 45% from 61 MW_{th} in 2020. The largest markets for new additions were France, the Netherlands, Israel, Germany and Spain.

WIND POWER

An estimated 102 GW of wind power capacity was installed in 2021, including a record 18.7 GW offshore. China led the market, followed distantly by the United States, Brazil, Vietnam and the United Kingdom. Annual additions increased total capacity by 13.5% to more than 845 GW.

While onshore additions dropped relative to 2020, as installations declined in China and the United States, offshore additions surged due largely to a dramatic policy-driven rise off the coast of China. Nearly every region of the world saw record market growth; not including China, global installations were up more than 14% in 2021. The economics of wind energy continued to be the primary driver for new capacity, combined with the need to increase energy security and to mitigate climate change.

However, the wind sector faces several challenges, including a lack of grid infrastructure and permitting issues. These were compounded in 2021 by rising costs due to pandemic-induced supply chain constraints, labour shortages, shipping backlogs and rising prices for major raw material inputs. While turbine prices continued to fall in China, average prices elsewhere rose to levels not seen since 2015, and major manufacturers reported losses. Outside of China, the industry is urging an increased focus on the system value of wind energy rather than solely on continually declining costs and prices.

Although the offshore segment accounts for a relatively small portion of global wind power capacity, it is attracting significant attention. An increasing number of governments and developers, as well as oil and gas majors and other energy providers, are turning to floating offshore turbines.

Turbine manufacturers continued to focus on technology innovation to achieve the lowest possible levelised cost of energy in response to the transition to renewable energy auctions as well as rising material costs and other pressures. The industry also is innovating to address challenges associated with scaling up production, transport and other logistical issues, and to enhance the value of wind energy while further improving its environmental and social sustainability.

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

By the end of 2021, 90% of the global population had access to electricity, although one-third (2.6 billion people) still lacked access to clean cooking, relying mostly on traditional use of biomass.

To improve their resilience to shocks – such as climate change, pandemics, economic fluctuations and conflict – these populations can benefit from distributed renewables for energy access (DREA). Energy access and gender equality also are strongly interlinked and are at the crossroads of the United Nations Sustainable Development Goals.

In 2021, the market for small off-grid solar devices continued to face supply issues, shortages, and price increases, although there were signs of recovery compared to 2020. An estimated 7.43 million off-grid solar lighting products were sold in 2021, of which around one-third were sold under the pay-as-you go (PAYGo) model and two-thirds as cash products. The level of electricity access that these technologies offer is still relatively low, as 83% of the sales were portable lanterns and small devices, with solar home systems representing only 17%. Despite efforts to address the poorest market segments, affordability remains a major barrier, especially in more remote rural communities with higher levels of poverty.

Solar PV has been the fastest growing mini-grid technology, incorporated into 55% of mini-grids and totalling around 365 MW of installed capacity as of 2019. Although national utilities own many mini-grids, private developers also have entered the space. These small companies face challenges in scaling their operational and financial capacity and mobilising equity. Large-scale portfolio approaches, which can attract global risk-mitigation facilities and unlock private equity, are increasing in scope.

A challenge for the productive appliance sector is the price competition with poorly manufactured, less-efficient products, many of which are being sold in sub-Saharan Africa. Only a few countries in the developing world have adopted minimum energy performance standards for appliances.

Clean cooking sales have been hampered by disruptions in supply chains and demand related to the COVID-19 pandemic. Non-biomass units accounted for a record 42% of the clean cookstoves purchased in 2020. Smart devices were a key breakthrough for making business models viable, with the emergence of PAYGo in the clean cooking sector and opportunities for broader uptake of carbon finance to fund stove programmes. Financing for clean cooking is shifting increasingly from grants to corporate equity. Most of the capital raised is concentrated in the top seven companies. These funds primarily financed liquefied petroleum gas (LPG) stoves (26%), followed by biomass (25%) and biogas systems (19%).

Achieving the target for universal access to

clean cooking by 2030 may fall 30% short.

05 INVESTMENT FLOWS

Renewable energy investment reached a record high in 2021 despite impacts from the COVID-19 pandemic.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) reached an estimated USD 366 billion in 2021, a record high. Solar PV and wind power continued to dominate new investment, with solar PV accounting for 56% of the total and wind power for 40%. China continued to represent the largest share of global investment, at 37%, followed by Europe (22%), Asia-Oceania (excluding China and India; 16%) and the United States (13%). Investment in new renewable energy projects showed remarkable resilience despite impacts from the pandemic.

Renewable power installations continued to attract far more investment than did fossil fuel or nuclear generating plants. Maintaining the shares of the past few years, investment in new renewable power capacity accounted for 69% of the total investment committed to new power generating capacity in 2021. The divestment trend continued in 2021 with more than 1,400 institutional investors and institutions worth more than USD 39 trillion in assets committing to partially or fully divesting from fossil fuels.

Although funds divested from fossil fuel companies are not necessarily re-invested in companies associated with renewables, changes in broader financing frameworks are increasingly relevant for renewable energy. Sustainable finance taxonomies may be relevant for: 1) companies producing or manufacturing renewable energy technologies, and 2) the owners or operators of renewable energy assets (such as a utility that operates a wind farm as part of its broader portfolio). Such stakeholders would be eligible for the technological screening of the taxonomy and thereby be pre-screened for interested investors. The number of sustainable finance taxonomies in use or under development has increased rapidly since the Paris Agreement was signed in 2015.

A majority (57%) of climate change mitigation finance was invested in renewables in 2019/2020, dominated by solar PV and onshore wind energy. The Paris Agreement highlights the need to make finance flows consistent with the goal of limiting global temperature rise to 1.5 degrees Celsius. Achieving this goal would require significant growth in the overall investment in renewables compared to the last decade.

06 RENEWABLE-BASED ENERGY SYSTEMS

For millennia, renewables derived from the sun, water and wind provided the backbone of energy supply for much of the human population, a reality that was overturned by the rapid rise of coal, oil and natural gas in the 19th and 20th centuries.

More recently, renewable energy has started to dominate again in certain parts of the world, particularly for electricity use, supported by rapid declines in the costs of wind and solar power.

The share of variable renewable energy sources (wind and solar) in the global electricity mix exceeded 10% for the first time in 2021. In Denmark, the annual share of wind and solar surpassed 50%, while in Ireland, Spain and Uruguay it was above 30%.

So far, no examples exist of fully renewable-based energy systems that span the electricity, heating and cooling, and transport sectors; however, the technological, infrastructural and operational foundations of such systems are now being laid. The rise of increasingly cost-effective energy storage combined with greater demand-side flexibility and the expansion of transmission infrastructure is making it possible for regions with widely differing resource endowments to transition to fully renewable-based power systems.

In addition, a growing number of jurisdictions are harnessing their renewable electricity sources to support the expansion of renewables to other sectors of energy use. Communication-enabled heating and cooling technologies such as heat pumps, thermal storage technologies and air conditioners are helping to enable higher shares of renewables in the heating and cooling sector, while renewably powered transport is enabled by the rise of electric vehicles, which can be charged with 100% renewable electricity.

07 RENEWABLES IN CITIES

City governments used a broad range of targets, policies and actions to show local commitment to renewables.

By the end of 2021, around 1,500 cities had renewable energy targets and/or policies. City governments also have taken action that indirectly supports the shift to renewables, such as setting net zero targets and targets for electrifying heating, cooling and transport.

Many challenges remain for cities to take climate and energy action, including the degree to which national governments grant their city counterparts regulatory power and access to financial markets; market rules and energy regulations set at higher levels of government; and a lack of institutional and human capacity and awareness of how cities can contribute to the energy transition. Some local governments have collaborated with their national governments to realise renewable energy projects, whereas others have initiated and/or supported legal barriers against climate and energy action.

DRIVERS FOR RENEWABLES IN CITIES

City governments are motivated to seek solutions that meet local energy demand while fostering healthy, resilient and liveable communities.

With the COVID-19 pandemic entering its second year in 2021, efforts to ensure public health and well-being while supporting local economic recovery and resilience were top urban priorities. Another priority in cities has been reducing local air pollution (and carbon emissions) from the burning of fossil fuels in road transport, buildings and industry. In the face of rising energy costs, municipal agendas also have been exploring how to use renewables to keep costs manageable.

CITY ENERGY AND CLIMATE TARGETS

City governments have given direct support to renewables deployment and investment by setting specific renewable energy targets, either for municipal operations or to shift city-wide energy use.

By year's end, more than 920 cities in 73 countries had set a renewable energy target in at least one sector (power, heating and cooling, or transport). Targets to shift to renewables in buildings are the most prevalent. In line with global trends, most city-level renewable transport targets focus on electric vehicles with around 100 cities having such targets in place.

The global momentum towards emission reduction targets in cities further accelerated in 2021, with more than 1,100 city governments having announced targets for net zero emissions. However, only a few city governments have anchored their net zero pledges in policy documents or developed plans with specific actions towards net zero, including the deployment of renewables.

FINANCING RENEWABLES

City governments have used a variety of mechanisms to finance renewable energy projects.

Options include using their own capital and/or assets to develop projects; raising funds through bonds, development finance and bank loans; and leveraging funds provided by higher levels of government. The available solutions depend on the context, including existing rules and regulations, ownership rights for infrastructure, the availability of capital, the ability of municipalities to collect fiscal revenue and borrow money, and the potential to mobilise private sector partners. Due to the spectrum of actors involved, tracking renewable energy finance in cities remains difficult.

30% of urban population

live in a city with a renewable energy target and/or policy.

BUILDINGS

Municipal policies aimed at decarbonising the building stock vary depending on whether they apply to buildings under municipal control or to residential, commercial and industrial buildings.

City governments have used their building assets to install stand-alone renewable energy systems, where most focus has been on solar PV. In cases where city governments have insufficient space to install renewables, or face other constraints, they have signed agreements to buy the electricity from off-site projects, mostly via power purchase agreements.

To encourage wider decarbonisation of buildings through renewable power and/or heating, city governments have expanded their policy portfolios. Typically, regulatory mechanisms such as building codes that mandate on-site generation of renewables for electricity and/or heating apply only to new buildings, although some cities also require this during retrofits and renovations. For existing buildings, financial and fiscal incentives such as grants, rebates and tax credits often are used to encourage renewables. In addition, a total of 59 cities in 13 countries had either passed or proposed a ban or restriction on cities have banned or restricted the use of natural gas, oil or coal for space and water heating and for cooking.

Low-emission zones exist in

270 cities.

TRANSPORT

City governments have undertaken efforts to decarbonise urban transport, in addition to reducing personal motorised transport by expanding walking and biking infrastructure and public transport systems.

Most efforts have focused on the electrification of municipal service fleets and public buses as well as the expansion of metro and light rail systems. Many cities have continued to use biofuels in transport, with some tapping into urban waste and wastewater resources as inputs for biofuel production.

Some municipal governments have provided fiscal and financial support for the purchase of biofuel or electric vehicles, in some cases targeted at taxi fleets and delivery companies. The most widespread policy support is measures that enable broader transport decarbonisation, such as low-emission zones, bans and restrictions, improving access to charging infrastructure and preferential parking. By the end of 2021, 270 cities had established low-emission zones and 20 had passed bans and restrictions on certain (fossil) fuels or vehicle types.

SNAPSHOT. SWEDEN

Green Steel Value Chain

In 2016, the Swedish industries SSAB, LKAB and Vattenfall launched the HYBRIT initiative to decarbonise steelmaking by replacing coking coal with hydrogen for ore-based steel production. The initiative aims to produce steel without using fossil fuels, thereby reducing Sweden's CO_2 emissions 10% by 2026. Finland joined the consortium in 2018, aiming to reduce its own CO_2 emissions by 7%.

In this effort to create the world's first entirely fossil-free value chain (from mine to steel), the pilot Luleå facility was commissioned in 2020 to test using renewable hydrogen to produce sponge iron for steel. Construction on a hydrogen storage facility started in May 2021, and SSAB produced its first fossil-free steel in August. At full capacity, the 100 GWh storage facility will be able to power a full-size steel mill for three to four days. The project required SEK 200 million (USD 22.1 million) in investment as well as SEK 52 million (USD 5.7 million) in support from the Swedish Energy Agency to build the storage facility.

In 2021, the town of Gällivare was selected as the site for a demonstration facility for industrial-scale steel production. In addition, innovation in green steel has continued along the value chain, with Volvo Group producing a first-of-its-kind vehicle using SSAB's green steel, and steel manufacturer Ovako developing a hydrogen filling station that will use surplus hydrogen to power Volvo's next-generation trucks.

Source: See endnote 224 for this chapter.

01 GLOBAL OVERVIEW

KEY FACTS

- **Renewables experienced yet another year of record growth in power capacity in 2021**, despite aftershocks from the pandemic and a rise in global commodity prices.
- The role of **renewables in improving energy security and sovereignty by replacing fossil fuels became central to discussions**, as energy prices increased sharply in late 2021 and as the Russian Federation's invasion of Ukraine unfolded in early 2022.
- For the first time ever, global electricity generation led to **solar and wind power providing more than 10% of the world's electricity**.
- Renewables shares in total final energy demand remained low in the buildings, industry and agriculture and transport sectors, where **policy support remains insufficient** for the uptake of renewable energy.
- Fossil fuels remain dominant, as evidenced by the slow progress in renewables. However, **a structural shift in the global energy system is increasingly urgent**.

INTRODUCTION AND HIGH-LEVEL TRENDS

In 2021, renewable energy continued to be impacted by the COVID-19 pandemic and was further influenced by economic and geopolitical developments. Aftershocks from the pandemic and a rise in commodity prices upset renewable energy supply chains and delayed projects. Additionally, a sharp increase in energy prices in late 2021 and the Russian Federation's invasion of Ukraine in early 2022 sparked rising discussion on the role of renewables in improving energy security and sovereignty by replacing fossil fuels. Meanwhile, international organisations laid out achievable pathways to a global net zero emission energy system, and a record number of countries had net zero targets by year's end.

Amid these events, renewables experienced yet another year of record growth in power capacity. Investment in renewable power and fuels rose for the fourth consecutive year, and the record increase in global electricity generation led to solar and wind power providing more than 10% of the world's electricity for the first time ever. Following a decline in 2020, a strong market rebound in solar thermal and biofuels improved the outlook for renewables in heating and transport. Strengthened political commitments and rapid growth in heat pump and electric vehicle sales also pointed to increased renewable electricity use in these sectors.

At the same time, diverse factors continued to slow the global shift to renewable-based energy systems. A rebound in worldwide energy demand in 2021, met largely with coal and natural gas, led to record carbon dioxide (CO_2) emissions. Large sums also continued to be invested in and to subsidise fossil fuels.

DEVELOPMENTS IN 2021

As in previous years, the greatest success for renewables was in the power sector. After largely withstanding the impacts of the COVID-19 pandemic, growth in global renewable power capacity accelerated in 2021, adding more than 314 gigawatts (GW).[1] (→ *See Table 1.*) The market also diversified geographically, with the top five countries accounting for 71% of all capacity added (down from 75% in 2020, but still less diverse than in 2019 and 2018).[2] (→ *See Table 2.*) Overall, the renewable power capacity additions reflected market growth of 11%; however, they still represented only a third of the additions needed annually to achieve the world's major goals for net zero carbon emissions.[3]

Renewable energy comprised 28.3% of the global electricity mix in 2021, roughly on par with 2020 levels.[4] The growth in renewable energy penetration was mitigated by the overall rise in electricity demand and by drought conditions that greatly reduced global hydropower generation.[5] (→ *See Figure 1.*) As economic activity rebounded in 2021, worldwide energy demand increased an estimated 4%, while CO_2 emissions rose 6% to record levels (adding 2 gigatonnes (Gt), after falling by 5% in 2020).[6] Despite the progress of renewables in the power sector, the surge in global energy demand was met mostly with fossil fuels.[7]

Prices for some fossil fuels, notably natural gas, increased sharply in 2021, reflecting a combination of supply, demand and investment factors.[8] These included a resurgence in natural gas demand during the year and a supply crunch that was worsened by low gas stocks in Europe and a reluctance among international suppliers to increase exports.[9] Natural gas prices rose more than 400% in most markets, leading to a spike in wholesale electricity prices in major markets by year's end.[10] Governments responded by freezing prices, reducing energy sales taxes, and providing financial assistance to lowincome households, among others.[11] High energy prices (further exacerbated by the Russian invasion of Ukraine) and increased climate ambitions prompted efforts to speed the shift to renewables.[12] (→ *See Sidebar 1.*)

The International Energy Agency's (IEA) Net Zero by 2050 scenario, released in May 2021, set the tone for a new norm, stimulating higher ambition among governments and corporations.[13] In the lead-up to the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP26), held in Glasgow, Scotland in November, 17 countries pledged to achieve net zero emissions by 2050 or a later date, with some countries targeting 2025.[14] The European Commission raised its 2030 target for renewables in total final energy consumption (TFEC) first to 40% in 2021, then to 45% in early 2022.[15] Also in the lead-up to COP26, 151 countries submitted new or updated Nationally Determined Contributions (NDCs) towards reducing their greenhouse gas emissions under the Paris Agreement.[16]

The Glasgow Climate Pact that emerged calls on countries to raise their ambition annually instead of every five years, and, for the first time in the history of UN climate agreements, it explicitly acknowledges the need to reduce fossil fuel use.[17] During the meetings, 140 countries agreed to "phase down" unabated coal power, while numerous companies, countries and public finance institutions committed to ending public support and funding for unabated fossil fuels.[18]

In total, more than 40 countries agreed to stop financing new coal plants, although commitments to shut down existing capacity were notably absent in Australia, China, India, and the United States, which as of 2021 together owned two-thirds of the world's operating[i] coal plants.[19] During the UN High-Level Dialogue on Energy in September 2021, the UN Secretary-General announced a roadmap for "global clean energy for all", for which governments and the private sector committed more than USD 400 billion.[20]

Renewable power additions **need to triple** to be on track with major net-zero scenarios.

i Data are for operating plants only, totalling 1,250 operating plants in 2021 (9 in Australia, 585 in China, 115 in India and 124 in the United States).

FIGURE 1.

RENEWABLE ENERGY **GLOBAL OVERVIEW**

Global CO_2
Energy-related emissions account for three-quarters of global CO_2 emissions

Modern renewables account for **12.6 %** of total final energy consumption (2020)

135 countries have some form of net zero target, covering **88 %** of global emissions

A rebound in economic activity led to a **6 % increase** in CO_2 emissions in 2021

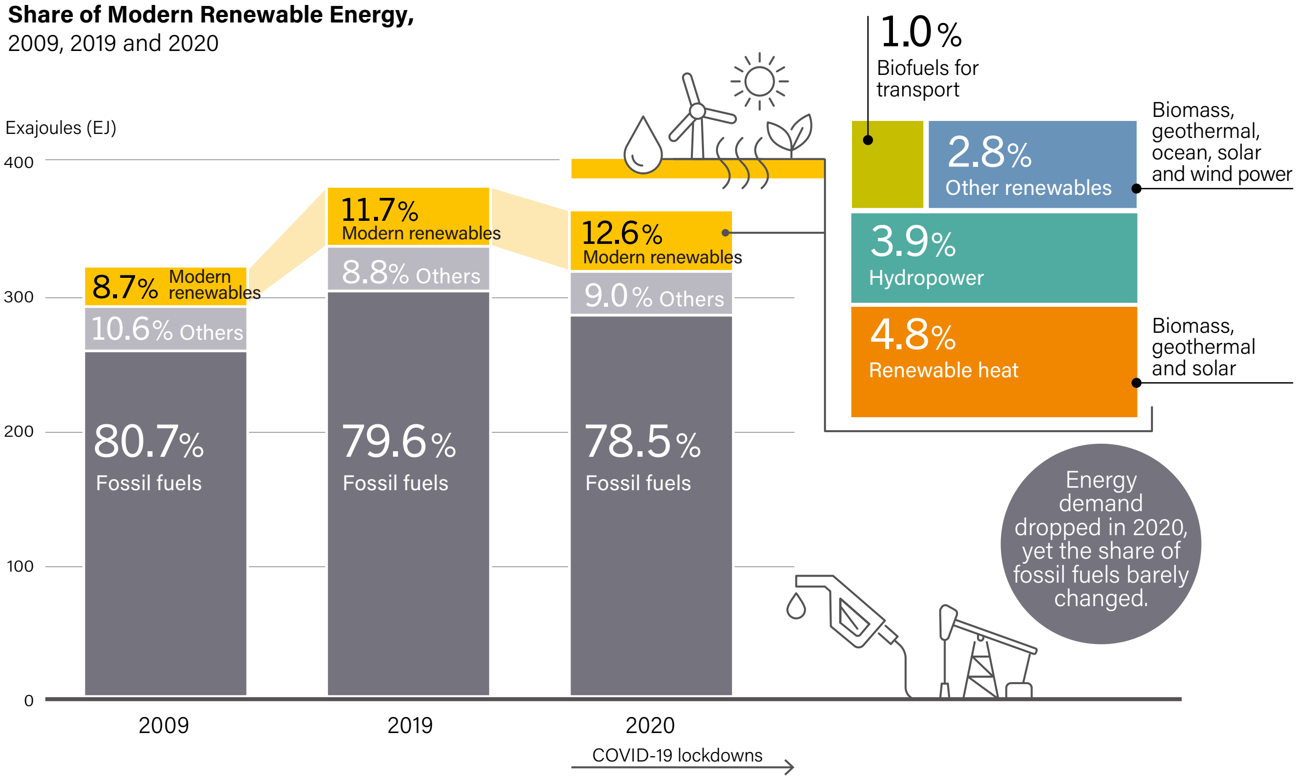
Total final energy demand grew **19 %** between 2009 and 2019

USD 366 billion was invested in renewables in 2021

Fossil fuel subsidies reached **USD 5.9 trillion** in 2020
equivalent to USD 11 million **per minute**

At the 2021 UN climate summit, countries agreed to a **phase-down** of unabated coal power

Share of Modern Renewable Energy,
2009, 2019 and 2020



Source: Based on IEA data.
See endnote 5 for this chapter.

SIDEBAR 1. Renewables to Support Energy Security

Global prices for oil and natural gas began rising rapidly in late 2020 as demand recovered following the easing of COVID-19 restrictions. This trend was exacerbated in early 2022 by the Russian Federation's invasion of Ukraine, with prices fluctuating daily. Between 2020 and early 2022, oil prices rose by a factor of three – returning to pre-2014 levels of more than USD 100 per barrel – while natural gas prices in Europe and Asia rose by a factor of six. Global coal prices doubled in the weeks between late February and early March 2022, with demand rising as coal was used to substitute gas-fired electricity generation. Price spikes and variability have major impacts for industry and for domestic consumers and give rise to strong inflationary pressures.

Most countries depend heavily on imported oil and gas from relatively few exporting countries. The main oil importers traditionally have been China, India, the United States, Japan, and the Republic of Korea, while the main exporters are Saudi Arabia, the Russian Federation and Iraq. China is the major importer of natural gas, along with Japan, Germany, and Italy, while the Russian Federation is the dominant exporter, along with Qatar, Norway and Australia.

However, import dependence has evolved in the past decade as some countries have sought to improve domestic energy production and to electrify their consumption. For example, Spain and the United Kingdom have increased the share of renewables in their total final energy consumption, and other countries have positioned themselves as exporters of renewable hydrogen. (→ *See Snapshot: South Australia in Executive Summary*.) At the same time, many European countries have greatly increased their dependency on fossil fuel imports, making them more vulnerable to price and supply variations.

In 2020, China imported around 73% of its crude oil and 60% of its natural gas. India imported nearly 90% of its crude oil requirements, while Japan and the Republic of Korea produced only a tiny share of their oil and gas needs. The European Union (EU-27) imported 97% of its oil and petroleum needs and 84% of its gas needs. The Russian Federation was the largest supplier to the EU of both fuels, providing 44% of gas and 25% of oil imports. In addition, many small and developing nations are highly dependent on imported oil, and their economies are especially vulnerable to volatile prices and risks of supply disruptions.

Heightened concerns about energy security and prices present both challenges and opportunities for the energy transition. The recent price hikes have created pressure on governments to compromise their ambitions to reduce greenhouse gas emissions in the short and long-term. High natural gas prices have favoured a return to coal-based generation and have increased pressure to develop local fossil fuel resources, including calls to restart fracking for shale gas (for example, in the United Kingdom). Emissions rebounded heavily in 2021 due in part to these developments, and additional investments in fossil fuel infrastructure will severely impact emission levels for decades to come. Several countries have opted to scale up production: China plans to increase coal production by 300 million tonnes (equivalent to 7% of current levels), while the United States has seen a boom in new fracking and drilling projects.

On the other hand, a strong synergy exists between measures needed to improve energy security and those associated with the energy transition, and especially the shift to renewables. High levels of locally produced renewable energy, coupled with energy saving and better energy efficiency, improve energy security, sovereignty and diversity. This helps to reduce exposure to energy price fluctuations while at the same time reducing emissions and providing other economic benefits.

Higher fossil fuel prices make renewable solutions more attractive in the short term, with wind and solar now highly competitive with gas-fired power generation. Rising fossil fuel prices also have narrowed the cost gap between biofuels and biomethane and fossil-based transport fuels, and have improved the cost competitiveness of bioenergy, solar, geothermal and heat pumps powered by renewable electricity. Renewable energy solutions can be implemented quickly – in as little as a year for wind and solar photovoltaics (PV) where permitting policies and regulatory regimes are streamlined. Although the risk of overdependence on imported components (such as PV modules) could lead to supply insecurity if production is overconcentrated in a few countries, some countries and regions have supported the development of domestic or regional manufacturing value chains. Domestic production of renewable energy components, or at least a diversified supply base, have become increasingly important aspects of energy security policy.

Energy security concerns also have prompted reviews of energy policies. For example, the EU aims to reduce its reliance on Russian gas 60% by the end of 2022 and entirely by 2030, based on measures that include doubling the level of renewable hydrogen production and ramping up its use. The newly released REPower EU plan aims to double the EU's solar PV and wind capacities by 2025 and to triple them by 2030.

Germany aims to accelerate its shift to renewable power – now labelled "freedom energy" – and is seeking a 100% renewable electricity supply by 2035. It is targeting 80% wind and solar power by 2030, including a tripling of solar energy capacity to 200 GW, a doubling of onshore wind energy capacity to 110 GW and offshore wind energy capacity of 30 GW. The United Kingdom has considered relaxing planning constraints on onshore wind farms to facilitate rapid growth in renewable power and to reduce dependence on gas imports. Spain is accelerating the approval of up to 7 megawatts (MW) of wind power projects and up to 150 MW of solar PV projects, and will also permit floating solar PV systems and facilitate self-consumption.

Japan aims to accelerate its efforts to develop offshore wind power projects, in response to the potential longterm increase in oil prices due to the Russian invasion of Ukraine. Japan's tender process for wind farms will be revised to take into account not only the price but also how quickly the projects can be developed. Globally, the added emphasis on energy security amplifies the imperative to move as swiftly as possible to an efficient, renewable-based energy system that is compatible with ambitious climate goals while also avoiding dependency on fossil fuels that exposes consumers and industry to price volatility and political pressures.

Source: See endnote 12 for this chapter.

Frameworks also emerged aimed at shifting energy investment towards low-emission technologies, some of which support the development of nuclear energy, carbon capture and storage, and fossilbased hydrogen. The new EU Taxonomy[i], which defines the terms under which economic activities may be considered "sustainable", covers renewable technologies as well as nuclear and natural gas.[21] The Association of Southeast Asian Nations (ASEAN) – which aligned its environmental objectives with the EU Taxonomy – also delivered its first version of a joint taxonomy.[22] The EU's proposed carbon border adjustment mechanism (CBAM) would place a carbon price on goods imported from outside the EU.[23] The rising regulatory and financial pressure to shift investment to clean technologies highlights the considerable risk of stranded assets in the fossil fuel sector.[24] (→ *See Box 11 in Investment chapter.*)

In Europe, the increase in coal generation and related emissions during 2021 led to a sharp rise in the price of carbon emission allowances, which were established under the EU Emissions Trading System (ETS) to encourage companies to reduce emissions through mitigation efforts and trading of allowances. The ETS hit record highs of more than EUR 89 (USD 100) per allowance in 2021 and nearly EUR 100 (USD 113) in early 2022.[25] The European Commission proposed extending the scheme and also introduced a new ETS covering fuel use in road transport and buildings[ii].[26] In mid-2021, China began operating the world's largest emission trading system[iii], regulating more than 2,200 power sector companies.[27]

With the increased attention to targeting net zero emissions, by year's end nearly 85% of the world's population and 90% of its gross domestic product (GDP) were covered by some form of net zero target.[28] These targets vary widely in their application (target date, status, greenhouse gas and scope) and in the governance indicators[iv] used for tracking progress.[29] Despite this worldwide coverage, less than a third of the national governments with net zero targets had targets for 100% renewable energy, although 60% of the governments had economy-wide targets for renewables.[30]

i The Taxonomy is aimed to frame and define sustainable investments that substantially contribute to meeting the EU's environmental objectives. It identifies energy activities under a life-cycle emission threshold, while fulfilling specific conditions and obtaining permits within a defined time frame.

ii The current ETS covers emissions from power stations, energy-intensive industries and aviation within Europe. With Fit for 55, the new ETS, expected to become operational by 2025, upstream fuel suppliers will be required to monitor and report the fuel amounts they introduce in the market (via greenhouse gas emission certificates), thus incentivising the decarbonisation of fuel products.

iii The Chinese ETS does not clearly promote the shift from coal to renewables; rather, it incentivises running more-efficient coal-fired plants versus less-efficient ones.

iv Different governance indicators – such as reporting mechanisms, published plans, interim targets and leader accountability – are used depending on the type of stakeholder and its net zero indicator.

Pushback against the oil and gas industry accelerated during 2021. Courts, executive boards and shareholders increasingly demanded that companies reduce their emissions and become more accountable for the environmental, social and climate impacts of their activities.[31] Public opinion continued to shift, affecting the advertising and marketing industry, as more than 120 agencies in Europe and the United States pledged to not work with fossil fuel companies due to the apparent conflict between companies' climate-friendly advertising campaigns and their actual strategic alignments.[32] (→ *See Box 1.*)

ONGOING CHALLENGES TOWARDS A RENEWABLE-BASED WORLD

The share of renewables in a country's total final energy consumption (TFEC) varies depending on the energy mix. The average renewable share in TFEC among selected countries in 2019 was 17%, up from 15% in 2009.[33] During this period, the renewable share fell in 18 countries, although 9 countries, mostly in Europe, have achieved high growth and large net increases in their renewable shares in TFEC.[34] (→ *See Figure 2.*) Only 3 countries out of 80 – Iceland, Norway and Sweden – had renewable shares above 50% in 2019, and 20 countries, mostly in Europe and Latin America, met at least a quarter of their total final energy consumption with renewables.[35]

The main structural reasons for the slow uptake of renewables in meeting global energy demand include:

- consistent increases in energy demand, despite the temporary decline in 2020 related to the COVID-19 pandemic;
- continued use of and investment in new fossil fuels, particularly coal; and
- the adoption of mainly fossil fuels to replace the declining use of traditional biomass in developing economies.

Modern[i] renewable energy accounted for an estimated 12.6% of TFEC in 2020 (latest data available[ii]), up modestly from 8.7% in 2009.[36] (→ *See Figure 1.*) This share was nearly one percentage point higher than in 2019 (11.7%), as the temporary reduction in energy demand during 2020 favoured higher shares of renewables.[37] Also for this reason, the share of fossil fuels in TFEC fell temporarily in 2020, to 78.5%.[38]

i Excludes the traditional use of biomass, i.e., the burning of woody biomass or charcoal, as well as dung and other agricultural residues, in simple and inefficient devices to provide energy for residential cooking and heating in developing and emerging economies.

ii The latest consolidated data available are from 2019. Data from 2020 are based on projections from 2019 data and on 2020 estimates. The unusual energy trends of 2020 make these estimations highly uncertain, although the general trend should be accurate.

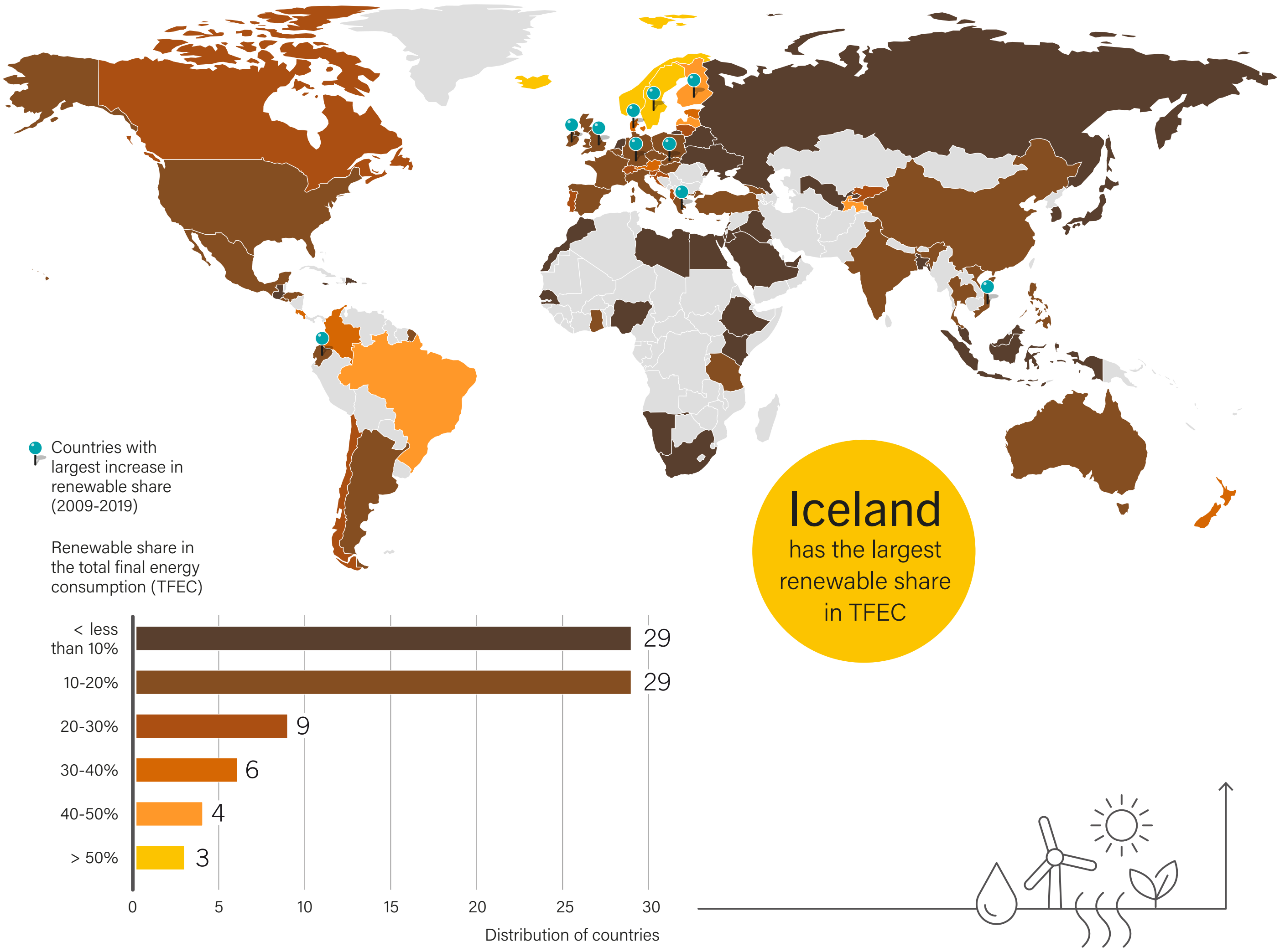
BOX 1. Public Communications Around Fossil Fuel Disinformation

Fossil fuel companies allocate billions of dollars each year to marketing and advertising campaigns that seek to rebrand their corporate identity as "climate-friendly", mask their impact on climate change and position their products as crucial for local development, small businesses and consumers. In 2020 alone, industry players spent nearly USD 10 million on Facebook ads to promote their self-proclaimed climate actions. Yet oil and gas companies' investments in renewables correspond to only around 1% of their total capital investments, while these companies remain responsible for around three-quarters of global greenhouse gas emissions.

Some players in the communications field, including agencies, creatives, and the media, are taking a stand against these disinformation campaigns. By early 2022, the Clean Creatives Pledge had brought together a coalition of 265 communication agencies and 700 creatives that refuse to accept contracts with clients from the fossil fuel industry. Some major news outlets, such as The Guardian (UK) have stopped publishing fossil fuel ads in their newspapers. In the United States, several sub-national governments, including New York City and the states of Delaware and Minnesota, have filed legal action against fossil fuel companies on the grounds of misleading the public. The city of Amsterdam (Netherlands) aims to ban oil and gas ads from its metro stations and other public spaces.

Source: See endnote 32 for this chapter.

FIGURE 2.
Renewable Energy Share in Total Final Energy Consumption for Selected Countries, 2019



Source: Based on IEA data. See endnote 35 for this chapter.

Note: This figure includes a selection of 80 nations among the largest energy-consuming countries in the world.

Overall, renewable energy use grew 4.6% annually on average (a total of 17.6 exajoules, EJ) between 2009 and 2020, outpacing growth in both total energy demand (1.2% annually; 41.8 EJ) and fossil fuels (0.9%; 26.6 EJ).[39] As in recent years, renewable electricity accounted for the largest share of TFEC (6.8%), followed by renewable heat (4.8%) and transport biofuels (1.0%).[40]

However, consistent growth in energy demand reduces the penetration of renewables in TFEC. Although energy efficiency helps to mitigate this growth, efficiency efforts are not on track to meet global decarbonisation goals.[41] Global energy intensity improved slightly in 2020 (up 0.5%) and again in 2021 (1.9%), but this remains far from the 4% improvement that international experts say is needed.[42]

In 2021, the renewable energy sector continued to receive COVID-19 recovery funding, mostly targeting renewable power and transport. Recovery spending on renewables nearly doubled between April and December, to USD 677 billion; however, this represented only 21% of the total amount that governments allocated to be spent, and was well below the annual support that fossil fuels receive in subsidies.[43] Between 2018 and 2020, more than USD 18 trillion[i] in subsidies was dedicated to fossil fuels, with the 2020 spending of around USD 5.9 trillion equivalent to roughly 7% of global GDP.[44]

Meanwhile, incentives for renewables have remained low and are less tracked.[45] Despite strengthened commitments to climate change and net zero, many countries have lessened their support for renewables while bolstering fossil fuel finance. Between 2017 and 2020, India reduced its financial support for renewable energy nearly 45% while continuing to increase fossil fuel subsidies.[46]

i All prices and subsidy values are in 2021 constant dollars. This corresponds to the cumulative value of explicit and implicit subsidies during this three-year period. In 2020, just 8% of the subsidies were explicit (reflecting undercharging for supply costs) and 92% were implicit (reflecting undercharging for environmental costs and foregone consumption taxes).

A shortage in renewable energy skills has been identified as a possible bottleneck in the deployment of infrastructure and technologies, including renewable power, batteries and heat pumps.[47] For example, meeting the labour needs in the offshore wind sector in a few of the leading[i] markets is estimated to require more than 70,000 workers.[48] Although in many cases fossil fuel workers can be re-skilled to support the changing energy industry, challenges persist in some places due to salary differences, relocation needs and insufficient funding for vocational training.[49] In 2021, some governments began dedicating funds and launching programmes to re-skill and train workers for new "clean energy" jobs, including renewables.[50] (→ *See Sidebar 5 in Policy chapter.*)

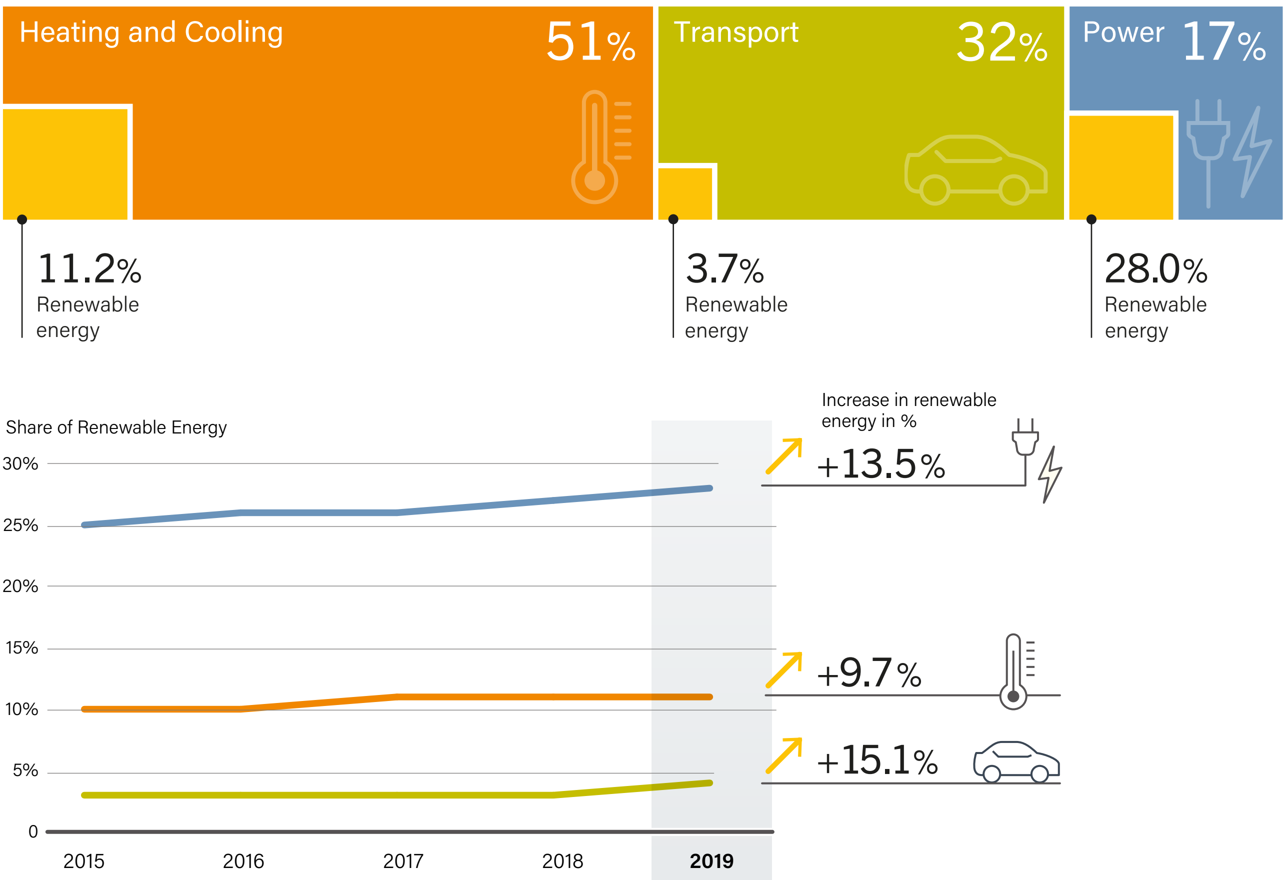
As in previous years, in 2019 (latest data available) the penetration of renewables was lowest in those sectors that consume the greatest amount of energy. The highest penetration was in the general use of electricity (such as for lighting and appliances but excluding electricity for heating, cooling and transport), which accounted for around 17% of TFEC[ii].[51] Energy use for transport represented around 32% of TFEC and had the lowest share of renewables (3.7%).[52] The remaining thermal[iii] energy uses, which include space and water heating, space cooling, and industrial process heat, accounted for more than half (51%) of TFEC; of this, around 11.2% was supplied by renewables.[53]

i These key markets are China, Chinese Taipei, Japan, the Republic of Korea, the United States, and Vietnam, representing projected combined installations of 30 GW of offshore wind power during the 2020-2024 period.

ii Due to losses during transformation, electrical applications account for a higher portion of primary energy consumption. See Glossary for definitions.

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

FIGURE 3.
Renewable Energy in Total Final Energy Consumption, by Final Energy Use, 2019



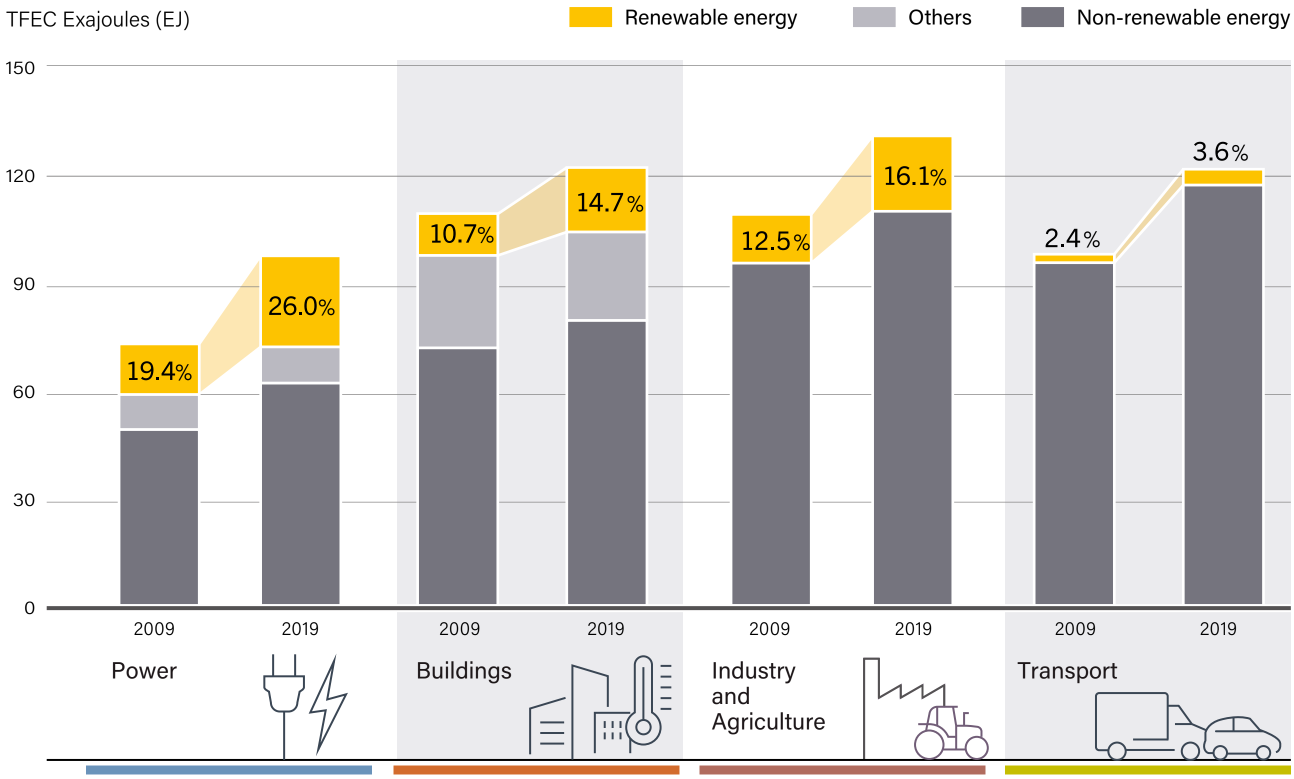
Source: Based on IEA data. See endnote 56 for this chapter.

The renewable share of the "worst-performing" sectors has grown the slowest. Between 2015 and 2019, the renewable share in transport increased only 0.5 percentage points, and in heating and cooling it grew only one percentage point.[54] The share of renewables in the power sector, meanwhile, increased more than three percentage points.[55] At the same time, these percentage point increases corresponded to larger growth of the share in each sector – 13.5% in power, 9.7% in heating and cooling, 15.1% in transport.[56] (→ *See Figure 3.*)

The following sections discuss key developments in the renewable energy share in power capacity and electricity generation as well as in buildings, industry and transport.[57] (→ *See Figure 4.*)

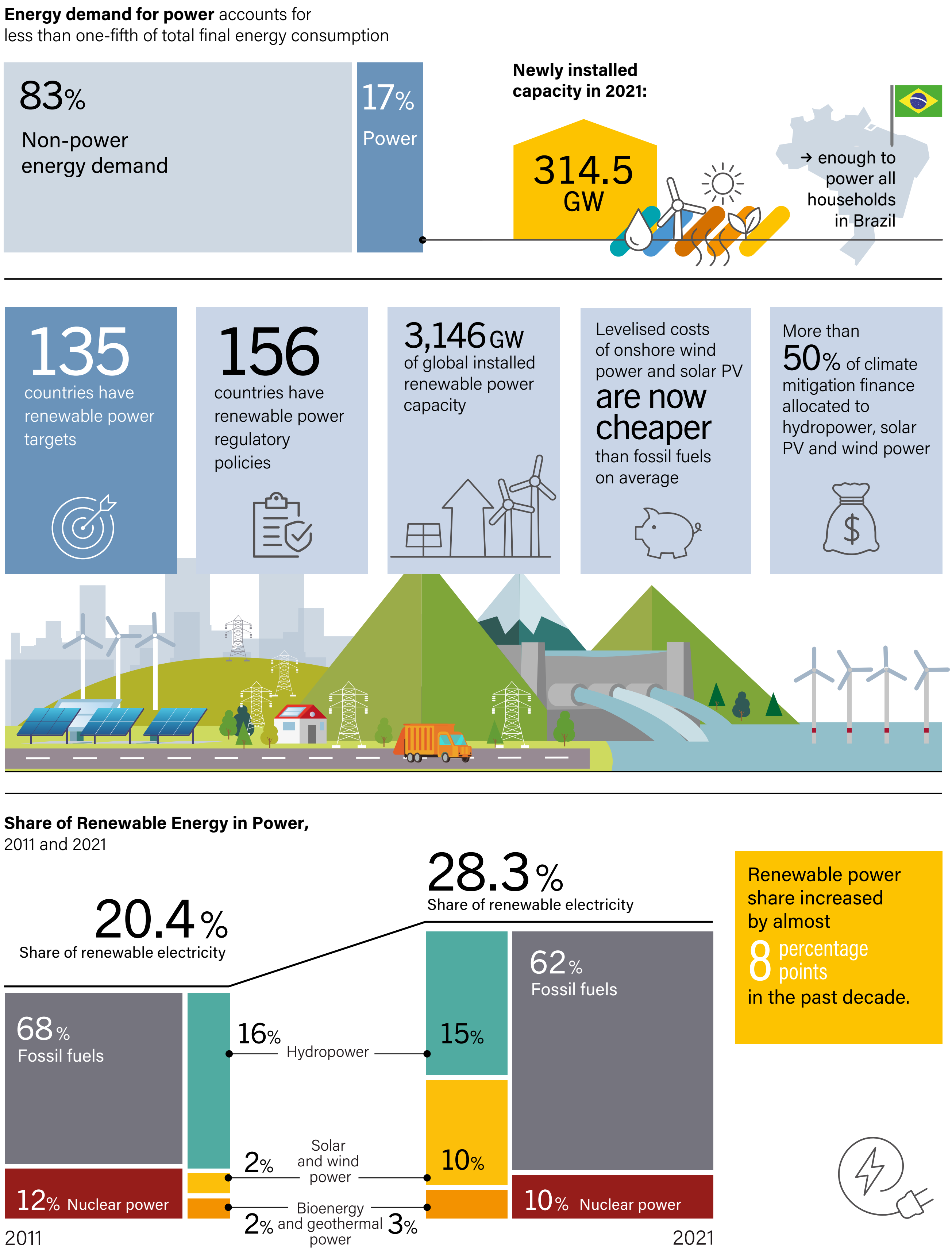
Renewables provide a slowly rising share of the energy use in all of the sectors **except in power.**

FIGURE 4.
Evolution of Renewable Energy Share in Total Final Energy Consumption, by Sector, 2009 and 2019



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

FIGURE 5. RENEWABLES IN **POWER**



Source: Based on IEA data. See endnote 60 for this chapter.

POWER

During a year of tentative economic recovery, the renewable power sector took a large step forward, deploying a record amount of new capacity and experiencing greater geographic diversification.[58] However, projects continued to be disrupted by supply chain issues and shipping delays, and a global rise in commodity prices led to surging prices for wind and solar power components.[59]

Renewable power capacity additions grew 17% in 2021 to reach a new high of more than 314 GW[i] of added capacity, driven by the record expansion in solar PV and wind power.[60] (→ *See Figure 5.*) Worldwide, the total installed renewable power capacity grew 11% to reach around 3,146 GW.[61] However, these trends remain far from the deployment needed to keep the world on track to reach net zero emissions by 2050. To reach the average milestones set by the IEA's Net Zero scenario by 2050, and by the World Energy Transitions Outlook scenarios from the International Renewable Energy Agency, the world would need to add 825 GW of renewables each year until 2050.[62] (→ *See Figure 6.*)

MARKET TRENDS

Most of the global power capacity that was newly installed in 2021 was renewable, continuing the trend since 2012. Even as global energy markets rebounded, the share of renewables in net power additions continued to increase, reaching a record 84%.[63] (→ *See Figure 7.*)

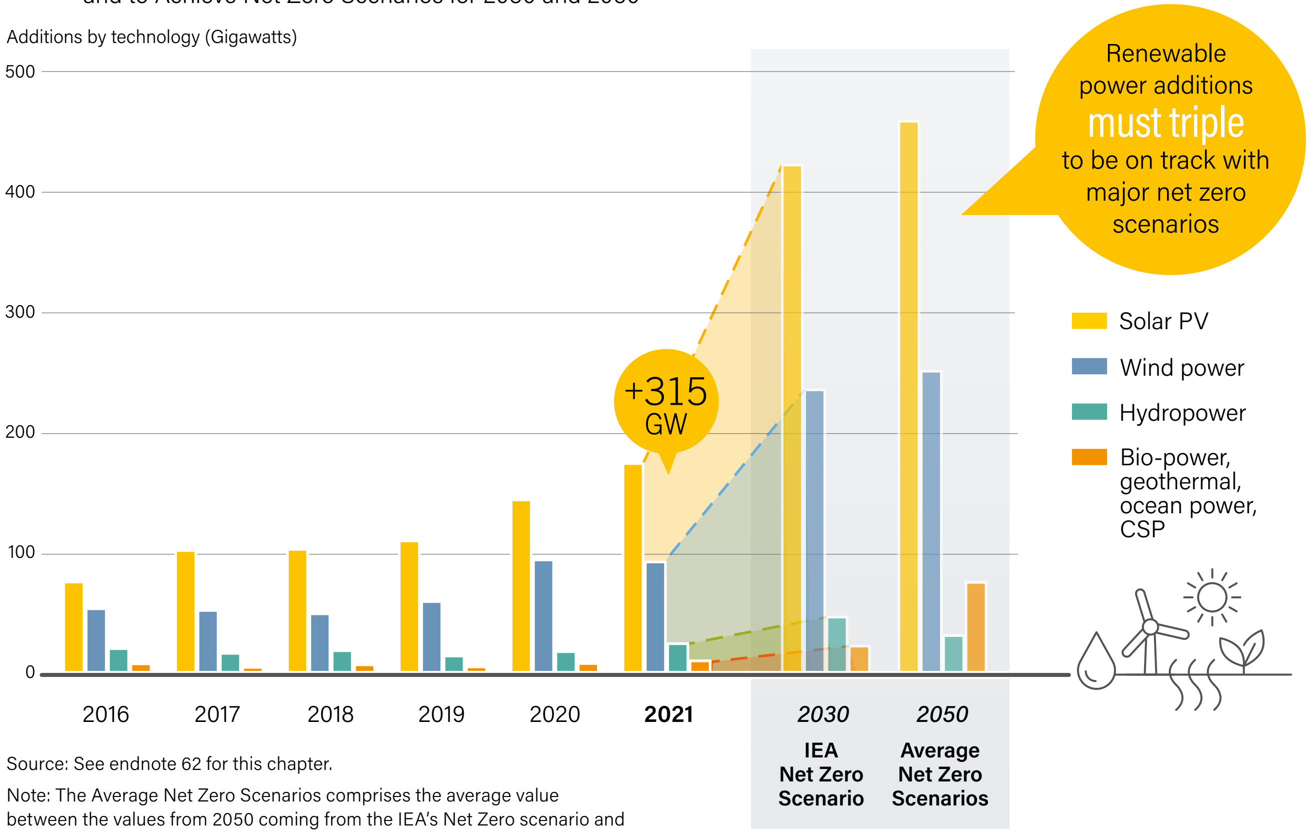
Solar PV and wind power comprised the bulk of new renewable power additions, driven by supportive government policies and low costs. After staying resilient in 2020, these markets saw significant growth in 2021, with solar PV up 26% and wind power up 7% (hydropower grew by a much higher 38%).[64] A record 175 GW of **solar PV**[ii] was added, accounting for well over half of the renewable additions.[65] This growth occurred despite uncertainty and disruptions along the PV supply chain related to the ongoing effects of the COVID-19 pandemic and to commodity price increases.

Although capacity additions for onshore **wind power** decreased in 2021 compared to 2020, 16 GW of offshore wind additions in China propelled the market to record-setting overall additions of 102 GW, representing 32% of the renewable energy total.[66] **Hydropower** capacity additions reached 27 GW, due to the commissioning of several large projects in China (as in 2020).[67] The remaining renewable energy additions were from **bio-power** and, to a lesser extent, **geothermal and ocean power**.[68] For the first time, the operating capacity of concentrating solar thermal power **(CSP)** decreased.[69]

i Global total consists of solar PV data reported in direct current, and wind power data reported as gross additions.

ii For consistency, the REN21 Global Status Report (GSR) endeavours to report all solar PV capacity data in direct current (DC). See endnotes and Methodological Notes for further details.

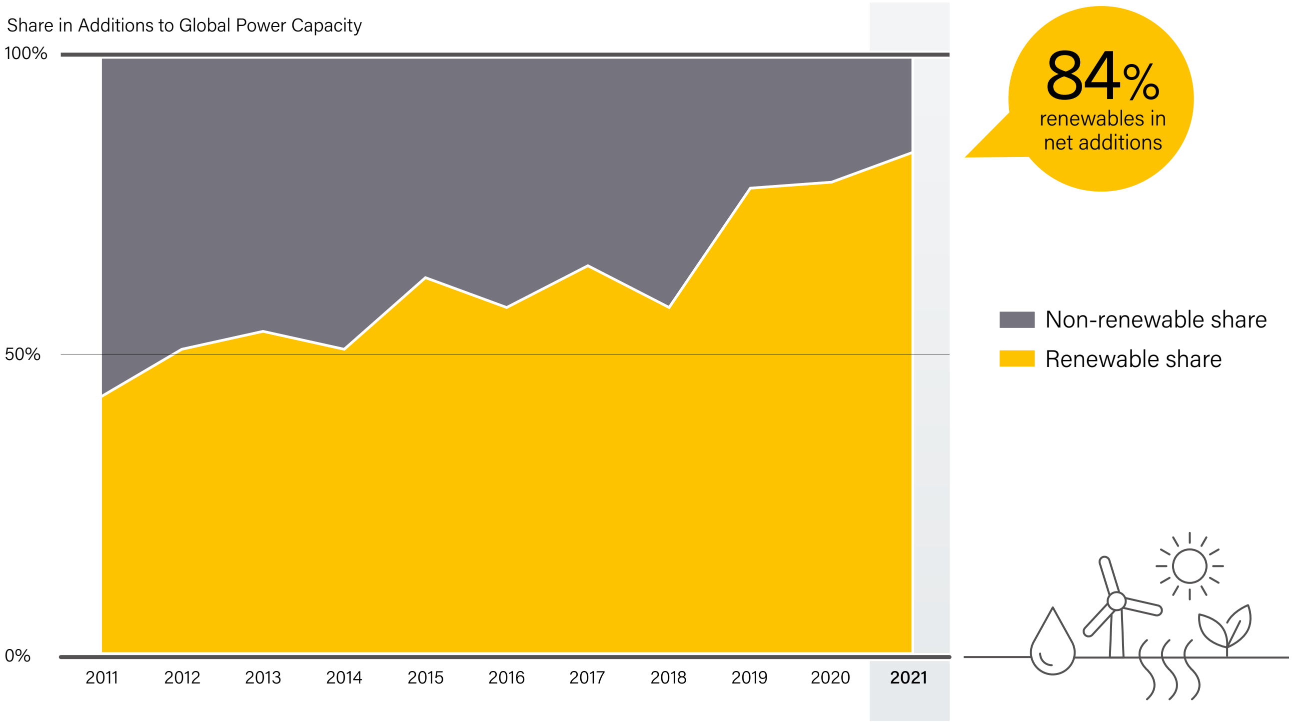
FIGURE 6.
Annual Additions of Renewable Power Capacity, by Technology and Total, 2016-2021, and to Achieve Net Zero Scenarios for 2030 and 2050



Source: See endnote 62 for this chapter.

Note: The Average Net Zero Scenarios comprises the average value between the values from 2050 coming from the IEA's Net Zero scenario and the World Energy Transitions Outlook scenario from IRENA.

FIGURE 7.
Shares of Net Annual Additions in Power Generating Capacity, 2011-2021



Source: Based on IRENA data. See endnote 63 for this chapter.

During 2021, **China** became the first country to exceed 1 terawatt (TW) of installed renewable energy capacity.[70] Its total installed capacity increased 136 GW during the year, accounting for around 43% of the total global additions.[71] China showed a notable surge in solar power, representing around 31% of global solar PV additions, although the country also dominated in capacity additions of other technologies.[72] China accounted for nearly 80% of global hydropower additions and an estimated 14.5 GW of offshore wind power additions, more than half of its total previously installed offshore wind capacity.[73] Overall, China led global markets for bio-power, hydropower, solar PV and wind power.

Countries outside of China added around 179 GW of new capacity, up 29% from 2020 levels and led by the United States (42.9 GW), India (15.4 GW), Brazil (10.2 GW), Germany (7.3 GW) and Japan (7.2 GW).[74] China remained the clear global leader in cumulative renewable energy capacity at year's end, followed by the United States (398 GW), Brazil (160 GW), India (158 GW) and Germany (139 GW).[75]

At least 40 countries had more than 10 GW of renewable power capacity in operation by the end of 2021, up from 24 countries in 2011.[76] This development is even more striking when hydropower is excluded, as markets for both solar PV and wind power have grown dramatically. By year's end, at least 22 countries had more than 10 GW of non-hydropower renewable capacity, up from 9 countries[i] in 2011.[77] The top countries for non-hydro renewable power capacity per capita were unchanged from previous years: Iceland, Denmark, Sweden, Germany and Australia.[78] (→ *See Table 2.*)

Most renewable power technologies, notably solar PV and wind power, experienced significant **cost declines** during the decade. This largely was the result of a maturing industry, economies of scale, technological improvements, more competitive supply chains and increased competition.[79] Solar and wind technologies both have followed experience curves correlated to steep cost declines for every doubling of deployment.[80] Alongside supportive regulatory and policy frameworks, these cost declines played a key role in the surge of capacity installations in recent years.

Although 2020 and 2021 highlighted the resilience of renewable energy markets during a time of economic turbulence, vulnerabilities also came to light. **Prices for key raw material inputs** used in the manufacture of solar PV modules and wind turbines increased sharply in 2021 due to delays and higher prices for shipping, labour shortages and other supply chain constraints. This led to rising prices for modules and turbines. Outside of China, major wind turbine manufacturers increased their prices 20% compared with the previous year, although within China turbine prices fell more than 25% because of competition between suppliers.[81] Prices for power purchase agreements (PPAs) rose as well in several regions and countries.[82]

i In 2011, the countries that exceeded 10 GW of non-hydro renewable power capacity were (in order of total installed capacity) the United States, Germany, China, Spain, Italy, India, France, the United Kingdom and Brazil. By the end of 2021, 12 countries joined the list: Australia, the Netherlands, the Republic of Korea, Turkey, Vietnam, Canada, Sweden, Mexico, Poland, Belgium, Denmark and Ukraine.

Despite equipment price rises, the global average **levelised cost of energy** from solar PV and onshore and offshore wind power continued to decline.[83] (→ *See Sidebar 6.*) This was driven largely by rising plant capacity factors (i.e., more output per dollar spent) and, in some markets, by larger projects with greater purchasing power that have mitigated the increases in total project costs. In many cases, the installed costs of projects completed in 2021 were based on module and turbine prices that had been locked in under contracts signed in previous years. Thus, the impact of increasing costs and prices is expected to be felt more strongly in 2022 and beyond.

Other drivers for renewable power growth were linked increasingly to **energy security**. With rising energy prices further exacerbated by the Russian invasion of Ukraine, European goods manufacturers began shutting down operations as electricity prices reached near-record highs.[84] Governments and analysts highlighted the potential for renewable energy to stabilise power prices and avoid the price swings that became problematic during 2021.[85] Some governments, such as Spain, took action to accelerate the deployment of renewables for reasons of energy security.[86]

POLICY DEVELOPMENTS

The renewable power sector continued to enjoy policy support during the year, mainly in the form of targets and incentives. The number of countries with **targets** for renewable electricity peaked in 2020 (at 137 countries), as the year was a milestone for target-setting.[87] During 2021, at least 51 countries updated their targets or introduced new ones, leading to 135 countries with some form of renewable electricity target.[88] (→ *See Snapshot: Egypt.*) Meanwhile, 156 countries had in place regulatory policies for renewable power, up from 145 in 2020.[89] (→ *See Policy chapter.*)

SNAPSHOT. EGYPT

Grid-Connected Small-Scale Solar PV

In 2016, Egypt adopted a plan to facilitate the transition to clean energy, and the country is targeting 42% renewables in total electricity generation by 2035. To invest in its solar energy potential, in 2017 Egypt established the Grid-Connected Small-Scale Photovoltaic Project (Egypt-PV)[i], which promotes pilot PV projects to increase small-scale distributed generation while supporting entrepreneurship, employment and solar capacity. The project finances up to 25% of the upfront costs of a PV system.

Egypt-PV targets installations in the industrial, educational, tourism, commercial, residential and public sectors, in addition to promoting building-integrated PV. It recently targeted the tourism sector in Sharm El Sheikh, to align with the Green Sharm initiative in the lead-up to the UN climate conference being held in the city in late 2022. The project also developed the online platform PV-Hub, which links Egypt's solar market with stakeholders and accelerates awareness, investment and implementation.

As of 2021, Egypt-PV had implemented 49 small-scale PV projects in 15 governorates and trained more than 350 people. The 125 individual systems installed so far have a combined capacity of 11 MW and produce 17,000 megawatt-hours of electricity annually, benefiting around 8,800 households and businesses.

i Egypt-PV is co-funded by the Global Environment Facility and the United Nations Development Programme, supported by the Egyptian government and implemented by the Industrial Modernization Centre.

Source: See endnote 88 for this chapter.

Driven by the increasing cost-competitiveness of renewable power, a shift towards **auctions and tenders** continued during the year. Governments outside of China, despite seeing a decline in auctions in 2021, awarded slightly more capacity than in 2020.[90] Overall, 131 countries held renewable energy auctions in 2021, up from 116 in 2020.[91] (→ *See Policy chapter.*)

Despite the trend towards competitive market processes, **feed-in policies** remained popular. For the first time in several years, the number of jurisdictions with such policies grew, from 83 in 2020 to 92 in 2021.[92] Several jurisdictions introduced feed-in policies for the first time, notably some sub-national regions (such as Guangdong in China) that were aiming to replace expiring federal-level policy.

Corporate commitments to renewable power also continued to grow. The amount of renewable power sourced through **corporate PPAs** increased by double-digit percentages, up 24% to more than 31 GW in 2021.[93] The Americas continued to lead regionally in corporate-sourced renewable power, with around 20 GW, up 35% from 2020 levels.[94] Corporate sourcing in Europe, the Middle East and Africa combined grew 19% to reach 8.7 GW.[95] In 2021, 45% of the reported electricity consumption of members of RE100, a global renewables initiative for large corporations, came from renewable energy, up from 41% in 2020.[96]

Electricity providers have sought to procure more power from low-carbon sources. As of early 2022, more than two-thirds of electricity customers in the United States were contracting with an electric utility that either had a 100% carbon-reduction target or was owned by a parent company with one.[97] US utility commitments have been driven by investor obligations and scrutiny as well as, increasingly, by economic reasoning.[98] In Europe, meanwhile, some of the highest-emitting utilities either lacked dates for coal phase-out and net zero emissions, or had not aligned them with benchmarks to reach net zero by 2050.[99] Some of China's largest electric utilities have set targets for peak emissions by 2025 or earlier.[100]

ELECTRICITY DEMAND AND GENERATION

Between 2009 and 2019, the **share of electricity** in TFEC[i] (known as the electrification rate) increased from 19% to nearly 22% globally.[101] The electrification rate of buildings rose from 29% to 32%, while the rate in industry grew from 24% to 29%.[102] Electrification of transport remains minimal but grew from 1.0% to 1.2%.[103] Some countries, such as Norway, have reached nearly 50% overall electrification.[104] Other countries recorded significant increases in their electricity share during this period[ii] – rising 59% in China and 29% in India – in line with their economic growth.[105] Drivers of electrification growth include the roll-out of electric heat pumps[iii] and electric vehicles to meet heating and transport needs, as well as improved electricity access in developing and emerging economies.

Renewables generated 28.3% of global electricity in 2021, up from 20.4% in 2011 and similar to 2020 levels (28.5%).[106] Hydropower still comprised most of this, although generation from wind and solar power has risen dramatically in recent decades. In 2021, for the first time, variable renewables (wind and solar) met more than 10% of global electricity production.[107] Shares were much higher in countries such as Denmark (53%), Uruguay (35%), Spain (32%), Portugal (32%) and Ireland (31%), among others.[108]

i Refers to the total contribution of electricity to TFEC. The share of electricity in "Power", as shown in Figure 5, has reallocated the amount of electricity used for heating and transport to those sectors, respectively. See Methodological Notes.

ii In China, the electricity share in TFEC grew from 17% in 2009 to 27% in 2019, and in India it grew from 14% in 2009 to 18% in 2019.

iii Heat pumps can provide both heating and cooling functions by drawing on energy from the ground, ambient air and bodies of water. During operation, they use an auxiliary source of energy (such as electricity) to transfer energy from a low-temperature source to a higher-temperature sink. When the auxiliary energy used to drive the heat pump is renewable, so is 100% of the output of the heat pump. (→ *See Heat Pumps section in Market and Industry chapter.*)

Global electricity demand rebounded strongly in 2021 from its pre-COVID levels, growing 6%.[109] Much of this surge was met by increased coal generation, which rose 9% and accounted for more than half of the increase in electricity demand.[110] Generation from renewables grew more than 5%, although extreme weather events affected the overall level of renewable electricity production, underscoring the potential impacts of climate change on renewables.[111] Hydropower was the most affected, as drought conditions in several hydro-heavy countries reduced generation 15%.[112] Windstorms, wildfires and dry seasons also contributed to generation losses.[113] As a result, renewable electricity generation ended its multi-year streak of meeting the majority of the world's electricity demand growth.

In the EU-27, wind power, hydropower, solar power and bioenergy remained the main sources of all electricity, growing from 22% of generation in 2011 to 37% in 2021.[114] However, this was down from a high of 38% in 2020, a period of low electricity demand.[115] In the United Kingdom, renewables represented 39% of generation, down slightly from the all-time high of 43% reached in 2020.[116]

In contrast, renewables generated a record share of net electricity in the United States in 2021, bolstered by a 29% surge in utility-scale solar generation.[117] Natural gas was the only fuel in the country with reduced generation in 2021 (down 3.1%), as coal use grew for the first time since 2014 (up 14%).[118] In China, electricity from hydropower, solar energy and wind energy provided around 27% of generation (roughly the same share as in 2020), despite a 10% surge in total electricity production.[119] Overall, electricity production from wind and solar power in China increased 35% from 2020 levels.[120]

In 2021, more than half of the 6% increase in global electricity demand was

supplied by coal power.

CHALLENGES

Despite the ongoing expansion of renewable power around the world, significant challenges remain.

They include:

- Certain renewable power markets follow a boom-bust cycle due to short-term, unpredictable policy making, as evidenced in 2021 by the surge in offshore wind power in China to meet a feed-in tariff deadline and by the collapse of Vietnam's solar PV market after two years of generous incentives.[121]
- Lengthy permitting processes and other regulatory obstacles remain large hurdles to the development of renewables in many markets.[122] The EU's REPowerEU plan in early 2022 specifically included, among other measures, the acceleration of permitting processes.[123]
- Transmission bottlenecks and stalled network expansion in some countries have held back the deployment of renewables.[124]
- Unstable supply chains (related to a concentration of technology suppliers in few countries) can delay projects and raise costs, leading to unpredictable price rises that put pressure on the economic validity of projects.
- Significant quantities of minerals such as copper, cobalt and nickel are expected to be required to meet the renewable energy deployment necessary to achieve global climate goals.[125] Procurement of these material inputs will be needed alongside extensive actions to minimise the associated negative social and environmental consequences.
- Public opposition, as well as efforts to meet sustainability criteria and address possible human rights abuses, have impeded some renewable energy and infrastructure projects.[126]
- Local capacity and knowledge gaps remain a challenge during the construction and operation phases in emerging markets and remote locations.[127]

TABLE 1.
Renewable Energy Indicators 2020 and 2021

		2020	2021
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	342.7	**365.9**
POWER			
Renewable power capacity (including hydropower)	GW	2,840	**3,146**
Renewable power capacity (not including hydropower)	GW	1,672	**1,945**
Hydropower capacity[2]	GW	1,168	**1,195**
Solar PV capacity[3]	GW	767	**942**
Wind power capacity[4]	GW	745	**845**
Bio-power capacity	GW	133	**143**
Geothermal power capacity	GW	14.2	**14.5**
Concentrating solar thermal power (CSP) capacity	GW	6.2	**6.0**
Ocean power capacity	GW	0.5	**0.5**
HEAT			
Modern bio-heat demand (estimated)[5]	EJ	14.2	**14.0**
Solar hot water demand (estimated)[6]	EJ	1.5	**1.5**
Geothermal direct-use heat demand (estimated)[7]	PJ	462	**508**
TRANSPORT			
Ethanol production (annual)	EJ	2.2	**2.2**
FAME biodiesel production (annual)	EJ	1.4	**1.5**
HVO biodiesel production (annual)	EJ	0.2	**0.3**
POLICIES[8]			
Countries with renewable energy targets	#	165	**166**
Countries with renewable energy policies	#	161	**164**
Countries with 100% renewable heating and cooling targets	#	0	**0**
Countries with 100% renewable transport targets	#	0	**1**
Countries with 100% renewable electricity targets	#	25	**36**
Countries with heat regulatory policies	#	22	**26**
Countries with biofuel mandates[9]	#	65	**65**
Countries with feed-in policies (existing)	#	83	**92**
Countries with feed-in policies (cumulative)[10]	#	136	**144**
Countries with tendering (held in 2021)	#	33	**29**
Countries with tendering (cumulative)[10]	#	111	**131**

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

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

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

4 Wind power additions in 2021 reported as 102 GW are gross and thus maybe not be equivalent to the difference between total installed capacity in 2021 and 2020.

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

6 Includes glazed (flat-plate and vacuum tube) and unglazed collectors only. The number for 2021 is a preliminary estimate.

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

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

9 Biofuel policies include policies listed in Reference Table R10 in the GSR 2022 Data Pack.

10 Data reflect all countries where the policy has been used at any time up through the year of focus at the national or state/provincial level. See Reference Tables R12 and R13 in the GSR 2022 Data Pack.

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

Source: see endnote 1 for this chapter and REN21 GSR 2022 Data Pack, available at www.ren21.net/gsr2022-data-pack.

TABLE 2.
Top Five Countries 2021

Net Capacity Additions / Sales / Production in 2021

Technologies ordered based on total capacity additions during 2021.

	1	2	3	4	5
Solar PV capacity	China	United States	India	Japan	Brazil
Wind power capacity	China	United States	Brazil	Vietnam	United Kingdom
Hydropower capacity	China	Canada	India	Nepal	Lao PDR
Geothermal power capacity	China	Turkey	Iceland	Japan	New Zealand
Concentrating solar thermal power (CSP) capacity	Chile	–	–	–	–
Solar water heating capacity	China	India	Turkey	Brazil	United States
Air-source heat pump sales	China	Japan	United States	France	Italy
Ethanol production	United States	Brazil	China	Canada	India
Biodiesel production	Indonesia	Brazil	United States	Germany	France

Total Power Capacity or Demand / Output as of End-2021

Countries in **bold** indicate change from 2020.

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

1 Per capita renewable power capacity (not including hydropower) ranking based on data gathered from various sources for more than 70 countries and on 2020 population data from the World Bank.

2 Ranking of countries in terms of demand for wood pellets for heating.

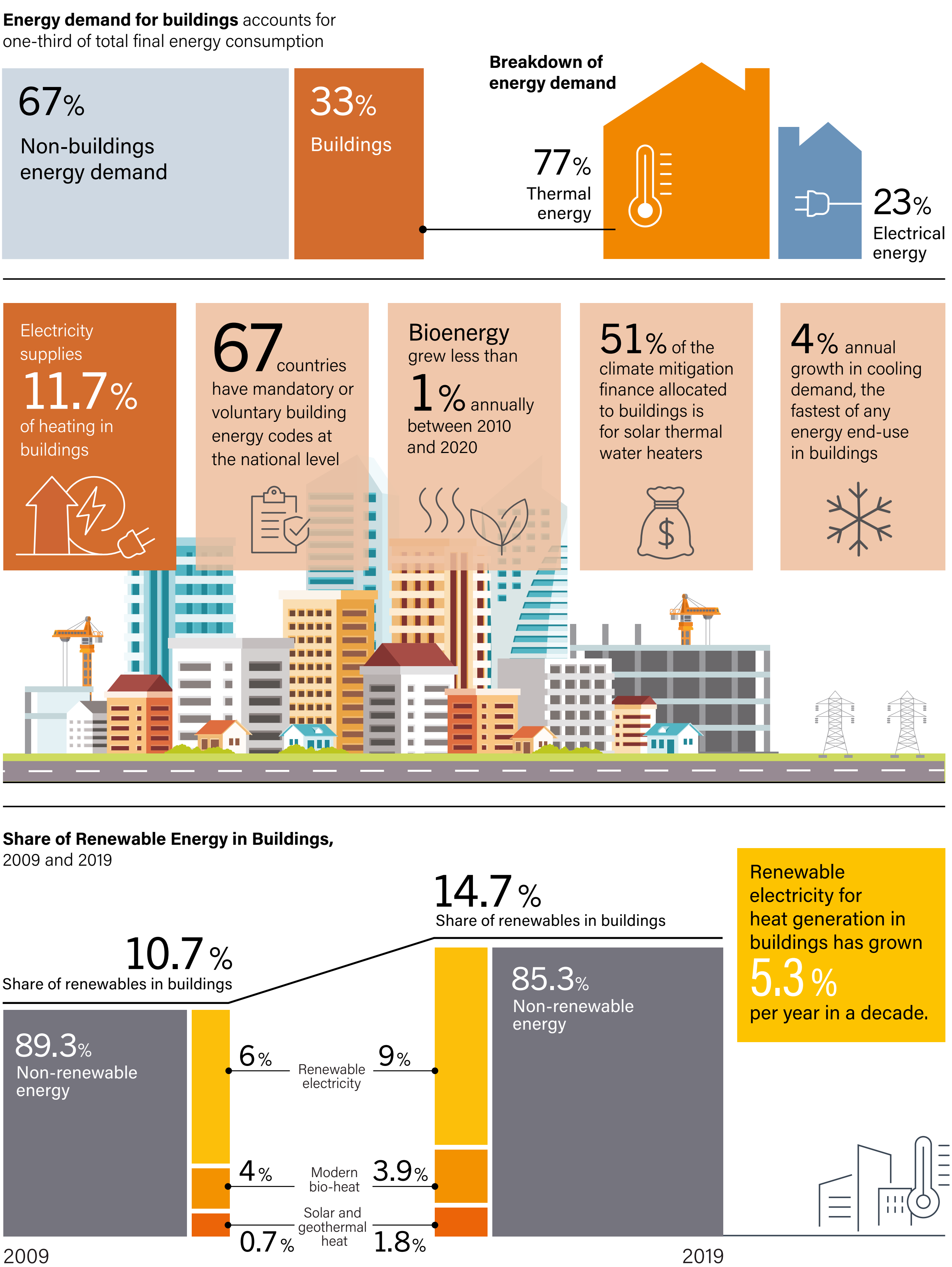
3 Solar water heating collector ranking for total capacity is for year-end 2021 and is based on capacity of water (glazed and unglazed) collectors only. Data from International Energy Agency Solar Heating and Cooling Programme.

4 Not including heat pumps.

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

Source: see endnote 78 for this chapter.

FIGURE 8. RENEWABLES IN **BUILDINGS**



Source: Based on IEA data. See endnote 129 for this chapter.

BUILDINGS

Around a third of the world's final energy is used directly in buildings.[128] As of 2019, an estimated 14.7% of building energy use was renewable, up from 10.7% in 2009.[129] (→ *See Figure 8.*) Most of this renewable energy demand is met by modern bioenergy. Renewables provide a slowly rising share of the energy use in buildings, with this growth driven mainly by renewable electricity.[130]

In 2020, building operations[i] accounted for 27% of **global greenhouse gas emissions**.[131] Absolute emissions from energy use in buildings rose steadily up to 2019, due mainly to growth in indirect emissions from electricity generation followed by emissions from on-site heat production.[132] Energy use in buildings also has negative air quality impacts, related both to the traditional use of biomass in developing countries and to natural gas combustion for heating and cooking, which can lead to heart disease, respiratory diseases and cancer.[133]

Energy use in buildings rose slowly but steadily between 2009 and 2019, at an average annual rate of 1%.[134] In 2020 and early 2021, the effects of the COVID-19 pandemic led to a slight and temporary decline in this demand, as use patterns shifted from public and commercial buildings to less energyintensive residential operations.[135] Initial estimates indicate that, as economic activity resumed in 2021, building energy use rebounded to its previous high.[136]

The steady growth in building energy use is driven by two main factors: the increasing floor area, particularly in residential units, and the growing building stock, especially with rising wealth and economic opportunities in developing and emerging economies.[137] Both the size and stock of the world's buildings increased in 2020, leading to an increase in the total energy demand of buildings.[138] Of the two main energy applications in buildings – thermal and electrical – increasing the uptake of renewables for thermal end-uses tends to be more challenging and is the focus of this section.[139] (→ *See Box 2.*)

i When considering the buildings construction industry, the share of global greenhouse gas emissions rises to 37% in 2020.

BOX 2. Thermal versus Electrical Uses: Data Challenges for Renewables in Buildings

Two main energy end-uses exist in buildings: thermal and electrical. Thermal end-uses refer to space heating and cooling, water heating and cooking (including the electricity used to providing heating and cooling). Electrical end-uses cover major appliances (refrigerators, washing machines, information technology equipment, etc.), lighting and other minor electricity demands. Globally, around 77% of building energy use is thermal and 23% is electrical.

Data on the thermal energy demand and fuel mix in buildings are challenging to collect, in terms of both **fuel sources** and end-uses. The first statistical step is collecting data on fuel sources. National governments and international organisations typically prepare statistics on the total direct fuel consumption in buildings, including electricity. These data are commonly grouped into different types of fossil fuels, "renewables" (which often include only biomass) and electricity. The data cover all final energy use, including both thermal and electrical.

The contribution from district energy systems is sometimes considered (for example, in Denmark and Germany); however, most often this refers to the quantity of heat sold from heat plant operators, not the quantity used in building operations. Other sources that typically are overlooked include the ambient renewable energy harnessed by heat pumps, as well as solar heat and geothermal heat. In addition, data on the contribution of renewables to these secondary energy sources, notably to electricity and district energy, tend to be omitted and must be found elsewhere, which leaves a large gap in calculating the total renewable heating use in buildings.

One example to the contrary is France, where the national statistics service provides comprehensive data on the fuels used, including data on district energy, on the heat delivered by electric heat pumps (ambient and renewable energy), and on the amount of electricity used to drive the heat pumps. The EU also has released a methodology for estimating the amount of ambient energy used by such devices.

The second statistical step is providing timely data on the **energy demand** for space heating, water heating, cooking and space cooling. In most cases, these data are not provided alongside the data covering the fuels used. Data on end-uses can be challenging for agencies to collect, often based on infrequent household and commercial building surveys to provide national-leveli estimates. As such, statistics can be unclear whether electricity use in buildings is for electrical or thermal end-uses. In the best cases, separate datasets on enduses are available that can be merged into full datasets covering the fuels used. Several studies on the heating and cooling sector in Europe and North America have recommended improving the data collection on heating.

i Local governments and organisations also often collect this data for their regions, which could be harnessed by national agencies.

Source: See endnote 139 for this chapter.

RENEWABLE HEATING AND COOLING DEMAND

In 2019[i], the share of modern renewables used to supply **heating and cooling** needs to buildings was an estimated 10.7%, up from 7.9% in 2009; this is lower than the share of modern renewables in overall building energy use.[140] These data include both direct renewable heat (from biomass, solar and geothermal) and indirect renewable heating and cooling (supplied by renewable electricity and district heating and cooling networks).

Although heating demand represents most of the thermal energy use in buildings, **cooling demand** is the fastest growing energy end-use in buildings, rising around 4% per year.[141] Because most cooling is supplied by electric devices, the contribution of renewables to meeting this demand depends largely on the prevailing electricity fuel mix.[142] Large regional variations exist, with sales of cooling devices growing fastest in developing and emerging countries, due mainly to rising wealth and energy access in these countries.[143]

In both heating and cooling, a key factor towards increasing the penetration of renewables in buildings is mitigating the growth in total energy demand. Global policy efforts to strengthen **energy efficiency** have helped to slow increased energy demand in buildings.[144] Measures include the adoption of appliance efficiency standards and building energy codes as well as supporting the uptake of efficient heating and cooling technologies.[145] Such efforts have led to a slight decrease in the energy intensity of buildings. Nevertheless, energy demand in buildings has continued to increase – including the energy used to operate buildings as well as to construct them[ii].[146]

Direct use of modern renewables supplies two-thirds of renewable heating, with the rest coming from indirect sources such as electricity and district heating.[147] Bioenergy accounts for most of the direct heat, although its use grew less than 1% annually on average between 2009 and 2019.[148] Direct use of solar and geothermal heat supply lower amounts overall, but demand for these sources rose 10% and 15% annually, respectively, during this period.[149] In 2019, solar supplied 1.4% of global heating needs in buildings, and geothermal supplied 0.9%.[150] Meanwhile, the use of renewable electricity to generate heat in buildings has grown 5.3% per year, with its share of building heating rising from 2.0% in 2009 to 3.3% in 2019.[151]

A significant share of global heating needs in buildings continues to be met though the **traditional use of biomass** in developing and emerging economies. However, this share fell from 30% in 2009 to an estimated 26% in 2020.[152]

REGIONAL TRENDS

Asia had the highest energy demand in buildings in 2019 (49 EJ), with around 33% of this from electricity and the rest from heating.[153] The next-highest regions were the Americas (29 EJ) and Europe (27 EJ), where electrification shares reached 28% and 48%, respectively.[154] Africa used only 15 EJ of energy in its buildings and had the lowest share of electricity use in buildings (8.4%).[155] At 1.3 EJ, this was only slightly more than the electricity used in all of the buildings across Canada.[156]

National-level data show varying success in providing renewable heat[iii] to buildings. Some countries – such as Denmark, where the renewable heat share in buildings is around 60% – have successfully installed large amounts of district heating and gradually converted networks to renewables.[157] Chile has relied largely on biomass (mainly wood) to help it reach 42% renewable heat in buildings in 2019.[158]

Some European countries, such as France, Italy, and Germany, still depend heavily on natural gas but have seen rapid growth in heat pump installations. This has contributed to rising shares of renewable heat in buildings, reaching 24.1% in France and 19.5% in Germany in 2019.[159] This compares to shares of only around 10% in gas-heavy countries such as the United States and the United Kingdom.[160] Among the Group of Twenty (G20) countries, the highest shares of renewable heat in buildings in 2019, above 19%, were in France, Canada, Italy and Germany.[161] (→ *See Figure 9.*) China's share was 15% (reflecting a surge in solar and geothermal heat), while both Turkey (geothermal) and Brazil (biomass) had shares of more than 10%.[162]

MARKET TRENDS

Markets for renewable heating and cooling technologies have been on the upswing. In 2020, for the first time, fossil fuel systems (e.g., gas boilers) comprised less than 50% of global sales of heating appliances, whereas sales of renewable heating systems (including electric heat pumps) reached 25%, up from 16% in 2010.[163]

Bioheat is both supplied by stand-alone systems and delivered through district heating networks. Bolstered by a strong policy framework, consumption of bioheat rose 10% in the EU between 2015 and 2020, reaching nearly 20% of the region's heat demand.[164] In the United States, bioheat consumption fell 11% during the same period, competing with low fuel prices and lacking sufficient policy support.[165]

Rising electrification of energy use in buildings (→ *see Power section of this chapter*) has boosted markets for renewable heat technologies, notably electric **heat pumps**. Sales of these devices, both airair and air-water, have risen around the world, especially in China, the EU, the United Kingdom and the United States.

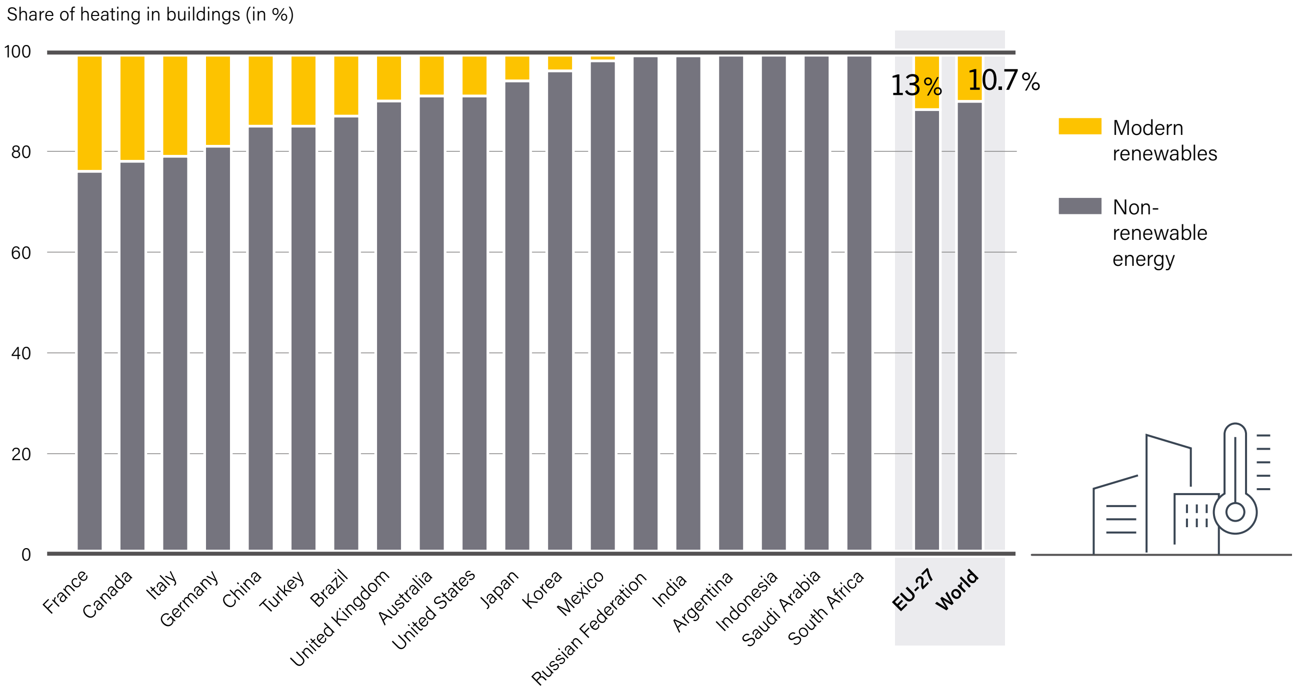
Although the global market for **solar thermal collectors** declined for seven years running, it expanded in 2021, even surpassing sales from the pre-pandemic year of 2019.[166] Stand-alone solar heat technologies have been used most commonly for water heating, but (hybrid) systems that provide space heating have grown, notably in China and Poland.[167] Solar heat also provides space heating via district heating, and this application also expanded in 2021, notably in France, Austria and possibly

i Latest data available for comprehensive energy end-use statistics.

ii In recent years, there have been growing efforts to reduce the embodied carbon in the buildings sector. Embodied carbon is a significant contributor to total energy demand and the emissions of buildings, and opportunities for renewables exist in these processes. However, this section focuses on the operation of buildings.

iii Data for cooling are more challenging to collect and are virtually exclusively provided by electricity.

FIGURE 9.
Share of Renewable Heating in Buildings, G20 Countries, 2019



Source: Based on IEA data.
See endnote 161 for this chapter.

China.[168] Space heating accounts for around 39% of **geothermal direct use**; overall, the installed geothermal capacity for heating has grown an estimated 7-8% annually in recent years.[169]

District heating networks meet a growing share of heat demand in buildings, and their renewable share is increasing. In 2019, district systems accounted for 6.8% of building heat demand (up from 6.6% in 2009), with a renewable share of 5.7% (up from 3.9% in 2009).[170] During 2021 and early 2022, district heat projects were brought online in Austria, Serbia, Denmark, Scotland, Bosnia and Herzegovina and the United Kingdom.[171] However, existing systems often have ageing infrastructure, and many European networks require upgrading to reach efficiency and renewable energy targets.[172]

POLICY DEVELOPMENTS

The slow growth in renewable energy use in buildings and the large share of emissions in the buildings sector has attracted government attention to renewable heating and cooling. During 2021, government policy played a significant role in growing these markets, focused on three main areas: **pricing policies** (e.g., carbon pricing, emissions trading, taxation), **financial support policies** (e.g., subsidies and rebates) and **regulatory policies** (e.g., targets, mandates, building codes and bans).[173]

The new **UK** Heat and Buildings Strategy[i], launched in October 2021, offers grants for homeowners to install renewable heat technologies and aims to restrict the sale of fossil fuel boilers after 2035.[174] Ireland set aside EUR 8 billion (USD 9.1 billion) for a home upgrade policy that includes grants for renewable heat systems.[175] The **United States** doubled its funding for energy assistance to low-income households and provided USD 3.5 billion to retrofit homes.[176] In early 2022, **France** announced an increase in its financing scheme to swap out fossil fuel heating systems for renewable ones.[177]

In **Germany**, a national emission trading system entered into force that applies to heating fuels.[178] The country also mandated that every new heating system in buildings use at least 65% renewables.[179] **China's** updated building policy, released in October 2021, targets the use of solar and geothermal energy in buildings by 2025.[180] **Chile** launched a National Heat and Cold Strategy that aims to replace fossil fuel combustion and unsustainable biomass use with electrification.[181] In **Canada**, the new Greener Home Grant provides grants for home renovations, installing solar PV and substituting heating systems.[182] Japan rolled out new efficiency standards for electric water heaters following its successful Top Runner programme.[183]

i Alongside the launch of the Heat and Buildings Strategy, the United Kingdom announced a consultation on a Market-based Mechanism for Low-Carbon Heat that would obligate manufacturers providing fossil fuel heating appliances to sell a rising volume of heat pumps. If implemented, this policy would be the first of its kind. See endnote 174 for this chapter.

Although these policy developments indicate rising attention to renewable energy use in buildings, they often exist alongside incentives for fossil fuel appliances, potentially undermining their effectiveness.[184] (→ *See Snapshot: Italy.*)

Some governments have prohibited the use of fossil fuels in buildings (usually new buildings) altogether. In addition to **national-level bans** in 2021 (such as in Slovenia), these measures have become increasingly common at the sub-national level.[185] By early 2022, 54 cities and counties in California (US) had committed to phase-outs of natural gas in buildings, while New York state (US) and Quebec and Vancouver (Canada) introduced similar policies in 2021.[186]

In some cases, particularly In the United States and the United Kingdom, these efforts have met heavy resistance from incumbent energy industry players. The natural gas industry has organised and lobbied extensively against growing electrification, while new US policies at the state level restrict the ability of local governments to prohibit natural gas use.[187]

Government policy continues to play an crucial role
in renewable heating and cooling.

New **building energy codes** that promote electrification, as well as high-level policy plans to address heat in buildings, were brought into force in 2021. US states and cities have strengthened building energy codes to promote electrification, while the European Commission put forth a revised Energy Performance in Buildings Directive that, among other measures, proposes that all new public buildings (starting in 2027) and all new buildings (starting in 2030) must be zero emission.[188]

SNAPSHOT. ITALY

Competing Incentives for Renewable Heating and Cooling

Even when policies are in place to encourage the use of renewable heating and cooling in buildings, they often compete with similar incentives that simultaneously support fossil fuel use. Policy approaches can be contradictory or aim to tackle challenges in an isolated rather than integrated manner. For example, a government may encourage the replacement of old, inefficient and potentially harmful appliances with newer ones, but may do so by introducing a subsidy that also finances fossil fuel technologies.

In Italy, the 2021 Superbonus 110% scheme provided tax reductions for up to 110% of the cost to replace an existing heating system with an efficient renewable-based system in residential or commercial buildings. However, Italy also provided an equal incentive for fossil fuel boiler replacement. If the new condensing boiler is more efficient than the model it replaces (up to a certain point), the subsidy applies as well. Many European countries offer subsidies for fossil fuel-fired appliances, including Belgium, France, Germany, Greece, Poland and the United Kingdom.

These policies can be well intentioned, as low-income households tend to suffer the most from ageing appliances and require support to cover the high upfront costs of replacing them. These appliance owners also require the most assistance when fuel prices become unstable. Governments can end up paying both for the subsidies to install a more expensive, yet more efficient fossil fuel appliance, while also paying to support consumers when they are faced with higher prices.

Some countries have begun phasing out existing financial incentives for fossil fuel systems. In early 2022, France announced that it will end subsidies for new gas boilers and increase financial support for renewable heating.

Source: See endnote 184 for this chapter.

CHALLENGES

Significant challenges have slowed the uptake of renewable energy in buildings, especially for providing heating and cooling services. They include:

- The higher upfront costs of renewable heating and cooling technologies pose a barrier to adoption. As of the end of 2021, natural gas boilers were more affordable than renewable heating systems in Canada, Germany, and the United Kingdom, among others, without direct policy interventions.[189] Although upfront costs have declined[i], those countries that have successfully deployed renewable heating systems typically have long-standing support policies; in Sweden, a carbon tax and a mature manufacturing industry have improved the economics of renewable heating technologies versus fossil fuel counterparts.[190]
- Government fiscal policy can make the operational costs of renewable heating more expensive, especially for electric heating (with renewables). Some countries apply levies or taxation regimes that can disadvantage renewable energy technologies by, for example, heavily taxing electricity use while lightly taxing natural gas.[191] In EU Member States, levies and taxes on electricity can be between 10-15 times higher per unit of energy than those on natural gas.[192] In 2020, the Netherlands[ii] was the only European country to apply higher surcharges and taxes on natural gas use than electricity.[193]
- Fossil fuel consumption received USD 5.9 trillion in subsidies in 2020, which distorts the costcompetitiveness of renewable heating options.[194] (→ *See Introduction in this chapter.*)
- In countries with large existing building stocks, renovation and heating system replacement rates are low.[195]
- Consumer awareness of renewable heat options, including new lower-cost business models, remains low.[196] (→ *See Box 3.*)
- Despite large job creation potential, the skilled workforce in renewable heat and energy efficiency installations remains understaffed.[197] (→ *See Sidebar 2.*)

BOX 3. Service-based Business Models: Lowering the Upfront Cost of Renewable Heating

New business models are emerging that help reduce the upfront cost burden of a renewable heating system. In heat-as-a-service (HaaS) models, energy suppliers provide a "heating service" rather than a fuel. HaaS contracts can range from appliance leasing to guaranteeing a constant temperature outcome within a building. Customers typically pay a monthly fee for the service, removing the significant upfront cost barrier that some renewable heating technologies can impose. The most commonly used technology in HaaS offerings is electric heating devices, but direct renewable heat technologies such as solar and geothermal heat also can apply.

Although heat supply contracts accounted for less than 1% of heating systems sold in Europe in 2020, such arrangements have seen increasing uptake across several European countries. HaaS contracts were first tested in 2015 in Denmark and Germany, and since then energy companies in Estonia, France, the Netherlands, Switzerland and the United Kingdom have begun offering the contracts in different forms. In Germany, Viessmann allows customers to "rent heat" by charging a monthly fee for the equipment, maintenance and units of heat delivered. Going one step further, as of 2021 the Dutch company Eneco guarantees a promised temperature of space heating and sanitary hot water for a monthly fee.

Challenges to the HaaS business model include the significant energy price risk assumed by the service provider, as well as regulations limiting third-party access to subsidies that are available for renewable solutions. Countries have begun putting in place policies to address these barriers, such as subsidies from the Danish government provided for heat pumps installed on a contract basis.

Source: See endnote 196 for this chapter.

i Solar thermal is already cost-competitive in several countries, including Mexico, due in part due to the strong solar resource. In Denmark, the world leader for operational district heat capacity, the levelised cost of heat for solar district heating systems fell 32% from 2010 to 2019 due to an increasingly competitive supply chain and developer experience that helped drive down costs. Projects in Austria and Germany also showed significant declines in installed cost. Recent price trends in natural gas point to the improving economics of renewable heat solutions, notably via electric heat pumps. See endnote 190 for this chapter.

ii The Netherlands will further increase taxation on natural gas in a stepped approach until 2026 and decrease taxation on electricity to proceed with its gas phase-out plans. Since January 2021, electricity used for space heating in Denmark has been subject to the minimum allowable taxation rate.

SIDEBAR 2. Jobs in Renewable Energy

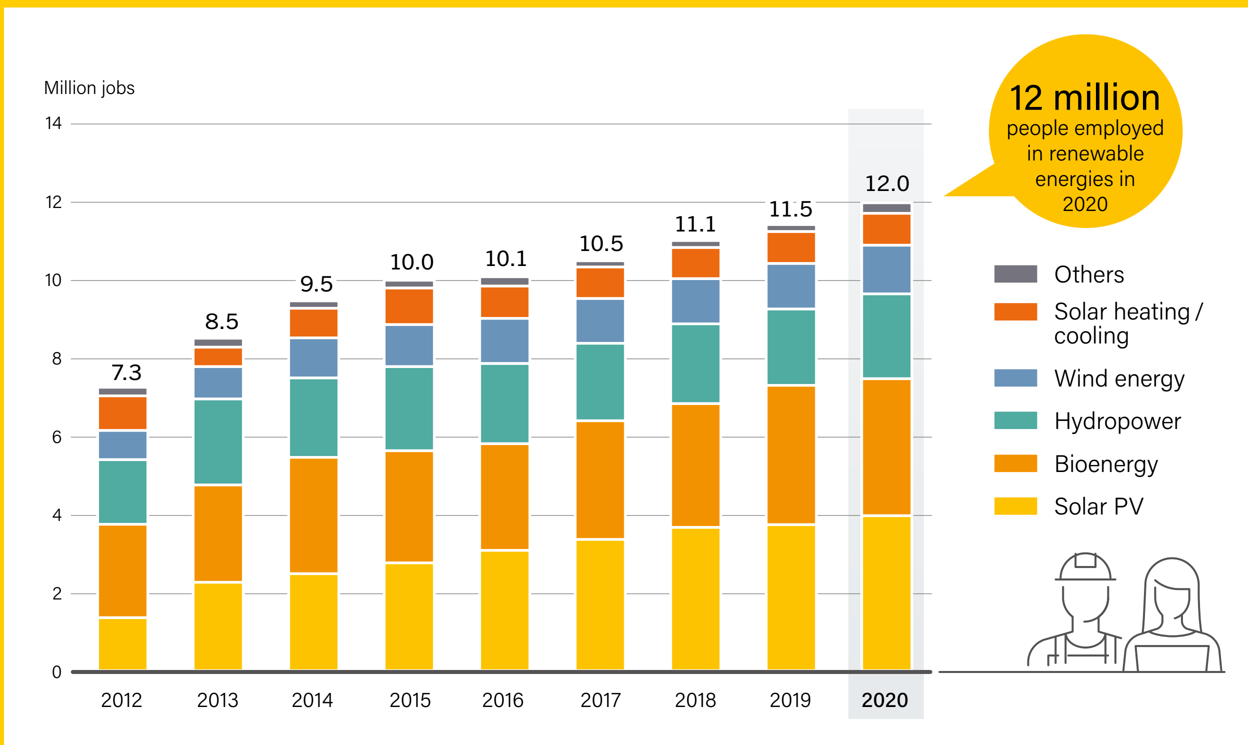
The renewable energy sector employed around 12 million people worldwide in 2020, both directly and indirectly. This was up from 11.5 million in 2019, indicating that renewables generally withstood the effects of the COVID-19 pandemic, although impacts varied among countries, technologies and segments of the value chain.

Several factors shape how much employment is generated in renewables, and where. Declining costs translate into growing competitiveness and more installations, and thus jobs. Policy guidance and support remain indispensable for establishing decisive renewable energy roadmaps to achieve the goals of limiting global temperature rise to 1.5 degrees Celsius (°C) and bringing CO_2 emissions to net zero by 2050. The physical location of the jobs depends on national markets, technological leadership, industrial policy, domestic content requirements, skills training efforts, and the resulting depth and strength of supply chains in countries.

Solar PV was the largest employer among all renewable energy industries in 2020, with around 4 million jobs, followed by biofuels, hydropower, wind power, and solar heating and cooling. (→ *See Figure 10.*) China had an estimated 2.3 million jobs in solar PV and continued to lead globally in this field, well ahead of the United States, Japan and India. Despite a rise in new installations, US employment in all solar technologies dropped slightly in 2020, to around 231,500 workers, in part reflecting growing labour productivity. The share of women in US solar employment increased from 26% to 30%. Vietnam has risen rapidly as a PV installation market and become a notable export manufacturer, with an estimated sola PV workforce of 126,300.

With global biofuels production falling in 2020 due to the effects of the pandemic, the International Renewable Energy Agency (IRENA) estimates that worldwide biofuels employment declined in 2020, to 2.4 million. Brazil had the largest number of jobs, some 871,000. Indonesia and other South-East Asian countries also have large biofuels workforces, given their labour-intensive feedstock operations. Indonesia's biodiesel employment remained virtually unchanged in 2020 at around 475,000. The United States and the EU are large biofuel producers but have more-mechanised operations that require fewer people.

FIGURE 10.
Global Renewable Energy Employment, by Technology, 2012-2020



Source: Based on IRENA. See endnote 197 for this Chapter.

Global employment in wind energy grew slightly to 1.25 million jobs in 2020, from 1.17 million in 2019. IRENA's gender survey indicated that women hold only around a fifth of these jobs. Most wind energy employment is concentrated in relatively few countries, with China alone accounting for 44% of the total. Europe continued to be a global wind manufacturing hub and led in offshore technology, accounting for around 333,200 jobs or 27% of total wind employment (of which EU members accounted for 21%). In Germany, employment fell to 90,000 jobs due to a precipitous decline in new installations. The Americas accounted for 17% of global wind energy jobs, most of them (117,000) in the United States where new installations expanded rapidly.

IRENA estimates hydropower employment at around 2.2 million direct jobs in 2020 (the best data available). China was home to 37% of these jobs, followed by India (15%) and Brazil (8%), with other countries weighing less heavily. The other renewable energy technologies employ far fewer people – less than 1 million each. Because these technologies are less dynamic, less information on employment is typically available.

COVID-19 slowed activity in the off-grid solar PV sector, as companies faced tight finances and as households reduced cash purchases. Worldwide sales of off-grid solar lighting products fell sharply in the first half of 2020 compared with the same period in 2019, especially in South Asia and in East Asia and the Pacific. The second half of 2020 brought only a partial recovery. However, rough data suggest that off-grid solar companies were able to retain much of their workforce during the pandemic, potentially around 342,000 workers in 2020 (191,400 in South Asia and 150,000 in parts of Sub-Saharan Africa). Women were more negatively affected than men because they often hold informal jobs that are more vulnerable to lockdowns and other economic disruptions.

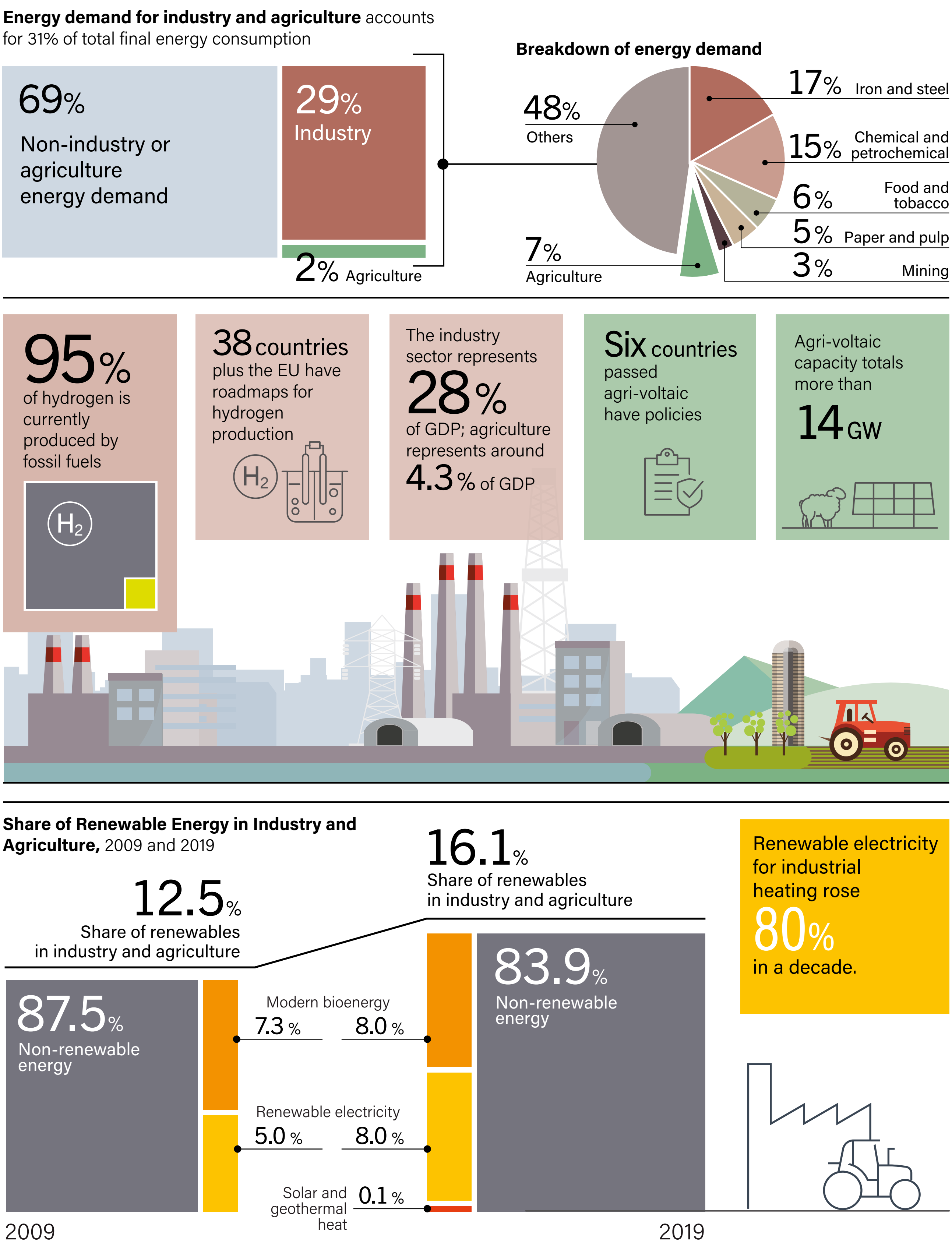
In addition to the data on jobs numbers and job creation dynamics, information on job quality is equally important – and is linked to skills training, workforce development, inclusivity, and a range of issues connected to just transition needs and the decent jobs agenda. A just transition requires that benefits be shared widely and equitably – and that the burdens of adjustment be minimised – during the decades-long process of transforming economies. Decent jobs find expression in good wages (and benefits), occupational health and safety, workplace practices and job security. Whether jobs are decent also depends on the extent of unionisation and labour rights and on the presence of collective bargaining and government enforcement of labour standards (which tend to be limited or absent in economies with a higher degree of informality).

Only limited information is available on such aspects for the renewable energy sector, in part because it spans many sectors of the economy, and national conditions vary widely. In general, a broad, holistic policy framework is required to address these dimensions, including industrial policies, labour market policies, social protection measures, and diversity and inclusion strategies.

Source: Based on IRENA. See endnote 197 for this chapter.

FIGURE 11.

RENEWABLES IN **INDUSTRY AND AGRICULTURE**



Source: Based on IEA data. See endnote 200 for this chapter.

INDUSTRY AND AGRICULTURE

The industry sector is one of the largest energy users, accounting for 29% of global TFEC.[198] Iron and steel are among the most energy-intensive sub-sectors, representing 17% of industrial energy consumption, followed by the chemicals sector (15%).[199] The agriculture sector, meanwhile, accounts for 2% of global TFEC.[200] (→ *See Figure 11.*) Globally, the industry and agriculture sectors[i] together contribute 32% of total GDP on average.[201]

Electricity use in industry and agriculture represents around 10% of global TFEC.[202] Meanwhile, industrial processes and their associated infrastructure contribute around a quarter of global greenhouse gas emissions.[203] In 2020, CO_2 emissions from industrial energy use and production processes totalled around 8.7 gigatonnes (Gt).[204] Emissions from agriculture reached an estimated 9.3 Gt in 2018 (latest data available) and represented more than 17% of global emissions.[205] On-farm[ii] energy-related emissions increased 23% between 2000 and 2018, representing 0.9 Gt in 2018 (10% of global emissions in agriculture).[206] Nearly half of these emissions (around 0.5 Gt) came from electricity and the other half from fossil fuel use (mainly natural gas and diesel products).[207] (→ *See Box 4.*)

The share of electricity used in the industry and agriculture sectors increased from 24% in 2009 to 29% in 2019.[208] The electrification of industrial processes has led to growing use of renewable electricity for industrial heating, which rose 80% during the decade.[209] The share of renewables in industry and agriculture increased 3.6 percentage points between 2009 and 2019, to represent 16.1% of TFEC in these sectors.[210] Half of the energy provided by renewables is used to produce electricity and the rest is used to produce heat, using mainly bioenergy followed by geothermal and solar thermal.[211]

MARKET TRENDS

The industry sector comprises diverse energy needs. It includes industries with requirements for lowtemperature process heat (such as food and beverages, mining, and pulp and paper), where renewables have the highest potential, as well as industries with high-temperature requirements for process heat (such as cement, chemicals, iron and steel), where renewables currently face limitations in meeting this type of heat requirements (> 400°C). In these hard-to-abate sectors, the main options for decarbonisation are energy efficiency linked with electrification of processes, biomass in gasification processes, as well as renewable hydrogen.[212] (→ *See Sidebar 3.*)

i These data correspond to the value added as percentage of GDP. The available data from the World Bank under the "Industry" category comprise value added in mining, manufacturing, construction, electricity, water and gas. The data under the "Agriculture" category comprise forestry, hunting and fishing, crops and livestock production.

ii Refers to emissions generated from energy use within the farm gate and from fisheries.

BOX 4. Renewables in the Agriculture Sector

The agriculture[i] sector accounts for around 4.3% of global GDP. Global energy use in agriculture has increased from 7.2 EJ in 1999 to 8.9 EJ in 2019, although the sector's share in TFEC has fallen from 2.7% in 1999 to 2.4% in 2019. Energy is used in all stages of agricultural activity, from food storage, production, and processing, to transport, fertilisation, manufacturing and machinery.

Agricultural energy consumption varies by region and depends on energy access levels, mechanisation of processes and the use of fertilising inputs. Between 1999 and 2019, agricultural energy demand in Asia increased from 3.5 EJ to 4.5 EJ, driven mostly by mechanical and chemical improvements to obtain higher yields. In Africa, energy demand in agriculture doubled (from 0.3 EJ to 0.5 EJ), while its share in TFEC remained roughly stable at 1.8%. In Europe, demand fell 7.7%, to reach 1.0 EJ of TFEC; oil and petroleum products contributed 55% of energy consumed, while renewables and biofuels contributed 9% and electricity 10%.

Renewables play important roles along the agri-food value chain. Biomass residues produce biogas used to generate heat and electricity, making it possible to cook and refrigerate products. Small hydropower and geothermal are used to power agri-processing facilities, while geothermal steam is used for drying and processing, greenhouse production facilities and aquaculture heating. (→ *See Snapshot: El Salvador in Market and Industry chapter.*) Solar PV technology is used mainly for agri-voltaics, agro-processing systems and solar irrigation (where it has proven its effectiveness and is deployed globally). By mid-2022, agri-voltaics reached a global installed capacity of more than 14 GW, helping to increase farmer revenues and reduce water use by limiting evaporation through shaded agriculture.

i GDP share for 2020 includes agriculture, forestry and fishing.

Source: See endnote 207 for this chapter.

SIDEBAR 3. Renewable Energy and Hydrogen

Interest in renewable hydrogen[i] – or hydrogen produced from electrolysis fuelled by renewable electricity – has surged in recent years. It is considered a key solution for reducing greenhouse gas emissions from hardto-decarbonise sectors such as steel, chemicals and long-haul transport. Hydrogen already is commonly used in the petrochemical and steelmaking industries, whether in oil refineries to remove impurities and upgrade heavy oil fractions, as a feedstock for chemical production (such as ammonia and methanol) or as a reducing agent in iron making.

Industry demand for pure hydrogenii totalled 87 million tonnes in 2020. Most of today's pure hydrogen is produced through steam methane reforming and coal gasification (particularly in China), which together account for 95% of production. Electrolysis produces around 5% of global hydrogen, as a by-product of chlorine production. However, no significant hydrogen production occurs from renewably fuelled electrolysis, and renewable hydrogen has been limited to demonstration projects. Only around 300 MW of electrolysers for renewable hydrogen were installed as of the end of 2021, with total production of around 1 million tonnes per year.

However, this is set to change. Several waves of interest in hydrogen have occurred in years past, driven mainly by oil price shocks, concerns about peak oil demand and air pollution, and research on alternative fuels. The latest wave is focused on delivering low-carbon solutions and additional benefits that only renewable hydrogen can provide, and is driven by the following factors:

- **Broader use of hydrogen.** Previous interest in hydrogen was focused mainly on expanding its use in fuel cell electric vehicles. In contrast, the new interest covers many possible uses of renewable hydrogen across the entire economy, in particular the hard-to-decarbonise sectors that already use hydrogen.
- **Government objectives for net zero energy systems.** Since the hard-to-decarbonise sectors have limited options for emission abatement, current government objectives can be met only by introducing renewable hydrogen. Moreover, electrolysers are flexible machines that also can help balance high shares of variable renewable energy on the electricity grid, by providing power reserves.
- **Lower costs.** The major cost driver for renewable hydrogen is the cost of electricity. The price of electricity procured from solar PV and onshore wind power has fallen substantially in the last decade. Meanwhile, many of the components in the hydrogen value chain have been deployed on a small scale and are ready for commercialisation, but they require investment to scale up.
- **Interest of multiple stakeholders.** As a result of all the above points, interest in hydrogen is now widespread in both public and private institutions.

An estimated 5 TW of electrolysers will be needed by 2050 to produce more than 400 million tonnes of renewable hydrogen. Yet the renewable hydrogen value chain remains in its infancy and faces many barriers to scaling. There is no real experience with electrolysers at the gigawatt-scale or with the manufacture of "green products" (materials and goods produced using renewable hydrogen, such as green steel or fertilisers). Renewable hydrogen infrastructure and markets do not yet exist, and technical and commercial standards are lagging. Hydrogen is not yet counted in official energy statistics, and there are no internationally recognised ways to account for greenhouse gas emissions linked to hydrogen. Renewable hydrogen also has to compete with the production of hydrogen using carbon capture and storage.

Renewable hydrogen is still expensive. The rising cost of fossil gas in Europe in early 2022 made renewable hydrogen theoretically cheaper than its fossil counterparts. However, if no high and stable carbon prices are put in place, renewable hydrogen and green products will remain financially risky as the cost of natural gas remains volatile. Moreover, renewable hydrogen production would require additional renewable energy capacity to meet the requirements for both the direct and indirect electrification of end-uses.

Given the strategic importance of renewable hydrogen in making a low-carbon future possible, governments are pursuing various industrial policies to support the technology. At least 38 countries plus the European Union have developed or are developing hydrogen strategies, outlining the drivers, targets and objectives they want to pursue in the hydrogen economy. (→ *See Policy chapter.*) In many cases, these strategies inform the policies to be adopted to support renewable hydrogen.

Some countries have provided support for the scale-up of electrolyser manufacturing capacity. The German research ministry allocated EUR 700 million (USD 793) to support three hydrogen projects: H2mare, TransportHyDE and H2Giga, which is dedicated to developing gigawatt-scale serial production of electrolysers. In 2021, Chile's National Development Agency (Corfo) launched a USD 50 million tender to select six electrolyser projects for a total of 45 kilotonnes of renewable hydrogen production annually by 2025. The projects will receive development funding once they install the promised electrolyser capacity and meet the established terms and conditions.

On the demand side, some governments have established sustainable public procurement schemes prioritising the purchase of green materials, including those produced using renewable hydrogen. In the United States, the Buy Clean California Act imposes a maximum acceptable global warming potential limit on selected construction materials. During the UN climate talks in November 2021, the governments of Canada, Germany, India, and the United Kingdom, among the world's largest steel and concrete buyers, pledged to buy low-carbon construction material when available. In addition, several countries – including Germany, Japan and the Netherlands – have signed trade agreements in recent years to identify opportunities to trade hydrogen.

Countries with an abundance of low-cost renewable power could become producers of renewable hydrogen, with commensurate geo-economic and geopolitical consequences. Hydrogen is a conversion business, not an extraction business, and has the potential to be produced competitively in many places. Hence, the industry is likely to be more competitive and less centralised than fossil fuels. As the cost of renewable hydrogen falls, new and diverse participants will enter the market, making hydrogen even more competitive.

i Also referred to as green hydrogen. See Glossary for definition.

ii Pure hydrogen rarely exists in its natural form. It usually is combined with other elements such as oxygen, water and fossil fuels. Pure hydrogen can be produced by gasification and electrolysis.

Source: See endnote 212 for this chapter.

At least
10 governments
(as well as the EU) have developed specific industry decarbonisation roadmaps that include renewables.

The **chemical** sector is among the highest emitting industrial sub-sectors, due largely to its significant demands on feedstocks as raw material and to the use of coal (28%) in chemical production.[213] A push for "green ammonia" projects in the sector has occurred in parallel to the development of renewable hydrogen activities. Green ammonia can be produced with the combination of hydrogen and nitrogen; it can be used to produce chemicals and fertilisers, or as an energy carrier for transport or energy storage.[214] Bio-based products also are used to reduce emissions in the chemical sector, and around 1% of plastics are now bioplastics.[215]

During 2021 and early 2022, more than 20 countries announced projects for green ammonia production based on renewable hydrogen from solar and wind power, for uses including industry, transport and energy storage.[216] Nearly 10 of these countries have projects involving the production of fertilisers for domestic use or export.[217] In Morocco, Total Eren announced a EUR 9.4 billion (USD 10.6 billion) investment to produce renewable hydrogen and green ammonia, and in Norway Aker Horizon, Statkraft and Yara aim to create Europe's first large-scale green ammonia and renewable hydrogen production centre.[218]

The **pulp and paper** sector relies on bioenergy and renewable fuels for around 40% of its total energy use, as on-site biomass waste and residues have been used to supply heat.[219] Several projects to reduce fossil fuel use in processes also have been explored, mainly in Europe.[220] Private companies are replacing natural gas with renewable hydrogen to produce tissue paper and are using co-generation plants able to run on biomethane.[221]

Energy demand in the **steel** sector, which alongside the iron sector ranks among the highest emitting industrial sectors, has increased in recent years with expanding production. The sector depends on coal for 75% of its energy, and efforts to improve the energy footprint have been limited largely to energy efficiency measures and to innovations in the steelmaking process.[222] During 2021, four pilot and demonstration projects successfully produced green steel using green hydrogen, and others were announced.[223] For the first time, a complete green steel value chain was implemented, including both the steel production and its use for vehicle manufacturing.[224] (→ *See Snapshot: Sweden in page 34 in this chapter.*)

Energy demand in the **aluminium sector** is largely consumed in the form of electricity. The sector selfgenerates more than half of the electricity that it consumes and has been improving its energy intensity in the past decade.[225] Coal supplies nearly 60% of the sector's electricity use, followed by hydropower (one-quarter).[226] Although the share of renewables in the energy mix is limited, it grew 3 percentage points between 2010 (when renewables other than hydropower were not yet used in the sector) and 2020.[227] Initiatives that rely on solar PV and CSP to produce "green aluminium" have been explored in Australia and the United Arab Emirates.[228]

The **cement** sector recorded an annual increase in carbon intensity of 1.8% between 2015 and 2020.[229] Biomass and waste fuels met around 6% of the industry's global energy needs in 2019, while in Europe this share reached around 25%.[230] Bioenergy and biomass-based wastes provided only 3% of the thermal energy used in the cement industry in 2020.[231]

As in other end-use sectors, chemical, fertiliser and steel companies are procuring renewable electricity through PPAs in order to limit CO_2 emissions and the impacts of high energy costs in their production.[232]

POLICY DEVELOPMENTS

The industry sector is considered to be a hard-to-decarbonise sector, with heavy dependency on fossil fuels due in part to its high temperature requirements and to the use of fossil input materials for production. Sectoral roadmaps and policies are essential to drive reductions in CO_2 emissions, including through carbon pricing, energy efficiency and renewable energy policies. Direct renewable energy policies in industry remained limited in 2021 and were focused mainly on renewable heat applications.

In 2021, the EU adopted a carbon border adjustment mechanism (CBAM)[i] that applies a carbon price to goods imported into the region, depending on their carbon footprint.[233] The initial focus of the CBAM is on the cement, iron and steel, aluminium and fertiliser industries. When the mechanism enters into full force in 2026, it will provide a strong incentive for decarbonisation of imports from these industry sectors to ensure that the goods remain cost competitive.[234]

During the COP26 meetings in 2021, the United Nations Industrial Development Organization (UNIDO) announced the Industrial Deep Decarbonization Initiative, under which several countries[ii] have pledged to procure low-carbon steel and concrete to meet between 25% and 40% of domestic material demand.[235] Since 2016, at least 10 governments (as well as the EU) have developed specific industry decarbonisation roadmaps that include the use of renewable energy and renewable hydrogen, among others.[236] Within these roadmaps, the sub-sectors that have received the most focus, with specific measures and strategies, are steel, chemicals, iron and cement.[237]

In 2021, the UK government published an industrial decarbonisation strategy to align its industrial sector with the national net zero target by focusing on pulp and paper, iron and steel, cement, and chemicals, among others.[238] Sweden expanded financing measures in its recovery plan for the industrial sector to reduce emissions that have a direct and indirect link with industry processes, including hydrogen production, battery production for electric vehicles and biorefineries.[239] Some countries have published national plans to limit fertiliser dependency, promoting local production of chemicals via renewable hydrogen.[240] Several broader hydrogen plans also have been announced, but only a handful focus on renewable hydrogen for industrial applications, including chemicals and steel.[241] (→ *See Policy chapter.*)

Another way to address decarbonisation is by developing **industrial clusters** that make it possible to reduce energy costs and emissions in the industry sector. Several countries and city governments have taken this approach.[242] Since 2013, China has developed 52 low-carbon industrial clusters.[243] Energy use in the Suzhou Industrial Park is supplied by more than 75% renewables[iii], the highest share across China's national development zones.[244] Between 2016 and 2019, energy consumption in the park increased 15%, while energy intensity per unit of GDP fell around 10%.[245]

In early 2022, four global cluster sites in Australia, Spain and the United Kingdom joined the Transitioning Industrial Clusters towards Net Zero initiative, launched by the World Economic Forum, Accenture and the Electric Power Research Institute.[246] This cluster approach aims to achieve energy savings and cost reduction through heat integration and utility-scale renewables and enabling technologies, including solar thermal, solar PV, renewable hydrogen and storage.[247]

CHALLENGES

Significant challenges remain to increasing the uptake of renewables in the industry sector. These include:

- The cost implications of reducing CO_2 emissions in high-temperature processes remain high, especially since many heavy industries are based on low-cost coal. Although the cost of renewable hydrogen has declined, its cost-competitiveness is dependent on the availability of renewable resources and site-specific conditions.[248] (→ *See Sidebar 3.*)
- As in other sectors, fossil fuel subsidies tend to discourage investment in energy efficiency and renewable energy to decarbonise the industry sector.[249] Materials and products from the industry sector are traded in a competitive market with low margins, which limits the possibilities.
- Energy demand in some industry sub-sectors – such as steel and chemicals – would likely increase in emerging economies as their economies mature and as demand grows. To limit CO_2 emissions, innovative technologies that are still under development today will be needed. [250]
- The energy transition could increase the number of stranded assets across the industry sector. In the steel sector alone, replacing coal-fired blast furnaces with electric arc furnaces represents an estimated USD 70 billion in stranded assets.[251]

i The CBAM targets in its initial phase cement, iron and steel, aluminium, fertilisers, and electricity goods, based on the embedded emissions of their production and import in the EU. The mechanism aims to limit the delocalisation of carbonintensive production and the import of carbon-intensive goods, by penalising those goods with the highest emissions and thus promoting emission reduction.

ii The governments of the United Kingdom, India, Germany, the United Arab Emirates and Canada.

iii More than 75% of the energy used in the industrial park is provided by direct electrification and renewable heat through renewable microgrids, renewable power for aluminium production, solar thermal and electrification for heating, and integrated transport through electric and hybrid vehicles.

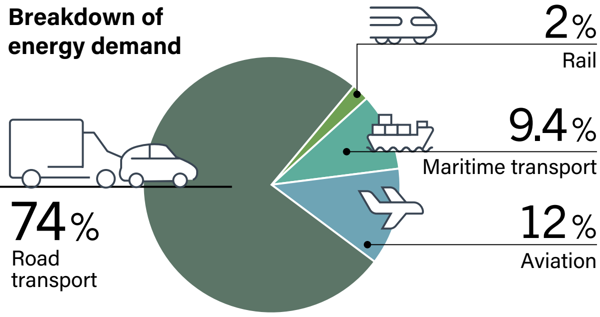
FIGURE 12.

RENEWABLES IN **TRANSPORT**

Energy demand for transport accounts for nearly one-third of total final energy consumption

68% Non-transport energy demand

32% Transport



Only **28 countries** have targets for renewable energy in transport

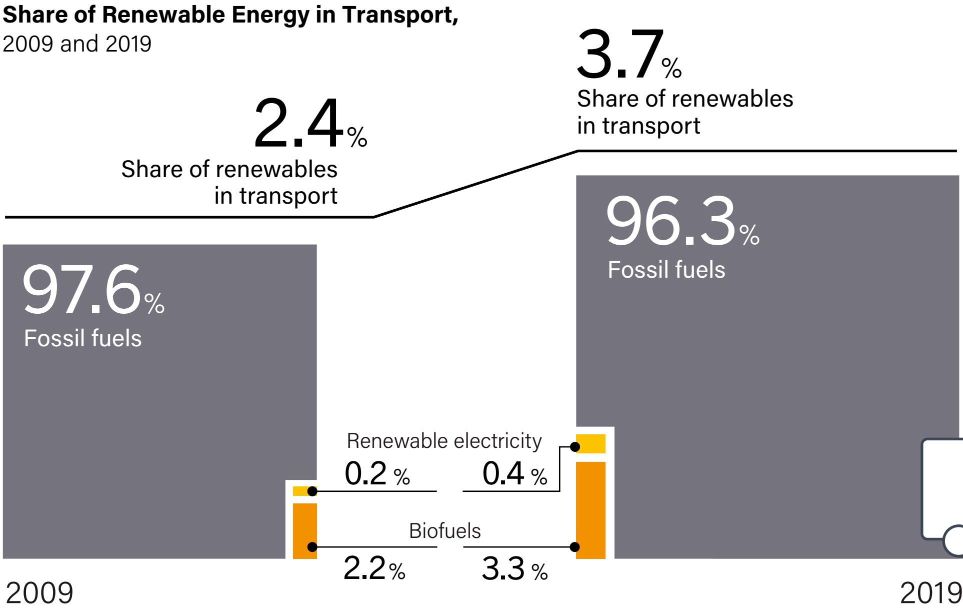
11 countries and 20 cities have targeted bans on sales of fossil fuel/ICE vehicles

31% of climate mitigation finance allocated to low-carbon transport

16 million electric cars on the world's roads, around **1%** of the global fleet

40% growth in electric bus sales in 2021, to total 4% of the global bus stock

Share of Renewable Energy in Transport,
2009 and 2019



Electric car sales tripled between 2019 and 2021.

Source: Based on IEA data. See endnote 252 for this chapter.

TRANSPORT

During 2021, the transport sector continued to experience impacts related to COVID-19, following a tumultuous 2020. However, activity increased for all transport modes, particularly passenger and freight transport, resulting in rising energy demand as well as greater use of renewables.[252] (→ *See Figure 12.*)

Global passenger car sales, particularly for electric vehicles[i] and sport-utility vehicles (SUVs), continued to grow.[253] Non-motorised transport[ii] and micromobility[iii] also increased in popularity, and freight and maritime transport largely rebounded.[254] Conversely, public transport continued to experience lower ridership than pre-pandemic levels in most markets despite showing some signs of recovery.[255] Air traffic remained significantly lower than pre-pandemic levels but experienced some rebound compared to 2020.[256]

Transport remains the sector with the lowest share of renewable energy use.[257] Despite the growth in electric vehicles in recent years, the overwhelming renewable energy contribution continues to be from biofuels.[258] As of 2019 (latest data available), the vast majority (96.3%) of global transport energy needs were met by fossil fuels (mostly oil and petroleum products, as well as 0.9% non-renewable electricity), with small shares met by biofuels (3.3%, mostly blended in various percentages with fossil fuels) and renewable electricity (0.4%).[259] (→ *See Box 5.*)

i Battery electric vehicles and plug-in hybrid electric vehicles.

ii Walking, cycling and their variants, which are important elements of "Avoid" and "Shift" in the Avoid-Shift-Improve framework because they help to limit overall transport energy demand. Also called "active transport" or "human-powered travel". See endnote 254 for this chapter.

iii Micromobility includes modes such as electric sidewalk/"kick" scooters and dockless bicycles (both electric and traditional), as well as electric moped-style scooters and ride-hailing and car-sharing services. Many "new mobility service" companies have committed to sustainability measures, including the use of renewable electricity for charging vehicles as well as for operations. See Box 2 in GSR 2020.

iv Because the year 2020 was impacted heavily by the pandemic, long-term trends can be better seen by looking at the data up to 2019.

BOX 5. Entry Points for Renewable Energy in Transport

Renewables can meet energy needs in the transport sector through the use of:

- **biofuels** in pure (100%) form or blended with conventional fuels in internal combustion engine (ICE) vehicles;
- **biomethane** in natural gas vehicles; and
- **renewable electricity**, which can be:
  - used in battery electric[i] and plug-in hybrid vehicles,
  - converted to renewable **hydrogen** through electrolysis for use in fuel cell or ICE vehicles, or
  - used to produce **synthetic fuels** and **electro-fuels**.

In addition to the use of biofuels or other renewable-based fuels for propulsion, maritime transport has the possibility to directly incorporate wind power (via sails) and solar energy.

i See Glossary for definition.

Source: See endnote 259 for this chapter.

Energy use for transport accounted for around one-third (31.9%) of global TFEC in 2019, with road transport representing the bulk of the sector's energy demand (74%), followed by aviation (12%), maritime transport (9.4%) and rail (2%).[260] Between 2009 and 2019[i], the use of renewable energy in transport grew 87% (from 2.35 EJ to 4.41 EJ); however, its overall share in the sector increased by only around one percentage point, from 2.4% to 3.7%, due to continued growth in transport energy use.[261]

Global energy demand in the transport sector increased more than 24% during the decade.[262] This was due mostly to the growing number and size of vehicles on the world's roads (and to increases in the tonne-kilometres and passenger-kilometres travelled), to a reduction in average passenger-kilometres travelled per person for buses, and to a lesser extent to rising air transport.[263] Energy intensity improvements have occurred mainly in passenger transport, almost entirely in developing and emerging countries[ii].[264] Longer-term trends indicate that the growth in energy demand for transport has far outpaced other sectors.[265] (→ *See Figure 3.*)

Energy use for transport accounted for

32%

of global energy demand in 2019.

MARKET TRENDS

Transport Overview by Fuel

Biofuels production[iii] bounced back in 2021 to surpass pre-pandemic levels for both ethanol and biodiesel.[266] Between 2011 and 2021, production and use of ethanol increased 26%, while biodiesel nearly doubled.[267] Production of hydrogenated vegetable oil (HVO or HEFA, also called renewable diesel) grew 36% in the same period, despite the effects of the pandemic.[268] Some biomethane and compressed biogas continued to be used in transport, but on a much smaller scale. (→ *See Bioenergy section in Market and Industry chapter.*)

The use of **renewable electricity** in the transport sector reached 0.35% in 2019, as electrification in the sector and the uptake of electric vehicles continued to increase.[269] Electrification grew across nearly all transport modes through 2021.[270] (→ *See Sidebar 4.*) This can help dramatically reduce CO_2 emissions in the sector, particularly in countries that are reaching high renewable shares in their electricity mix. Electric vehicle batteries essentially work as energy storage systems, storing surplus renewable energy which can be fed back to the grid when necessary. Transport electrification also offers the potential for significant final energy savings, as electric vehicles are inherently more efficient than ICE vehicles.[271] However, the overall share of electricity (let alone renewable electricity) in the transport sector remains low and has increased relatively little in recent years.[272]

Some regions saw increased interest in **hydrogen** and **synthetic fuels** as transport fuel. However, the use of or investment in renewable hydrogen and synthetic fuels for transport remained minimal, as nearly all hydrogen production globally continues to be based on fossil fuels.[273]

i Because the year 2020 was impacted heavily by the pandemic, long-term trends can be better seen by looking at the data up to 2019.

ii Passenger transport activity increased 74% between 2000 and 2015, while its energy intensity fell 27%. Meanwhile, surface freight (road and rail) activity increased 40%, but its energy intensity declined only 5% due to vehicle attributes, payloads and a lack of supportive policy frameworks to incentivise improvements. See endnote 264 for this chapter.

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

SIDEBAR 4. Market and Industry Trends for Electric Vehicles

Electrification has increased across nearly all transport modes in recent years. Much of the growth in electric vehicles[i] can be attributed to targets and policy support, in addition to the rising economic competitiveness, technological advancement and model availability of electric vehicles.

ELECTRIC VEHICLE MARKET

Electric car sales reached 6.6 million in 2021, more than doubling from 2020 and tripling from 2019. The market share of electric cars in overall car sales grew from only 2.5% in 2019 to nearly 9% in 2021. Electric cars accounted for all of the net growth in car sales of any type globally in 2021, with battery electric vehicles representing around 70% of the growth. By year's end, an estimated 16 million electric cars were on the world's roads, comprising around 1% of the global car fleet. (→ *See Figure 13.*)

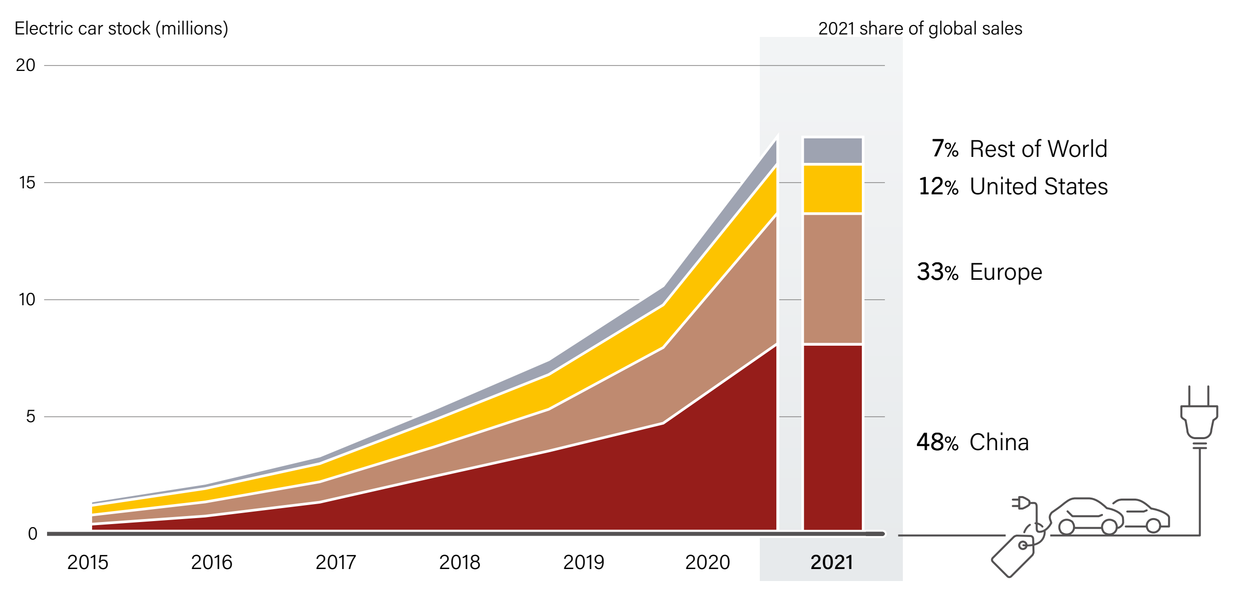
Most of the growth was in China, where electric car sales nearly tripled in 2021 to reach 3.4 million, the fastest market growth worldwide since 2015. Globally, the rapid uptake of electric cars during the year reflected extended government financial support in the wake of the COVID-19 pandemic, anticipated declines in government support in 2022, expanded small car models, and shrinking price differentials between electric and ICE vehicles. In China, the median price of an electric car was only 9% higher than for an ICE vehicle, whereas in the United States and Europe it was more than 50% higher (although some European markets, such as the Netherlands, Norway, and the United Kingdom, showed lower price differentials).

Electric car sales in Europe slowed from 2020 but still jumped nearly 70% in 2021 to reach 2.3 million. Sales were supported by new CO_2 emission standards and by expanded financial support in most major markets. For the first time ever, electric car sales surpassed diesel car sales in the region. The highest market shares for electric cars were in Norway (86% of all cars sold), Iceland (72%), Sweden (43%), and the Netherlands (30%), while Germany (25%) remained Europe's largest market by the number of electric car sales, with nearly 700,000 vehicles sold.

Sales in the United States more than doubled to surpass 600,000 in 2021, exceeding the country's total electric car sales in 2019 and 2020 combined. The share of electric cars in the overall US market doubled during the year to reach 4.5%. This followed two consecutive years of sales declining 10%.

i Electric vehicles refer here to battery electric vehicles and plug-in hybrid electric vehicles in the road transport sector; these include cars, two- and three-wheelers, light commercial vehicles and heavy-duty vehicles (including trucks and buses).

FIGURE 13.
Electric Car Global Stock, Top Countries and Rest of World, 2015-2021



Source: Based on IEA data. See endnote 270 for this chapter.

China, Europe and the United States together account for two-thirds of the global car market (all types) and for 95% of electric car sales. Outside these regions, electric car sales were less than 2% of most markets. In developing countries, low sales reflected high costs compared to ICE vehicles and a lack of charging infrastructure. However, sales surged in 2021 in developing Asia, Central Europe, West Asia, the Middle East, and Latin America and the Caribbean.

Investment in electric cars jumped in 2021 after steady increases during 2016-2020. Consumer electric car spending more than doubled to nearly USD 250 billion, while government spending doubled to nearly USD 30 billion. In China, consumer electric car spending nearly tripled to USD 90 billion.

Charging infrastructure also expanded, with the number of publicly available charge points up nearly 40% in 2021. Installations of slow chargers grew 33% – down from average annual growth of 60% during 2015-2020 – while installations of fast chargers increased 45%.

The market for **electric two- and three-wheelers** (such as motorcycles and auto-rickshaws) continued to grow, with China adding 9.5 million new registrations in 2021 to comprise 97% of the global market. Vietnam and India experienced high sales of 230,000 and 89,000, respectively. As of 2021, 25% of all electric two- and threewheelers in Asia were electric. While electric two- and three-wheeler models cost less than ICE models in many regions, they remain more expensive in Europe and the United States.

Sales of **electric light commercial vehicles** (LCVs, such as pick-up trucks and vans) grew more than 50% in 2021, to reach 2% of the overall LCV market. Compared to cars, the economic case for electrifying LCVs is stronger because LCVs tend to see greater use and to operate on more predictable routes. However, LCV electrification has been slower due to weaker fuel economy policies and fewer zero- or low-emission mandates in most markets. China led with 86,000 electric LCVs sold in 2021, followed by Europe with 60,000 sold.

New registrations of **electric heavy-duty vehicles** (HDVs, including buses and heavy-duty trucks) also increased. While the overall bus market contracted 7%, sales of electric buses grew more than 40%, bringing e-buses to 4% of the global bus stock in 2021. Sales of electric medium- and heavy-duty trucks more than doubled, bringing electric heavy-duty trucks to 0.1% of the total global stock. China remained home to most e-buses and electric HDVs, although sales in the United States and Europe have grown rapidly since 2019.

ELECTRIC VEHICLE INDUSTRY

By the end of 2021, at least 450 **electric car models** were available globally, up more than 15% from 2020 and more than five times since 2015. Automakers continued to promote larger vehicles, such as SUV and luxury models, which tend to have greater profit margins. Overall, SUVs comprised around half of all electric car models available in major markets, while medium-sized models comprised 22% and small models just 10%. The number of HDV models also increased. However, fewer models (of LDVs and HDVs alike) were available in developing and emerging markets.

After a year of no growth, the **driving range** of battery electric vehicles increased 3.5% in 2021 to reach 350 kilometres. The weighted average range for new battery electric vehicles grew at a compound annual rate of 9% for 2015-2021, demonstrating continued industry efforts to improve the performance of both vehicles and batteries. For plug-in hybrid electric vehicles, range increased 8.5% to reach 60 kilometres, with compound annual growth of 2.7% during 2015-2021. Globally, the price-per-range for battery models fell 10% and for plugin hybrid models fell 14%, reflecting increasing battery range and decreasing average vehicle prices. Range for HDVs also increased.

Electric vehicle and battery companies have experienced greater **market capitalisation** than traditional original equipment manufacturers (OEMs). Tesla (US) dominated the automaker market for electric vehicles, accounting for three-quarters of the total market capitalisation. Tesla also led in electric car sales globally, followed by VW Group (Germany), BYD (China), GM (US) and Stellantis (Netherlands). Regionally, VW Group led in Europe, BYD led in China, and Tesla led by a large margin in the United States and several other countries.

Nearly all major automakers announced sales **targets** for electric vehicles in 2021. Early in the year, both Honda and the European division of Ford announced targets for phasing out ICE vehicles (by 2040 and 2030, respectively). During the UN climate talks in November, 24 countries and a group of auto manufacturers (including Ford, Mercedes-Benz and Volvo) agreed to phase out ICE vehicles by 2040 (notably absent were BMW, Toyota and Volkswagen). Some automakers, including Ford, GM, and Toyota, also announced **training programmes** to accelerate electric vehicle deployment and ensure a well-trained transition workforce.

New **charging technologies** to support vehicle electrification were developed during the year. StoreDot (Israel) developed batteries capable of being charged in five minutes, manufactured by Eve Energy (China). In the United States, Ford and Purdue University announced a partnership to create a new cable for charging stations to deliver increased current and faster charging speed. Tesla's Supercharger network also opened to other electric car types during the year.

Source: IEA and others. See endnote 270 for this chapter.

TRENDS BY TRANSPORT MODE

Road transport accounts for three-quarters of transport energy use.[274] In 2021, global **passenger car** sales increased more than 4%, slightly stronger than in 2020 in most regions but still not reaching prepandemic levels.[275] In contrast, electric car sales surged 108% in 2021, with even higher growth in some markets.[276] Although 55% of the electric car models for sale on the market were SUVs, more than 98% of the SUVs on the roads globally were still ICE vehicles, running mostly on fossil fuels.[277] Sales of **two and three-wheelers** increased in many markets, while electric versions increased in popularity, driven by rising consumer concerns about air pollution and by growing demand for "low-noise" transport.[278]

A few local governments and companies have begun using renewable energy in their **bus fleets**. While many cities have used biofuels in buses for some time, a growing number are now linking renewable electricity to e-bus charging (such as charging the buses with solar power), notably in Europe, the United States and China.[279]

Road freight consumed around half of all diesel fuel in 2018 (latest data available) and was responsible for 80% of the global net increase in diesel use between 2000 and 2018, with the increase in road freight activity offsetting any efficiency gains.[280] However, an increasing number of companies continued to use renewable energy options, such as biogas in the United Kingdom.[281]

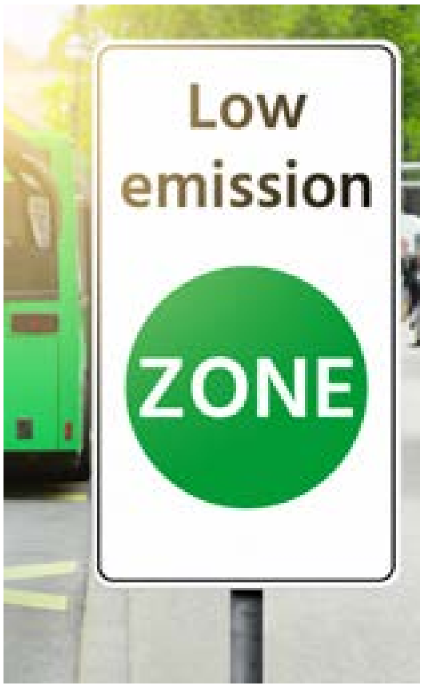
As the most highly electrified transport sector, **rail** transport accounted for around 2% of the total energy used in transport in 2019.[282] Renewables contributed an estimated 11% of global rail-related energy consumption in 2019.[283] Some jurisdictions have increased the share of renewable energy in rail transport to well above its share in their power sectors.[284] Many cities are running public **urban rail** systems on electricity, sometimes directly linked to renewable electricity and in other cases using biofuels.[285] Several deals signed in 2021 supported renewable energy uptake in the sector, including for renewable electricity in New South Wales (Australia), biodiesel in Canada, and renewable electricity, renewable HVO, biogas and hydrogen dual-fuel technology in the United Kingdom.[286] Passenger rail volumes increased compared to 2020, although trips were below pre-pandemic levels.[287]

Rail freight rebounded somewhat during 2021, with some regions reaching pre-pandemic levels as supply chains normalised and demand increased.[288] However, in some regions rail operators have gone back to using diesel. For example, following a sharp rise in electricity prices in the United Kingdom, including a 40% tax on renewable energy, some rail freight operators replaced (at least temporarily) electric freight services with diesel services as a more cost-effective option.[289]

Maritime transport[i] largely recovered in 2021 following a nearly 4% decrease in 2020.[290] Maritime activity consumed around 9% of the global energy used in transport in 2019 – with around 0.1% estimated to be renewable – and was responsible for around 2.9% of global greenhouse gas emissions.[291] Some fleets have moved to 100% renewable fuels, while others have moved to hybrid systems with energy storage (although not always operating on renewables[ii]).[292] In 2021, several companies announced or launched renewable-based shipping endeavours, including using e-methanol made from renewables, offering renewable-based shipping and investing in biomethane production capacity.[293] Others expanded renewable fuel production to meet growing demand in the sector.[294]

i The transport of goods or people via sea routes, including inland and coastal shipping.

ii At a smaller scale, electric outboard engines increasingly are being used in many markets and can be charged directly with renewable energy; some governments, such as Sweden, have offered incentives for electric models. See endnote 292 for this chapter.



In the **aviation** sector, air traffic increased slightly in 2021 – after having plummeted with the onset of the pandemic – but remained more than 58% lower than in 2019.[295] Meanwhile, air cargo reached higher levels than pre-pandemic.[296] In 2019, aviation accounted for around 12% of the total energy used in transport – less than 0.1% of which was renewable – and for around 2% of global greenhouse gas emissions.[297]

Several initiatives supported renewable fuels for aviation during 2021. These included the largest sustainable fuel agreement in aviation history, targets for 100% biofuel planes by 2030, multi-year partnerships for sustainable aviation fuel and the opening of the world's first plant dedicated to producing carbon-neutral jet fuel.[298] The number of airports with regular distribution of blended alternative fuel nearly tripled, from 14 in 2020 to 44 in 2021, while the number of airports with batch deliveries of such fuels increased from 16 to 23[i].[299] By early 2022, more than 360,000 commercial flights had flown on blends of alternative fuels[ii].[300] However, this remains a negligible share of the tens of millions of flights performed each year.[301]

POLICY DEVELOPMENTS

Only 28 countries globally have targets for renewable energy in transport, typically for multiple objectives including supporting energy security, reducing CO_2 emissions and improving air quality. (→ *See Policy chapter.*) As of mid-2021, two-thirds of the 2020 targets for renewables in transport had not been achieved, and around 40% of the countries that had set 2020 targets had not established new ones after the 2020 targets expired.[302] Countries have failed to meet their targets in large part because they lack supportive policy frameworks that encourage an energy and transport transition, or because the frameworks in place are ineffective or not enforced.

The number of countries with support policies for biofuels in transport plateaued in 2017 at 65 countries globally and has not increased since.[303] Targeted **bans** on sales of fossil fuel/ICE vehicles (or targets for 100% electric vehicle sales, typically light-duty vehicles only) were in place in 26 countries (and 8 states/provinces) by early 2022, doubling from the year before.[304] However, many of these countries target relatively low shares of renewable power, and some lack national renewable power targets altogether.[305] In 2021, only three countries – Germany, Austria and Japan – had an electric vehicle support policy with a direct link to support for renewable power, the same as in 2020.[306]

Fuel economy standards push manufacturers to seek to improve fuel **efficiency** and facilitate the adoption of alternative drivetrains based on low-carbon solutions, including renewable energy.[307] As manufacturers seek to decrease fuel consumption, this could result in a higher renewable share in final energy consumption. In 2021, 48% of energy use in transport across all modes globally was covered by mandatory fuel efficiency standards, nearly double from a decade earlier.[308]

i On a smaller scale, some companies planned for small electric planes to take flight by as early as 2024, while others advanced plans for fully electric airlines to carry 100 passengers, or aimed for hydrogen-fuelled commercial aircraft by 2035. See endnote 299 for this chapter.

ii Up from 315,000 in 2020 and just 200,000 the year before.

Fuel economy standards apply to 80% of light-duty road vehicles worldwide, yet they cover just 51% of the global road freight market.[309] Only five countries – Canada, China, India, Japan and the United States – apply them to heavy-duty vehicles, and no new countries have adopted such standards since 2017, although the EU adopted CO_2 emission standards for new heavy-duty vehicles in 2019.[310] In aviation, although carbon emissions per passenger-kilometre have fallen more than 50% in the past three decades due to fuel efficiency improvements, emissions have grown more rapidly than expected as global demand for air travel surges.[311]

Many countries still lack a **holistic strategy** for decarbonising transport that encompasses the Avoid-Shift-Improve framework[i]. (→ *See Global Overview in GSR 2020.*) Such strategies can greatly decrease energy demand and associated greenhouse gas emissions in the sector and thus allow for the renewable share in transport to increase.[312]

Despite the improvement in carbon intensity in the transport sector, continued increases in energy demand (most of which have been met by fossil fuels) have resulted in a general trend of rising greenhouse gas **emissions**.[314] Emissions from the sector increased in 2021 after falling in 2020, although they remained below 2019 levels.[315] The sector as a whole accounts for nearly a quarter of global energy-related greenhouse gas emissions.[316] Nearly three-quarters of all transport emissions are from road vehicles.[317] Emissions from SUVs alone tripled between 2010 and 2020 due to the increasing number and larger sizes relative to other passenger vehicles.[318]

Overall, the transport sector is not on track to meet **global climate goals** for 2030 and 2050.[319] The majority of countries worldwide have acknowledged the sector's role in mitigating emissions by including transport in their NDCs under the Paris Agreement.[320] However, the role of renewables is largely not specified, and as of mid-2021 only 10% of NDCs included measures for renewable-based transport.[321] Based on one estimate, to be on track with net zero scenarios for 2050, emissions from the sector would need to decrease at least 20% by 2030[ii].[322]

Still, a record number of transport-related commitments were announced during or surrounding COP26 in 2021, supported by countries in every major world region.[323] Commitments covered nearly all transport modes – from zero-emission vehicles and charging infrastructure, to decreasing emissions in aviation and shipping, to supporting cycling as an emission reduction measure.[324] While some commitments directly mentioned renewable fuels, others supported renewables more indirectly.[325] Notably, 38 countries and 44 city, state and regional governments signed the UK-led "COP26 declaration on accelerating the transition to 100% zero-emission cars and vans", promising to work towards all sales of new cars and vans being zero emission by 2040 or earlier, or by no later than 2035 in leading markets.[326]

i These actions also seek to address broader concerns among policy makers in the transport sector at the national and sub-national levels, such as environmental and health impacts (e.g., congestion, pollution, road safety), transport security and equity in access to mobility. See Figure 60 in GSR 2020.

ii Further, current targets made by the international maritime and aviation bodies (the International Maritime Organization and the International Civil Aviation Organization, respectively) are not consistent with Paris Agreement goals of limiting global warming to below 2°C but rather are in line with a rise of more than 3°C. See endnote 322 for this chapter.

CHALLENGES

While there have been some advances for renewables in the transport sector, renewable energy is not making as significant a stride as it has in other sectors. Reasons for this include:

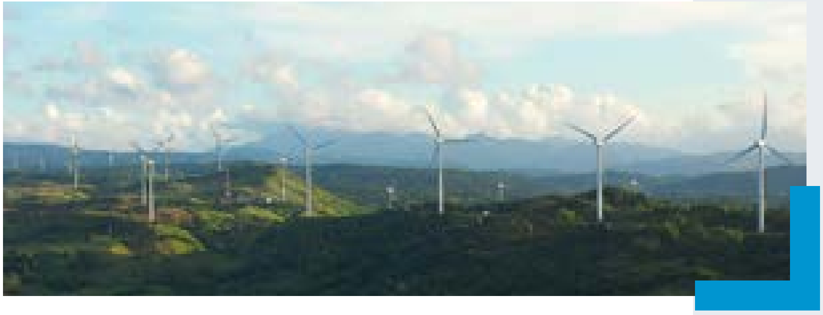
- Historical global transport systems and infrastructure favour motorised transport demand based on fossil fuels, supported by subsidies and strong lobbying efforts to maintain the status quo.
- Rising transport demand due to population and economic growth, particularly in developing and emerging countries, has led to energy demand growing much faster than in other sectors.
- The sector remains characterised by dependency on individual behaviour and consumptionoriented lifestyles (particularly in industrialised countries), trends toward larger vehicles, and reluctancy to change behaviour, all supported by strong lobbying and marketing efforts.
- Sufficient policy support is lacking for reducing the overall demand for motorised transport, transitioning to more efficient transport modes (such as public transport), and improving vehicle technology and fuels – together known as Avoid-Shift-Improve.
- Cost-effective solutions are lacking, particularly for decarbonised long-haul aviation and shipping.[313]
- The transport sector is characterised by a strong fragmentation of policies and governance structures, with many decisions taken at local and regional level. National policy frameworks are therefore not sufficient to trigger change at the national level and support local efforts.

SNAPSHOT. PHILIPPINES

Renewable Energy Programme for the Agri-Fishery Sector

In 2021, the Philippine Departments of Energy and Agriculture announced a new Renewable Energy Programme for the Agri-Fishery Sector. The programme supports the use of renewables to power agricultural and fishery operations such as drying and other heat-based applications, to electrify farm production and processing facilities and machinery, to fuel engines used in irrigation, and to mechanise farm operations. The programme also aims to develop new renewable technologies and human resources specialising in renewables; to develop and enforce new standards for renewables; and to provide technical support for suppliers and manufacturers of locally produced renewable energy equipment and components.

Source: See endnote 205 for this chapter.



02 POLICY LANDSCAPE

KEY FACTS

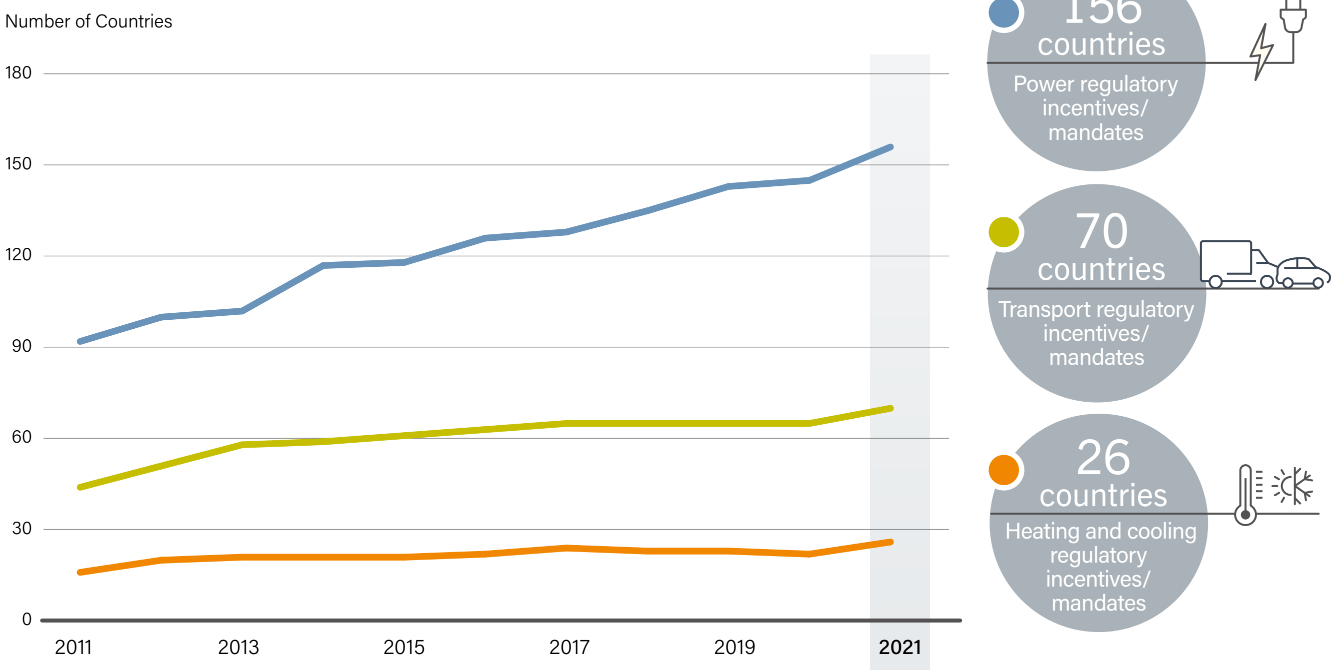
- **By the end of 2021, nearly all countries** worldwide had in place a renewable energy support policy, with most support continuing to occur in the power sector and fewer efforts to accelerate renewables in buildings, transport and industry.
- **Commitments to climate change mitigation** accelerated in 2021, as governments, corporations and others made a flurry of pledges to reduce greenhouse gas emissions. By year's end, at least 135 countries and the European Union had some form of net zero targets in place.
- **As in previous years, policies supporting renewables** in transport focused mainly on road transport, with rail, aviation and shipping receiving far less attention.
- **The industrial sector** continued to receive far less policy attention than other end-use sectors.

In the past decade, interest in a global transition to an energy system that relies more heavily on renewables has increased, in response to wide-ranging goals related to climate change and decarbonisation, energy security, job creation, equity and energy access. To achieve these goals, decision makers at various levels have enacted new renewable energy policies and strengthened existing ones.[1] Policy support for renewables – whether directly through, for example, renewable energy mandates and incentives, or indirectly through measures such as carbon pricing and fossil fuel bans – remains critical for driving the energy transition, particularly in harder-to-decarbonise sectors such as heating in buildings, as well as the transport and industry sectors.

By the end of 2021, nearly all countries worldwide had implemented at least one regulatory policy in direct support of renewables[i,2] (→ *See Figure 14.*) Although most of this activity continued to focus on the power sector, the number of renewable energy policies in both transport and heating increased for the first time since 2018 (albeit with weaker policy frameworks).[3] In addition to policy developments at the national level, cities increasingly have passed policies in support of renewables, although these are not the focus of this analysis. (→ *See the Renewables in Cities chapter* for a discussion of policy developments at the city level.)

i This chapter is intended to be only indicative of the overall landscape of policy activity and is not a definitive reference. Data from GSR 2021 should not be used as a comparison, due to updated methodology and data availability. Generally, listed policies are those that have been enacted by legislative bodies. Some of the listed policies may not yet be implemented, or are awaiting detailed implementing regulations. For further information, see endnote 2 for this chapter.

FIGURE 14.
Number of Countries with Renewable Energy Regulatory Policies, 2011-2021



Note: The figure does not show all policy types in use. In many cases countries have enacted additional fiscal incentives or public finance mechanisms to support renewable energy. A country is considered to have a policy (and is counted a single time) when it has at least one national or state/provincial-level policy in place. Power policies include feed-in tariffs (FITs) / feed-in premiums, tendering, net metering and renewable portfolio standards. Heating and cooling policies include solar heat obligations, technology-neutral renewable heat obligations and renewable heat FITs. Transport policies include biodiesel obligations/mandates, ethanol obligations/mandates and non-blend mandates. For more information, see Reference Table R3 in the GSR 2022 Data Pack.

Source: See endnote 2 for this chapter.

The push to decarbonise is an increasingly important driver of renewable energy support policies.[4] In 2021, governments around the globe announced a flurry of commitments towards mitigating climate change through reductions in greenhouse gas emissions.[5] In addition, rising energy prices during the year and the Russian Federation's invasion of Ukraine in early 2022 have heightened policy makers' concerns about energy security, leading to growing interest in renewables.[6]

Globally, decision makers are converging on the key role of electrification in decarbonisation efforts and have enacted policies to support greater use of electricity, which is increasingly generated by renewables.[7]

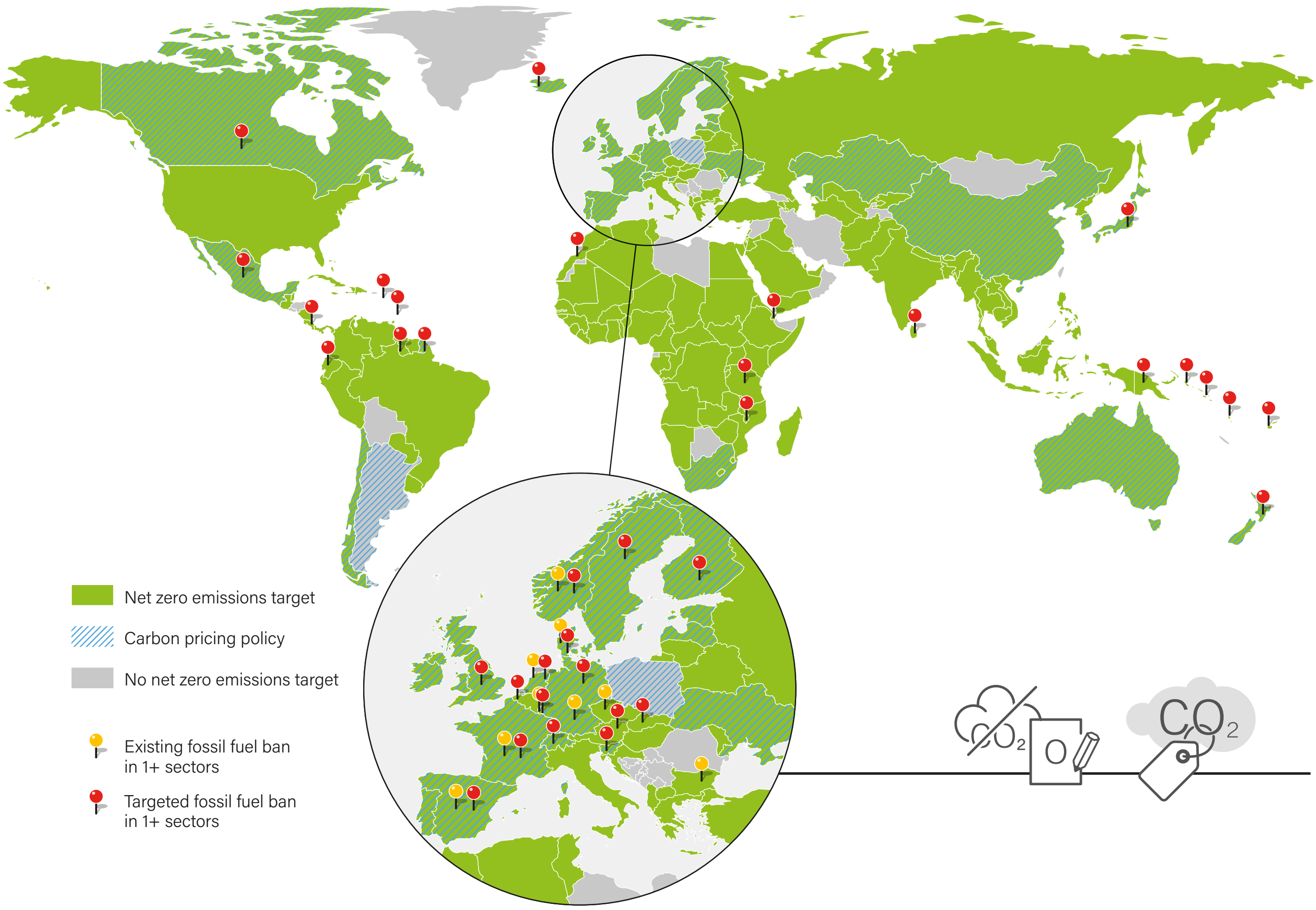
Climate change policies play a critical role in increasing interest in – and uptake of – renewable energy technologies across all end-use sectors.

CLIMATE CHANGE POLICY AND RENEWABLES

Policies aimed at mitigating climate change can indirectly stimulate the deployment of renewables by mandating a reduction or elimination of greenhouse gas emissions.[8] Most climate change policies related to energy do not focus explicitly on renewables; however, these policies play a critical role in increasing interest in – and uptake of – renewable energy technologies across all end-use sectors.

The year 2021 was important for climate policy developments. After the United Nations climate negotiations were postponed in 2020 due to the COVID-19 pandemic, stakeholders convened in November 2021 for resumed talks in Glasgow, Scotland.[9] Although countries' revised Nationally Determined Contributions (NDCs) – which outline their commitments to reducing emissions under the Paris Agreement – were due in 2020, they were given additional flexibility to submit their new or updated NDCs ahead of the Glasgow meetings.[10]

FIGURE 15.
Countries with Selected Climate Change Policies, 2021



Note: Carbon pricing policies include emission trading systems and carbon taxes. Net zero emissions targets shown include all levels of implementation (declaration/pledge, in discussion, in policy document, in law and achieved). Fossil fuel ban data include both targeted and existing bans across the power, transport and heating sectors. Jurisdictions marked with a flag have some type of fossil fuel ban in one or more sector. See GSR 2022 Data Pack for details. No cities with policies are shown; see *Renewables in Cities* chapter for more comprehensive city policies.

Source: Based on World Bank, Climate Watch, IEA Global Electric Vehicle Outlook and REN21 Policy Database. See Reference Table R4 in GSR 2022 Data Pack and endnote 13 for this chapter.

In total, 151 countries submitted new or updated NDCs in 2021, with most of the submissions showing increased ambition on reducing emissions.[11] However, not every NDC contains a quantified renewable energy target, and those that do focus mainly on the power sector; only 30 of the submitted NDCs explicitly mentioned heating or transport, and only 13 NDCs outlined a commitment to a share of renewables in the total energy mix.[12]

Numerous countries, states and provinces implemented additional climate change policy during 2021, whether by setting targets (including commitments to net zero[i]), banning or phasing out the use of fossil fuels, or increasing the cost of fossil-based energy through carbon pricing.[13] (→ *See Figure 15.*) However, while commitments to decarbonisation have been gaining traction globally, this has not always led to the replacement of existing fossil fuels with renewable energy sources.[14]

Greenhouse gas emission targets (including net zero and carbon-neutral targets) reflect goals specifically set for reducing emissions. During 2021, many countries announced new greenhouse gas emission targets.[15] For example, Zimbabwe committed to 40% emission reductions by 2030 compared to business as usual (conditional on international finance support), and Lebanon raised its target to a 20% reduction by 2030, up from 15% previously.[16]

i See Glossary for definition.

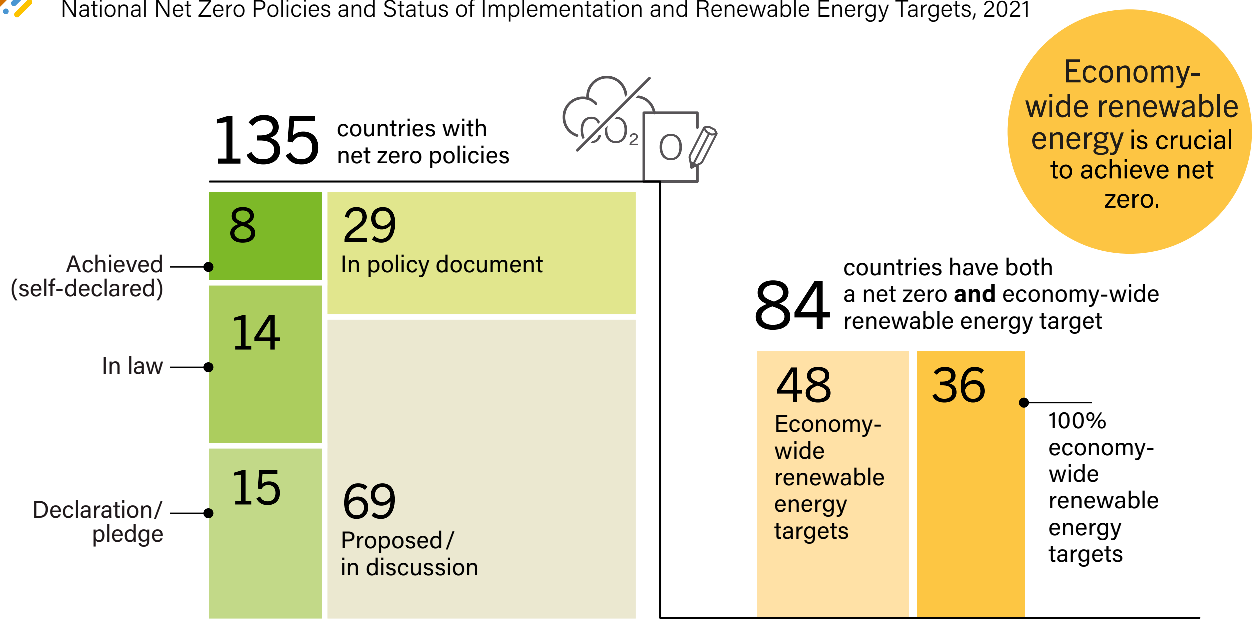
More than 17 countries announced new **net zero** commitments in 2021, many in advance of the November climate talks.[17] By year's end, at least 135 countries as well as the European Union (EU) – together accounting for around 88% of global emissions – had in place some form of net zero target (including announcements and targets under discussion).[18] The EU made its climate neutrality target for 2050 legally binding and set an interim target for 55% emission reduction by 2030.[19] Brazil passed a net zero target for 2070, and India for 2050.[20]

The degree of implementation varies, as many net zero targets are not backed by specific legislation.[21] (→ *See Figure 16.*) Of countries' 2021 targets, only around a fifth were enshrined in law, around half were included in some type of policy and the remaining third were in the declaration stage.[22] Eight countries (Benin, Bhutan, Cambodia, Gabon, Guinea-Bissau, Guyana, Liberia, Madagascar and Suriname) declared they had already achieved net zero emissions by late 2021; however, these places are considered to still be developing and include in their calculations the role of forests as natural carbon sinks.[23] Meanwhile, only 84 of the 135 national governments with net zero targets also had economy-wide renewable energy targets (and only 36 had targets for 100% renewables), highlighting the gap between commitments to net zero and plans to scale up renewables to help achieve this.[24]

Carbon pricing policies aim to increase the price of fossil-based energy compared to non-fossil sources such as renewables (and nuclear power). By the end of 2021, such policies were in place in 65 jurisdictions at the national and sub-national levels, covering an estimated 21.5% of global greenhouse gas emissions.[25] At least four countries (Austria, China, Germany and Indonesia) and Washington state (US) introduced new carbon pricing policies in 2021, which are set to go into effect in 2023.[26] China launched the world's largest emission trading scheme for power generation as part of its targets to achieve peak emissions by 2030 and carbon neutrality by 2060.[27]

Policies **banning or phasing out the use of fossil fuels** can stimulate the uptake of renewables in various end-use sectors, depending on the fuel being targeted. In 2021, the most common type of fossil fuel ban enacted at the national and state/provincial level was on coal, which is used primarily to generate electricity (and, to a lesser extent, to provide heat for buildings and industrial processes).[28] **Coal bans or phase-outs** can indirectly stimulate investment in renewable power capacity, although they also can increase the uptake of nuclear generation. At the same time, increases in wholesale energy prices have led national governments to put in place measures to shield consumers from the direct impact of rising energy prices.[29] (→ *See Box 6 and Table 3.*)

FIGURE 16.
National Net Zero Policies and Status of Implementation and Renewable Energy Targets, 2021



Note: Numbers exclude sub-national targets.
Source: Based on Climate Watch and REN21 Policy Database. See endnote 21 for this chapter, Reference Table R4 in the GSR 2022 Data Pack.

BOX 6. National Policies to Shield Consumers from Rising Energy Prices

With the energy crisis unfolding in late 2021, followed by the Russian Federation's invasion of Ukraine in early 2022, countries in Europe and around the world have experienced energy price hikes. To shield consumers from these increases, several governments have implemented short-term policies to mitigate the price effect. Most of the measures have focused on lowering energy taxes on fossil fuels, with many specifically targeting low-income groups, which have been among the most vulnerable to rising prices. (→ *See Table 3.*)

In addition, several countries have planned medium-term strategies to reduce reliance on fossil fuels and increase national and regional energy security. For example, much of the discussion in the EU has focused on reducing reliance on Russian fossil fuels (in particular natural gas), including by speeding up renewable energy solutions. (→ *See Sidebar 1 in Global Overview chapter.*)

TABLE 3.
Measures to Address Fossil Fuel Price Increases in Selected Countries, as of Early 2022

Country	Reduced energy tax / VAT	Retail price regulation	Wholesale price regulation	Transfers to vulnerable groups	Mandate to state-owned firms	Windfall profits tax	Business support	Other
Austria	■			■			■	
Belgium	■	■		■				■
Brazil	■							
Bulgaria		■				■	■	
Croatia	■			■				
Cyprus	■			■	■			
Czech Republic	■	■		■			■	
Denmark				■				
El Salvador	■							
Estonia	■	■		■			■	
Finland	■			■			■	
France	■		■	■	■			
Germany	■			■		■		■
Greece				■	■		■	
Hungary		■						
Ireland	■			■				■
Italy	■			■		■	■	
Korea, Republic of	■							
Latvia	■			■				
Lithuania		■		■				■
Luxemburg				■				
Mexico	■							
Netherlands	■			■				
Norway	■			■			■	
Peru	■							
Poland	■	■		■				
Portugal	■		■	■	■			
Romania	■	■		■		■		
Slovenia	■			■		■	■	
South Africa	■							
Spain	■	■	■	■		■	■	
Sweden	■			■			■	■
United Kingdom		■		■			■	■
United States	■							

Note: Table includes measures enacted between September 2021 and March 2022. Excludes sub-national and supra-national policies.
Source: Bruegel and REN21 research. See endnote 29 for this chapter.

By year's end, at least seven countries had committed to banning or phasing out coal either at the national or state/provincial level.[30] Indonesia's state-owned energy utility announced that it would end the construction of new coal-fired power plants after 2023 (although more than 20 gigawatts, GW, of new coal capacity will be built until then).[31] In Europe, Hungary expedited the closure of its last coalfired power plant by five years (targeting 2025 instead of 2030), and Bulgaria, Germany, Romania and the United Kingdom committed to exiting coal, with timelines varying between 2024 and 2040.[32] At the state level, Oregon (US) banned the expansion or new construction of coal-fired as well as natural gas and other fossil fuel plants.[33] In addition to individual country commitments, a key outcome of the Glasgow climate talks was an agreement by more than 40 countries and several sub-national jurisdictions to phase down[i] "unabated" coal power generation[ii] by the 2030s in developed economies and by the 2040s in developing economies.[34] (→ *See Global Overview chapter.*)

In the buildings sector, **bans or support for phasing out fossil fuels for heating** (such as heating oil and fossil gas) have the potential to stimulate the use of renewables. While such bans typically are enacted by municipalities (→ See *Renewables in Cities chapter*), in 2021 at least two countries took this step: Slovenia banned fuel oil and coal for heating starting in 2023, and France banned fossil gas for heating in new single-family homes starting in mid-2022 (and in new collective housing starting in 2024).[35] At the sub-national level, the province of Quebec (Canada) banned fossil fuel heating in new construction.[36]

In the transport sector, **bans on fossil fuels for road transport** can incentivise biofuels-based transport and the use of electric vehicles. While electric vehicles are not a renewable energy technology in themselves, they provide a critical entry point for higher uptake of renewables in transport, especially if combined with policies for renewable electricity generation. Bans on **internal combustion engine (ICE) vehicles** also support uptake of electric vehicles and have been the most widespread type of ban.

Policy support for decarbonisation of the transport sector increased significantly in 2021, with new announcements bringing the total number of national and sub-national jurisdictions with bans on fossil fuel use in road transport to 30, up from 26 in 2020; in addition, a partial ban exists in Mexico.[37] Canada banned the sale of fuel-burning new cars and light-duty trucks starting in 2035, the United Kingdom banned the sale of new petrol and diesel heavy-goods vehicles and buses by 2040 (and the sale of smaller diesel trucks from 2035), and Spain enacted a law prohibiting the sale of fossil fuel vehicles by 2040.[38] Singapore's new Green Plan includes ceasing sales of diesel cars and taxis from 2025 and requiring all new car and taxi registrations to be "cleaner energy" models starting in 2030.[39] At the state level, New York (US) enacted a law requiring all passenger vehicles sold in the state to be emission-free by 2035 and to eliminate emissions from medium- and heavy-duty vehicles by 2045.[40]

Ending government support for fossil fuel production and exploration and enacting **bans on funding for international fossil fuel projects** and on **fossil fuel exports** also have the potential to indirectly support the uptake of renewables. In 2021, China, Japan and the Republic of Korea committed to ending funding for the construction of new coal power projects overseas (but not necessarily domestically).[41] Spain banned all new coal, gas and oil exploration and production permits.[42] Canada announced that it would stop exporting thermal coal (but not other types) by 2030 at the latest.[43]

At least **seven countries** had committed to banning or phasing out coal either at the national or state/provincial level.

i Ultimately, the agreement was to "phase down", rather than "phase out" coal generation.

ii This refers to coal burning that is carried out without some form of carbon capture and storage.

RENEWABLE ENERGY TARGETS

By the end of 2021, 166 countries had in place some type of target at the national and/or state or provincial level to increase the uptake of renewables, either economy-wide or in specific sectors – up from 165 countries at the end of 2020.[44] (→ *See Figure 17.*). As in previous years, the greatest number of targets were in the power sector, followed by the heating and cooling sector, while the number of targets for transport was significantly lower.[45]

Several countries committed to economy-wide targets for 100% renewable energy during the year. In Africa, the Democratic Republic of the Congo, Kenya and Uganda all set targets for 100% renewables economy-wide by 2050.[46] Fiji set a similar target for 2036, the Marshall Islands for 2050, and Austria and Barbados for 2030 – bringing the total number of countries with economy-wide targets for 100% renewables to 36 by the end of 2021, up from 32 the previous year.[47]

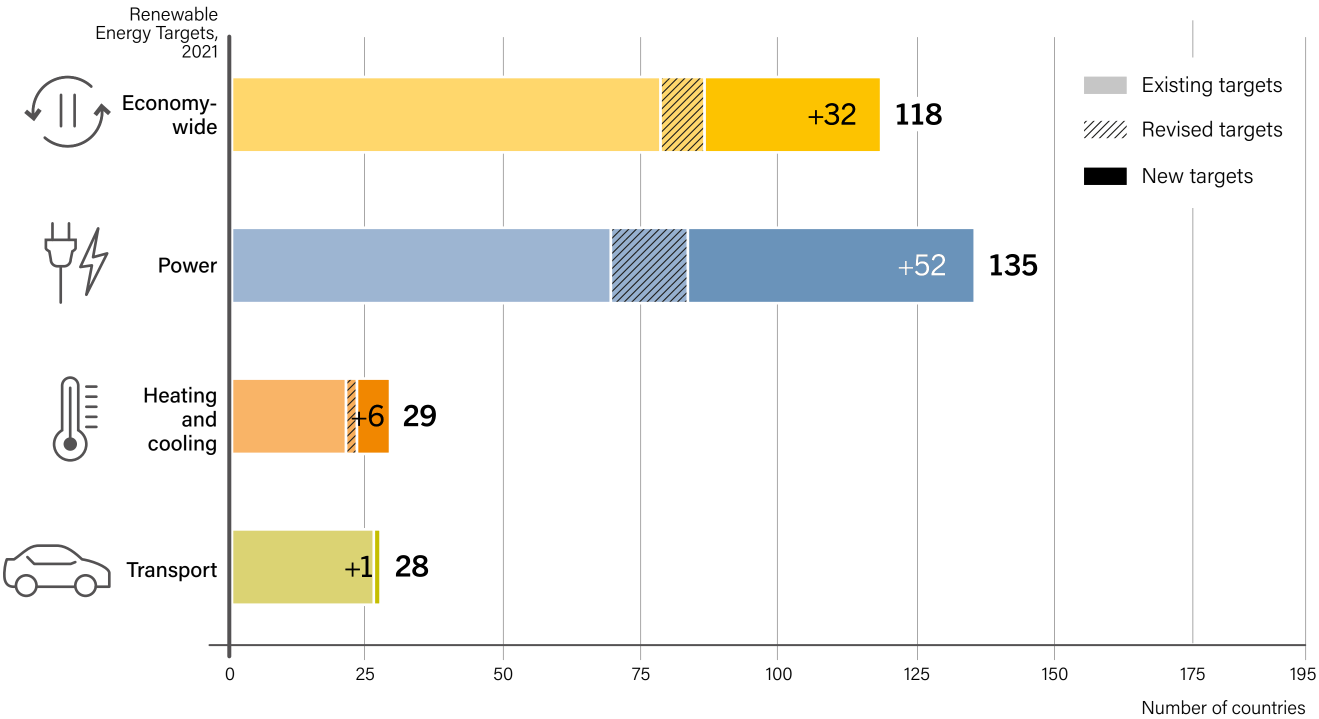
Targets in the power sector continued to dominate, with renewable power targets in 135 countries by year's end, followed by the heating and cooling sector, where 7 new countries announced new or revised targets; this raised the total number of countries with renewable heating targets from 22 in 2020 to 29 in 2022.[48] Many of the new heating and cooling targets were implemented in Europe, including in Croatia, North Macedonia, Slovenia and Spain.[49]

Targets to increase the share of renewables in transport saw further decline, with the number of countries with such targets in place falling from 46 in 2019 to 28 in 2021, as many targets that expired in 2020 were not updated and/or renewed.[50] Most of the existing targets are in EU Member States, guided by a region-wide target to achieve at least 14% renewables in transport by 2030.[51] Only Iceland passed a new transport target in 2021, aiming for 100% renewable-based road transport by 2050, with an intermediate target of 40% by 2030.[52] In addition, several countries adopted or revised biofuel and electric vehicle targets. (→ *See Transport section in this chapter.*)

An emerging trend has been to adopt renewable energy targets specific to military operations.[53] (→ *See Table 4.*) Most of these targets are for the use of solar PV to support the operations of remote army bases, driven by opportunities to save energy costs, boost resilience against grid outages from extreme weather events or from cyberattacks, and contribute to national emission reduction targets.[54]

Although targets on their own generally are insufficient to stimulate investment, they continue to be an important expression of a jurisdiction's commitment to renewables. However, these targets need to be converted into action through the adoption and implementation of other complementary renewable energy policies and regulations.

FIGURE 17.
Renewable Energy Targets, 2021



Note: New targets were announced in 2021, revised targets can include a revised target date or a revision of the actual share of renewable energy for a future year. Transport target calculation excludes signatory countries to the Glasgow declaration calling on all new cars to be zero emission by 2040. See Reference Tables R3 and R5-R10 in GSR2022 Data Pack.

Source: See endnote 44 for this chapter.

TABLE 4.
Renewable Energy Targets in Military Operations in Selected Countries, as of End-2021

Country and Scope	Target(s)
China: Chinese People's Liberation Army	Micro-power grid systems (based on solar and wind with battery storage and diesel back-up) for more than 80 border defence outposts in remote regions.
France: Ministry of Armed Forces	Phase-out of 1,600 heavy fuel oil boilers by 2030; making available 2,000 hectares of land through 2022 for utility-scale solar PV projects.
India: Indian Navy	24 MW of solar PV by 2022 as part of the Environment Conservation Roadmap.
Japan: Japan Defense Ministry	100% of defence facilities powered by renewable energy (proposed).
Pakistan: Pakistan Army	1-5 MW solar parks in each garrison, with a total capacity of 40 MW.
Republic of Korea: Ministry of Trade, Industry and Energy and the Ministry of National Defence	25% renewable electricity consumption by 2030. Installation of 137 MW of solar PV on military bases and 320 MW on military land and use of geothermal cooling and heating systems.
United Kingdom: Army	Four pilot solar farm projects installed in 2021, with total capacity of 2.3 MW
United States: Army	Carbon-free electricity for Army installations by 2030, with renewable-based microgrids on all posts by 2035 and net zero emissions from installations by 2045. An increasingly electrified vehicle fleet, including developing electric tactical vehicles by 2050.

Source: See endnote 53 for this chapter. Table also includes targets which have already been achieved.

RENEWABLES FOR ECONOMIC DEVELOPMENT AND RECOVERY

Increasingly, renewables are being included as core components of national **economic development** plans and strategies, particularly given concerns about rising energy prices and the security of energy supply.[55] (→ *See Snapshot. Bangladesh.*) While no comprehensive data exist on this trend, an analysis of the BRICS[i] countries – the largest emerging economies worldwide – shows that all but the Russian Federation (a major fossil fuel producer) have explicitly included renewables in their national plans.[56]

The Brazilian government launched a Green Growth National Program in October 2021 with the goal of aligning economic growth with sustainable development towards a green and low-carbon economy while also generating jobs; as part of the programme, Brazil will invest BRL 400 billion (USD 71 billion) in areas including renewable energy, biodiversity and waste management.[57] India's 2047 vision, currently under development, has discussed aims to make the country a leader in renewables.[58] China, in its 14th Five-Year Plan released in March 2021, committed to ramping up wind and solar PV power as well as expanding power infrastructure development and energy storage.[59] South Africa's 2012 national development plan includes the goal of procuring at least 20 GW of renewable electricity by 2030 and providing support to meet the country's target of 90% grid-connected electricity access.[60]

Several countries have used **post-COVID recovery plans** as opportunities to support the shift to renewables. Between the start of the pandemic and early 2022, governments committed more than USD 710 billion to sustainable recovery measures by 2030 (→ *See Investment chapter*); most of this was invested in member countries of the Organisation for Economic Co-operation and Development (OECD), particularly EU countries.[61] Greece and Italy both announced post-COVID recovery plans that include billions of dollars each of investment in renewables, storage, energy efficiency, and electric vehicles, and Spain announced a plan to allocate EUR 6.9 billion (USD 7.8 billion) to renewables and related technologies (including renewable hydrogen, storage and electric mobility).[62] Canada's federal recovery plan supports renewable energy and electric vehicles.[63]

Several countries announced investment in renewable energy **research and demonstration** projects during 2021, with some of the funds earmarked in development plans (China) or as part of recovery funds (France and the United Kingdom).[64] For many energy technologies, public funding is needed for initial research and demonstration projects and to help leverage private investment[ii].[65] The United States announced USD 100 million in

i The BRICS countries are Brazil, the Russian Federation, India, China and South Africa.

ii Global public energy R&D spending, including on demonstration projects, reached USD 32 billion in 2020, up 2% from 2019, although not all of this is dedicated to renewable energy research. See endnote 65 for this chapter.

SNAPSHOT. BANGLADESH

Mujib Climate Prosperity Plan

The Mujib Climate Prosperity Plan, published in September 2021, serves as Bangladesh's roadmap for climate resilience, energy independence and access, and renewable energy through 2030. Through this plan, the country aims to achieve 30% renewable energy consumption and 30% electrified transport, driven by the need to protect vulnerable communities and encourage economic development. This includes goals to modernise the grid, extend energy access to 100% of the population, replace domestic energy capacity with renewables (including green hydrogen) and achieve 100% clean cooking solutions.

The framework is expected to result in the creation of 4.1 million climate-resilient jobs. Investment needs of USD 80 billion will be financed through a mix of public and private financing along with international partner support. In 2021, Bangladesh rejected proposals to build 10 new coal-fired power plants. Instead, the plan foresees that existing coal and natural gas plants will become energy hubs, converted to either green hydrogen, waste-to-energy or biomass plants. The goal is to reduce natural gas imports and to upgrade existing infrastructure to be capable of handling 30% green hydrogen starting in 2030.

Source: See endnote 55 for this chapter.

funding for clean energy technology research.[66] In China, the 14th Five-Year Plan gives a central role to innovation research, and Japan's Green Innovation Fund plans to allocate around USD 19 billion to low-carbon technology demonstration until 2023 (complemented by USD 15 billion in tax credits for private involvement in such projects).[67] The EU allocated EUR 1.1 billion (USD 1.2 billion) for seven large innovation projects, most of them for renewables, under its Innovation Fund.[68] France, as part of its EUR 100 billion (USD 113 billion) recovery and resilience plan, will invest EUR 1 billion (USD 1.1 billion) in renewable innovation projects as well as hydrogen research.[69]

Some jurisdictions have used economic development and post-COVID recovery plans as an opportunity to foster job creation and workforce training in the renewables sector.[70] (→ *See Sidebar 5 in this chapter, and Sidebar 2 in Global Overview chapter.*) India, Scotland (UK) and the United States, as well as several sub-national governments, have developed plans mentioning the importance of developing a skilled workforce to advance the energy transition.[71]

SIDEBAR 5. Educating the Workforce for the Energy Transition

To meet the growing demand for a renewable energy workforce, several national governments, as well as universities, technical schools, non-governmental organisations, and oil and gas companies, are taking steps to build the necessary workforce for the future and to re-skill existing workers. In addition to the 12 million people already working in renewables as of 2020, an estimated additional 85 million jobs related to the energy transition will need to be filled by 2030. (→ *See Sidebar 2 in Global Overview chapter.*)

Several national and sub-national jurisdictions have launched and supported programmes to address the issue of re-skilling. In the United States, where the positions of wind turbine service technician and solar PV installer are expected to grow 68% and 52% respectively by 2030, government-funded resources such as WINDExchange and the Solar Training Network outline educational and training programmes. India's Skill Council for Green Jobs public-private partnership has provided trainings, through partners, for around 500,000 persons in areas such as renewables, electric vehicles and carbon sinks. After a drastic increase in oil and gas unemployment from 2014 to 2017, Scotland provided GBP 12 million (USD 16 million) for an Oil and Gas Transition Training Fund that re-skills workers for careers in wind turbine engineering and infrastructure.

At the sub-national level, the Renewable Denver Initiative, funded by the state of Colorado, includes a workforce training programme for solar PV, supporting the installation of community solar gardens on municipal land. In New York, a USD 25 million fund was announced in late 2021 to re-skill displaced workers in the fossil fuel sector and from disadvantaged communities, to new renewable energy jobs. A workshop in Canberra (Australia) helps to up-skill auto mechanics to work with electric vehicles and to train police, firefighters and paramedics on how to safely respond to incidents involving electric vehicles. Victoria (Australia) launched a USD 11 million plan to subsidise 50% of the cost of apprenticeships, professional mentoring and ongoing education for women entering the renewables industry as electricians, plumbers, solar installers and more.

Although no consolidated data exist, initial research indicates that education on renewables is most common at the master's level and in short-term professional development training. At least 126 masters' programmes in G20 countries were dedicated to renewable energy as of early 2022; in addition, programmes in other disciplines have integrated renewables (and energy efficiency) into their curricula. The Royal Institute of British Architects is making climate literacy a mandatory component in its 109 schools in 23 countries, which includes factoring transport, waste and energy efficiency into construction. Universities such as Yale and Harvard offer courses for working professionals in business and finance to understand and support renewable energy projects. Duke, MIT and the University of Pennsylvania, among many others, have massive open online courses for public skills learning on renewable energy systems and policy.

Several initiatives aim to build up a local workforce for distributed renewables for energy access, to improve educational opportunities for the more than 230 million children worldwide who attend primary schools without electricity[i]. New Energy Nexus has provided training, investment and financing to create 650 new jobs in renewables for local communities supporting education, clean cooking and electricity access in rural Uganda. The Bharatiya Vikas Trust has up-skilled 15,000 financiers and 50,000 entrepreneurs since 1996 to close the finance gap on people and businesses using renewable as a means to earn an income.

Oil and gas companies have initiated programmes to re-skill their workers towards renewables, mirroring efforts to shift from fossil fuel production to greater integration of renewable energy. (→ *See Sidebar 7 in the Investment chapter.*) Saudi Aramco, Saudi Arabia's state-run oil company, established the National Power Academy to provide vocational training and education in areas such as smart grids, energy efficiency and renewables. Ørsted, Denmark's oil giant-turned-renewables company, is teaming up with Falck Renewables and BlueFloat Energy to create a streamline for colleges in Scotland and industry partners to meet the need for workers to install offshore wind farms. Iberdrola (Spain) aims to re-skill 15,000 people over a two-year period, including installers of solar panels and electric vehicle charging infrastructure, and electric heat technicians.

Several initiatives exist to increase the share of women in the renewable energy workforce[ii]. Sri Lanka, in its 2019 National Energy Policy and Strategies plan, includes empowering women and youth in agriculture, rural and primary industries through electricity access, energy efficiency and conservation. In Africa, the state-owned Ethiopia Electric Utility looks to employ 30% women by 2030 by providing scholarships and internships in STEM (science, technology, engineering and math) fields.

i Only 27% of primary schools in low-income countries had access to electricity in 2020 (latest data available).

ii The share of women in the renewable energy sector was around 32% in 2018 (latest data available), up from 22% in 2010.

Source: See endnote 70 for this chapter.

POWER

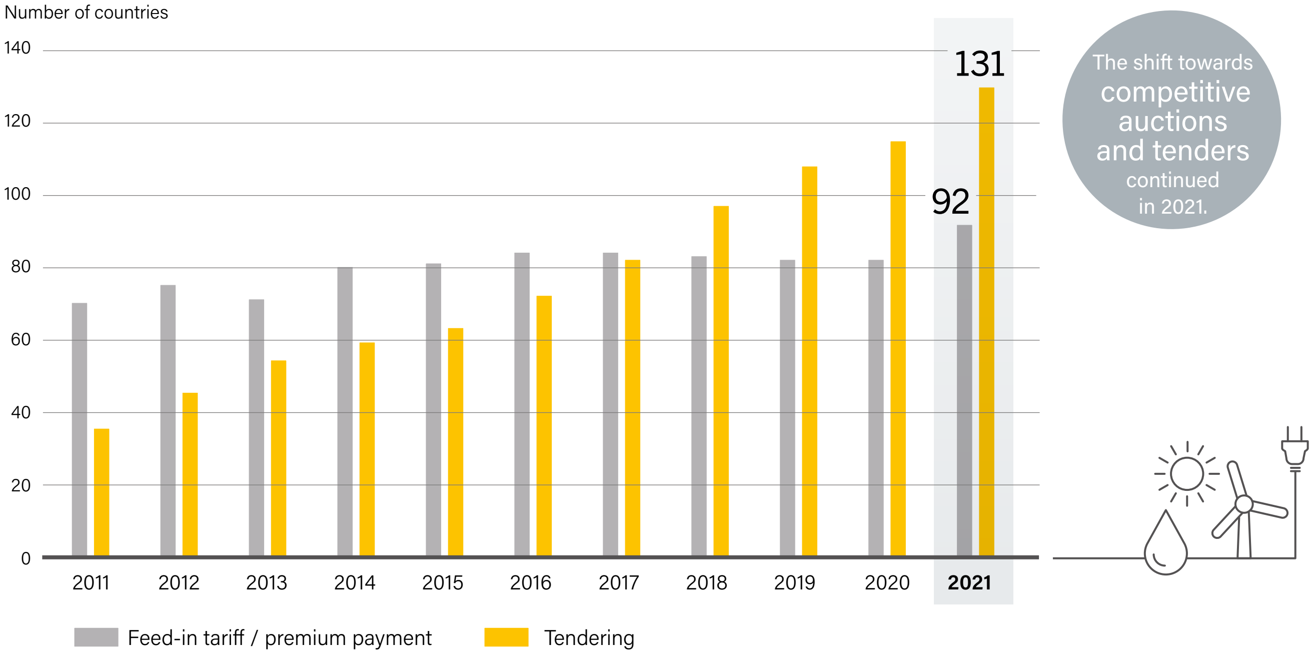
The number of countries with renewable power policies again increased in 2021, continuing a multiyear trend. Policies to support renewables in the power sector include: targets, renewable portfolio standards (RPS), feed-in policies (tariffs and premiums), auctions and tenders, renewable energy certificates (RECs) or Guarantees of Origin (GOs), net metering and other policies to encourage self-consumption, as well as fiscal and financial incentives (such as grants, rebates and tax credits). Most countries support renewable power with a mixture of policy instruments that often vary depending on the technology, scale or other features of installation (e.g., centralised or decentralised).

At least 51 countries introduced new or updated **targets** for the power sector in 2021, and by year's end at least 135 countries had some form of renewable electricity target; this was down from 137 countries in 2020, as some targets expired in 2020 and were not replaced.[72] Meanwhile, the number of countries with regulatory policies for renewables in the power sector continued to expand, rising from 145 in 2020 to 156 in 2021.[73] As in prior years, auctions, tenders and other competitive pricing strategies continued to overtake feed-in tariff policies.

Feed-in policies, including feed-in tariffs (FITs) and feed-in premiums (FIPs), are used to promote both large-scale (centralised) and small-scale (decentralised) renewable power generation, and they remain among the most widely used policy mechanisms for supporting renewable power.[74] (→ *See Figure 18.*) In 2021, the number of jurisdictions with FITs increased for the first time in recent years, to 92 (up from 83 in 2020).[75] Ireland, which had removed its FIT in 2015, re-introduced it to boost citizen and community participation in the energy transition.[76] Trinidad and Tobago introduced a FIT to support solar PV rooftop systems.[77] In China, where the last national-level FIT was set to expire by the end of 2022, Guangdong become the first province to introduce a FIT, in mid-2021.[78] (→ *See Snapshot: China.*)

Several countries held renewable energy **auctions or tenders** at the national or sub-national levels during the year.[79] Albania launched its first tender for onshore wind power capacity (following two tenders for solar PV capacity in 2020), driven by the need to diversify its electricity mix, which is dominated by hydropower.[80] In Spain, nearly 1 GW of wind power capacity was awarded to seven companies at a wind-specific renewables auction.[81] Outside of Europe, Japan held its first tender for floating offshore wind power, and Chinese Taipei awarded 5.5 GW of offshore wind power capacity through auctions (the national FIT was applied to the first 3.8 GW of projects).[82]

FIGURE 18.
Renewable Energy Feed-in Tariffs and Tenders, 2010-2021



Note: A country is considered to have a policy (and is counted a single time) when it has at least one national or state/provincial-level policy.
Source: See endnote 74 for this chapter and Reference Tables R12 and R13.

Net metering continued to be a popular policy instrument to support renewable power. At least 10 countries or sub-national jurisdictions implemented new – or enhanced existing – net metering policies in 2021.[83] In India, the state of Kerala introduced a new net metering rooftop programme with a goal of installing solar panels on 75,000 homes, and West Bengal introduced net metering for household rooftop solar PV between 1 kW and 5 kW.[84] Malaysia introduced a new programme that allows residential customers to export 100 MW of surplus solar generation to the grid, and Indonesia revised its legislation for rooftop PV to ensure that customers earn credit for the surplus power they inject to the grid at the same tariff they pay for buying electricity.[85]

Bolivia introduced net metering for distributed renewable generation for both small-scale generation and larger commercial systems.[86] In Europe, Romania amended its net metering programme to support residential solar PV, and Montenegro implemented its first net metering programme for 3,000 residential rooftop PV systems.[87] The Russian Federation introduced net metering for solar and other renewable energy generators under 15 kW.[88]

SNAPSHOT. CHINA

A Renewable Policy Transition

China has undergone a major policy change In recent years, shifting its renewable energy pricing from a premium feed-in tariff (FIT) model to a "grid parity" model where renewable and coal plants sell electricity at the same price. The country's National Energy Administration stopped approving FITs for new renewable projects in 2018, followed by a decision to phase out key FIT support schemes, including: for utility-scale, industrial and commercial rooftop solar PV systems and onshore wind power by the end of 2020; for residential solar PV power by the end of 2021; and for offshore wind power by the end of 2022. The move was driven by backlogs in FIT payments and by the plunging cost of PV modules, which has made systems more affordable. The central government policy permits local subsidisation of offshore wind power and CSP at a regional level, with Guangdong becoming the first province to provide such a subsidy in mid-2021.

This policy transition led annual solar PV installations in China to fall more than 30% in 2019. However, as installers sought to benefit from the final years of FIT support, the market grew more than 60% in 2020, to reach a record 55 GW of new installations in 2021. The government's 14th Five-Year-Plan, released in March 2021, puts a continued focus on wind and solar PV power as well as energy integration and energy storage, aiming for a 20% non-fossil fuel share in the energy mix by 2025. China's recently announced targets for peak carbon emissions by 2030 and carbon neutrality by 2060 also have driven demand for renewables.

Source: See endnote 78 for this chapter.

Several US states reduced or removed their net metering credits during the year. Indiana reduced its net metering rate, and Connecticut replaced net metering with a new programme that changes how owners are compensated for their power generation.[89]

At least 17 countries introduced new **financial or fiscal policies** in 2021 – including Denmark, France, and Italy in Europe, and Australia and New Zealand in Oceania.[90] Morocco provided MAD 52.1 billion (USD 5.6 billion) for major solar projects in the country, and Bangladesh provided USD 50 million to install 80,000 solar home systems and 5,000 community arrays.[91] In Europe, Croatia implemented a EUR 7.4 million (USD 8.4 billion) rebate programme for rooftop solar PV installations for businesses and homeowners, Malta announced EUR 26 million (USD 29.4 million) in funding for large-scale renewable energy projects, Sweden made available SEK 260 million (USD 28.7 million) in rebates for homeowners who install solar PV, and the United Kingdom provided GBP 265 million (USD 357 million) in subsidies for renewables.[92] At the state level, Kerala (India) began offering a subsidy to install rooftop solar PV, with eligible participants having to pay only 12% of the costs.[93]

Renewable portfolio standards (RPS) – mandates requiring utilities (or companies) to install or use a certain share of renewable energy – also expanded. As of 2021, 31 US states and the District of Columbia had legally binding RPS and goals, 12 of which require 100% clean electricity by 2050 or earlier; in addition, 7 US states have non-binding renewable portfolio goals.[94] Four states – Delaware, Illinois, North Carolina and Oregon – updated their RPS policies during the year, while Nebraska approved its first clean energy goal (100% clean electricity by 2050).[95] Outside of the United States, Colombia introduced an obligation for all power companies operating in the wholesale energy market to ensure that at least 10% of the electricity they distribute is generated with renewable technologies, as of January 2022.[96]

While no rooftop solar PV mandates for new or existing buildings exist at the national level, several states/provinces have implemented such policies.

While no **rooftop solar PV mandates** for new or existing buildings exist at the national level, several states/provinces have implemented such policies.[97] (→ *See Table 5.*) In 2021, the US state of California adopted a building code making it mandatory to include solar PV with battery storage in new commercial buildings and high-rise residential buildings.[98] In Germany, 7 out of 16 states have solar PV mandates, most of which apply not only to new buildings but also to major rooftop renovations.[99] Several Chinese provinces have solar mandates, and the national government launched a call to provincial offices to suggest counties where such mandates could be trialled.[100]

TABLE 5.
Solar PV Mandates at the Sub-national Level in Selected Jurisdictions, as of End-2021

Country/Jurisdiction	Solar PV mandate
China	
Fujian, Guangzhou, Shaanxi Jiangxi, Gansu and Zhejiang	Mandatory on 20% of residential rooftops, 30% of commercial/industrial, 40% of public facilities and 50% of government buildings; more trial provinces are expected
Germany	
Baden-Württemberg	Mandatory for non-residential buildings from January 2022, for new residential buildings from May 2022 and for renovated buildings from 2023
Berlin	Mandatory (along with solar thermal) for new buildings and building renovations for residential buildings as of 2023
Hamburg	Mandatory on new buildings from 2023 and for building renovations from 2025
Niedersachsen	Mandatory on new commercial buildings with rooftops greater than 75 square metres
Nordrhein-Westfalen	Mandatory on new car parks of more than 35 spaces from January 2022
Rheinland-Pfalz	Mandatory (along with solar thermal) on new commercial buildings and new car parks of more than 50 spaces
Schleswig-Holstein	Mandatory on new car parks of more than 100 spaces, on at least 10% of rooftop space for solar PV for new buildings, and for building renovations on non-residential buildings, from 2022 onwards
United States	Four pilot solar farm projects installed in 2021, with total capacity of 2.3 MW
California	Mandatory (with battery storage) in new commercial buildings and high-rise residential buildings, starting in 2023

Source: See endnote 97 for this chapter.

POLICIES TO SUPPORT COMMUNITY ENERGY

Despite the growth in policy support for renewables, local opposition to renewable energy projects continued to limit project deployment in some regions.[101] To support a more positive public response to renewables, governments at all levels have adopted policies that enable residents, businesses, communities and others to develop, own, operate, invest in and otherwise benefit from projects.[102] Such community energy arrangements occur mainly in the power sector, with related policies supporting self-consumption, virtual net metering and various forms of shared ownership.[103]

During 2021, at least 13 Canadian provinces and US states implemented new community energy policies. Nova Scotia (Canada) for the first time allowed shared community ownership of net metered solar PV generation.[104] In the United States, New Mexico established a community solar programme requiring that 30% of the output go to low-income customers or service organisations.[105] Delaware and Illinois increased their limits on the size of community solar, and Oregon provided USD 50 million in grants for community projects in cities outside Portland.[106] New York state provided USD 53 million in incentives for community solar projects that dedicate at least 20% of their capacity to low- and moderate-income households, affordable housing providers and facilities serving disadvantaged communities.[107] Community programmes also are starting to emerge outside North America and Europe.

The supply of heat in buildings remains heavily dependent on fossil fuels, with renewable sources meeting only around 11% of global heat demand in 2020.

SYSTEM INTEGRATION POLICIES

Policies that support energy storage, extensions and improvements to grid infrastructure, smart grid technologies and electric vehicle charging stations can help minimise the potential negative impacts and maximise the benefits associated with variable renewable energy.[108] (→ *See Energy Systems chapter.*)

Policies to improve **electric grid infrastructure**, including those aimed at expanding or modernising transmission and distribution systems, continued to gain ground in 2021. Cyprus, Greece and Israel agreed to implement an underground cable to link the countries' power grids and boost their ability to use and trade renewable energy.[109] In the United States, the Bipartisan Infrastructure Deal included USD 65 billion to upgrade power infrastructure by building thousands of kilometres of new transmission lines to facilitate the expansion of renewables.[110] The country also announced plans to provide up to USD 8.25 billion in loans to companies to expand transmission capacity, including support for offshore wind power connections.[111] At the state level, New York approved a 150-kilometre transmission line to help meet its renewable energy goals.[112] China plans to invest USD 350 billion during 2021-2025 to upgrade its grid and build new power systems with improved voltage regulation and better compatibility with renewables.[113]

Policies that promote **energy storage** also help with successful system integration, since storage can make it easier to balance electricity supply and demand and minimise the curtailment of generation. In 2021, the EU implemented a EUR 12 billion (USD 14 billion) 12-nation European Battery Innovation project, which will permit Member States to support innovation in battery storage.[114] Spain launched an Energy Storage Strategy that targets 20 GW of large-scale and distributed storage by 2030, and 30 GW by 2050, to increase system flexibility and network stability.[115] At the sub-national level, Queensland (Australia) announced plans to install five large-scale, network-connected batteries, and Maine (US) announced a goal of 400 MW of installed battery capacity by the end of 2030.[116]

Policies also were enacted to support direct linking of solar PV and energy storage. For example, India extended its national INR 18,100 crore (USD 24 billion) solar production programme, which provides incentives to domestic and international companies for setting up battery manufacturing plants.[117] At the sub-national level, Oregon (US) allocated USD 10 million to a solar-plus-storage rebate programme focused on low-income customers.[118]

HEATING AND COOLING IN BUILDINGS

Heating of space and water for buildings accounted for just under a quarter of global final energy consumption in 2021.[119] Worldwide, the supply of heat in buildings remains heavily dependent on fossil fuels, with renewable sources meeting only around 11% of global heat demand in 2020, a share that has remained relatively unchanged during the last decade.[120]

Bioenergy is the main source of renewable heat in buildings[i]; other sources include geothermal and solar thermal energy as well as the use of renewable electricity, for example through electric heat pumps.[121] Interest in electrification of heating[ii] in buildings has gained traction. To the extent that the electricity is generated from renewables, this can increase the penetration of renewables in the buildings sector. (→ *See Heat Pumps section in Market and Industry chapter.*) In 2021, several jurisdictions implemented policies targeting the electrification of heating and cooling in buildings.[122]

i Mainly through the use of wood and pellet stoves and boilers and in district heating networks.

ii The electrification of heating is only 100% renewable to the extent that the electricity used is generated from renewable sources. Thermal energy provided by heat pumps also has a component of ambient energy that is considered renewable.

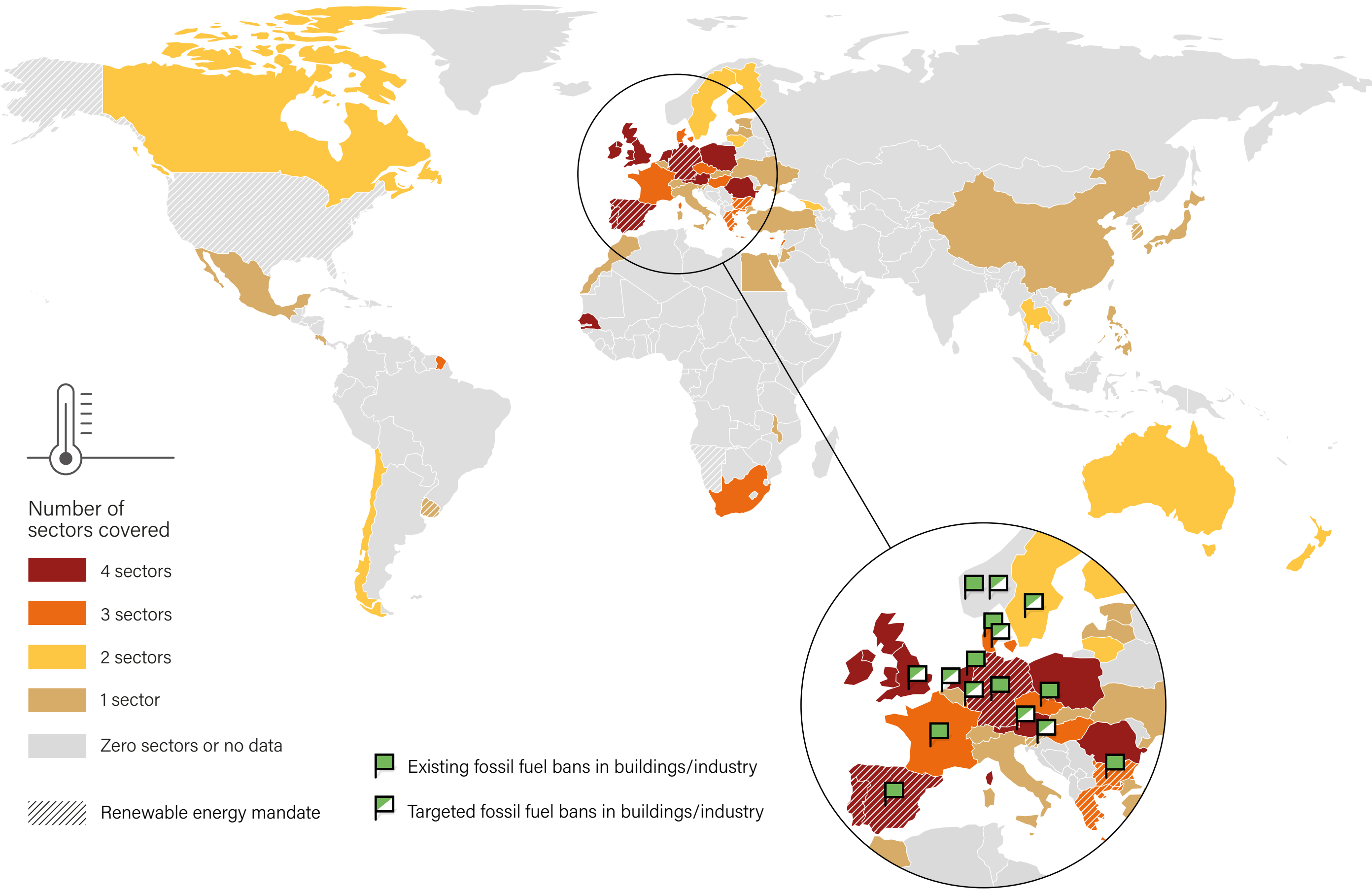
Policies that promote renewable heating in buildings include: targets, financial incentives, support for electrification and support for renewable district heating. Bans on fossil fuel heating and greenhouse gas emission reduction targets, including net zero targets, also can indirectly encourage the production and use of renewable heating. Heating policies for buildings tend to differentiate among new and existing buildings as well as building types (residential, commercial, industrial and public)[i]. For example, regulatory policies such as technology mandates typically apply to new construction, whereas existing buildings often are targeted by financial policies to install renewable heat systems. In regions with high urbanisation and population growth, the distinction between new and existing buildings can be critical, since half of the building stock projected to be in place in 2060 has not yet been built (mainly in Africa and Asia).[123] In Europe, where building replacement is slow, the focus on retrofitting has grown.[124]

By the end of 2021, at least 29 countries had committed to **renewable heating and cooling targets**. Although this was up significantly from only 22 targets in 2020, it too reflects the trend of numerous expired targets not being replaced.[125] Chile, in its 2021 National Heat and Cold Strategy, announced an 80% renewable energy target for household heating and cooling by 2050 (using mainly solar PV and biomass).[126] Croatia set a 36.6% renewable heating and cooling target by 2030 (including cogeneration), and Lebanon passed a 11% renewable heating by target by 2030.[127]

At least 13 national jurisdictions implemented or updated some form of building-specific renewable heating policy in 2021.[128] However, the total number of countries with building-specific heating policies remained the same as in 2020, at 55, as all countries that implemented or revised their policies in 2021 already had existing policies.[129] Policy developments in heating and cooling for buildings continued to be more scarce than policies directed at electricity generation and transport. As in 2020, only 10 countries had renewable heat support policies covering heating in all type of buildings (including residential, commercial, industrial and public).[130] (→ *See Figure 19.*)

i For example, electrification is often more cost-effective in new buildings, where builders can avoid the cost of installing natural gas lines and meters, whereas it is more difficult and costly to electrify existing buildings.

FIGURE 19.
Sectoral Coverage of National Renewable Heating and Cooling Financial and Regulatory Policies, as of End-2021



Note: Sectors include residential, industrial, commercial and public facilities. Policy types used for map shading include investment subsidies/grants, rebates, tax credits, tax deductions, loans and feed-in tariffs. Renewable energy mandates are the obligation to meet a certain renewable standard for heat, such as the use of a specified technology. Figure does not show policies at the sub-national level.

Source: REN21 Policy Database. See Reference Table R11 in the GSR 2022 Data Pack and endnote 130 for this chapter.

Fiscal and financial incentives, including grants, rebates, tax incentives, and loan programmes, remained the most popular form of support to scale up renewable heating. During 2021, most financial and fiscal support covered multiple heating technologies, and most new policies were adopted in Europe[i]. France extended an existing tax credit for households that install solar thermal water heaters as well as ground- and air-source heat pumps, and Luxembourg extended through the end of the year a programme that provides financial assistance for installing solar thermal systems and wood-fired boilers (as well as heat pumps) and for connecting to a renewable heating network.[131] Malta launched several programmes to encourage the use of renewables for air and water heating in buildings (with a focus on solar water heaters and air-to-water heat pumps for households without roof access), and Austria allocated funds to support feasibility studies and the installation of solar thermal systems.[132]

Outside of Europe, Canada provided funding to reduce remote communities' reliance on diesel for heating by increasing the use of local renewable sources such as modern bioenergy.[133] The country's Greener Homes Grant provides up to CAD 5,000 (USD 3,912) for energy efficiency improvements and electrification of heating, including through the installation of heat pumps.[134] New Zealand provided nearly NZD 3 million (USD 2 million) to support renewable heat installations for Maori and public housing, including solar thermal water heating (as well as solar PV plus storage).[135]

While no new **building codes** were adopted at the national level to require the use of renewable heat in buildings, at least two US states enacted mandates. Connecticut and Rhode Island increased blending requirements for heating oil to be 50% biodiesel by 2035 and 2030 respectively.[136] In addition, several states/provinces around the world mandated the use of solar PV in buildings, often linked to codes requiring all-electric buildings. (→ *See Power section in this chapter.*)

Electrification of heating and cooling can increase the penetration of renewables in the buildings sector if the electricity is generated from renewable sources. Globally, electrification of heating and cooling has increased: in 2020, electric heaters, boilers and heat pumps for buildings consumed around 11% of total global electricity generation.[137] In 2021, as in previous years, policy makers continued to give attention to policies targeting the electrification of heating and cooling in buildings, with some countries setting specific targets for heat pumps. For example, Ireland announced its ambition to install 600,000 heat pumps by 2030, of which 400,000 are to be added in existing buildings.[138]

Governments also committed funding for **heat pump** installations.[139] (→ *See Table 6.*) For example, the United Kingdom launched its Ten Point Plan for heating and buildings, which includes phasing out the installation of new natural gas boilers from 2035 and providing a boiler upgrade programme that offers households GBP 5,000 (USD 6,744) to switch to an air-source heat pump and GBP 6,000 (USD 8,093) to switch to a ground-source heat pump.[140]

In 2020, electric heaters, boilers and heat pumps for buildings consumed **around 11%** of total global electricity generation.

i For example, in Austria, Denmark, France, Ireland, Italy, Luxembourg, Sweden and the United Kingdom.

TABLE 6.
New Financial and Fiscal Policies for Heat Pumps Adopted in Selected Countries/Sub-regions, 2021

Country	Incentive
Canada	Up to CAD 5,000 (USD 3,912) for the installation of heat pumps
British Columbia	CAD 260 million (USD 203 million) over five years for fuel switching from fossil fuels to electricity
Denmark	Exemption of grid disconnection fee, and funding for installation of heat pumps
France	Tax incentive for heat pumps
Italy	110% Superbonus tax deduction that includes residential heat pumps
Luxembourg	Up to 25% of the installation costs for heat pumps
Malta	Grant of up to GBP 1,000 (USD 1,348)
United Kingdom	Boiler upgrade programme for households of GBP 5,000 (USD 6,744) for air-source heat pump and GBP 6,000 (USD 8,093) for ground-source heat pump
United States	Four pilot solar farm projects installed in 2021, with total capacity of 2.3 MW
New York	USD 15 million fund for community heat pump systems

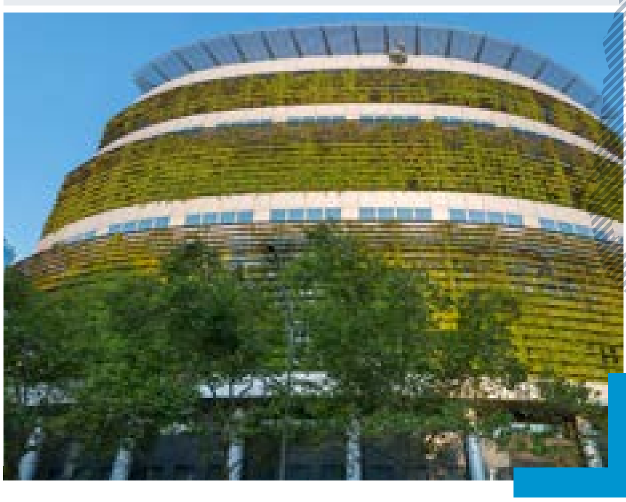
Note: The table includes financial and fiscal incentives passed in 2021; the list of countries is not exhaustive.
Source: See endnote 139 for this chapter.

SNAPSHOT. CHILE

Heating and Cooling Strategy

Chile's National Heat and Cold Strategy, issued in 2021, aims for 80% "sustainable" energy use in household heating and cooling by 2050, including a 65% reduction in the greenhouse gas emissions from supplying heat and cold by 2050. These goals are to be met through renewables, including replacing fossil fuels with biomass energy or with solar PV plus electric heat pumps. The Strategy also promotes district energy projects using ground- and air-source heat pumps, as part of a goal to assure that 75% of Chilean residents can meet their heating and cooling needs in a sustainable, reliable and affordable way. The strategy aims to improve health, create new jobs, increase savings, and decrease emissions and fossil fuel dependency.

Source: See endnote 141 for this chapter.



District heating networks are another entry point for renewable energy use in buildings. Several governments provided financial support in 2021 to advance the use of direct thermal renewable technologies as well as heat pumps for district heating.[141] (→ *See Snapshot: Chile.*) Denmark provided DKK 44.6 million (USD 7 million) to support the installation of commercial-scale electric heat pumps for use in district networks, with eligible projects required to source at least 50% of their heat from renewables or surplus heat.[142] In the United Kingdom, a GBP 10 million (USD 13.4 million) fund was available for developing low-carbon district energy networks; this scheme was replaced in early 2022 by a GBP 288 million (USD 388 million) Green Heat Network Fund.[143] In Serbia, a 2021 law provides financial support for renewable heating and cooling, allows companies to feed it into existing district energy infrastructure and requires these utilities to purchase surplus heat from both private and public operators of renewable heat plants.[144]

District heating networks are another entry point for renewable energy use in buildings.

SNAPSHOT. CYPRUS

Renewable Energy and Energy Efficiency

In 2021, Cyprus implemented a new financial incentive focused on energy efficiency and renewables in residential buildings. The funding encourages homeowners to install efficiency measures such as insulation and new windows and doors, as well as solar PV, battery storage, heat pumps and smart energy management systems. With the help of a qualified expert, homeowners can decide on the work required to reduce household energy consumption at least 60%. The government will reimburse 60-80% of the eligible renovation budget, depending on the homeowner's income status. The European Regional Development Fund and the Cyprus government are co-financing the project, which kicked off in March 2021 with a budget of EUR 30 million (USD 33.9 million).

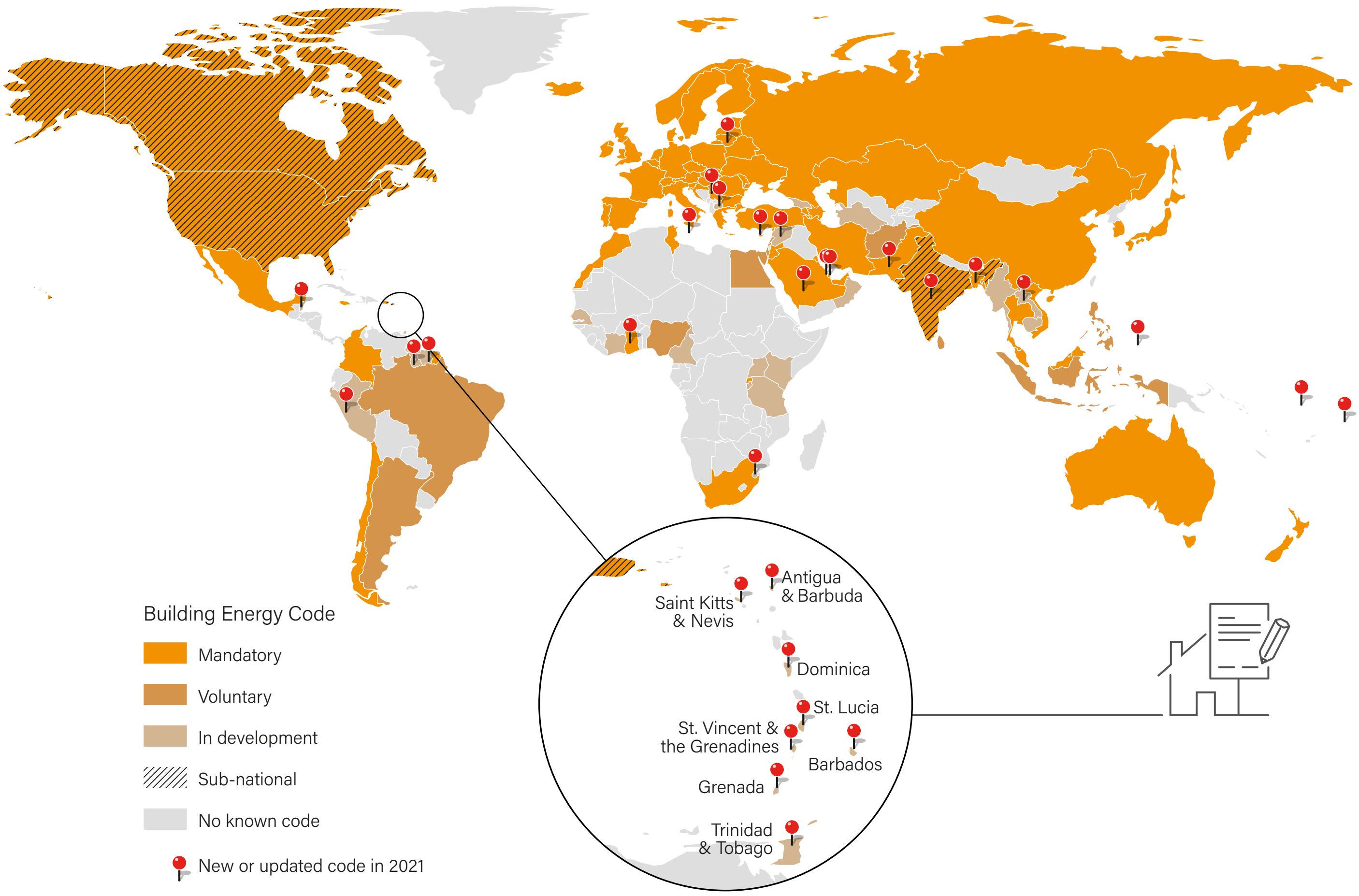
Source: See endnote 145 for this chapter.

ENERGY EFFICIENCY

Policies that mandate or encourage improvements in the efficiency of energy use in buildings play an important role in enabling new opportunities for renewable energy technologies.[145] (→ *See Snapshot: Cyprus.*) During 2021, at least nine countries implemented new energy efficiency policies, some of which included support for renewables.[146] For example, the UK government provided GBP 562 million (USD 758 million) in funding for energy efficiency upgrades for 50,000 households, including installations of heat pumps and solar PV systems.[147]

Energy efficiency in buildings also has been advanced through building codes mandating the construction and maintenance of low-energy buildings. Even when renewables are not required explicitly, such codes can positively affect building energy demand by mandating energy efficiency improvements.[148] By the end of 2021, 80 countries had in place mandatory or voluntary building codes for new buildings (up from 67 countries in 2020), either on the national or sub-national level.[149] (→ *See Figure 20.*) Of these 80 countries, 43 had mandatory national codes for both residential and non-residential new buildings.[150] As part of its carbon neutrality objective, China published an energy code that emphasises reducing the energy consumption of buildings.[151]

FIGURE 20.
Coverage of Energy Codes for New Buildings, 2021



Source: Based on GlobalABC and IEA. See endnote 149 for this chapter.

TRANSPORT

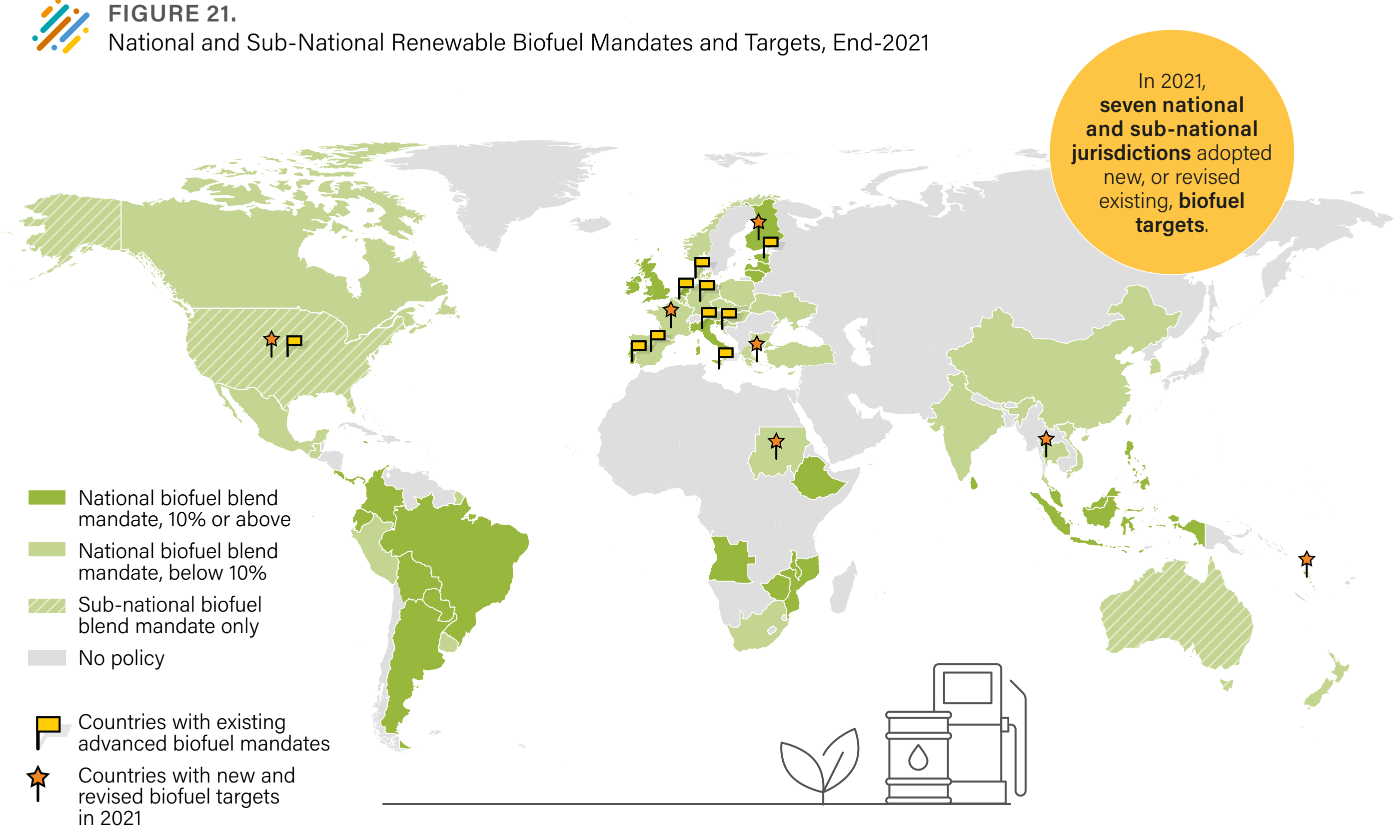
The transport sector accounted for around 30% of global final energy consumption in 2021.[152] It has the lowest renewable energy share among the end-use sectors, with 3.3% biofuels and 0.3% renewable electricity; the remaining energy is consumed in the form of diesel, petrol, aviation kerosene, and marine gas and oil.[153] As of 2021, only a handful of countries included measures for renewable-based transport in their NDCs, but policy makers increasingly are focusing on greenhouse gas emissions from transport and the potential role of renewables (particularly renewable electricity in electric vehicles) in reducing them.[154] As in previous years, policies supporting renewables focused mainly on road transport, with rail, aviation and shipping receiving far less attention.

Although biofuel support policies have been the most common type of renewable energy policy in the transport sector for many years, policies aimed at the electrification of transport – particularly road transport – have increased significantly. Most transport electrification policies are not linked explicitly with renewable power generation, and as such they increase the penetration of renewables in the sector only to the extent that the electrified transport relies on renewable generation.

> Policies supporting the **electrification of road transport** through the use of electric vehicles continued to garner increased policy attention.

Some countries have adopted strategies to reduce energy demand in transport, complementing a shift to renewables with strategies to promote more efficient transport modes, such as improved vehicle technology, (renewables-based) public transport, walking and cycling. Together, these strategies – commonly referred to as Avoid-Shift-Improve – can greatly decrease (or slow the increase in) energy demand, enabling a faster shift to renewables.[155] In 2021, the United Kingdom published its transport decarbonisation plan, which includes not only a strategy to decarbonise road, maritime and air transport, but also a shift to electric buses and a strategy to boost walking and cycling by improving street infrastructure and increasing investments in local transport systems.[156]

FIGURE 21.
National and Sub-National Renewable Biofuel Mandates and Targets, End-2021



Note: Shading shows countries and states/provinces with mandates for either biodiesel, ethanol or both. See Reference Table R10.
Source: REN21 Policy Database. See endnote 162 for this chapter.

ROAD TRANSPORT

Policies to incentivise renewables in road transport include mandates and incentives to support the production and use of biofuels as well as the use of renewable electricity in electric vehicles. Some climate change policies, such as fossil fuel bans and restrictions, carbon pricing, and requirements for zero-emission vehicles, also have indirectly increased the use of renewables in road transport.

The use of **biofuels in road transport** continued to increase in 2021, despite a dip during 2020 and early 2021 related to transport disruption during the COVID-19 pandemic. The principal drivers of expanded biofuel use are blending requirements, financial incentives for producers, public procurement programmes, and financial support for fuelling, blending and distribution infrastructure.[157]

Only two countries passed new targets for biofuels in 2021, as part of their updated NDCs: Sudan included a 10% biofuels blend as a key greenhouse gas reduction policy, and Vanuatu included a biodiesel blending target of 20% by 2030.[158] India's goal of 20% ethanol blending in petrol, previously set for 2030, was moved up to 2025.[159] Indonesia revised its biodiesel target up to 40% by 2022 (from 30% by 2025) and has targets for 20% ethanol blending by 2025 and 5% biofuels in aviation fuel by 2025.[160] In total, more than 30 national and sub-national jurisdictions had biofuel targets in 2021 (10 of them with advanced biofuel targets), and 7 national and sub-national jurisdictions adopted new, or revised existing, biofuel targets during the year.[161]

Biofuel blending mandates remain the most widely used renewable transport policies; 65 countries had national-level blending mandates at year's end (unchanged since 2017).[162] (→ *See Figure 21.*) However, at least two countries reduced existing requirements: Argentina lowered its national biodiesel blending mandate from 10% to 5% with the aim of keeping fuel prices in check, and Indonesia reduced its ethanol blending mandate from 5% to 2% due to a lack of supply (it also delayed plans to increase the palm oil content of its biodiesel programme to 40% due to record-high palm oil prices).[163]

Malaysia pushed the roll-out of its biodiesel blend mandate (20% palm oil component) to early 2022.[164] Citing sustainability concerns, Belgium announced a ban on palm oil-based biofuel from 2022 and soybased biofuel from 2023.[165]

Although Bolivia did not change its blending requirements, the government announced the increased construction of biodiesel plants (to enter into operation in 2024, with expected output of 12,000 barrels per day) in order to reduce fuel imports.[166] Sweden extended its tax exemption for biofuels by one year, to 2022.[167] At the sub-national level in 2021, the province of Manitoba (Canada) increased its ethanol blending requirement from 8.5% to 9.25% (and then to 10% in 2022) and its biodiesel blending requirement from 2% to 3.5% (5% in 2022).[168]

Increased support **policies for electric vehicles**[i] have helped stimulate a major expansion in the last decade. Although this support spans the globe, China, India, Japan, the United States and the EU have led in policy development.[169] Economic stimulus measures enacted during the COVID-19 pandemic included electric vehicle development as a way to create jobs and decarbonise the transport sector.[170]

In 2021, policies supporting the electrification of road transport through the use of electric vehicles continued to garner increased policy attention.[171] (→ *See Figure 22.*) Electric vehicle support policies include targets, financial incentives, public procurement, funding for charging infrastructure, free parking and preferred access. Targets and financial incentives were the most common forms of electric vehicle policies implemented during the year. For example, Indonesia announced that all motorcycles sold starting in 2040 will be electric-powered, while all new cars sold from 2050 will be electric vehicles.[172] In the United States, President Biden signed an executive order targeting half of new cars to be electric or plug-in hybrids by 2030.[173] Singapore plans to double its number of electric vehicle charging points by 2030.[174]

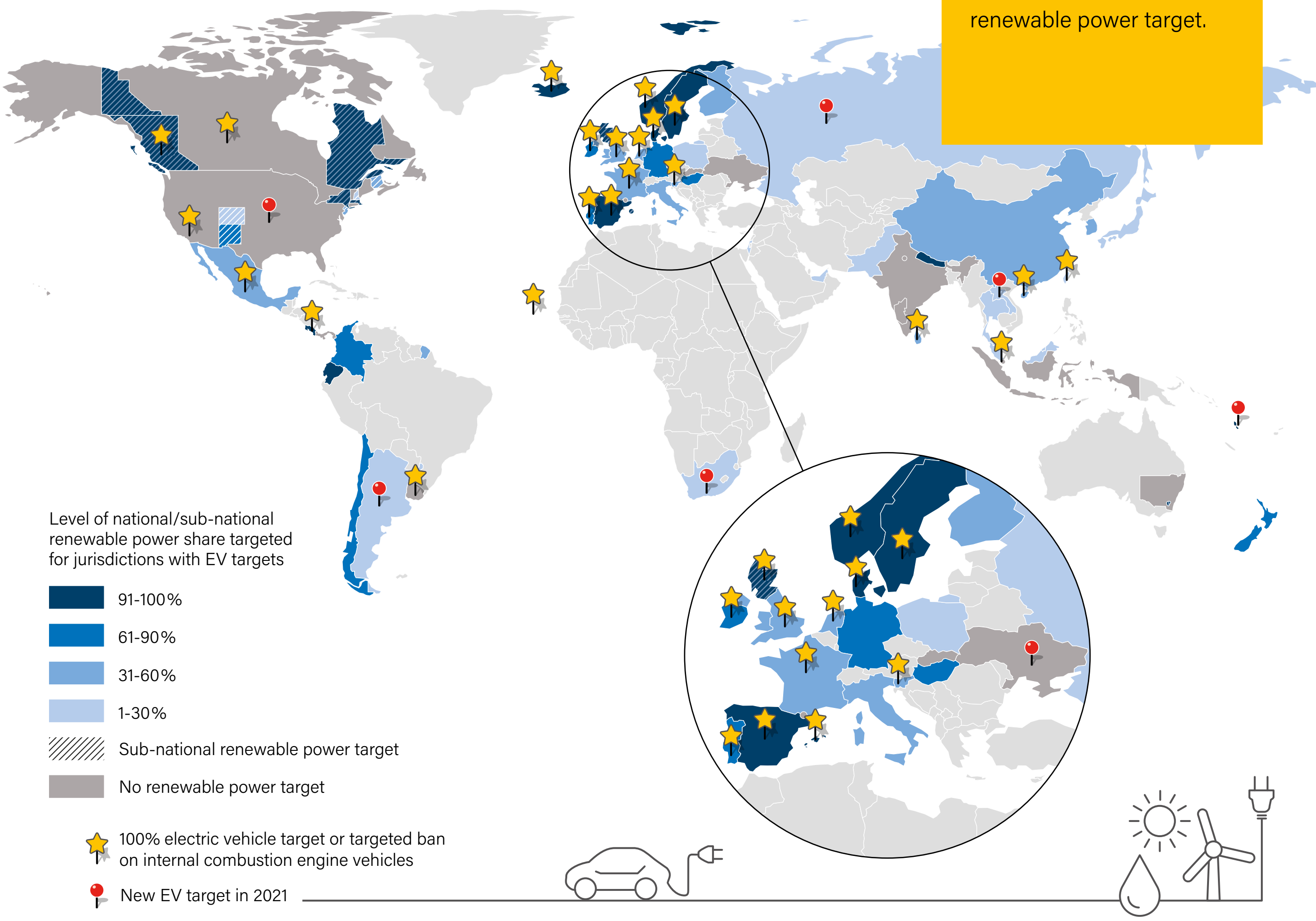
Several national and sub-national jurisdictions provided new financial incentives for the purchase of electric vehicles in 2021. At the sub-national level, Nova Scotia (Canada) began offering rebates of up to CAD 3,000 (USD 2,347) for new electric vehicles, CAD 2,000 (USD 1,564) for used vehicles and CAD 500 (USD 391) for e-bikes (with a total budget of USD 9.5 million available).[175] These provincial rebates are in addition to federal rebates of up to USD 5,000.[176] In New South Wales (Australia), an AUD 490 million (USD 356) support package for electric vehicles was passed that includes a stamp duty waiver and a rebate programme.[177] India's state of Gujarat offers a subsidy for electric cars and support for charging infrastructure.[178]

Most electric vehicle policies continued to lack a direct link to renewable electricity, although Mauritius adopted a policy with a direct link to the use of renewables.[179] (→ *See Snapshot: Mauritius.*) In jurisdictions with high shares of grid-connected renewable electricity, electric vehicle policies can support renewables in the road transport sector even if these are not directly linked in the same policy.

i Electric vehicles are defined as battery electric vehicles and plug-in hybrids.

FIGURE 22.
Targets for Renewable Power and Electric Vehicles, as of End-2021

Only
9 countries
with electric vehicle targets also had a 100% renewable power target.



Note: All colour-coded areas of the map have electric vehicle targets or targeted bans on internal combustion engine vehicles. ICE = internal combustion engine; EV = electric vehicle; HEV = hybrid electric vehicle. Renewable power targets include only targets for a specific share of electricity generation by a future year. Where a jurisdiction has multiple targets, the highest target is shown. Nepal and Quebec show actual renewable power shares; both jurisdictions along with Iceland and Norway have already achieved nearly 100% renewable power. The European Union has a renewable target of 57% for all member states. EV targets vary; for details, see Reference Table R10 in the GSR 2022 Data Pack. In addition, over 100 cities have EV targets, see Renewables in Cities chapter.

Source: see endnote 171 for this chapter

RAIL, AVIATION, SHIPPING AND PORTS

Policies supporting **renewables in the rail sector** generally focus on electrification, although they remained scarce in 2021. Only two countries enacted new policies to advance the electrification of rail during the year.[180] Romania allocated EUR 3.9 billion (USD 5.3 billion) for rail modernisation, which includes funds to support the purchase of electric locomotives; the country also aims to phase out coalfired generation by 2032.[181] A UK plan to electrify around 21 kilometres of rail lines received GBP 78 million (USD 105 million) in government funding, although this was not tied directly to renewable electricity.[182]

Policies to stimulate production of and demand for **renewable fuels in aviation** remained scarce and have lagged behind technological advances.[183] By the end of 2021, only three countries (Finland, Indonesia and Sweden) had biofuel targets for the aviation sector; meanwhile, Germany issued a new target for sustainable PtL kerosene[i] (created from electricity) to comprise one-third of the fuel used in domestic flights by 2030.[184] Also during the year, the United Kingdom announced a goal to achieve net zero emissions in its aviation industry by 2050 (through the use of more efficient planes that operate with synthetic fuels or have electric motors, combined with carbon offsetting), and Portugal implemented carbon fees for consumers travelling by air and sea.[185]

The United States announced USD 65 million in funding for projects focused on producing costeffective, low-carbon biofuels to replace petroleum fuels used in heavy-duty transport, such as airplanes and ships.[186] The country also published an Aviation Climate Action Plan, which describes the government's approach to achieving net zero emissions in the sector by 2050; the plan includes, among others, the production and use of sustainable aviation fuels (SAF) and the use of electrification and potentially hydrogen for short-haul aviation.[187]

Policies to stimulate production of and demand for renewable fuels in **aviation** remained scarce and have lagged behind technological advances.

In the areas of **shipping and ports**, no jurisdictions adopted new targets or policies to advance the use of renewables during 2021. However, the EU announced that it would consider including shipping in the EU Emission Trading System's carbon market, to be implemented between 2023 and 2025.[188]

i Similar to renewable hydrogen, PtL kerosene is created from water, CO_2 and electricity. If the electricity is generated by renewable sources, PtL kerosene is considered a renewable fuel.

SNAPSHOT. MAURITIUS

EV Charging Using Solar PV

In late 2021, the state-owned electric utility of Mauritius initiated a policy to incentivise the deployment of 20 MW of household and commercial solar PV systems for charging EVs. Customers accepted to the programme will be permitted to install the solar systems to power their vehicles, and eligible customers will be able to deduct the full cost of the system from their income tax. Any excess electricity generated by the solar PV systems will be exported to the grid and bought by the utility under a gross metering approach. This programme is part of the country's goal to reach 35% renewable electricity by 2025 and 60% by 2030.

Source: See endnote 179 for this chapter.

INDUSTRY

Industrial processes require the direct use of electricity and/or thermal energy to meet various needs and are responsible for more than a quarter of global final energy consumption.[189] Historically, the industrial sector has received far less policy attention than other end-use sectors, a trend that continued in 2021. Only a few countries developed new or updated their renewable energy policies for industry in 2021, bringing the year-end total to 30 countries.[190] (→ *See Reference Table R11 in GSR 2022 Data Pack.*)

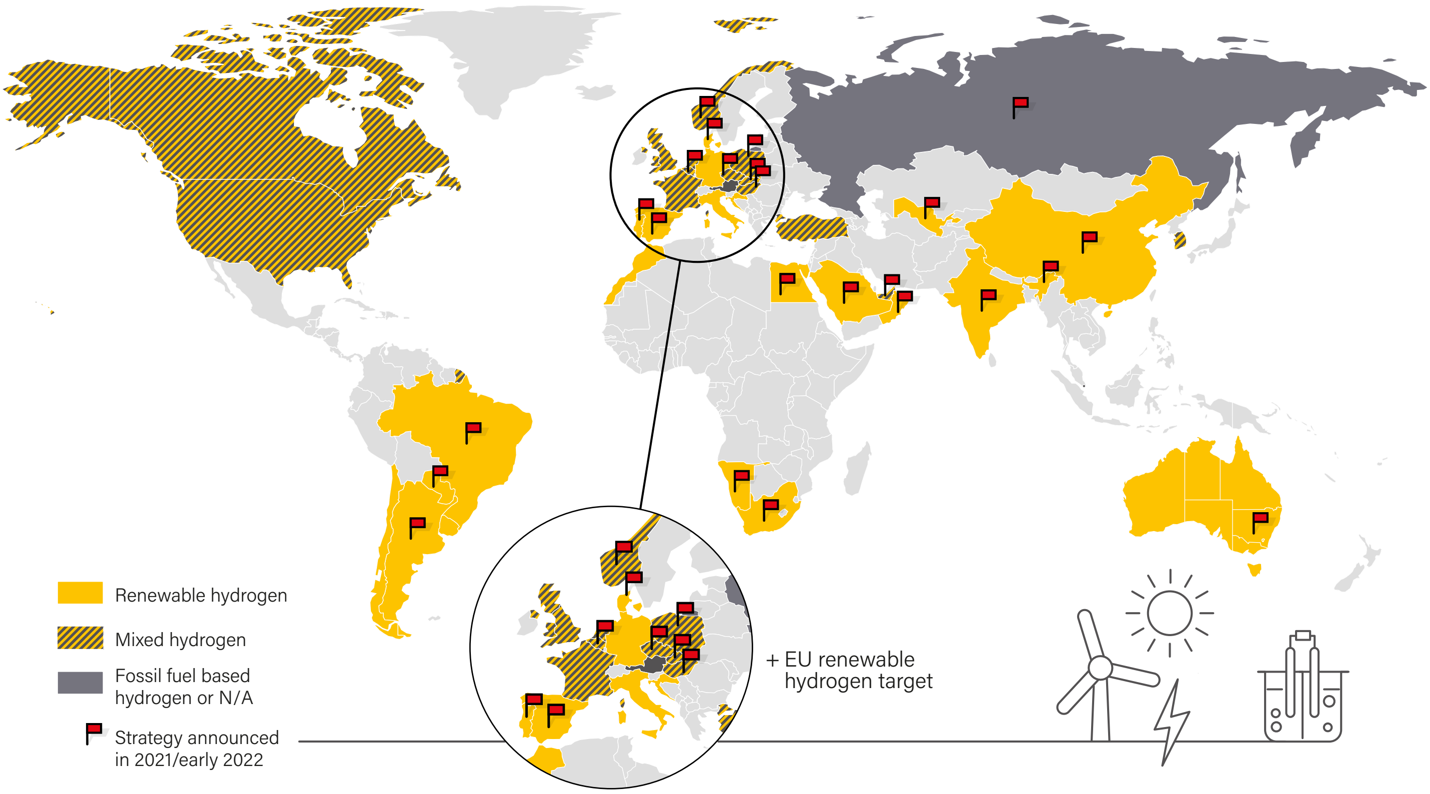
As in previous years, financial incentives remained the most common policy support for renewable heat in industry. During 2021, a few European countries implemented such policies: Austria launched a grant scheme for large solar thermal plants for industry, and Spain implemented a grant programme for thermal renewables in industrial processes.[191] In late 2021, the first call for renewable heat projects for the industry and service sectors in Spain resulted in awarded grants of EUR 108 million (USD 122 million) to support the financing of 51 solar heat projects with a total capacity of 62 MW.[192] In early 2022, the Netherlands' Renewable Energy Transition Incentive Scheme (SDE++) committed EUR 13 billion (USD 15 billion) for renewable heat (geothermal, biomass and solar thermal), low-carbon heat (including heat pumps), and renewable gas, as well as carbon capture and storage.[193]

RENEWABLE HYDROGEN

Renewable hydrogen is an energy carrier produced through renewable-driven electrolysis or gasification using renewable feedstocks. It can be used to increase the penetration of renewables beyond the power sector, including in sectors that are hard to decarbonise, such as high-temperature applications in industry, shipping and aviation.[194] However, nearly all hydrogen today is manufactured using fossil fuels.[195]

Several countries announced policies to support hydrogen in 2021, and at least 38 countries plus the EU had a hydrogen roadmap or strategy in place by year's end, mostly in Europe, but also several in sub-Saharan Africa and Latin America.[196] (→ *See Figure 23.*) An analysis of existing roadmaps shows that most were aimed at scaling up renewable-based hydrogen production.[197] Most hydrogen roadmaps do not focus exclusively on the industrial sector, although several refer to the use of hydrogen in high-temperature industries.

FIGURE 23.
Hydrogen Roadmaps in Selected Countries, as of End-2021



Note: Type of hydrogen (renewable, mixed, fossil fuel based) is unknown for Austria and Singapore.
Source: REN21 Policy Database. See endnote 196 for this chapter.

Several countries made policy announcements related to renewables and hydrogen (although not necessarily committing to renewable hydrogen). Saudi Arabia and Oman announced that they would build hydrogen electrolysis plants relying entirely on renewable electricity.[198] Uzbekistan established a strategy to boost the production of renewable hydrogen, including support for the deployment of new renewable power capacity.[199]

In Europe, Spain committed EUR 1.5 billion (USD 1.7 billion) in funding for facilities to develop renewable hydrogen production over a three-year period, and Germany committed EUR 8 billion (USD 9.1 billion) for 62 hydrogen production projects, of which around EUR 2 billion (USD 2.3 billion) will go towards integration into the steel sector.[200] Portugal committed to installing 2-2.5 GW of new renewable power capacity for hydrogen production and to building 50-100 hydrogen fuelling stations by 2030.[201] At the state level, New South Wales (Australia) announced a renewable hydrogen strategy that includes AUD 3 billion (USD 2.2 billion) in financial incentives for renewable hydrogen production.[202]

AGRICULTURE

Large-scale agriculture is a major consumer of electricity and heat. Energy is used for livestock feed, irrigation, greenhouses, fertilisation, water pumping, processing and transport, among others.[203] Around 30% of the world's energy is consumed within agri-food systems.[204] Several countries have proposed specific policies to support the scale-up of renewables in agriculture, and in 2021 at least five national policies and one sub-national policy of this kind emerged. [205] (→ *See Snapshot: Philippines.*)

Japan released new guidelines to develop and build ground-mounted agrivoltaic[i] facilities, and Israel committed ILS 3.5 million (USD 1.2 million) for studies examining how to combine agriculture and solar power generation.[206] In India, the state-owned electricity company of Maharashtra solicited bids to develop 1.3 GW of ground-mounted solar capacity for agricultural operations and will enter into 25-year power purchase agreements with the successful developers.[207] Portugal launched a EUR 10 million (USD 11.3 million) call for innovative solar PV projects built in combination with agricultural activities.[208]

Several countries have proposed specific policies to support the scale-up of renewables in agriculture.

i See Glossary for definition.

03

SNAPSHOT. ARGENTINA

Using Wind Power to Produce Hydrogen for Export

In 2021, the Australian company Fortescue Future Industries, a subsidiary of Fortescue Metals Group Ltd., announced that it would develop one of its five largest green hydrogen projects in Sierra Grande, a former mining town in eastern Argentina's Río Negro province. The company plans to install the project, powered by 2 GW of new onshore wind power capacity, along the Patagonian steppe, investing USD 8.4 billion. The region has outstanding wind resources but lacks a power grid and adequate road infrastructure.

The ongoing wind resource assessment, started in 2021, will allow the pilot phase of the project to kick off in 2022 with an investment of USD 1.2 billion and the production of 35,000 tonnes of hydrogen by 2024. A first production phase will follow, involving a USD 7.2 billion investment and generating around 215,000 tonnes of hydrogen until 2028. The project is expected to create around 15,000 direct jobs when fully operational and to bring local development to the region, which closed its last iron mine in 2016.

Near the existing San Antonio port, dedicated mainly to fruit and fish exports, Fortescue will build a seawater desalination plant and a port focused exclusively on the export of hydrogen to countries using hydrogen to fuel vehicles and engines. By 2030, the project is expected to produce 2.2 million tonnes of green hydrogen for export. Argentina's Ministry of Productive Development is working to establish a regulatory framework – including a tax-free zone – to underpin the viability of green hydrogen. Fortescue also announced several collaborations during 2021 to produce green hydrogen and green ammonia in Brazil, Canada, Indonesia, Jordan and Papua New Guinea.

Source: See endnote 151 in the wind section for this chapter.

03 MARKET AND INDUSTRY TRENDS

KEY FACTS

- **Modern bioenergy** provided 5.6% of total global final energy demand in 2020, accounting for 47% of all renewable energy in final energy consumption.
- **In 2020**, modern bioenergy provided 14.7 exajoules (EJ) for heating, or 7.6% of global requirements; two-thirds of this was used in industry and agriculture and the rest in buildings.
- **In 2021**, global biofuel production recovered to 2019 levels at around 4.1 EJ. Overall biofuel production has increased 56% since 2011, with rising shares of biodiesel and rapid growth in hydrotreated vegetable oil (HVO) which grew 36% in 2021 to 0.33 EJ.
- **Bioelectricity production** grew 10% in 2021, dominated by China. Generation has increased 88% since 2011, driven by growth in China and some other Asian and European producers.

BIOENERGY

Bioenergy involves the use of many different biological materials for energy purposes, including residues from agriculture and forestry, solid and liquid organic wastes (including municipal solid waste and sewage), and crops grown especially for energy.[1] Use of these feedstocks can reduce greenhouse gas emissions by providing substitutes for fossil fuels when providing heat for buildings and industrial processes, fuelling transport and generating electricity.[2] Coupled with carbon capture and use/storage, bioenergy can lead to additional emission reductions and even negative emissions.[3]

When sustainable, the production and use of bioenergy can help promote energy security and price stability while delivering social and economic benefits that support the achievement of the United Nations Sustainable Development Goals, including stimulating rural economic activity.[4] However bioenergy can pose sustainability risks if projects are not managed carefully, and strong governance frameworks are essential to ensure positive outcomes.[5] Other barriers to bioenergy deployment include its relatively high costs, as well as challenges related to market access.[6]

Bioenergy use worldwide totalled an estimated 44 exajoules (EJ) in 2020 (latest available data), or around 12.3% of global total final energy consumption (TFEC).[7] (→ *See Figure 24.*) More than half of this (24.1 EJ) was the traditional use of biomass[i] for cooking and heating in developing and emerging economies (6.7% of TFEC).[8] Other, more modern and efficient uses of bioenergy[ii] provided an estimated 20.3 EJ or 5.6% of TFEC.[9] Overall, bioenergy represented around 47% of the estimated renewable energy use in global TFEC in 2020, down from 54% in 2010.[10]

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

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

Modern bioenergy for heating in buildings and industry provided around 14.7 EJ in 2020 (7.6% of the global energy use for heating).[11] Transport use amounted to 3.7 EJ (3.5% of transport energy needs).[12] Bioenergy also provided 1.8 EJ to the global electricity supply (2.4% of the total).[13]

BIO-HEAT MARKETS

The **traditional use of bioenergy** – which involves burning biomass in simple and inefficient fires or stoves – has fallen 8% since 2011 to an estimated 24.1 EJ in 2020.[14] (→ *See Distributed Renewables chapter.*) To reduce the impacts of unsustainable harvesting of biomass and to avoid the severe impacts on air quality and public health, a major international effort is under way to transition from traditional bioenergy use towards clean cooking solutions for all.[15] Options include liquefied petroleum gas (LPG, although this is less compatible with long-term climate ambitions) as well as solutions based on renewable electricity and cleaner biomass, such as ethanol fuels and wood briquettes and pellets.[16]

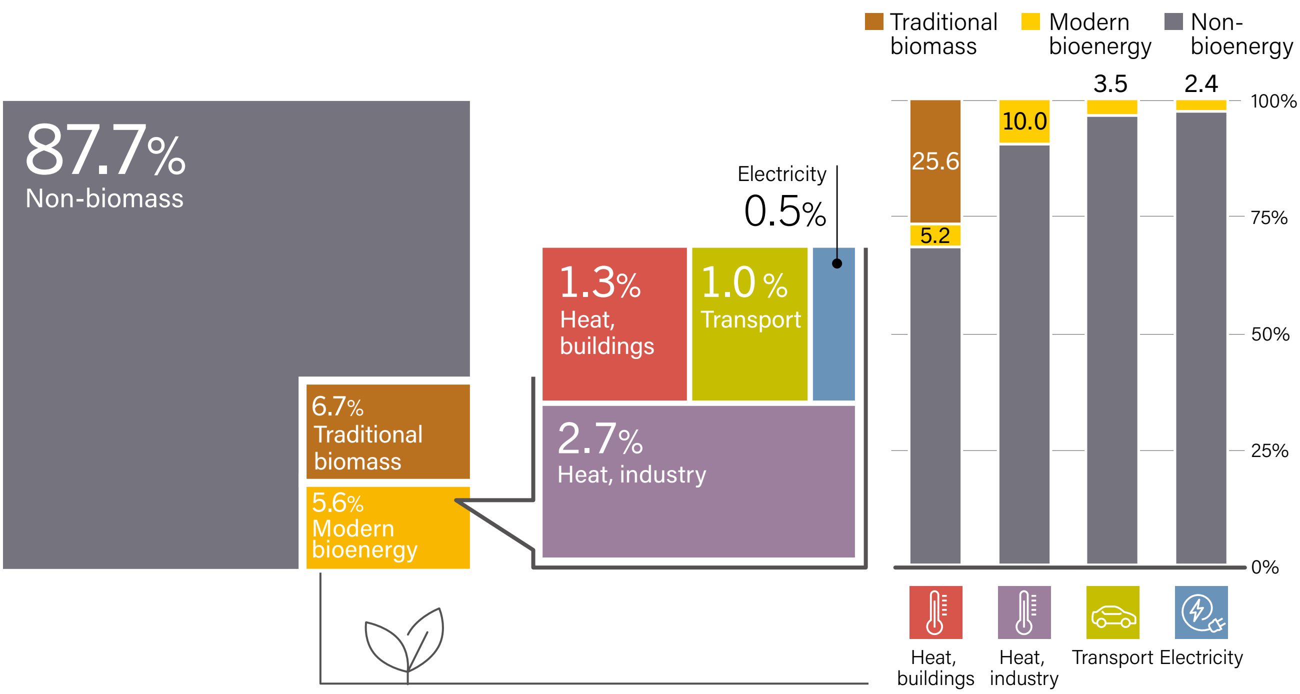
Modern bioenergy can supply heat for industry and buildings, using systems such as stoves and boilers that are designed to be much more efficient than open fires and that can achieve low emission levels. Biomass fuels can be used directly to produce heat, or, alternatively, bio-heat can be produced and distributed to consumers – including through the co-generation of electricity and heat using combined heat and power (CHP) systems and through the use of district heating networks to reach final consumers. Most of the biomass used for heating is wood fuel, although liquid and gaseous biofuels also are used, including biomethane, which can be injected into natural gas distribution systems.[17] (→ *See Box 7.*)

The traditional use of bioenergy – which involves burning biomass in simple and inefficient fires or stoves – has fallen

8%

since 2011.

FIGURE 24.
Estimated Shares of Bioenergy in Total Final Energy Consumption, Overall and by End-Use Sector, 2020



Source: Based on IEA data. See endnote 7 for this section.

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

BOX 7. Biogas and Biomethane

Biogas – a mixture of methane, carbon dioxide (CO_2) and other gases – is produced by anaerobic digestion, a biological process that occurs when organic materials ferment in the absence of oxygen. The same process occurs in waste landfills, and the resulting landfill gas can be collected and used, providing energy while also reducing emissions from the landfill site. The gases can be used directly for heating or power generation. Alternatively, the methane component can be separated and compressed (forming biomethane) and used to replace fossil gas by injecting it into gas pipelines or for transport purposes.

Around 80% of the biogas produced worldwide is used for power generation, split roughly equally between power generation alone and co-generation, often stimulated by favourable feed-in tariffs and other support mechanisms. The remaining biogas is used for heating, transport and other applications. Biomethane production totalled an estimated 1.4 EJ in 2020, or just over 1% of total global fossil gas demand Production of biomethane has grown rapidly, doubling between 2015 and 2019 to 140 PJ, with more than 1,000 biomethane production plants now in operation. The United States is the largest producing country, stimulated by the national Renewable Fuel Standard (RFS) and by California's Low Carbon Fuel Standard (LCFS). Production also has grown in Europe, where policy priorities determine the use of biomethane. Where extensive natural gas networks exist, it often is used to replace pipeline fossil gas: for example, the UK's Green Gas Support Scheme encourages pipeline injection of biomethane. In Sweden, where gas distribution is less common, transport use of biomethane dominates.

In developing economies, biogas has been used at a small scale as a sustainable fuel source for cooking, heating and electricity production and to improve energy access. (→ *See Global Overview chapter.*).

Source: See endnote 17 for this section.

Between 2010 and 2020, modern bioenergy use in **buildings** increased an estimated 7% to 4.9 EJ, providing 5.2% of the world's building heat in 2020.[18] The demand for heat in buildings, and for biomass to heat them, was not greatly affected by the COVID-19 pandemic during that year.[19] The major markets are in Europe and North America.[20]

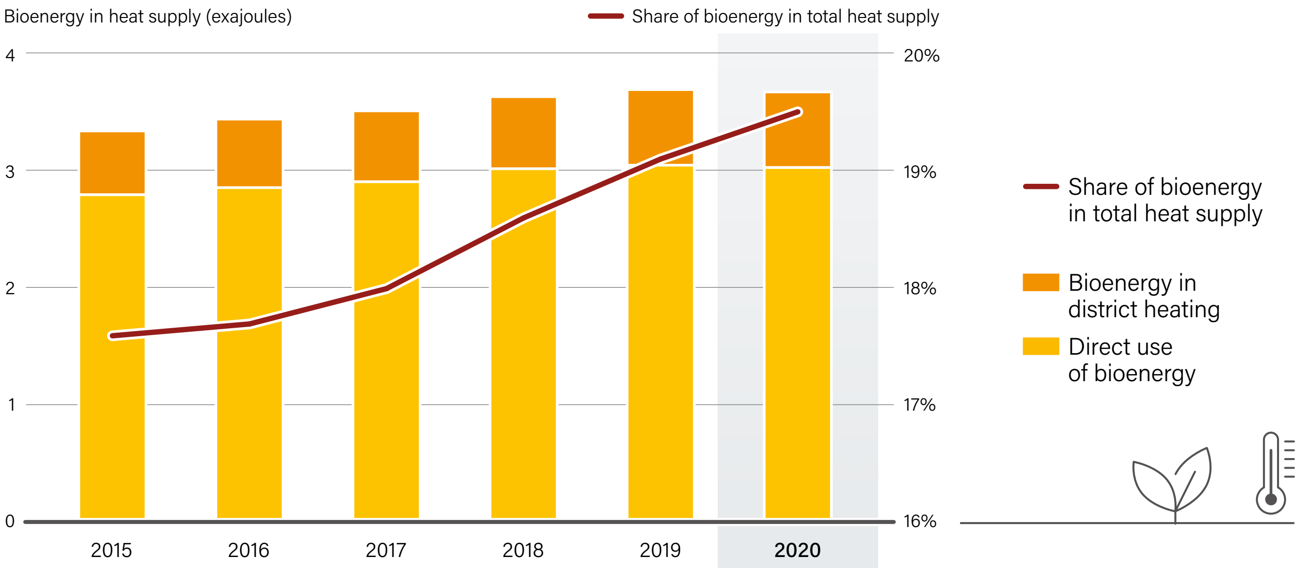
The use of biomass for heat production in **industry** occurs primarily in bio-based industries and agriculture, such as paper and board, sugar and other food products, and wood-based industries. These industries often use their wastes and residues to generate energy: for example, sugarcane bagasse is used to produce electricity and heat for sugar processing. Between 2015 and 2020, the use of bioenergy for industrial heat increased 8% to 9.9 EJ.[21]

Bioenergy use for industrial heating is concentrated in countries with large bio-based industries, such as Brazil, China, India and the United States. This production (and use) also is linked to the level of industrial production, although bio-heat use in industry remained stable in 2020 despite overall reductions in the production of paper products and sugar-based ethanol (where bagasse is used to produce heat and power).[22]

Bioenergy's contribution to heating in industry and buildings in 2020 included some 0.7 EJ provided through **district heating systems**.[23] This sector has expanded rapidly, up nearly 70% since 2015, especially in Europe.[24] The use of district heat was split nearly evenly between buildings (49%) and industrial and agricultural uses (51%).[25]

In general, the use of biomass for heating, like other renewable sources, receives insufficient policy attention. However, the European Union (EU) has promoted the uptake of renewable heat alternatives to meet the requirements of the EU Renewable Energy Directive (RED).[26] The policy measures include capital grants for biomass heating systems, taxes and duties on fossil fuels (including carbon taxes) and, increasingly, constraints on the use of oil and gas for heating.[27] In part because of these measures, between 2015 and 2020 the use of bio-heat in the EU-27 grew 10% to 3.7 EJ (→ *see Figure 25*) and increased from 17.6% to 19.5% of regional heat demand.[28] The direct use of biomass for heat in the EU-27 rose 8%, while bioenergy use in district heating systems grew 18% to 0.64 EJ.[29]

FIGURE 25.
Bioenergy Use for Heating in the EU-27, 2015-2020



Source: Based on Eurostat data. See endnote 28 for this section.

In 2020, Germany, France and Sweden were the top EU countries for bio-heat use.[30] Poland became the fourth largest user, with its bio-heat use rising 62% between 2010 and 2020, notably for district heating.[31] Italy was the EU's fifth largest bio-heat user as well as the world's largest user of wood pellets.[32] Together, these five countries accounted for 55% of the EU's bio-heat demand in 2020.[33]

More than 90% of the biomass used for heating in the EU-27 in 2020 was in solid form such as wood logs, chips and pellets.[34] The use of wood pellets in the EU more than doubled between 2010 and 2020 to 294 petajoules (PJ) (16.4 million tonnes).[35] (→ *See Box 8.*) Municipal solid waste provided around 5% of the bio-heat supplied and is an important contributor to EU district heating schemes; its use in district heating increased 45% between 2010 and 2015, and it supplied just over one-fifth (21%) of the EU's district heat in 2020.[36] The use of biogas and biomethane for heating in the EU-27 grew 45% between 2010 and 2015, and these sources provided 5% of the region's biomass heating in 2020.[37] In Denmark, biomethane provided nearly one-quarter of all gas used in 2021, up sharply from 2020.[38]

North America is the second leading user of modern bioenergy for heating, but demand fell around 10% between 2015 and 2020 in the absence of strong policy measures and due to the relatively low costs of oil and natural gas.[39] Bioenergy use for heating in industry also declined during this period, down 9% to 2.1 EJ.[40] Demand for bio-heat in the US residential sector fell 11% to 0.4 EJ.[41] The number of people in the United States relying primarily on wood fuels dropped from 2.5 million to below 1.8 million.[42] Biomass use in the US commercial sector fell 3% during 2015-2020 to reach 0.14 EJ.[43]

TRANSPORT BIOFUEL MARKETS

Current production and use of biofuels for transport are based on ethanol (produced mainly from corn, sugar cane and cereals), FAME (fatty acid methyl ester) biodiesel and, increasingly, HVO (hydrogenated vegetable oil) or HEFA (hydroprocessed esters and fatty acids), also called renewable diesel.[44] In addition, biomethane is used in transport. Although most biofuels today are used in road transport, the industry is developing and commercialising new biofuels designed to serve new markets, notably in aviation.[45]

Biofuels can provide a renewable alternative to fossil fuels. They typically can be used in vehicles designed for fossil fuels, either as blends with petrol and diesel fuels, or with relatively minor engine modifications. The main barriers to widespread biofuel uptake include higher costs than conventional fuels, limited availability of certain feedstocks and the need to carefully manage the sustainability risks.

Between 2011 and 2021, the production of transport biofuels grew 56% (in energy terms), from 2.6 EJ to 4.1 EJ.[46] (→ *See Figure 26.*) Biofuel production fell sharply in 2020 as the COVID-19 pandemic led to reduced transport energy demand and restricted blending; however, production recovered in 2021 to levels near those of 2019, although growth was constrained by very high feedstock costs.[47] Since 2011, the share of biodiesel in the biofuel mix has grown from 29% to 37%, due largely to rising production in Asia.[48] Production and use of HVO have grown strongly from low levels in 2011 to 9% of the total in 2021.[49]

BOX 8. Biomass Pellets

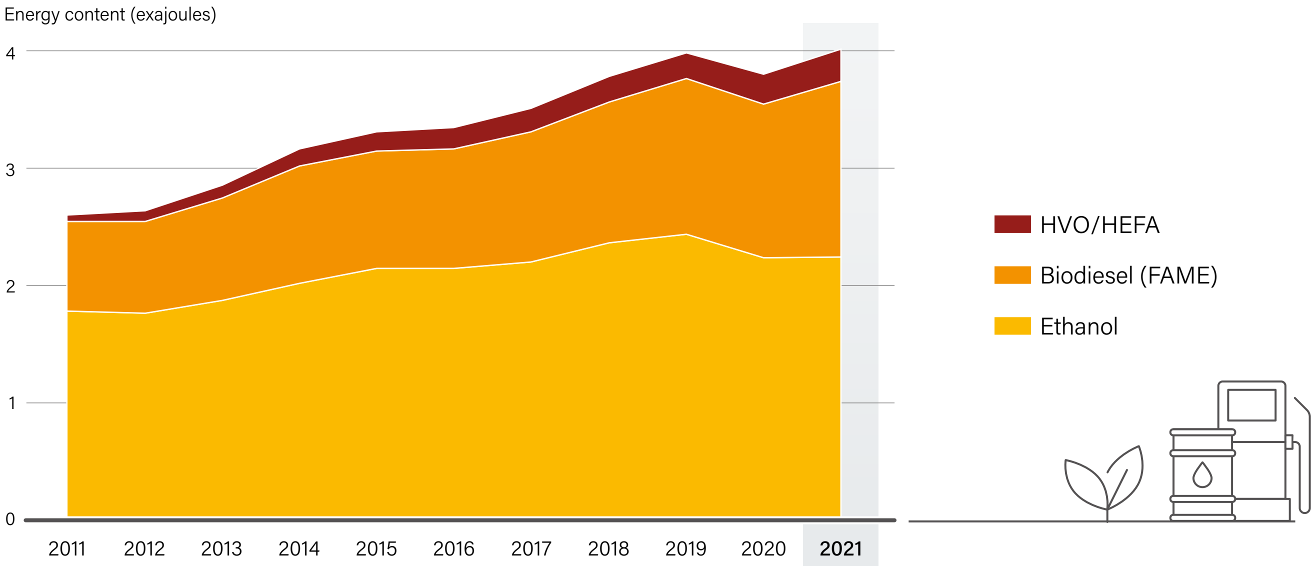
Between 2015 and 2020, the annual global production of wood pellets increased from 27 million tonnes to 41 million tonnes (0.51 EJ to 0.78 EJ). The EU was the largest regional producer in 2020 with 18 million tonnes (45% of global production), while other European countries provided nearly 5 million tonnes (12%). North America produced some 12.5 million tonnes in 2020, up from 9.5 million tonnes in 2015. Despite the COVID-19 pandemic, global pellet production grew 5% between 2019 and 2020.

In 2020, 22 million tonnes of wood pellets were used worldwide to provide heat in the residential and commercial sectors, with the market growing by 0.3 million tonnes between 2019 and 2020. Pellet use for power generation, CHP production and other industrial purposes increased more than 10% to 20 million tonnes in 2020, mainly because of a sharp rise in imports to Japan. The United States was the world's largest exporter of wood pellets in 2020; exports rose 1% to 6.8 million tonnes, even though US pellet production fell 2% to 9.3 million tonnes.

Debate continues regarding the carbon savings and other environmental impacts associated with pellet production from forestry materials and their use in power generation. Starting in 2020, the EU's RED set tighter sustainability criteria for the use of solid biomass, and starting in 2021 it set minimum greenhouse gas reduction thresholds for new projects seeking national support. Japan is enacting sustainability criteria aimed at reducing the use of palm-based products but increasing the use of certified wood pellets.

Source: See endnote 35 for this section.

FIGURE 26.
Global Production of Ethanol, Biodiesel and HVO/HEFA Fuel, by Energy Content, 2011-2021



Source: See endnote 46 for this section.

Ethanol remains the leading source of transport biofuels. Production increased 26% overall between 2011 and 2021 to 2.3 EJ (105 billion litres), although it declined in 2020 precipitated by the pandemicrelated drop in global petrol use for road transport.[50]

The United States and Brazil remain the dominant ethanol producers, together accounting for 80% of global production in 2021.[51] The United States produced 54% of the global supply, principally from corn, while Brazil produced 29%, mainly from sugar cane but with growing levels from corn.[52] Since 2010, China has been the third largest ethanol producer, providing 3% of the global supply (70 PJ or 3.3 billion litres) in 2021, followed by India, where production and use increased nine-fold during this period to 68 PJ (3.2 billion litres), to represent nearly 3% of global supply.[53] This reflects India's national initiative to reduce its import dependence by increasing the ethanol blend in petrol to 20% by 2025.[54]

Global production of **biodiesel** nearly doubled between 2011 and 2021 to 1.5 EJ (45 billion litres).[55] Biodiesel production is more widely distributed than that of ethanol, due to the wider range of feedstocks that can be processed, including vegetable oils from palm, soya, and rapeseed, and a variety of wastes and residues, including used cooking oil.

Biodiesel production in Asia has grown rapidly. Indonesia is now the world's biodiesel leader, increasing production 11-fold since 2011 to more than 8 billion litres in 2021, or 18% of the global total.[56] In an effort to reduce its dependence on imported oil, Indonesia raised its biodiesel blending target from 20% to 30% in January 2020 and was aiming for a 40% target in 2021.[57] However, this step-up was pushed to 2022 because of high feedstock costs.[58] By using domestically produced biodiesel, Indonesia was able to reduce its oil import costs by a reported USD 4.0 billion in 2021.[59]

Brazil is the world's second largest biodiesel producer, with production rising by a factor of 2.5 since 2011 to 6.8 billion litres in 2021.[60] Production has been stimulated by a rising domestic blending level, slated to reach 13% in 2021 and 15% by 2023.[61] However, in 2021 the blending limit was reduced from 12% to 10% because of high soya prices, which raised the cost of biodiesel and reduced demand.[62]

US biodiesel production grew 70% between 2011 and 2021, boosted by the federal Renewable Fuel Standard (RFS2), by California's LCFS and by the re-introduction of the federal Biodiesel Blender's Tax Credit.[63] US biodiesel production was constrained in 2019 by the pandemic-related drop in transport demand.[64] While production (and sales) of biodiesel recovered partially in 2020, they fell again in 2021 due largely to the high cost of soya oil, which rose by a factor of three during the year and rendered manufacture financially unattractive.[65]

The production of **HVO**, produced by hydrogenating bio-based oils fats and greases, has grown rapidly from very low levels in 2011 to an estimated 9.5 billion litres in 2021, a 36% increase from 2020.[66] Capacity continues to rise quickly, with investments in stand-alone plants, but also with several oil companies, including TotalEnergies, Phillips, ENI, Marathon, converting refineries to HVO processes.[67] While early production capacity was concentrated in Finland, the Netherlands, and Singapore, more recently production has surged in the United States, driven by a strong domestic market heavily incentivised by the RFS2, by California's LCFS and by the availability of an investment tax credit.[68]

Global production of biodiesel **nearly doubled** between 2011 and 2021 to **1.5 EJ**.

The use of biofuels as an **aviation fuel** has become a focus of policy attention. Switching to sustainable aviation fuel[i] (SAF) is a key pillar of aviation industry commitments to reduce emissions from the sector, and increasingly of regional and national policy.[69] The EU introduced its REFuelEU Aviation package as part of its Fit for 55 initiative, which targets 2% SAF use for all flights taking off from within the EU by 2025, rising to 63% by 2050.[70] In the United States, the Sustainable Aviation Challenge sets a goal for the aviation industry to use 11 billion litres of SAF by 2030.[71] The country is proposing a tax credit for SAF and is considering post-2022 targets for SAF in the federal Renewable Fuel Standard.[72]

Although many trials of SAF based on biofuels have been carried out, the share of SAF in all aviation fuel has remained tiny (below 1%).[73] However, production has increased rapidly, from a very low level in 2015 to an estimated 80 PJ (255 million litres) in 2021.[74] Production is concentrated in Europe, the United States and China.[75]

Fuels used in aviation must meet strict standards set by ASTM. So far, eight production routes have been approved.[76] These are all based on fuels produced from vegetable oils and fats by hydrogenation, using processes similar to those for HVO production but tuned to optimise the jet fuel fraction. While sufficient feedstock sources exist to meet short-term targets, production and use are likely to be limited by the availability of suitable and sustainable feedstocks. Other technology options include the gasification of solid biomass feedstocks (such as wood and crop residues) and conversion to jet fuels via the Fischer-Tropsch process and the conversion of ethanol to biojet fuel.[77]

Biomethane is used as a transport fuel mainly in the United States (the largest producer and user of biomethane for transport) and in Europe.[78] US production and use are incentivised by the RFS2 (which includes biomethane in the advanced cellulosic biofuels category) and by California's LCFS.[79] Under the RFS2, US biomethane use has increased 10-fold since 2014 (when the fuel was introduced into the standard), reaching 41 PJ in 2021.[80] In Europe, transport use of biomethane increased around 30% between 2015 and 2020, to 12 PJ.[81]

i According to the International Civil Aviation Organization, sustainable aviation fuels are produced from three families of bio-feedstock: the family of oils and fats (or triglycerides), the family of sugars and the family of lignocellulosic feedstock.

BIO-POWER MARKETS

Many biomass feedstocks can be used to produce electricity. Around 82% of bioelectricity is produced from solid feedstocks such as wood and forestry products (including wood pellets), agricultural residues (notably sugarcane bagasse, used for 10% of global generation) and municipal solid waste (12%).[82] These fuels are combusted, and the heat is used to drive steam turbines to produce electricity. Where possible the overall efficiency can be increased by using CHP systems with the heat used on site (for example, in industry) or transported for use elsewhere in district heating systems or sold for use as process heat by other companies.[83] In 2019, 16% of all bioelectricity was produced from feedstocks converted to biogas or biomethane (→ *see Box 7*) and around 1% from liquid biofuels.[84]

Global bio-power capacity and generation both increased significantly during 2011-2021 and were not impacted greatly by the pandemic in 2020, with generation protected by long-term power purchase contracts.[85] Global capacity more than doubled during the period, reaching an estimated 158 gigawatts, while global generation rose 88% to 656 terawatt-hours (TWh).[86] (→ *See Figure 27.*) Since 2017, China has been the top bio-power producing country, followed (in 2021) by the United States, Brazil, Germany, Japan, the United Kingdom and India.[87]

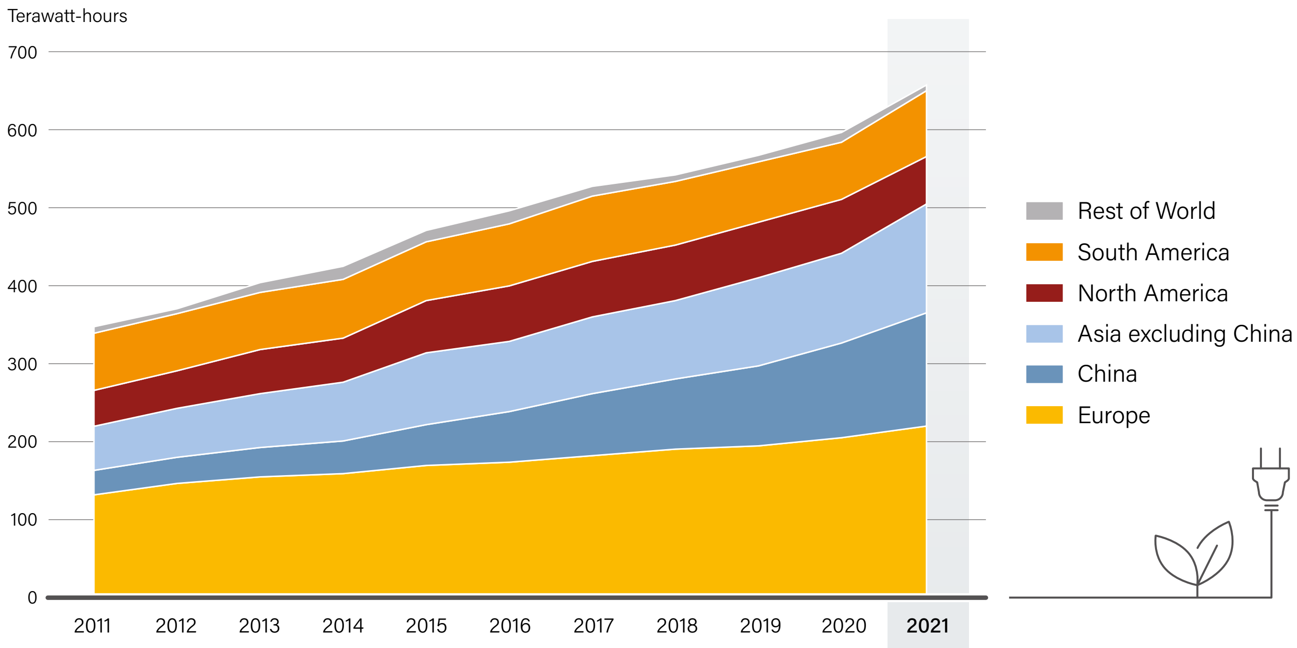
China was the fastest growing bio-power producer during 2011-2021, with generation increasing by a factor of 4.5 from 32 TWh annually to 146 TWh annually.[88] This reflects mainly the strong growth in power production from waste, driven by rising urbanisation, the country's 14th Five-Year Plan, and financial support for this activity, totalling CNY 2.5 billion (USD 400 million) in 2021.[89]

Bio-power growth also was relatively rapid in the rest of Asia, with generation rising by a factor of 2.4 during 2011-2021 to 138 TWh.[90] Japan overtook India as the leading regional producer with 42 TWh in 2021, up from 13 TWh in 2011.[91] In India, bioelectricity production grew from 19 TWh to 34 TWh over the period, and in the Republic of Korea it increased more than 14-fold to 13 TWh, encouraged by the Renewable Energy Certificate Scheme and feed-in tariffs.[92] In both Japan and the Republic of Korea, growth was due mostly to increased use of imported pelletised fuels.[93] Electricity generation also grew significantly in Indonesia, Thailand and Vietnam.[94]

In Europe, bioelectricity generation grew 67% during 2011-2021 to reach 221 TWh, mainly in the EU (stimulated by the EU RED) and in the United Kingdom.[95] Germany remained the top regional producer, mainly from biogas, although recent growth has been limited.[96] In the United Kingdom, bio-power generation rose three-fold during the period, due mostly to higher use of imported wood pellets at the converted Drax power station and to rising generation from municipal solid waste.[97] Bioelectricity provided 12.5% of UK electricity production (39.4 TWh) in 2021, with increases in large-scale pelletfired generation, biogas and municipal waste plants.[98] Electricity generation in the Netherlands increased to 11 TWh supported by the SDE feed-in premium scheme and to help the country meet its obligations under the EU RED.[99] Generation also surged in Denmark, Sweden and France.[100]

In the Americas, the United States remained the world's second largest bioelectricity producer with 60 TWh in 2021.[101] However, US generation fell 15% from its peak in 2015.[102] In South America, bio-power generation grew 11% between 2011 and 2021, led by Brazil, which was the third largest global producer in 2021 (560 TWh), with generation doubling since 2011 (based mostly on sugarcane bagasse).[103] Generation remained stable in both Chile (7 TWh) and Argentina (3 TWh) in 2021.[104]

FIGURE 27.
Global Bioelectricity Generation, by Region, 2011-2021



Source: Based on IEA data. See endnote 86 for this section.

KEY FACTS

- **New geothermal power** generating capacity of 0.3 gigawatts (GW) came online in 2021, bringing the global total to around 14.5 GW. This was more than double the additions in 2020 but below the five-year average of 0.5 GW since 2016.
- **Geothermal power** and heat development is highly concentrated across a few countries and typically is concentrated in key geographic locations within countries.
- **During 2016-2021**, the top markets in reported power capacity additions were Turkey (0.9 GW added), Indonesia (0.7 GW), Kenya (0.2 GW) and the United States (0.2 GW), followed by Iceland, Chile, Japan, New Zealand, Costa Rica and Mexico (all less than 0.1 GW each).
- **In the most active markets** (Turkey and Indonesia), further development of geothermal resources is contingent on government support mechanisms; however, lower feed-in tariffs in Turkey may be causing a slowdown.
- **Geothermal heat (direct) use** may have increased nearly 10% in 2021, mostly in China. The top countries for geothermal direct use remain (in descending order) China, Turkey, Iceland and Japan.

GEOTHERMAL POWER AND HEAT

Geothermal energy is harnessed by using the thermal and pressure differentials in the Earth's crust either to supply thermal energy directly or to generate electricity. For heat applications, geothermal fluid can be used directly or via heat exchangers, where the fluid is re-injected into the crust. For electricity generation, geothermal steam[i] is used directly to drive turbines (either dry or flash steam), or, in the case of binary-cycle plants, geothermal fluid is used to heat a secondary working fluid that powers the turbine.

Geothermal electricity generation totalled an estimated 99 terawatt-hours (TWh) in 2021, while direct useful thermal output totalled an estimated 141 TWh (508 petajoules, PJ)[ii,1] In some instances, geothermal plants produce both electricity and heat for thermal applications (co-generation), but this option depends on location-specific thermal demand coinciding with the geothermal resource.

GEOTHERMAL POWER

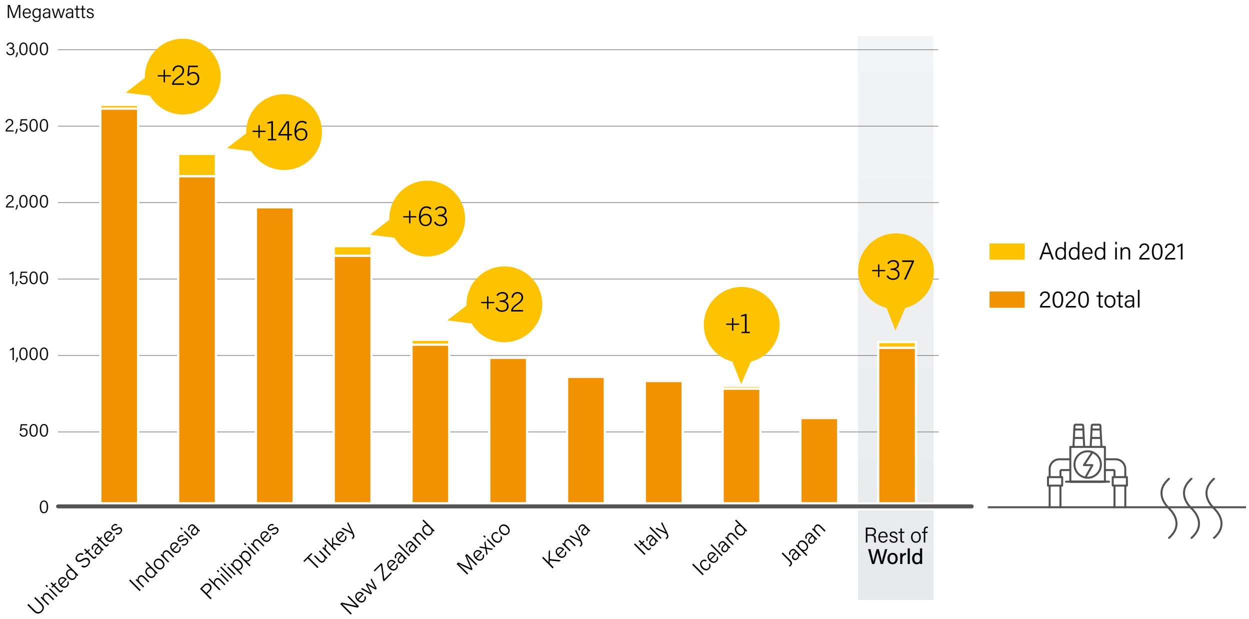
New geothermal power generating capacity of 0.3 gigawatts (GW)[iii] came online in 2021, bringing the global total to around 14.5 GW.[2] This was more than double the additions in 2020 but below the five-year average of 0.5 GW since 2016.[3] Capacity was added in Chile, Chinese Taipei, Iceland, Indonesia, New Zealand, Turkey and the United States.[4] (→ *See Figure 28.*)

i Sub-surface geothermal fluid undergoes flash evaporation to steam as pressure drops ascending a wellbore and at the power plant.

ii This does not include the renewable final energy output of ground-source heat pumps. (→ *See Heat Pumps section in Markets and Industry chapter.*)

iii Net additions tend to be lower than the sum of new plants due to decommissioning or de-rating of existing capacity.

FIGURE 28.
Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2021



Source: See endnote 4 for this section.

The top 10 countries for geothermal power capacity at the end of 2021 were the United States, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Kenya, Italy, Iceland and Japan.[5] However, capacity values are subject to high uncertainty due to a lack of standardised reporting criteria. In some instances, the effective geothermal generating capacity (achievable or running capacity) may be lower than indicated values, due to gradual degradation of the steam-generating capability of geothermal fields or to insufficient drilling of make-up[i] wells to replenish steam flow over time.

For example, the effective net[ii] generation capacity in the United States was 2.6 GW at the end of 2021, as resource depletion in particular has limited the effective output far below the stated gross nameplate capacity of 3.9 GW.[6] In Mexico, resource depletion has reduced the effective capacity at the country's largest geothermal field, Cerro Prieto, to around one-half of the installed capacity of 0.7 GW, suggesting that the country's total reported running capacity of more than 0.9 GW is overstated.[7] In Japan, gradual degradation of steam output since the 1970s has reduced the effective running capacity to around 0.3 GW, below the stated nameplate capacity of more than 0.5 GW.[8]

Country rankings also do not reflect how active these markets have been in recent years. The most active geothermal power markets have been Turkey and Indonesia, while some other countries (such as the Philippines) have seen little or no capacity additions in recent years. During the 2016-2021 five-year period, the top 10 markets by reported capacity additions (new plant installations) were Turkey (0.9 GW added), Indonesia (0.7 GW), Kenya (0.2 GW) and the United States (0.2 GW), followed by Iceland, Chile, Japan, New Zealand, Costa Rica and Mexico (all less than 0.1 GW).[9]

Turkey has been one of the most prolific geothermal power markets over the last decade. However, following robust growth during 2015-2019 (around 200-240 megawatts (MW) added annually), annual capacity additions in the country declined from 99 MW in 2020 to a net 63 MW in 2021 – the smallest annual increment since 2012.[10]

As in recent years, new installations completed in Turkey in 2021 were all relatively small (25 MW or less), including the first 3.2 MW phase of Transmark's 12 MW Mount Ida plant and the second 25 MW unit at the Efeler complex.[11] Turkey continued to rank fourth globally for total geothermal power capacity, at 1.7 GW.[12] Geothermal's share of the country's power supply grew from 1.3% in 2015 to 3.3% in 2020 as generation nearly tripled to 10 TWh.[13]

Past growth in Turkey's geothermal energy development was driven by the technology-specific feed-in tariff (FIT) in place since 2011.[14] This FIT was repealed in mid-2021 (following a six-month pandemic-related reprieve), which encouraged some project completions before the expiration date.[15] A new FIT, significantly lower than the previous one, abandoned the USD-based structure in favour of the Turkish lira, both for the basic tariff and for the local content increment.[16]

Turkey's geothermal industry has attributed the slowing market growth to detrimental changes in the FIT and suggests that without stronger, long-term incentives the country's remaining geothermal power potential (estimated at 2 GW) will not be realised.[17] The current weakness of the Turkish lira is said to make the foreign currency risk prohibitive to new investment, along with the high cost of borrowing in the local currency, especially with the FIT no longer pegged to the US dollar.[18]

In late 2021, the World Bank announced the approval of two USD 300 million loans, supplementing its previous USD 250 million in funding, to support geothermal development in Turkey.[19] The funds will be used to fund drilling and steam-field development, in support of direct-use applications as well as electricity generation.[20]

The United States maintains a commanding lead in installed geothermal power capacity, although new capacity built has averaged only 66 MW annually during 2011-2021.[21] One 25 MW project completed in 2021 helped keep the total net operating capacity at 2.6 GW.[22] The new capacity was the culmination of the McGinness Hills expansion project, which used the most advanced binary-cycle[iii] technology at an existing facility in the state of Nevada.[23] Geothermal power in the United States generated around 16.2 TWh in 2021, or less than 0.4% of US net electricity generation.[24]

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

ii In general, a power plant's net capacity equals gross capacity less the plant's own power requirements and any seasonal de-rating. In the case of geothermal plants, net capacity also would reflect the effective power capability of the plant as determined by the current steam production of the geothermal field. See endnote 6 for this section.

iii In a binary-cycle plant, which has become the most common design at plants built in recent years, the geothermal fluid heats and vaporises a separate working fluid (with a lower boiling point than water) that drives a turbine to generate electricity. Each fluid cycle is closed, and the geothermal fluid is re-injected into the heat reservoir. The binary cycle allows an effective and efficient extraction of heat for power generation from relatively low-temperature geothermal fluids. Organic Rankine Cycle (ORC) binary geothermal plants use an organic working fluid, and the Kalina Cycle uses a non-organic working fluid. Conversely, geothermal steam can be used directly to drive the turbine but this is more typical for high-entalpy applications.

Indonesia completed two projects that had been delayed from 2020, when no capacity was added.[25] By mid-2021, the 45 MW Sorik Marapi Unit 2 on North Sumatra came online.[26] On South Sumatra, the 98 MW Rantau Dadap facility commenced operation towards the end of the year.[27] In addition, the 10 MW Dieng unit advanced during the year and is said to be an example of the small-scale renewable technology that Indonesia wishes to emphasise for reasons of fast deployment and compatibility with environmental imperatives and other economic activity, such as tourism.[28]

Indonesia has seen relatively steady growth in geothermal power capacity in recent years (except for pandemic-induced delays in 2020), with average growth of around 150 MW annually during the five-year period from 2016 to 2021, for a total installed capacity of 2.3 GW.[29] In 2020, geothermal power supplied 15.6 TWh, or 5.3% of the country's total generation.[30]

Geothermal power is relatively expensive in most locations, due largely to the high risk inherent in the early stages of exploratory drilling and field development. To alleviate some of this risk, the Indonesian government began directly funding exploratory drilling in 2021 in the hope of reducing upstream risk, lowering investment thresholds and reducing overall project development costs (and thus the final cost of energy).[31] State-funded drilling started in September in a national park on West Java, with two 2-kilometre deep boreholes planned in an area with an estimated 45 MW potential.[32] The government estimates the incremental geothermal power capacity to cost USD 4 million per MW, requiring more than USD 28 billion in investment to meet the country's 2035 target of 7.1 GW of new geothermal capacity.[33]

New Zealand commissioned its first new geothermal power project since 2018 with the completion of the 32 MW Ngawha plant, following three years of construction.[34] Most of the country's geothermal capacity (1.1 GW) was built before 2016, but only 57 MW has been added since.[35] The need for additional capacity has been curtailed in part by the decline in industrial and commercial electricity demand over this period, as geothermal generation has continued to account for around 18% of the country's total electricity generation.[36]

A new 168 MW geothermal power plant is under development near Taupō on New Zealand's North Island, to be completed by late 2023.[37] The project's geothermal field was found to be more productive than initially expected, but the increase in power capacity (up from 152 MW) was offset by higher estimated project costs, rising more than 9% per unit of output, to USD 4.9 million per MW.[38]

In Chile, the Cerro Pabellón plant was expanded in 2021 to 81 MW with a new 33 MW binary-cycle unit. The plant is notable for being the first and only geothermal power plant in South America and the highest-altitude plant of its kind, located in the Atacama Desert at 4,500 metres above sea level.[39]

Chinese Taipei celebrated the completion of its first geothermal plant in 2021. The 4.2 MW binary-cycle unit uses hot water from depths of as much as 2 kilometres, at temperatures up to 180 degrees Celsius (°C).[40]

Geothermal power capacity in Iceland grew modestly in 2021 with six 150 kW binary-cycle power modules installed at two locations, all implemented in conjunction with low/medium-temperature (about 120°C) direct-use (district heating) systems.[41]

New geothermal power generating capacity of

0.3 GW

was more than double the additions in 2020 but below the five-year average of 0.5 GW since 2016.

GEOTHERMAL HEAT

Worldwide, the capacity for geothermal direct use[i] – direct extraction of geothermal energy for thermal applications – totalled an estimated 35 gigawatts-thermal (GW_{th}) in 2021.[42] The estimated 2021 annual capacity increase of 2.5 GW_{th} is based on reported values for 2019 and the preceding five-year growth rate. By the same estimation, geothermal energy use for thermal applications grew 12.8 TWh during 2021 to an estimated 141 TWh (508 PJ).[43]

The largest applications for geothermal heat are bathing and swimming (44% of the total in 2019 and growing around 9% annually) and space heating (39% in 2019, growing at 13%).[44]

The remaining 17% of direct use was allocated to greenhouse heating (8.5%), industrial applications (3.9%), aquaculture (3.2%), agricultural drying (0.8%), snow melting (0.6%) and other uses (0.5%).[45] (→ *See Snapshot: El Salvador.*)

The top countries for geothermal direct use in 2021 were (in descending order) China, Turkey, Iceland and Japan.[46] (→ *See Figure 29.*)

The global distribution of geothermal energy use for heating remains uneven and sparse, with at least 75% concentrated among the top four countries. Other countries, each estimated to represent less than 2% of direct use, include (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil.[47]

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

SNAPSHOT. EL SALVADOR

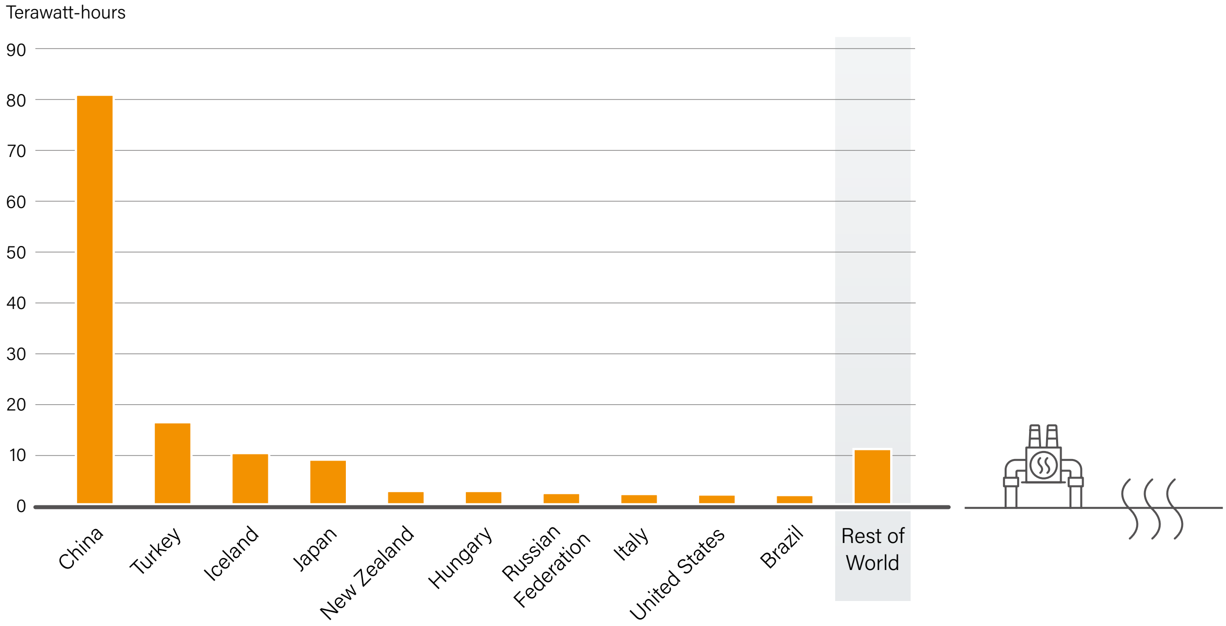
Geothermal Heat Use in Agriculture

Agricultural practices can require prolonged, high-temperature heat to yield final food products. Globally, communities and companies have been using the by-product heat from nearby geothermal plants to help improve processes for local producers. Because of its proximity to the geothermally active Ring of Fire area, Latin America has the potential for an estimated 70 GW of geothermal energy.

In El Salvador, where 27% of electricity comes from geothermal energy, the rural communities of Ahuachapán and Berlin use waste heat to dry fruits, displacing fossil fuel-intensive processes. Condensation from the nearby geothermal power plant is used to water the plants sold by the communities. In Costa Rica, the Ministry of Environment and Energy has published a law related to the direct use of geothermal resources, including in agriculture.

Source: See endnote 45 for this chapter.

FIGURE 29.
Geothermal Direct Use, Top 10 Countries and Rest of World, 2021



Source: See endnote 46 for this section.

Geothermal heat use reflects local needs and priorities. In China, around 46% was allocated to district heating in 2019 and 44% went to bathing and swimming applications.[48] In Iceland, 73% is used for space heating, with swimming pools coming a distant second at less than 10%.[49] In Turkey, pools and baths consume 42%, while space heating absorbs less than 30%.[50] In Japan, more than 80% of direct use is believed to be associated with bathing facilities located near geothermal springs.[51]

China's use of geothermal heat was a reported 197 PJ in 2019 and may have exceeded 290 PJ in 2021 based on recent growth trends, representing well over half of global use.[52] In 2017, China issued its first geothermal industry plan, which called for rapid expansion of geothermal energy use, especially for heat applications.[53] The country's 14th Five-Year Plan for energy efficiency and green building development, issued in early 2022, emphasises continued expansion of geothermal energy use for space heating.[54] China's geothermal heat market is by far the fastest growing globally, with consumption increasing more than 21% annually during 2015-2019.[55]

As of 2019, China had an estimated 14.2 GW_{th} of installed geothermal capacity for direct use (excluding heat pumps), with 7 GW_{th} allocated to district heating, 5.7 GW_{th} serving bathing and swimming applications, and the rest used for food production and other industry.[56] Based on growth trends during 2015-2019, installed capacity may have been close to 20 GW_{th} by the end of 2021.[57] Unlike countries that use geothermal energy mostly for electricity generation rather than for direct heat applications (or both), China emphasises heat use, in part because most domestic hydrothermal resources are of relatively low enthalpy (with most reservoirs below 100°C).[58]

Growth among the other top users of geothermal heat (Turkey, Iceland and Japan) has been far more moderate, at 3-4% annually.[59] In Turkey, reported geothermal heat use grew 3.9% annually on average during 2015-2019 and may have reached 59 PJ in 2021.[60] While total geothermal energy use in Turkey is skewed towards thermal applications (15 TWh direct use and 10 TWh electricity), drilling activity and other investment in recent years (before the change in the FIT in 2021) have strongly favoured electricity generation.[61]

Iceland ranks third globally in the use of geothermal heat, but modest growth in this mature market is defined largely by economic and population growth.[62] With around 2.5 GW_{th} of capacity, the country produces around 34 petajoules (PJ) of geothermal heat annually, enough to cover more than 97% of overall thermal demand

Global distribution of geothermal energy use for heating remains uneven and sparse, with **at least 75%** concentrated in only four countries.

and around 90% of space heating demand.[63] The total contribution of geothermal energy to space heating is even greater since the balance is met largely with electricity, which is generated in part from geothermal power (31% of Iceland's electricity is geothermal).[64]

The high penetration of geothermal energy for thermal applications in Iceland is made feasible in part because most buildings are located near known and available geothermal resources, specifically in the greater capital area in the more geothermally productive southwest. At an existing heat and power plant in the region, a new make-up borehole was completed in 2021 with peak fluid temperature of 360°C.[65] The plant operators observed that the chemical make-up of such hot geothermal fluid may be corrosive to plant equipment, but normal acidity and high steam content was promising.[66]

Well outside the most geothermally active parts of Iceland, the community of Höfn in the southeast completed a new district heating system in 2021, after 30 years of searching for sufficiently productive geothermal wells.[67] After some 54 exploratory wells were drilled, a final 5 production wells were completed at a depth of 1.1 to 1.75 kilometres each, producing a sustainable yield of 30-40 litres per second at 70-78°C.[68] The system, which received a critical state subsidy, displaced electric boilers that used fuel oil as a back-up.[69]

In continental Europe, clusters of geothermal heat developments can be found, and some continue to grow. Germany expanded geothermal district heating at two facilities, both in Bavaria. The Kirchstockach geothermal plant began distributing district heat (12 megawatts-thermal, MW_{th}) in addition to the facility's existing electricity generation (5.5 MW_e).[70] A new plant in the town of Garching was completed in early 2021, supplying both electricity (4.9 MW_e) and district heat (6.9 MW_{th}).[71]

Three geothermal heat projects were completed near Paris (France). A plant serving the communities of Champs-sur-Marne and Noisiel will provide 82% of the local district heat supply, while new plants at Vélizy-Villacoublay and Drancy/Bobigny will each raise the renewable energy share in local heat networks above 60%.[72]

Vienna (Austria) hopes to tap a deep geothermal aquifer to supply 125,000 households with heat by 2030.[73] Extensive surveys done since 2016 indicate a promising resource at around 3,000 metres below the city (at temperatures up to 100°C), but exploratory boreholes are needed to confirm those expectations, with further research planned in 2022.[74]

Despite favourable resource conditions, development of geothermal energy in Hungary (which ranks sixth globally for direct use) has not been robust in recent years.[75] In an effort to turn the tide, the Hungarian government initiated a programme in 2021 to mitigate financial risk associated with geothermal drilling, funded at the level of HUF 6 billion (USD 18 million).[76]

KEY FACTS

- **In 2020**, heat pumps met only around 7% of the global heating demand in residential buildings, as fossil fuel-powered heaters and water heaters still comprised around half of the heating equipment sold. However, this trend is changing as heat pumps become more common in new buildings.
- **Globally, air-source heat pumps** continue to dominate the market, with the top regions being China, Japan, Europe and North America. Ground-source heat pumps have the second largest market share globally.
- **Factors that have led governments** to integrate heat pumps into plans for decarbonising heating in buildings include the technology's maturity and the ability to provide additional flexibility in the electricity network or heating system.
- **Many countries** are using financial support and pricing measures to balance the price of electricity relative to natural gas, which improves the economic prospects for heat pumps.

HEAT PUMPS

Heat pumps are used to meet space and water heating and cooling needs for residential, commercial and industrial applications within a wide range of temperatures.[1] In general, they are highly efficient heating and cooling devices, typically able to deliver 3-5 units of heat for every unit of auxiliary energy input.[2] However, heat pumps differ in performance based on their inherent technical efficiencies, external operating conditions and system designs.[3] (→ *See Figure 30 and Box 9.*)

The classification of heat pumps as a renewable energy technology varies by location. Because groundsource heat pumps rely on geothermal heat, they generally are defined in national legislation as being renewable.[4] In Japan, air-source heat pumps have been recognised as renewable energy technologies since 2009.[5] The European Union (EU) also has considered, since 2009, the aero- and hydro-thermal energy extracted by heat pumps as renewable, provided that the final energy delivered greatly exceeds the external energy required for heat pump operation.[6] As of early 2022, China did not recognise air-source heat pumps as a renewable energy technology at the national level.[7]

In 2020, heat pumps met only around 7% of the global heating demand in residential buildings, as fossil fuel-powered heaters and water heaters still accounted for around half of the heating equipment sold.[8] However, this trend is changing, particularly as heat pumps become more common in new buildings.[9] In the United States, heat pumps account for between 40% and 50% of heating equipment sales for newly constructed buildings, depending on the building type.[10] In Europe, more than 20% of all heating devices sold in 2021 were heat pumps.[11] On the Swiss market, heat pumps are the most-sold heating technology, in both new and existing buildings.[12]

Heat pumps met **only around 7%** of the global heating demand in residential buildings, as fossil fuel-powered heaters and water heaters still accounted for around half of the heating equipment sold.

BOX 9. Operational Principles of a Heat Pump

A A heat pump extracts heat from an ambient heat source, which can include heat from the air, water, and ground, as well as different types of waste heat (such as from industrial processes and sewage treatment). The heat is extracted by evaporating a refrigerant, thus cooling the source.

B During operation, the device uses an external source of energy to transfer the ambient energy from a low-temperature source to a higher-temperature sink by way of a refrigeration cycle. This typically is achieved with an electric compressor. When the energy used to drive a heat pump is renewable, so is 100% of the energy delivered.

C The most efficient systems, operating under optimal conditions, can deliver 4.5 to 7 units of thermal energy (either heating or cooling) for every 1 unit of external energy consumed (especially in moderate climates (the Mediterranean region, central and southern China). In cold climates (Canada, northern China), low outside temperatures can reduce the energy co-efficient of air-source heat pumps over the winter season.

The difference between the energy delivered and the external energy is considered the renewable portion of the heat pump output, regardless of the external energy source.

D The heat can then be used for:

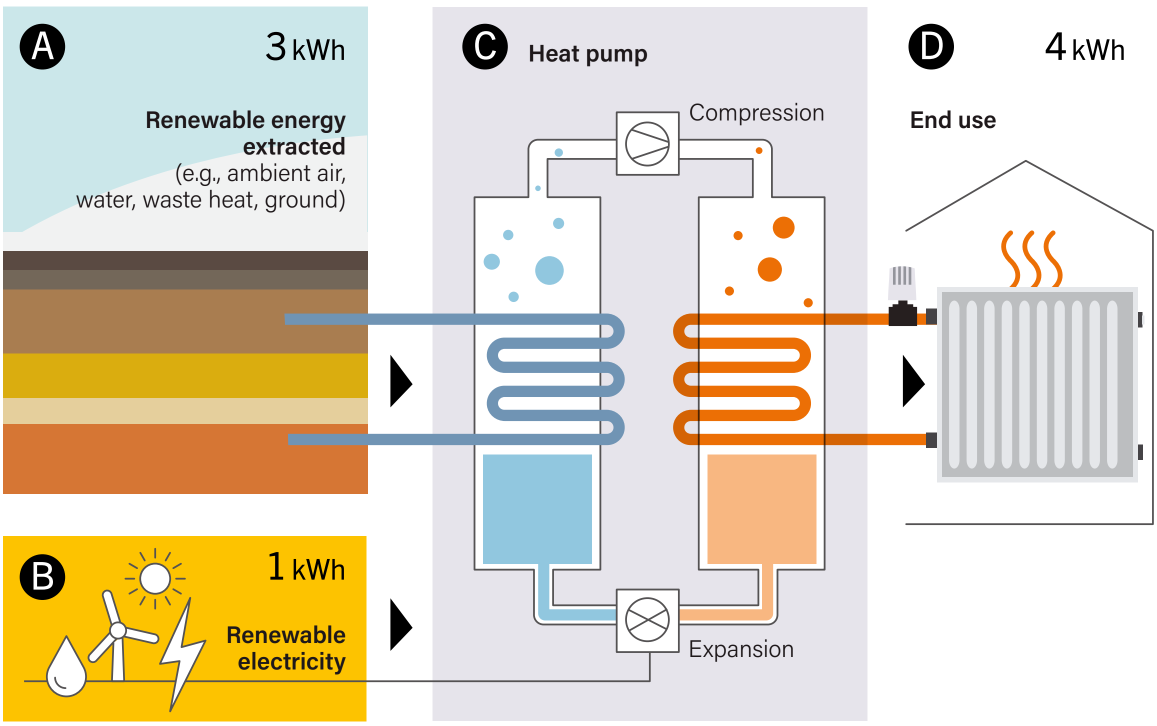
- residential and commercial space heating (through heated air, radiators or underfloor heating; or applied in district heating systems);
- sanitary hot water production;
- heat provision for industrial processes.

Heat pumps typically are reversible units that provide heating as well as cooling functions[i].

i Air conditioners can be considered heat pumps that provide only cooling.

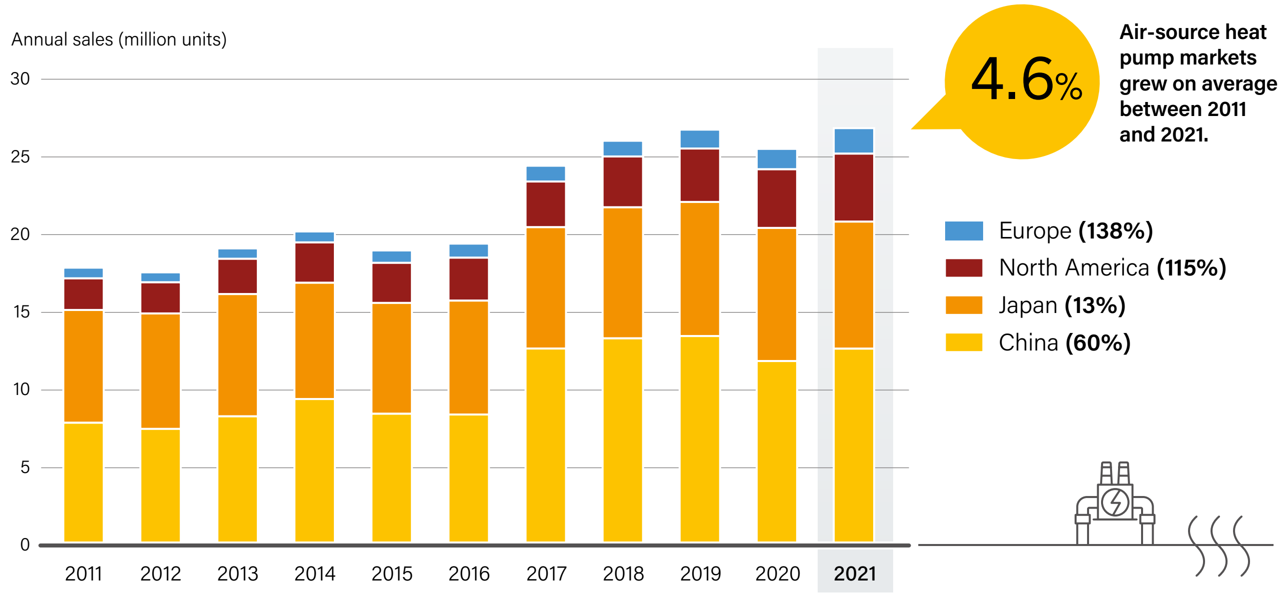
Source: See endnote 3 for this section.

FIGURE 30.
Example of a Heat Pump with a Co-efficient of Performance of 4



Source: See endnote 3 for this section.

FIGURE 31.
Air-Source Heat Pump Annual Sales, Selected Markets, 2011-2021



Source: China total from ChinaIOL. Europe total from EHPA. See endnote 13 for this section.
Note: For China, data for 2011-2013 do not include air-water heat pumps.

MARKET DEVELOPMENT BY HEAT PUMP TYPE

Heat pumps can be differentiated based on the combination of their energy source (air, water or ground) and the heat distribution system (air or water). Globally, air-source heat pumps continue to dominate the market, with the top regions being China, Japan, Europe and North America.[13] (→ *See Figure 31.*) In general, comparisons across heat pump markets remain challenging due to differences in data collection, the overall lack of data availability, and the difficulty in distinguishing units used only for cooling from those used for both heating and cooling.

In certain regions, growing demand for air conditioning could boost the demand for reversible heat pumps that provide both cooling and heating.[14] In Europe, Japan, the Republic of Korea, and the United States, reversible air-air heat pumps generally are used for both space heating and cooling.[15] In China, such units are sold mainly in the north, although primarily for cooling purposes, since more than 80% of the Chinese population relies on district heating networks for their heat needs.[16]

Overall, the air-source heat pump market slowed in 2020 due to the effects of the COVID-19 pandemic, as sales fell 3% globally relative to 2019; however, air-source sales increased in both Europe (up 7.4%) and North America (up 9.4%).[17] In China, air-source heat pump sales peaked in 2017 (attributed to implementation of the Air Pollution Act, which boosted the replacement of coal-based heating systems), whereas in Japan air-source heat pumps have been a common offering for more than 20 years and sales are relatively stable.[18] US heat pump sales have risen steadily and are growing faster than other heating alternatives in the country.[19]

In Europe, heat pump sales experienced double-digit growth during 2015-2019 due in part to the implementation of new building thermal regulations in many countries.[20] Since then, the acceleration of heat pump uptake (up 25% for air-source heat pumps and up 34% for total sales in 2021) can be attributed to the rise in home renovations during the pandemic, and to the overall positive perception of the technology by end-users.[21]

In 2021 (as in 2020), the top three European markets were France, Italy, and Germany, with the latter experiencing 28% growth for the year.[22] (→ *See Snapshot: Germany.*) Other countries showing substantial market growth included Italy (up 64%), Poland (60%, due mainly to regulations phasing out coal), France (36%) and Switzerland (20%).[23] The largest market penetration for heat pumps in buildings is in the Nordic countries, in particular Sweden, where more than one in two single-family homes has a heat pump installed.[24]

SNAPSHOT. GERMANY

Rapid Growth in the Heat Pump Market

Germany's heat pump market expanded considerably in 2020 – up 41% relative to 2019 – and entered the European top three for the first time ever. This expansion continued in 2021, with the market growing 28% for an annual total of 154,000 units sold. The German market is dominated by air-to-water heat pumps (increasing from a 79% share in 2020 to 82% in 2021), followed by ground-source heat pumps (18% in 2021).[i] The federal government also has set a target of a cumulative six million heat pumps to be installed by 2030 – six-times the stock of 2020.

The market has benefited from a succession of climate policies aimed at promoting more sustainable heating systems. For example, Germany's 2019 Climate Policy Package bans the use of oil heating in new and existing buildings starting in 2026, and the 2020 National Energy and Climate Plan sets a target for 27% renewable heating by 2030. In practice, the right conditions for replacing oil with heat pumps in new buildings are set by a combination of energy performance building regulations (the Energy Saving Ordinance, or EnEV) and an aggressive subsidy system, supported through the government-funded Market Incentive Programme (MAP) and preferential interest loans delivered through the KfW development bank.[ii]

Launched in 2000, the MAP provides low-interest loans or investment grants of up to 35% for conversion to a renewable heating system if gas boilers are replaced and up to 45% if an oil heater is replaced. Because the programme has significantly lowered the upfront costs of heat pump installation, by 2016 around 23% of new homes in Germany were using a heat pump as their main heating system, up from less than 1% in 2000. For existing buildings, the country requires replacing all fossil fuel heating systems that are more than 30 years old; however, even though the MAP grant is higher in such cases, these systems typically still are replaced with more efficient gas or oil boilers. Germany's national heat pump association estimates that nearly a quarter of the heat pumps installed in 2020 replaced old oil-fired systems, amounting to some 30,000 units.

A barrier to greater uptake of heat pumps is the high price of electricity in Germany, among the highest in Europe due to significant taxes and surcharges, amounting to 53% of the total bill in 2020. A carbon tax, introduced in 2021, will be redirected towards green subsidies, helping to reduce the gap between the electricity price and the price of natural gas or oil. In early 2022, the government went a step further by announcing the removal of the renewable energy levy ("EEG surcharge") on electricity bills by 2023. in April 2022, the timeline was moved up in response to the sharp rise in energy prices and the need for a secure heating supply, and the EEG is now slated to be transferred to the federal budget as early as July 2022.

i German statistics do not include reversible air-to-air heat pumps to avoid counting units used only for cooling.

ii KfW supports businesses and municipalities using larger heating systems, while the MAP incentives are directed towards private consumers, professionals, companies, municipalities and other eligible parties such as non-profit organisations.

Source: See endnote 22 for this section.

Heat pumps for sanitary hot water production are used mainly in China and Japan, where sales have tripled since 2010; in 2021, more than 1.27 million units were sold in China, and 585,000 units were sold in Japan.[25] France dominates the European market for hot water uses, with 110,320 heat pump water heaters sold in 2020.[26]

Ground-source heat pumps have the second largest market share globally after air-source units.[27] The United States remains a prominent market, with more than 1.7 million units installed and annual growth of around 3% in 2020.[28] In Europe, around 100,000 ground-source units were sold in 2020, mainly in Sweden, Germany, and the Netherlands, with the latter accounting for more than half of total sales.[29]

DRIVERS OF HEAT PUMP UPTAKE

Various factors have driven the development of heat pump markets. With digital control measures and thermal storage, heat pumps can use excess electricity from variable renewable energy sources (such as wind and solar power) for heating and cooling purposes, providing additional flexibility in the electricity network.[30] The use of large-scale heat pumps in district heating systems also can add flexibility to heating systems.[31] These factors, coupled with the sector's technological maturity and the capacity to manufacture and distribute large volumes of equipment, have led governments to integrate heat pumps into their climate plans as a key means for decarbonising heating in buildings.[32]

For example, the implementation of China's new Carbon Neutrality Policy is expected to foster domestic growth in heat pump installations, while the United Kingdom's 2021 Heat and Buildings Strategy sets a target for installing 600,000 heat pumps annually by 2028.[33] (→ *See Policy chapter.*) In response to the Russian invasion of Ukraine, the European Commission announced in March 2022 its new REPowerEU plan, aimed at installing 10 million heat pumps between 2023 and 2028 to reduce EU reliance on Russian gas supplies.[34]

Updates of building codes and regulations also stimulate heat pump uptake.[35] France's new building energy code, which entered into force in early 2022, limits the emission intensity of space heating and cooling systems, effectively phasing out the use of fossil fuels in new homes.[36] In the United States, multiple states and cities have updated or are in the process of updating their building codes to favour electrification in buildings; these include, in 2021, California (which in August adopted the first US building code to designate efficient electric heat pumps as a baseline technology), Maryland, New York (which in December approved a ban on natural gas use in new buildings) and Washington state.[37]

Air pollution prevention policies have driven the deployment of heat pumps in some regions where coal-based heating is prevalent, such as northern China, China's Beijing-Tianjin-Hebei region and Poland.[38]

Purchase subsidies (grants, loans or tax credits), in association with national policies, can help counterbalance the upfront costs of heat pumps, particularly during building renovations; in new buildings, meanwhile, heat pumps can be an affordable solution.[39] The barriers associated with upfront costs vary by region, technology and brand[i].[40] In some regions, economies of scale have made heat pumps more affordable; however, frequent changes to legislation regarding minimum efficiency or the use of refrigerants with low global warming potential[ii] have created a continuous need for manufacturers to innovate their products, which can slow cost reductions.[41]

Subsidies to incentivise the switch from coal-fired boilers to heat pumps have been effective in China (where the subsidy runs from 2014 to 2026).[42] Until recently, US heat pump subsidies were aimed at ground-source units, but the November 2021 Build Back Better Act introduced new tax rebates for installing heat pumps.[43] In Canada, nearly all provinces provide rebates for heat pumps, and in 2021 the federal government started the Greener Homes Grants Program rebate scheme for energyefficient homes.[44]

In 2021, most countries in Europe offered some kind of fiscal or financial support to incentivise the purchase of heat pumps.[45] However, only six countries support renewable heating technologies exclusively, while the rest simultaneously support fossil fuel-based technologies (mainly gas boilers), reducing the competitiveness of heat pumps.[46] In March 2022, France decided to stop incentivising gas or fuel oil boilers to reduce dependence on fossil fuels.[47] The United Kingdom is the only country that has opted (with little success) to subsidise the energy generated[iii] rather than the cost of the technology.[48]

The efficiency of heat pumps, coupled with continued improvements in their energy performance[iv], can help balance their higher costs relative to fossil fuel alternatives.[49] However, the typically higher price of electricity compared to natural gas can reduce the cost efficiency that heat pumps provide.[50] On average, electricity prices in the EU are twice as high as natural gas prices – and up to 5.5 times higher in certain Member States – impeding heat pump uptake.[51] This is due mainly to higher taxes and levies on electricity and to the fact that fossil fuel prices do not internalise environmental costs.[52]

A carbon tax on heating fuels and/or tax relief for electric power generation can help balance the price of electricity relative to natural gas, while also being used to fund grant programmes for heat pumps.[53] Ireland announced in late 2021 that it would use its carbon tax to support the implementation of its target for 600,000 heat pumps by 2030, and Germany has followed a similar model.[54] (→ *See Snapshot: Germany.*) Finland, Sweden, and Norway, which have the highest carbon prices in Europe, also benefit from the highest deployment of heat pumps per capita.[55]

i Ground-source heat pumps tend to be the most expensive, while air-air heat pumps are generally more affordable. In the case of renovation work, considering that many heat pumps are designed to deliver heat at relatively low temperatures (35-60 degrees Celsius, °C) compared to a conventional fossil fuel boiler (which supplies heat of around 60-80°C), additional costs often occur to improve the insulation of the building and to replace or adapt the existing heat distribution system. In practice, this is realised by increasing the size of the heat emitters and switching from high-temperature radiators.

ii Refrigerants circulate through the heat pump to absorb, transport and release heat. When they are released or leaked from the heat pump, refrigerants have a negative impact in terms of greenhouse gas emissions, which is measured by their global warming potential (which is lower for refrigerants that emit fewer greenhouse gases).

iii The Renewable Heat Incentive (RHI), initiated in 2011, was designed to provide an ongoing tariff for the production of renewable heat. The non-domestic RHI closed to new applicants in 2021, and the domestic RHI closed in March 2022. A total of 513,000 new installations were planned by 2020, but by the end of 2021 only 20,920 installations related to the non-domestic RHI and 87,337 installations related to the domestic RHI had been delivered. See: UK Parliament, "Renewable Heat Incentive in Great Britain," 2018, https://publications.parliament.uk/pa/cm201719/cmselect/cmpubacc/696/69606.htm; OFGEM, 2020-21 NDRHI Annual Report, November 2021, https://www.ofgem.gov.uk/publications/2020-21-ndrhi-annual-report; OFGEM, Domestic RHI Annual Report 2020-2021, July 2021, https://www.ofgem.gov.uk/publications/domestic-rhi-annual-report-2020-2021.

iv Ensured by energy performance regulations, such as the EU Ecodesign legislation, the US National Appliance Energy Conservation Act and the Japanese Top Runner Program.

KEY FACTS

- **In line with long-term trends**, global installed hydropower capacity grew an estimated 26 GW in 2021 to reach around 1,197 GW. China maintained the lead in capacity additions, followed by Canada, India, Nepal, Lao PDR, Turkey, Indonesia, Norway, Zambia and Kazakhstan.
- **Despite these additions**, global hydropower output fell around 3.5% in 2021, driven by significant and sustained droughts that have affected major producers in the Americas and parts of Asia.
- **Climate-induced changes** in operating conditions, such as the loss of Himalayan glacial icecaps, appear to be causing long-term change in output.
- **Large hydropower producers** with the greatest declines in generation in 2021 were Turkey (-28.7%), Brazil (-9.1%) and the United States (-8.8%). Other major markets that showed more modest annual contraction (but in some instances larger multi-year declines) included India (-2.2%), Canada (-1.5%) and China (-1.1%).
- **Global pumped storage capacity** grew around 1.9% (3 GW) during the year, with most new installations in China.

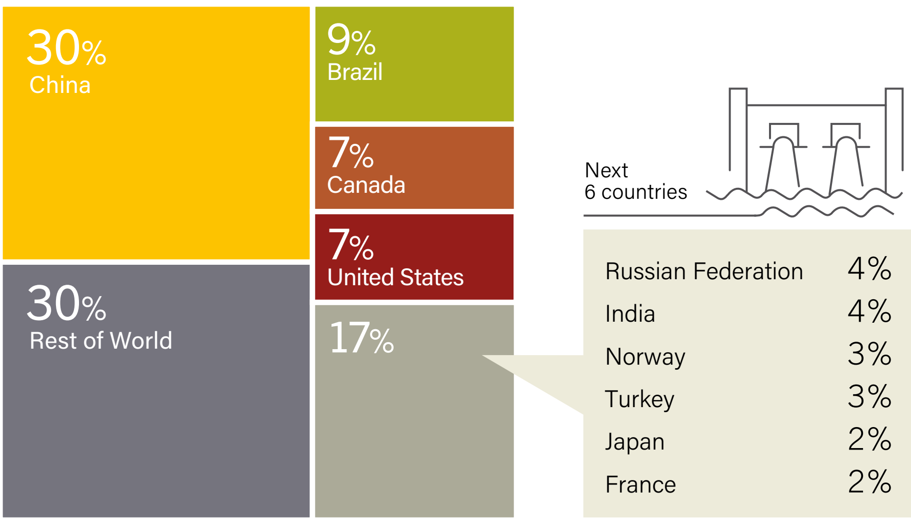
HYDROPOWER

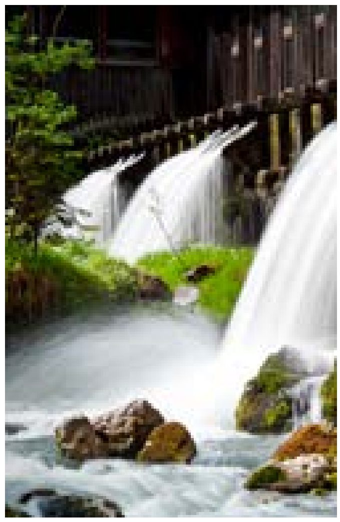
The global hydropower market progressed in line with long-term trends, with new capacity additions of at least an estimated 26 gigawatts (GW) in 2021, raising the total global installed capacity to around 1,197 GW[i,1]. The top 10 countries for installed capacity accounted for more than two-thirds of the global total and were (in descending order): China, Brazil, Canada, the United States, the Russian Federation, India, Norway, Turkey, Japan and France.[2] (→ *See Figure 32.*)

Global generation from hydropower fell an estimated 3.5% in 2021 to around 4,218 terawatt-hours (TWh).[3] This reflected changes in hydrological conditions, specifically the significant and sustained droughts that have affected major hydropower producers in the Americas and in many parts of Asia. Loss of glacial icecaps, such as in the Himalayas, is causing long-term change in output in affected areas.[4] The large producers experiencing the greatest decline in generation in 2021 were Turkey (-28.7%), Brazil (-9.1%) and the United States (-8.8%).[5] Other major markets with more modest contractions (although in some cases larger multi-year declines) included India (-2.2%), Canada (-1.5%) and China (-1.1%).[6]

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

FIGURE 32.
Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2021





Source: Based on IHA. See endnote 2 for this section.
Note: Totals may not add up due to rounding

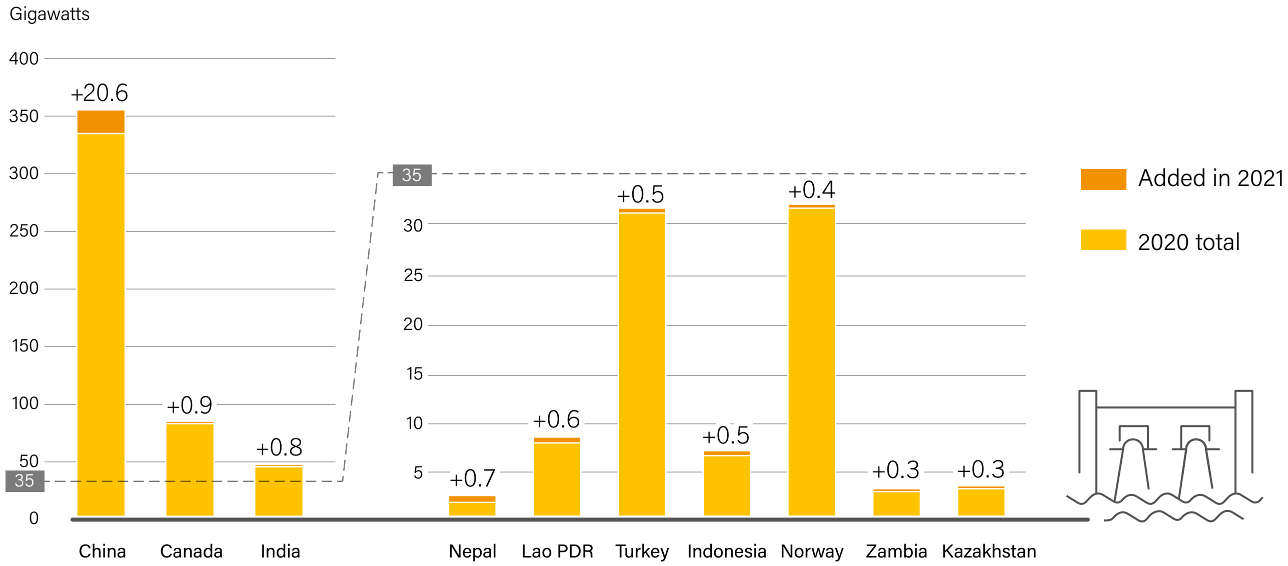
China maintained the lead in commissioning new hydropower capacity in 2021, followed by Canada, India, Nepal, the Lao People's Democratic Republic (PDR), Turkey, Indonesia, Norway, Zambia and Kazakhstan.[7] (→ *See Figure 33.*) Global pumped storage capacity (which is counted separately from hydropower capacity) increased around 1.9% (3 GW), with most new installations in China.[8]

In line with a long-term pattern, Asia continued to be the most active market globally in 2021, based on capacity additions. **China** had the largest share by far, with 20.6 GW of new capacity added in 2021 (excluding pumped storage), for a year-end total of 355 GW.[9] Completed hydropower projects in the country during the year represented an investment of CNY 98.9 billion (USD 15.5 billion), down 7.4% compared to 2020.[10]

While China's net hydropower capacity grew around 5.6%, generation fell 1.1% to 1,340 TWh in 2021.[11] Hydropower's relative contribution to the country's energy mix has declined in recent years as other generating technologies have gained market share and as capacity utilisation has decreased (due likely to changing weather patterns).[12] During the period 2016-2021, China's overall electricity generation rose more than 36%, while hydropower output grew only around 12% (with capacity growth of 16%), causing hydropower's share of supply to drop from 19.4% to 16%.[13]

By mid-year, China had completed installation of all twelve 850 MW units at the 10.2 GW Wudongde plant on the upper Yangtze River (Jinsha).[14] Also on the Jinsha, the initial 8 GW of the Baihetan station (eight 1 GW turbines) began operation, representing the largest single-unit turbine capacity to date.[15] Upon its expected completion in 2022, with 16 GW, it will be the world's second largest hydropower station after the Three Gorges Dam in Hubei Province.[16] These two plants, along with the Xiluodu and Xiangjiaba plants, will form a cascade of power stations on the Jinsha River totalling 46.5 GW.[17]

FIGURE 33.
Hydropower Global Capacity and Additions, Shares of Top 10 Countries, 2021



Source: Based on IHA. See endnote 2 for this section.

Hydropower's share in
China's electricity mix
has declined in recent years due to shrinking market share and decreasing capacity utilization.

By year's end, five 500 megawatt (MW) units were in operation at the 3 GW Lianghekou station on the Yalong River.[18] Located in the Tibetan Autonomous Prefecture of Garze, in Sichuan Province, the plant is built at an altitude of around 3,000 metres, higher than any other hydropower plant in China.[19] It also has one of the world's deepest reservoirs, up to 285 metres in depth.[20]

Lao PDR has been one of the most active Asian markets for hydropower in recent years as it harnesses the Mekong River and its tributaries mainly for electricity export to neighbouring countries, wishing to become the "hydroelectric battery" of South-East Asia.[21] In 2021, the second phase (732 MW) of the 1.27 GW Nam Ou River cascade of dams was completed with the last 600 MW going online.[22] Phase 1 was completed in 2016, and the first unit of Phase 2 came online in 2019.[23] The project is the first investment by a Chinese company (PowerChina) outside China under a build-operate-transfer model; it also is the first instance of a Chinese company being granted the development rights to an entire river basin outside its home country.[24] The complex of plants is to be transferred to the Lao government after 29 years of operation.[25]

In 2021, the Mekong River Basin experienced extreme low flows (the lowest in more than 60 years) for the third year in a row, due to greatly reduced rainfall, with further changes to flow patterns caused by the Basin's many storage reservoirs.[26] Such changes have had varied impacts on the ecology and livelihoods in the Mekong Delta.[27] Expected economic and social benefits of further hydropower development in the Basin (including flood control, irrigation and poverty reduction) are countered by adverse effects including the loss of fisheries, damage to wetlands and mangroves, and loss of sediment deposits that support agriculture in the Delta.[28]

Among the more notable developments in **Nepal** during the year was the start of operations at the country's largest hydropower facility, the run-of-river 456 MW Upper Tamakoshi.[29] Located in a remote region in the upper Himalayas, the plant's expected 2.3 TWh of annual output has increased Nepal's electricity generation 60% and alleviated severe shortfalls in supply.[30] The facility is expected to enable national supply to exceed current consumption during the rainy season, and to spur economic growth.[31]

Indonesia completed several new hydropower projects in 2021, expanding its installed capacity 0.5 GW to reach a total of 6.6 GW.[32] These projects included a 260 MW expansion at the Poso hydropower plant on the Poso River in Central Sulawesi (now 515 MW), serving as a dedicated load-following generator (peaker).[33] Also completed were the 90 MW Malea plant on the Saddang River in South Sulawesi, along with 18 small hydropower units totalling 111 MW.[34]

India added 843 MW of hydropower capacity in 2021, raising the total to 45.3 GW.[35] Among project completions were the last two 150 MW turbines at the 600 MW Kameng project in Arunachal Pradesh, two 50 MW units at Sorang, 113 MW at Rongnichu and three 60 MW units ready for service by year's end at the Bajoli Holi plant.[36] As of the end of 2021, India had more than 12 GW of hydropower capacity under development.[37]

Although India's hydroelectricity generation fell slightly during 2021 (-2.2%) to 168.4 TWh, the overall trend in recent years has been a large increase in output, driven mainly by the melting of glacial icecaps.[38] In the five years since 2016, hydropower generation rose 31% while installed capacity increased only 9.2%.[39] Glacial melting in the Himalayas contributes to increased river flow, as the mountain range has lost an estimated half metre of ice (8 billion tonnes of water) on average per year over the last two decades.[40] In early 2021, the Rishi Ganga River in Uttarakhand swelled more than 15 metres in an avalanche-induced flash flood of glacial meltwater.[41] In additions to the many lives lost, the torrent destroyed the 13.2 MW Rishi Ganga plant and damaged the 520 MW Tapovan-Vishnugad plant under construction.[42]

Turkey's installed hydropower capacity grew 0.5 GW in 2021, for a year-end total of 31.5 GW, which is just under a third of the country's overall generating capacity.[43] However, generation has faltered since setting a record in 2019, when short-lived improvements in hydrological conditions raised output to 88.8 TWh, around 30% of the country's total electricity supply.[44] Output dropped to 78 TWh in 2020, then plummeted in 2021 to 55.7 TWh (16.8% of supply).[45] The remaining two 155 MW turbines were installed at the 500 MW Lower Kaleköy on the Murat River, completing the project.[46] In addition to the hydropower plant, the facility incorporates an 80 MW solar PV array.[47]

Also on the Murat River, Turkey's 280 MW Alpaslan II plant was completed by its Czech developer.[48] The plant's four Francis turbines are differentiated (two at 110 MW and two at 30 MW) to optimise energy production across varying operating conditions.[49] Because the first unit was operational as of 2020, the plant qualified for a USD-based feed-in-tariff (FIT) for its first decade of operation with a local content increment.[50] Turkey replaced the FIT in 2021 with one based on the Turkish lira for both the basic tariff and a local content increment, resulting in an effective tariff reduction of 56% as of the end of 2021.[51]

In South America, **Brazil** added 13 generating units totalling 119 MW in 2021 (each less than 10 MW), for a year-end installed capacity of 109.4 GW, following a similar pattern in 2020 (178 MW installed).[52] The Brazilian hydropower market has looked very different in the last two years compared to years past, when annual additions were usually counted on a gigawatt-scale (averaging 3.8 GW annually during 2014-2019).[53] The national market, which led globally in annual capacity additions as recently as 2019 (4.95 GW added), is now much smaller.[54] This appears to be a trend, as Brazil expects just over 300 MW to come online in 2022.[55] The drop in additions reflects in part social and ecological restrictions on all but 12 GW (23%) of the country's remaining undeveloped capacity potential (of unit sizes larger than 30 MW), as well as the vastly higher environmental costs of developing hydropower relative to the faster growing technologies of wind power and solar photovoltaics (PV).[56]

The Brazilian authorities and system operator acknowledged in 2021 that the country was undergoing the worst hydrological crisis since 1930, following seven years of sub-average rainfall.[57] Hydropower generation dropped sharply from the previous year (down 9.1%) to 378 TWh, comprising 63% of supply.[58] In terms of both energy generated and the share of Brazil's electricity mix, hydropower has been in long-term decline since its peak in 2011 (when it reached 453 TWh and a 91% share).[59]

Chile brought into service two units, the 24 MW Digua and the 14.9 MW Hidromocho.[60] The country has focused mostly on building small hydropower plants in recent years; in the five years since 2016, the 28 units that went into service (200 MW in total) averaged only around 7 MW each.[61] The exception is the 531 MW Alto Maipo complex, which synchronised its first unit to the grid in early 2022.[62] The developer entered bankruptcy protection in late 2021 and initiated a process of financial reorganisation.[63] Hydropower generation in Chile fell sharply in 2021 (down 20%) to represent 20% of the country's electricity supply, well below the 30% average share over the preceding decade.[64]

Peru completed the 84 MW La Virgen hydropower plant, following years of delays.[65] All other new hydropower units in the country completed since 2016 (188 MW) have been around 20 MW or less.[66] In 2021, Peru generated 28.3 TWh from hydropower, or around 53.2% of its total electricity supply.[67]

Ecuador began synchronisation of the first of three 16.3 MW units of the 49 MW Sarapullo plant, with the rest to follow in early 2022.[68] Located on the Pilatón River, this plant and the adjoining Alluriquín facility make up the 254.4 MW Toachi Pilatón complex completed in 2021.[69]

To the north, the **United States** ranks fourth globally in hydropower capacity at 80 GW[i], with its stated net capacity expanding 103 MW in 2021.[70] Nine small hydropower units were added (totalling 65 MW), and nine were retired (8 MW).[71] Pending projects also are all relatively small: 85 projects are in the pipeline, averaging 4 MW apiece, with the largest being 10 MW.[72] US hydropower generation fell 8.8% in 2021 to 260 TWh, around 7.3% below the average for the preceding decade.[73]

Refurbishment occurred at existing plants such as the Grand Coulee Dam in Washington state. This 6.8 GW facility, the largest power generating complex in the country, is undergoing multi-year overhaul and modernisation work, with one 805 MW unit completed in 2021.[74]

i This excludes 22.9 GW of US pumped storage capacity.

In **Canada**, the 824 MW Muskrat Falls facility in Labrador brought into service the second half of its generating units during the year.[75] The project suffered significant delays and budget overruns. Difficulties also remain with the transmission interlink with Newfoundland, limiting access to intended customers.[76] In Manitoba, the first five of the seven generating units making up the 695 MW Keeyask plant were placed into service in 2021.[77]

Public opposition remains a major obstacle to new transmission projects aimed at exporting Canadian hydropower to the United States. In late 2021, construction on a new transmission corridor from Quebec through the US state of Maine was halted after a public referendum in Maine firmly rejected the plans; a previous attempt to make the crossing via neighbouring New Hampshire failed in 2018 due to similar local opposition.[78] In 2020, after some setbacks, the Manitoba-Minnesota transmission link was completed to carry 250 MW of firm power from the Keeyask facility to the US state of Minnesota.[79]

In Africa, **Ethiopia** began generating electricity at its 5 GW Grand Ethiopian Renaissance Dam on the Blue Nile in early 2022, having partially filled the vast reservoir since 2020.[80] The country stressed the project's importance for wider electrification of the country while refuting long-standing concerns from downstream neighbours Sudan and Egypt, which claim that Ethiopia's actions risk their vital interests in the water resource.[81] Filling the reservoir will take some time, and at the proposed schedule of three to five years, Egypt's water supply could be reduced by more than a third (the country relies on the Nile for 90% of its water), affecting arable land and agricultural output.[82] International engagement in the decade-old dispute between the parties has not led to a resolution, and Egypt has vowed not to let the dam impede its water supply.[83]

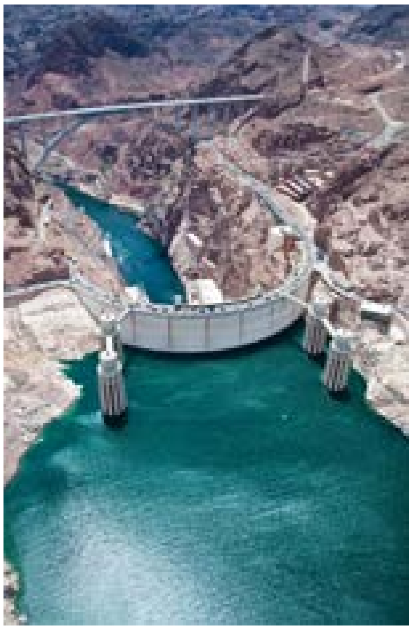
Zambia completed the first two of five 150 MW units at the Kafue Gorge Lower station.[84] The project, built by Sinohydro (China) and funded by Exim Bank of China, has experienced delays attributed to creditors not dispersing funds due to concerns about sovereign debt.[85] Commissioning was reportedly delayed by Sinohydro, which is seeking further financial guarantees from the debt-laden state utility.[86]

Pumped storage capacity increased significantly in 2021, rising around 3 GW to 163 GW.[87] By year's end, China completed the second phase of the world's largest pumped storage plant, the 3.6 GW Fengning station in Hebei Province.[88] Under construction since 2013, the facility uses twelve 300 MW reversible turbines and is intended to meet peak demand and to support grid stability and variable renewable generation in Hebei and Inner Mongolia.[89] Notably, it is the first direct current (DC)-coupled pumped storage plant in China, making it more efficient in function.[90] In total, China completed 2.85 GW of pumped storage in 2021, spread across nine units.[91]

In the US state of South Carolina, continuing upgrades at the Bad Creek pumped storage plant added 70 MW of capacity.[92] When all four turbines are upgraded by 2023, the plant's capacity will have grown by 280 MW to 1.64 GW, making it one of the largest such facilities in the United States.[93] In Portugal, the first 220 MW unit of the 1,158 MW Tâmega pumped storage facility was synchronised in early 2022.[94]

After design and implementation missteps in previous years, the World Bank re-approved partial funding of Indonesia's first pumped storage facility, the 1,040 MW Upper Cisokan on West Java.[95] With more than 80% of electricity on the Java-Bali grid coming from fossil fuels, the objective of the facility is to serve peak power demand and to accommodate larger penetration of renewable energy, while alleviating grid congestion.[96]

A modernisation project at South Africa's second largest pumped storage facility (built in 1981) was completed in 2021, with new generators expected to last another 40 years.[97] The power plant for the 1 GW facility in the Drakensberg mountains of KwaZulu Natal province is built entirely underground.[98]



MARKET AND INDUSTRY TRENDS

KEY FACTS

- **The ocean power industry** rebounded in 2021 as supply chains recovered from disruptions caused by the COVID-19 pandemic.
- **More than USD 180 million** in new investment flowed into the sector from diverse sources, including public funding programmes, private investment, initial public offerings and crowdfunding.
- **Maintaining revenue support** for ocean power technologies remains crucial for helping the industry achieve greater maturity.

OCEAN POWER

OCEAN POWER MARKETS

Ocean power technologies[i] represent the smallest share of the renewable energy market. Deployments increased significantly in 2021, with devices adding 4.6 megawatts (MW) of capacity to reach a total operating installed capacity of around 524 MW by year's end.[1]

Two tidal range systems – the 240 MW La Rance station in France and the 254 MW Sihwa plant in the Republic of Korea – account for the majority of this installed capacity. Tidal range systems operate similarly to hydropower; however, because potential locations are limited and large-scale environmental engineering is required, few proposals have been advanced to expand such systems.

The main focus of development efforts today is tidal stream devices and wave energy converters. Advancements in these technologies have been concentrated in Europe and especially in the United Kingdom, which has significant ocean power resources. Elsewhere, revenue support and ambitious research and development (R&D) programmes are spurring increased development and deployment in countries such as Canada, China and the United States.[2]

Tidal stream devices are approaching maturity, and pre-commercial projects are under way. Since 2010, around 40 MW of tidal stream capacity has been deployed, with around 15 MW currently operational.[3] Device design for utility-scale generation has converged on horizontal-axis turbines mounted either on the sea floor or on a floating platform.[4] Total generation exceeded 68 gigawatthours (GWh) as of the end of 2021.[5]

Wave power devices have yet to see the same level of design convergence. Developers generally aim to tap into utility-scale electricity markets with devices above 100 kilowatts (kW) and to meet specialised applications with devices below 50 kW.[6] Around 25 MW of wave power has been deployed since 2010, with around 3 MW currently operational.[7]

OCEAN POWER INDUSTRY

The ocean power industry rebounded in 2021 as supply chains recovered from disruptions caused by the COVID-19 pandemic and as significant new public and private investment flowed into the sector. Most capacity additions were test deployments, with developers continuing to demonstrate, refine and validate their technologies.

Six **tidal stream** devices totalling 3.1 MW were successfully deployed in 2021.

A 500 kW SIMEC Atlantis Energy (UK) tidal turbine was installed in Japan, producing more than 90 megawatt-hours (MWh) at high availability in its first five months[8] SIMEC's turbines also continued to generate power at the MeyGen array in Orkney, Scotland and have delivered more than 37 GWh since they entered into operation in 2016.[9] Also in Orkney, the European Marine Energy Centre (EMEC) deployed the 2 MW Orbital O2 device and the 2 MW Magallanes Renovables tidal platform.[10]

i Ocean power technologies harness the energy potential of ocean waves, tides, currents, and temperature and salinity gradients. In this report, ocean power does not include offshore wind, marine biomass, floating solar photovoltaics or floating wind.

In Canada, Sustainable Marine (UK) installed a 420 kW floating tidal energy platform in the Bay of Fundy, Nova Scotia, with grid connection scheduled for early 2022.[11] The French company Guinard Energies Nouvelles deployed two 3.5 kW devices, designed for use in isolated communities, in France and Togo.[12] Slow Mill Sustainable Power (Netherlands) commissioned a 40 kW device following prototype testing in the North Sea.[13] The Ocean Renewable Power Company (ORPC, US) deployed a second 35 kW RivGen unit in a remote Alaskan community, providing baseload power and reducing diesel consumption 60-90%.[14]

Wave power projects continued to face significant delays, but 10 deployments occurred, totalling nearly 1.4 MW in capacity.[15]

Wello (Finland) deployed a 600 kW device at the Biscay Marine Energy Platform in Spain.[16] In China, the Penghu aquaculture platform completed 28 months of operation, and the 500 kW Zhoushan wave energy unit completed its first round of testing and a second unit was deployed.[17] Wave Swell Energy (Australia) installed a 200 kW floating oscillating water column device at King Island in Tasmania, and Azura Wave Power (New Zealand) deployed a 20 kW grid-connected device for testing at the US Navy's Wave Energy Test Centre in Hawaii.[18] Two small wave power plants were installed in breakwaters in the Republic of Korea and Norway, and a 1 MW breakwater project was agreed to in Portugal.[19]

Development of other ocean power technologies, such as **ocean thermal energy conversion** (OTEC), remains slow, and only a handful of pilot projects have been launched.[20] In 2021, São Tomé and Príncipe announced a public-private partnership to deploy a floating OTEC platform.[21]

Technology improvements and steep cost reductions are still needed for ocean power to become competitive in utility markets, and the industry has not yet received the clear market signals it needs to take the final steps to commercialisation. The lack of consistent support schemes for demonstration projects has proved especially challenging for developers, and dedicated revenue support is considered paramount for providing predictable returns until the industry achieves greater maturity.[22]

As of 2018, more than EUR 6 billion (USD 6.8 billion) had been invested in ocean power projects worldwide, of which 75% was from private finance.[23] A 2018 European Commission implementation plan estimated that EUR 1.2 billion (USD 1.4 billion) in funding was needed by 2030 to commercialise ocean power technologies in Europe, requiring equal input from private sources, national and regional programmes, and European Union (EU) funds.[24]

Although the sector remains highly dependent on public funding to leverage private support, the 2020 announcement of two large private investments totalling USD 13.7 million spurred additional momentum in 2021.[25] ORPC secured USD 25 million from an investment consortium; Eco Wave Power (Sweden) raised USD 9 million in its initial public offering; the owners of Minesto (Sweden) contributed EUR 4.4 million (USD 5.0 million) to support commercialisation; and three other developers – Nova Innovation (UK), Wavepiston (Denmark) and QED Naval (UK) – raised a total of USD 6.8 million through crowdfunding.[26]

Significant policy measures and public funding programmes were announced. The EUR 45 million (USD 51 million) EU-SCORES project and the EUR 21 million (USD 24 million) FORWARD-2030 project focus on the development of hybrid systems, such as ocean power co-located with wind, while the EuropeWave R&D programme will support the development of wave power by combining nearly EUR 20 million (USD 23 million) in national, regional and EU funding.[27]

The United Kingdom announced a GBP 20 million (USD 27 million) annual investment in tidal stream as part of its Contracts for Difference Scheme, aiming to drive technology development, lower costs and make tidal power more competitive with offshore wind power.[28] This could spur deployment of 30-60 MW between 2025 and 2027.[29] The five-year, GBP 10 million (USD 13 million) Ocean-REFuel project was launched to explore methods for converting ocean power into fuels.[30]

Deploying ocean energy at scale will require streamlined consenting processes.[31] Uncertainty about environmental interactions has led regulators to require significant data collection and strict environmental impact assessments, which can be costly and threaten the financial viability of projects and developers.[32] Current science suggests that the deployment of a single device poses little risk to the marine environment, although the impacts of multi-device arrays are not well understood.[33] This calls for an "adaptive management" approach that responds to new information over time, supported by more long-term data and greater knowledge-sharing across projects.[34]

Ocean power bounces back with 16 deployment and **USD 180 million** in new investment.

KEY FACTS

- **Solar PV** maintained its record-breaking streak, with new capacity increasing 25% in 2021; global solar penetration averaged 5% in 2021, up from 3.7% in 2020.
- **For the ninth consecutive year**, Asia dominated all other regions in new solar PV installations, representing 52% of the global added capacity in 2021.
- **France was a new entrant** to the top 10 solar PV installers (tenth globally and third in Europe), adding 3.4 GW of capacity; this was more than triple the amount in 2020, bringing France's total installed capacity to 14.3 GW.
- **After many years of declines**, PV module costs jumped an estimated 57% in 2021 as the cost of raw materials increased sharply. Factors contributing to rising module costs included a polysilicon shortage and a rise in shipping container costs from China, the world's dominant module producer.
- **Supply chain disruptions** in 2021 highlighted the importance of domestic production of PV modules, with the United States extending its import tariff and India setting unprecedently high solar import duties.

SOLAR PV

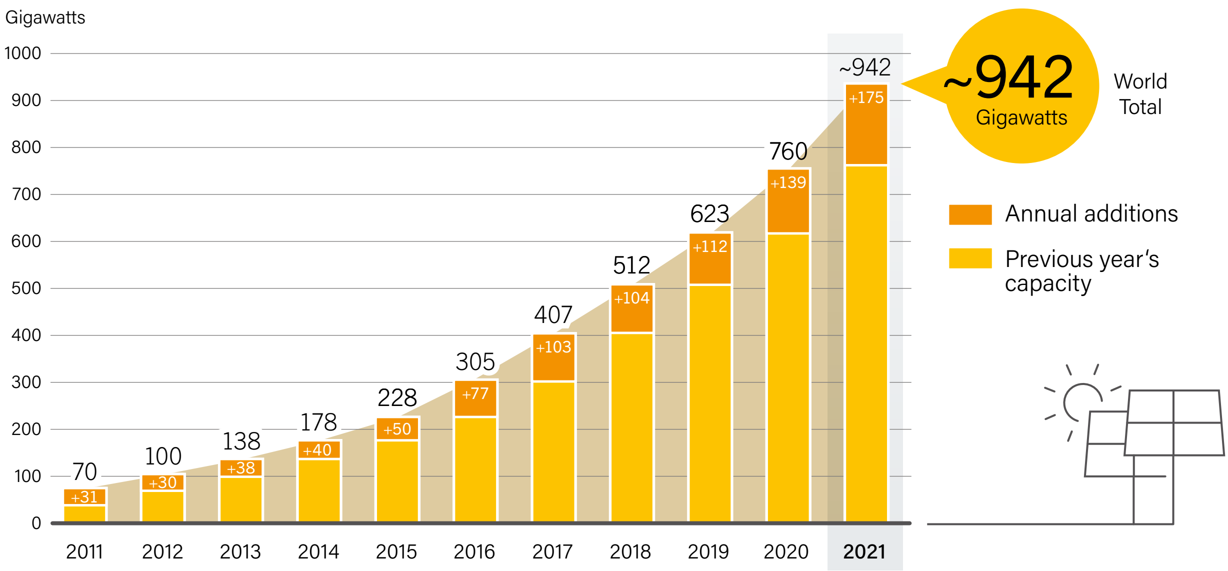
The solar photovoltaics (PV) market maintained its record-breaking streak, with new capacity installations totalling an estimated 175 gigawatts (GW) in 2021 – up 36 GW compared to 2020.[1] This was the largest annual capacity increase ever recorded and brought the cumulative global solar PV capacity to 942 GW.[2] (→ *See Figure 34.*) The market continued its steady growth despite disruptions across the solar value chain, due mainly to sharp increases in the costs of raw materials and shipping.[3]

Solar PV generation continued to play a substantial role in numerous countries. By the end of 2021, at least seven countries had enough capacity installed to meet at least 10% of their electricity demand from solar PV, up from only two countries in 2020.[4] At least 18 countries had enough solar PV capacity installed to meet 5% of their electricity demand, up from 15 countries in 2020.[5] Australia had the highest share of solar PV in annual generation, at 15.5%, followed by Spain (14.2%), Greece (13.6%), Honduras (12.9%), the Netherlands (11.8%), Chile (10.9%) and Germany (10.9%).[6] In total, solar PV contributed around 5% of global electricity generation, compared to 3.7% in 2020.[7]

For the ninth consecutive year, Asia dominated all other regions in new solar PV installations, representing 52% of the global added capacity in 2021.[8] (→ *See Figure 35.*) It was followed by the Americas (21%), which again surpassed Europe (17%).[9] The top five country performers[i] (in descending order) were China, the United States, India, Japan, and Brazil, together comprising around 61% of newly installed capacity.[10] (→ *See Figures 36* and *37.*) This top five share was lower than in 2020 (66%) as more players entered the market in response to solar PV's declining capital and operational costs.[11]

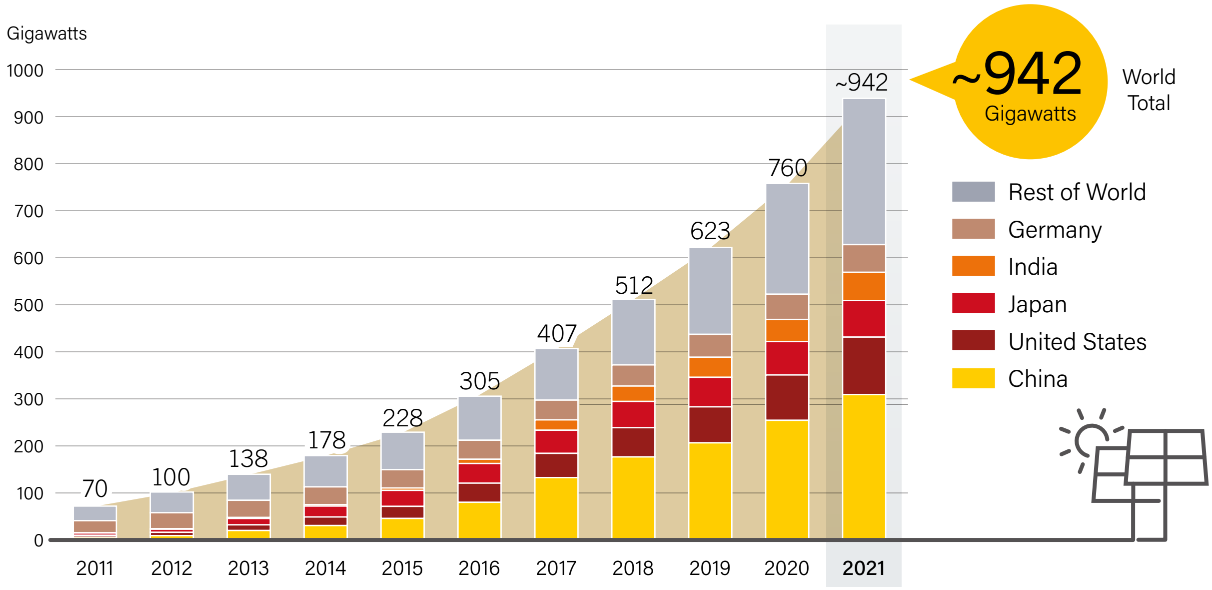
i Vietnam and the Netherlands exited the top 10 countries for capacities added in 2020, replaced in 2021 by new entrants Spain and France.

FIGURE 34.
Solar PV Global Capacity and Annual Additions, 2011-2021



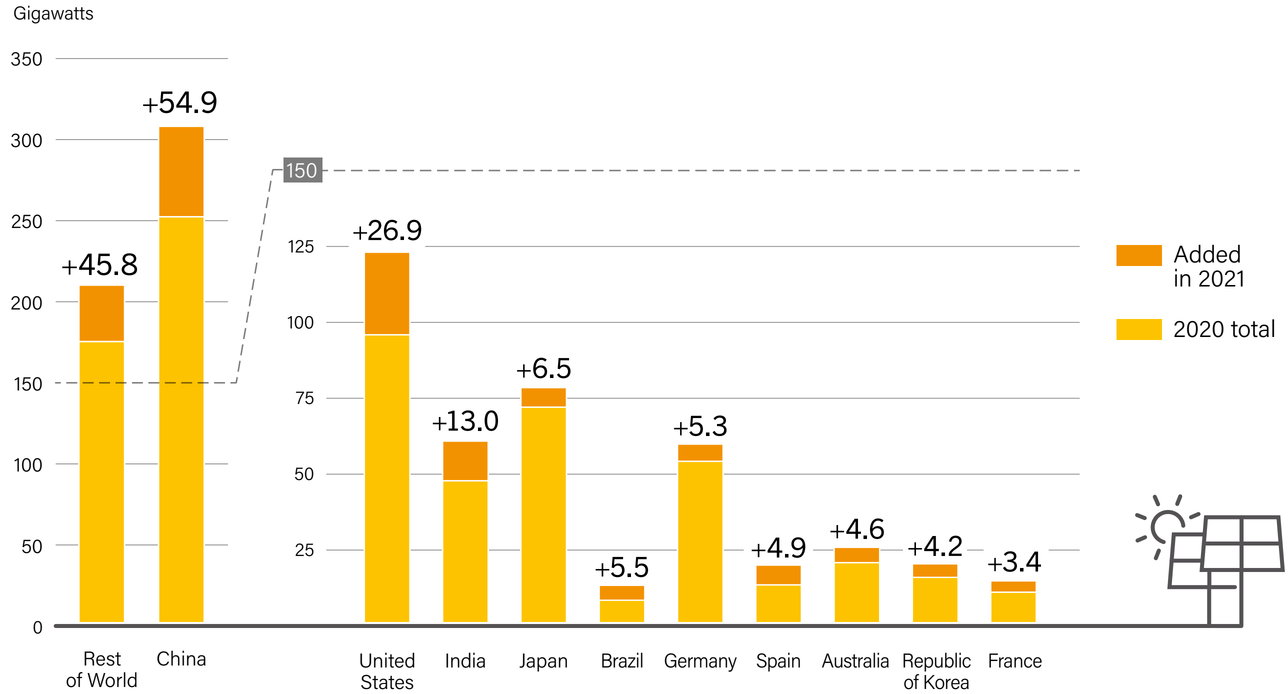
Source: Based on IEA PVPS. See endnote 2 for this section.

FIGURE 35.
Solar PV Global Capacity, by Country and Region, 2011-2021



Source: See endnote 8 for this section.

FIGURE 36.
Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2021



Source: See endnote 10 for this section.

The next five markets in 2021 were Germany, Spain, Australia, the Republic of Korea and France.[12] The threshold of annual market size required to rank among the top 10 countries in 2021 was 3.4 GW, up from 3 GW in 2020.[13] The leading countries for cumulative solar PV capacity remained China, the United States, Japan, India, and Germany, while the leading markets for per capita capacity were Australia, the Netherlands and Germany.[14]

China added 54.9 GW of solar PV capacity in 2021, of which around 29.3 GW (53%) was distributed[i] solar PV and 25.6 GW was centralised solar PV.[15] Overall, China's market grew 21.5% to reach a cumulative capacity of 305.9 GW, with 107.5 GW (35%) from distributed generation and 198.4 GW (65%) from centralised plants.[16]

China's market for centralised PV plants grew around 15% in 2021, while distributed solar PV was up 37%.[17] Given that 2021 was the final year to benefit from central government subsidies for residential systems, residential PV expanded 113% year-on-year.[18] Total electricity production (from all sources) increased 9.8% in China, while electricity produced from solar increased 25.2%, to 327 terawatt-hours (TWh).[19] Solar PV's share of total generation increased 15%, rising from 3.4% in 2020 to 3.9% in 2021.[20] Curtailment of solar energy in China averaged 2% in 2021, unchanged from the previous two years.[21]

India was the second largest market in Asia for new solar PV capacity, and third globally. Following two years of contraction, annual solar additions in the country underwent substantial growth in 2021 with an additional 13 GW installed, more than double the amount in 2020 and more than in any previous year, setting a new record.[22] This brought India's cumulative total to nearly 60.4 GW, enough to vault it into fourth place globally, ahead of Germany.[23] New capacity in India included around 9 GW (63%) of utility-scale solar (large-scale, centralised systems connected to the grid) and nearly 3.4 GW (23%) of distributed generation, with the rest being off-grid applications.[24] Market expansion was driven mainly by the focus on local manufacturing and the continuation of projects delayed since 2020 due to the COVID-19 pandemic.[25]

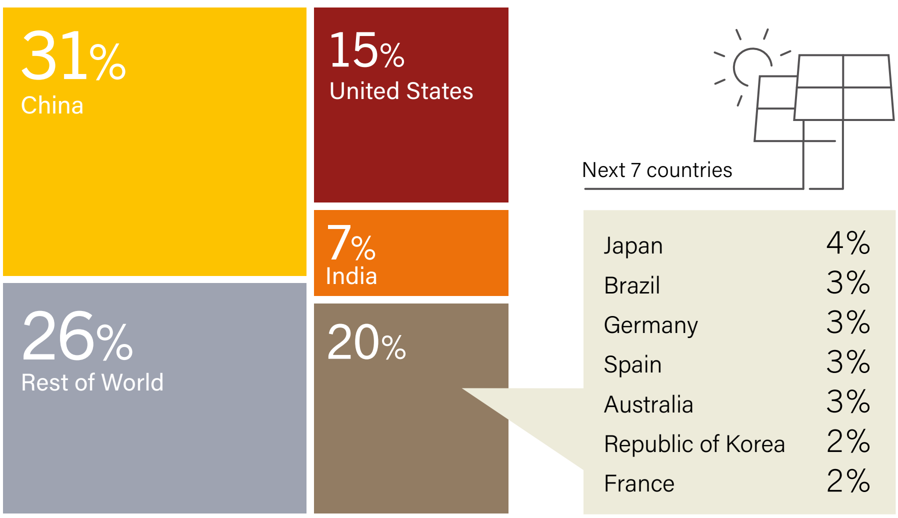
Distributed rooftop installations in India reached an all-time high in 2021, to comprise around 17% of the country's cumulative solar market.[26] Major potential lies in the commercial and industrial segment, which consumes around 49% of India's electricity generation and accounts for some 70% of distributed generation capacity.[27] Among the obstacles to solar expansion reported by commercial and industrial consumers are prolonged government approval processes and resistance from distribution companies.[28] On a positive note, after stakeholders protested the government's December 2020 announcement that it would allow net metering only for PV installations up to 10 kilowatts (kW), the government adjusted the scheme in April 2021 to allow loads up to 500 kW to be eligible.[29]

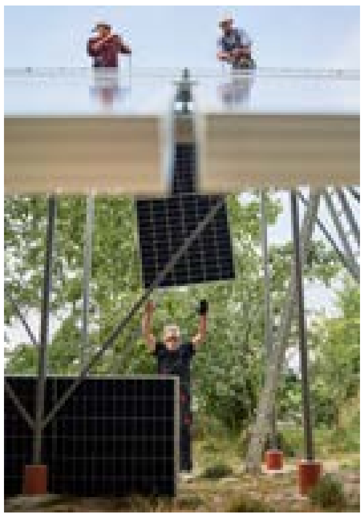
Japan's solar PV market declined in 2021.[30] The contraction was a result of challenges witnessed prior to 2020[ii], including grid connection constraints, a rising levelised cost of electricity for solar systems, limited land availability (and higher associated costs), and unfavourable conditions for off-site power purchase agreements (PPAs), such as high wheeling, grid integration and balancing fees.[31]

i Distributed generation refers to systems that provide power to grid-connected consumers, or directly to the grid, but on distribution networks rather than on bulk transmission or off-grid systems. In this section, it refers to rooftop and groundmounted PV for residential, commercial and industrial applications.

ii Japan's contraction in annual solar PV additions lasted four consecutive years, ending in 2020.

FIGURE 37.
Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2021





Note: Totals may not add up due to rounding.
Source: See endnote 10 for this section.

In 2021, the Japanese government developed a set of measures to expand solar PV, including requiring 60% of new residential buildings to include rooftop PV; introducing rooftop PV at airports nationwide; deregulating land zoning to allow PV installations on agricultural land (→ *see the sub-sections on floating PV and agrivoltaics*); and revisiting the climate law with the aim of shifting to carbon-neutral governmental institutions (i.e., zero-emission buildings).[32] To mitigate the land scarcity challenge, Japan's New Energy and Industrial Technology Development Organization (NEDO) issued guidelines to further support ground-mounted agricultural PV facilities that support dual land uses.[33]

Japan added an estimated 6.5 GW in 2021.[34] Despite the proposed measures to counteract the market contraction, capacity additions fell 25% from the previous year, bringing the country's cumulative capacity to 78 GW (an amount eclipsed only by China and the United States).[35] Around 50% of Japan's newly installed capacity was utility-scale solar PV, with another 40% in the commercial and industrial segment and the rest residential.[36] Solar PV accounted for an estimated 9.3% of Japanese electricity generation in 2021, up from 8.5% in 2020, with the highest local contributions in Kyushu (14.6%) and Shikoku (14.2%).[37]

Other Asian countries that added noteworthy capacity in 2021 included the Republic of Korea (4.2 GW), Chinese Taipei and Pakistan (around 2 GW each), and Vietnam (1 GW).[38] The Republic of Korea moved down a spot for capacity added, to ninth place globally, and continued to rank eighth for cumulative capacity, with 20.1 GW in 2021.[39] Turkey added at least 1.1 GW in 2021, and its market continued to be driven by net metering and self-consumption.[40]

Vietnam, which in 2020 had added around 11 GW and ranked third globally for new solar PV capacity installations, experienced only minimal additions in 2021, due mainly due to the ending of the feed-in tariff and the absence of a replacement solar pricing policy.[41] This freeze, which came after the country's abrupt solar surge, demonstrated the importance of long-term renewable energy policies to support consistent PV deployment.[42] It also highlighted the relevance of investment in system upgrades to unlock further solar PV potential and achieve minimal curtailment.[43] Even so, Vietnam made it into the top 10 countries for cumulative solar capacity in 2021, ranking tenth with 17.4 GW.[44]

The Americas represented around 21% of the global solar PV market in 2021, mainly because of developments in the **United States**, which continued to rank second globally for both new installations and total capacity.[45] The country added a record 26.9 GW during the year, up 19% to reach a cumulative capacity of 121.4 GW.[46] Solar PV was the leading source of US added generation capacity for the third consecutive year, accounting for a record 46% of US total capacity in 2021.[47]

The top state for new additions was Texas, which (with 6 GW) for the first time outranked California (3.6 GW), followed by Florida (1.6 GW).[48] Total US solar PV generation was 163 TWh, with the majority of this utility-scale (114 TWh) and the rest grid-connected distributed rooftop systems (49 TWh); in total this represented 3.9% of all generation in the country in 2021.[49]

The US market was again led by centralised utility-scale plants, which reached a national record of 17 GW of newly added solar PV capacity in 2021, for a total of 76.8 GW.[50] After three consecutive years of contraction, non-residential[i] installations grew 14%, adding 2.4 GW to reach 19 GW.[51] With increased consumer demand, the residential sector broke records with installations of 4.2 GW – up 30% from 2020 and the highest annual growth rate since 2015 – to reach a total capacity of 23.1 GW.[52]

Solar PV uptake continued to grow in Latin America, despite a slow recovery from the impacts of the COVID-19 pandemic.[53] The top four performers in newly installed capacity were **Brazil** (5.5 GW), Mexico (1.8 GW), Chile (1.3 GW) and Argentina (0.2 GW).[54] Brazil led in total installed capacity, ending the year with around 13 GW.[55] The country's newly added capacity advanced Brazil to fifth place in the global ranking (up from ninth in 2020).[56] For the third consecutive year, distributed solar installation led Brazil's market for newly added capacity, with 4 GW, driven by soaring electricity prices due to a hydropower crisis and by a national net metering regulation.[57] The residential sector accounted for the bulk of installations (77.4%), with commercial systems coming in second (12.7%).[58]

i Here, non-residential refers to commercial, government, non-profit and community solar PV systems.

Europe followed the Americas for new additions in 2021, adding around 28 GW for a year-end total of 191 GW; it was able to maintain its second place ranking for total installed capacity, with a 21% share of the global PV market.[59] New installations in the EU-27 increased 29.5% relative to 2020, with notable additions in countries across the region.[60] In total, the EU-27 brought online around 25 GW, raising its overall solar PV capacity 17.8% to reach 165.5 GW, marking the region's best year for solar.[61]

The top EU markets for new additions were Germany (5.3 GW), Spain (4.9 GW), France (3.4 GW) and the Netherlands and Poland (3.3 GW each). The top countries for total capacity at year's end remained Germany, Italy, Spain, France and the Netherlands.[62] In addition to the EU-27, the United Kingdom added 0.7 GW, up from 0.5 GW in 2020, for a total capacity of 14.4 GW.[63] The UK market continued to experience consistent, unsubsidised growth across different market segments, driven in part by higher gas prices.[64] Switzerland installed another 0.6 GW, bringing its cumulative capacity to 3.6 GW.[65]

Germany's capacity's additions were up 8% in 2021, which was well below the 26% growth rate in 2020.[66] The country's cumulative capacity reached 59.2 GW, ranking it fifth behind India for the first time ever.[67] Solar PV accounted for 9.9% of Germany's electricity production in 2021.[68] Market drivers in the country continued to be auctions, government tenders, and effective regulatory amendments to support further market investment (for example, cancellation of the energy surcharge for selfconsumption). To unlock potential synergies between solar PV and battery storage, a June 2021 amendment to the German Energy Industry Act abolished double charges and levies for battery systems, enabling better use of the flexibility potential of batteries in the energy system.[69]

Spain added 4.9 GW of solar capacity in 2021, 44% more than in 2020 (3.5 GW).[70] This marked a new record for annual installations, bringing Spain's total capacity to 18.5 GW, representing annual growth of 36.7%.[71] As in 2020, much of the capacity addition was unsubsidised power purchase agreements (PPAs), making Spain the largest stakeholder of PPAs in the European market.[72] In comparison to large ground-mounted systems, Spain's self-consumption market accounted for a smaller share of installations, but the new national self-consumption strategy, approved in 2021, aims to develop this largely untapped segment.[73] Also during the year, the country's first utility-scale solar plant (40 MW) combined with batteries (9 MWh) was commissioned.[74]

France, a new entrant to the top 10 solar PV installers (tenth globally and third in Europe) added 3.4 GW of capacity, more than triple the amount in 2020, bringing its total installed capacity to 14.3 GW.[75] Solar PV generation increased around 12% in 2021, accounting for some 3% of the country's total electricity production.[76] Most of the additions (54%) were systems larger than 250 kW.[77] To increase its relatively small rooftop PV share, France, in line with current EU guidelines, raised its feed-in threshold from 100 kW to 500 kW, making procedures easier for this market segment, where projects previously were limited by tendering.[78] France's second largest PV plant came online in September with an installed capacity of 152 MW.[79] Also in 2021, the government announced its aim to install at least 3 GW of solar capacity annually to 2025 and released an action plan of 10 measures to facilitate this expansion.[80]

Australia remained the largest solar PV market in the South Pacific, ranking eighth globally for additions and sixth for total capacity.[81] It added around 4.6 GW in 2021, for a cumulative capacity of around 25.4 GW.[82] In 2021, Australia set a new global record of 1 kW of installed solar PV per capita, which was 31% higher than in the runner-up country the Netherlands (0.765 kW per capita).[83] Solar PV generation rose more than 26%, to 28.5 TWh, to represent 12.4% of Australia's total generation; rooftop PV alone accounted for 24.9% of renewable generation and for 8.1% of all generation.[84]

Europe followed the Americas for new additions in 2021,
adding around 28 GW
for a year-end total of 191 GW.

The rooftop sector continued to contribute most of the new capacity in Australia, setting new records for both solar PV and small-scale battery storage installations. More than 3.3 GW of small-scale solar PV systems (under 100 kW) was installed in 2021, up from 2.9 GW in 2020, for a total exceeding 16 GW.[85] Household battery additions grew significantly (45%) in 2021, with an estimated 34,741 battery systems added with a combined capacity of 347 MWh.[86] By year's end, a record 3 million homes across Australia had rooftop solar systems.[87] However, the country's remarkable uptake of rooftop solar has challenged the stability of the grid, leading some jurisdictions to introduce export limits and remote disconnection in 2021.[88] Another proposed measure recommended charging rooftop solar customers for exporting their surplus electricity to the grid.[89]

The **Middle East and Africa** added an estimated 5.2 GW in 2021, up 3% for a total of 28 GW.[90] Off-grid installations grew rapidly, and rooftop PV outside of any regulatory scheme has progressed quickly in many countries.[91] Despite the region's favourable irradiance, it had the fewest countries reaching the milestone of covering 5% of their electricity demand with installed solar PV; by year's end, Egypt and the United Arab Emirates – the hosts of the next two United Nations climate summits – were at 3%.[92]

Globally, both the **utility-scale PV** market and the rooftop market experienced growth in 2021, while their relative shares of annual installations stayed the same as the previous year.[93] Capacity additions of utility-scale PV increased around 20%, to reach a total of 100 GW of installations, while rooftop PV rose around 25% to reach 75 GW.[94]

As of 2021, more than 40% of global utility-scale installations were in China (25.6 GW) and the United States (17 GW).[95] Utility-scale solar is now growing even in the absence of government subsidies, driven by the economic competitiveness of solar electricity and the attractiveness of PPAs. In Denmark, where solar PV installations surged in 2021, more than 90% of the added capacity was from large-scale, unsubsidised projects, driven by clearly defined market regulations, co-operative municipalities and utilities, and high maturity of the PPA market.[96] Utility-scale projects also played a crucial role in the expansion of solar markets in Spain and France.

The main installations in the **rooftop market** occurred in China, the United States, Spain, Australia and Germany.[97] In Europe, the expansion of distributed generation installations was driven by the fuel crisis and by surging electricity prices, pushing entities to rely on self-consumption and to reduce their dependence on the electrical grid, where possible.[98] Globally, the residential rooftop segment outperformed both the commercial and industrial rooftop segments for the first time, growing 30% in 2021.[99] Rooftop PV installations on residences and small commercial buildings grew around 33% in 2021, whereas installations in the commercial and industrial segment fell 3-4%.[100]

This discrepancy is attributed to the rising price of PV modules as a result of supply chain disruptions. Medium-scale solar PV plants (greater than 500 kW) commissioned on the premises of commercial and industrial customers are more vulnerable to such disruption than small-scale residential solar systems. For smaller-scale PV installations, the labour and sales costs represent a higher share of the overall system cost for users, making these systems less influenced by price fluctuations.[101]

A number of countries took steps in 2021 to expand the market share of rooftop PV systems and their contribution to the energy mix. China announced a programme that requires government, public, commercial and rural buildings to have a specified percentage of rooftop solar systems by 2023.[102] Norway has introduced modifications to its rebate scheme for residential solar installations to allow further market expansion.[103] In South Africa, where electricity production has been declining for a decade, the public utility Eskom was able to minimise the generation gap by tapping into rooftop solar that feeds into the grid, while generating revenue from wheeling fees.[104] Egypt and the United Arab Emirates both wish to position themselves as positive climate actors and have increased their rooftop PV ambitions (in the case of Egypt, raising the target from 300 MW to 1,000 MW).[105] After India increased its cap on solar PV installations under its net metering scheme, the country's rooftop PV market hit an all-time high in 2021.[106]

Floating photovoltaics and **agricultural PV**[i] are niche markets that are increasingly gaining interest despite being around for more than a decade. Such installations have managed to overcome the land availability challenge that typically faces conventional solar installations. In South-East Asia and Africa, where solar projects tend to compete with agricultural land uses, these solutions are of particular interest because they enable solar installations without compromising water and food resources.[107]

i Agricultural PV use the same site for both energy and crop production.

Floating PV plants continued to expand with installed capacity exceeding 3 GW in 2021, up from only around 100 MW in 2016.[108] The world's largest floating PV plant (320 MW) came online in China in 2021.[109] In Europe, Portugal held an auction for 500 MW of floating solar to be located at seven hydropower dams and to be operational by year's end.[110] Singapore unveiled a 60 MW floating solar farm, located on a reservoir in the country's west, that fully powers five water treatment plants.[111]

The world's largest agricultural PV project, located in China, was completed in 2021 with a capacity of around 1 GW.[112] Asia hosts the majority of agrivoltaic plants, although countries elsewhere, such as Chile, the Gambia, and Mali, also have considerable installations.[113] In Europe, success stories can be found in France, Greece, the Netherlands, and Spain, among others.[114] Italy included EUR 1.1 billion (USD 1.24 billion) in support for agrivoltaics in its post-COVID recovery plan.[115] Farmers are beginning to gain wider awareness of the benefits of agricultural PV – including higher crop yields – and of the types of crops suitable to grow under the shade of the PV panels, based on research studies.[116]

Building-integrated PV systems and **vehicle-integrated PV**[i] are niche methods of installation that entail integrating the PV within a surface. Nearly half of the estimated installed building-integrated PV capacity is in Europe, which has provided significant financial support.[117] Italy and France both implemented supportive policies and together have around 5 GW of capacity.[118] The expansion of building-integrated PV installations requires innovations in the design of PV-integrated surfaces to encourage architects to embrace the technology; multiple building manufacturers now integrate PV into their products, including the largest manufacturer, based in Canada.[119]

Vehicle-integrated PV remains nascent, although the concept is not new.[120] It can result in a 40% annual reduction in a vehicle's charging time and has progressed from the research and development phase towards prototyping and demonstration, with a few pilot projects (mainly in Germany) for heavy-duty trucks and light vehicles.[121] In January 2022, Mercedes-Benz launched a prototype electric car with integrated PV that reportedly produces an additional 25 kilometres of range per day.[122]

Micro-distributed solar generation is growing not only in off-grid areas but increasingly in cities. In this set-up, both the solar panel installation and the use of the output electricity occur in the same location; it typically is used in outdoor spaces to charge mobile phones or to power small cooking appliances.[123]

After many years of declines, **PV module costs** jumped an estimated 32% in 2021, from an average of USD 0.21 per Watt-peak to USD 0.33 per Watt-peak.[124] The cost of industrial silicon surged some 300%, aluminium rose more than 50%, and soda ash, a key material for solar glass, increased 80%.[125] Polysilicon[ii] also experienced a significant cost increase (around 350%) to an unprecedented USD 38 per kilogram.[126] To put this in perspective, the input materials (polysilicon, metal commodities, coatings and glass) comprise around 65% of the total cost of a PV module, while PV manufacturing (module assembling, cell processing and wafer processing) represents around 22% and shipping 12.5%.[127] Polysilicon alone makes up around 35% of the total module cost.[128] Most of the recent price increase has been absorbed by upstream manufacturers of solar wafer, cells and modules.[129]

A variety of factors contributed to the rising costs of PV module materials and components. In response to a Chinese national policy aimed at reducing the energy intensity of the economy, several provincial governments in China restricted industrial production, which resulted in reduced manufacturing of solar PV components, primarily polysilicon.[130] On top of the ongoing supply chain disruptions, there were also **shipping delays** in 2021, as well as a major increase in the price of transporting shipping containers: for example, the cost of shipping a container from China to California increased 43%, while the cost of shipping from China to West Africa grew by a factor of five to six.[131]

In response to these and other (pandemic-related) disruptions and uncertainties, some PV plant developers have **postponed**

i Not to be confused with building and applied PV (BAPV and VAPV), which consist of fitting PV modules onto a surface.
ii Polysilicon is the raw material for crystalline silicon which is used to manufacture PV wafers.

installations to secure lower module prices.[132] This means that as soon as PV module prices go down, multiple installations could be triggered.[133] However, time limits in PPA contracts, as well as expirations of government policies, could constrain how long developers can postpone project construction.[134]

Multiple countries intensified a desire to lessen their dependence on international markets for solar PV manufacturing. The importance of **domestic production** was emphasised after the US government banned imports of materials manufactured in Xinjiang, China, following speculation that polysilicon producers were using forced labour in the region, which supplies 45% of the world's polysilicon.[135] Under the US ruling, importers are required to provide solid evidence disproving the use of forced labour (including child labour).[136] Prior to the US ban, the EU considered proposing a ban on products produced through forced labour, but as of April 2022 it had not taken any steps yet towards this.[137]

In the wake of its ban, the United States aims to expand domestic solar PV manufacturing to minimise its **supply chain** dependence on China and to position itself as leading solar supplier.[138] Chinese PV manufacturers have responded by shifting their solar supply chain away from Xinjiang – including to Inner Mongolia, where the region's more robust power grid offers greater access to renewable energy, which can be used to offer customers a product with a reduced carbon footprint.[139]

US actions to support local production of solar modules date back to 2018 when the US International Trade Commission imposed a 30% **tariff on solar cells and modules** imported from China.[140] Initially set to expire in February 2022, the tariff was extended for another four years, with annual reductions of 25% per year; however, it does not apply to the first 5 GW (cumulative) of imported solar cells annually (the previous quota was 2.5 GW).[141] Imported bi-facial modules, which were exempt from the tariff from June 2019 to October 2020, remain exempt.[142]

India also is jockeying to take the lead in solar PV manufacturing, not only to reduce its reliance on China but also to export cells internationally. Steps towards Indian solar self-sufficiency at the end of 2021 included setting unprecedently high **solar import duties** that increased the price of imported panels around 40%; banning the import of Chinese panels for at least the first quarter of 2022; and offering very attractive subsidies for companies aiming towards local manufacturing.[143]

Multiple countries

intensified a desire to lessen their dependence on international markets for solar PV manufacturing.

In 2021, passivated emitter cell (PERC)[i] solar panels remained the dominant cell technology, with around 90% of the PV market share, as compared to n-type cells such as tunnel-oxide passivated contact (TOPCon)[ii] and heterojunction technology (HJT).[144] Following China's successful localisation of factory equipment needed to produce TOPCon cells and HJT panels, the **investment per gigawatt** dropped in 2021 (from USD 35 million to USD 28 million for TOPCon, and from USD 62 million to USD 55 million for HJT), bringing these closer to the cost level of PERC (USD 22 million per GW).[145] The investment cost is lower for TOPCon than for HJT, since PERC manufacturers can adapt their manufacturing lines to TOPCon, whereas HJT requires an all-new cell production line.[146]

In line with previous years, installations of **bi-facial modules**, which capture light on both sides, continued to grow. By the end of 2020, the total installed capacity of bi-facial systems was around 20 GW (additions in 2021 remain uncertain).[147] Bi-facial modules have an energy yield of around 6% to 10%, more than PERC modules; however, the yield aspect by itself does not imply a lower levelised cost of electricity.[148] Recent studies that considered other factors concluded that the levelised electricity cost from bi-facial modules is either lower than or close to that of mono-facial.[149]

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.

ii TOPCon cells adapt a sophisticated passivation scheme to advance cell architectures for higher efficiencies.

CONCENTRATING SOLAR THERMAL POWER

KEY FACTS

- **CSP market growth** declined in 2021 due to the decommissioning of an older 300 MW plant.
- **Spain and the United States**, the market leaders in cumulative installed CSP capacity, have not added new capacity for eight and six years, respectively.
- **More than 1 GW** of new CSP capacity was under construction in 2021 in Chile, China, the United Arab Emirates and South Africa.
- **Around 70% of the CSP capacity** under construction in 2021 was based on parabolic trough technology, while the rest was tower systems. These facilities include 8.8 gigawatt-hours (GWh) of thermal energy storage capacity.

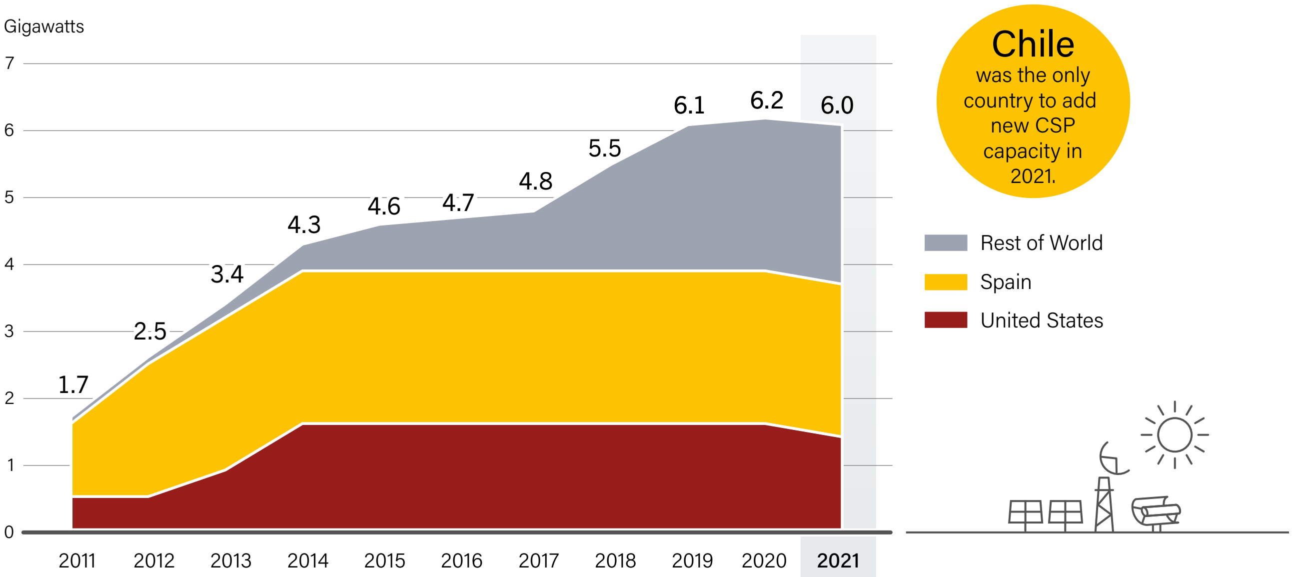
CSP MARKETS

In 2021, the global market for concentrating solar thermal power (CSP)[i] contracted for the first time since the commercial establishment of the industry in the 1980s, to reach a total cumulative capacity of 6 gigawatts (GW).[1] (→ *See Figure 38.*) This contraction occurred as the launch of the long-awaited 110 megawatt (MW) Cerro Dominador plant in Chile was offset by the decommissioning of nearly 300 MW of older CSP plants in the United States.[2]

Growth in the global CSP market has trended downwards since 2015, despite consistent cost declines during this period.[3] Prior to 2015, the market grew just under 40% annually on average for eight years.[4] The recent decline is due largely to inactivity in the two countries with the most CSP installations, Spain and the United States, which added no new capacity for eight and six years, respectively, because of policy changes, project failures and competition from solar PV.[5] Some market recovery was expected in 2022 with the addition of 750 MW of new capacity in China and the United Arab Emirates.[6] Crucial to scaling the sector are policies that place greater value on the flexibility of CSP with thermal energy storage (TES), as well as continued efforts to reduce costs and increase capacity factors.[7]

i CSP is also known as solar thermal electricity (STE).

FIGURE 38.
Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2006-2021



Source: See endnote 1 for this section.

Around 70% of the CSP capacity under construction in 2021 was based on parabolic trough technology, with the rest based on tower systems.[8] The facilities under construction will include 8.8 gigawatt-hours (GWh) of TES capacity.[9]

Chile's 110 MW Cerro Dominador facility is the first commercial CSP plant commissioned in Latin America and incorporates 17.5 hours of TES (1,925 megawatt-hours, MWh)[i].[10] The plant began construction in 2014 but experienced protracted delays after the original developer, Spain's Abengoa, was restructured during 2016.[11]

In the United Arab Emirates, construction continued on the Mohammed bin Rashid Al Maktoum Solar Park, consisting of a 600 MW parabolic trough facility (11 hours; 6,600 MWh) and a 100 MW tower facility (15 hours; 1,500 MWh).[12] These installations, expected to be operational during 2022, would bring the total CSP capacity in the Middle East and North Africa to 1.7 GW.[13]

In China, around 250 MW of CSP capacity was under construction, with the 50 MW Yumen Xinneng/Xinchen tower plant (9 hours; 300 MWh) expected to be operational in 2022.[14] China's 14th Five-Year Plan emphasises support for CSP, and the country has been one of the most active CSP markets in recent years: plans were announced in early 2022 to complete 11 new plants with TES by 2024.[15]

In South Africa, construction started on the 100 MW Redstone CSP tower facility (12 hours; 1,200 MWh), after protracted delays.[16] The plant will bring the total CSP capacity in the country to 600 MW upon its anticipated completed in 2023.[17] Also in southern Africa, Namibia's national electricity utility, NamPower, announced plans to tender a 50-130 MW CSP project during 2022.[18]

Spain remained the global leader for cumulative CSP capacity in operation, with 2.3 GW at the end of 2021.[19] However, the country's share of global CSP capacity in operation declined from a high of nearly 80% in 2012 to just under 40% by the end of 2021, reflecting no new capacity additions in eight years.[20]

Spain's government has signalled an end to this hiatus with the announcement of an auction for 200 MW of CSP capacity in the first half of 2022 and a target of 5 GW of new CSP capacity by 2027.[21]

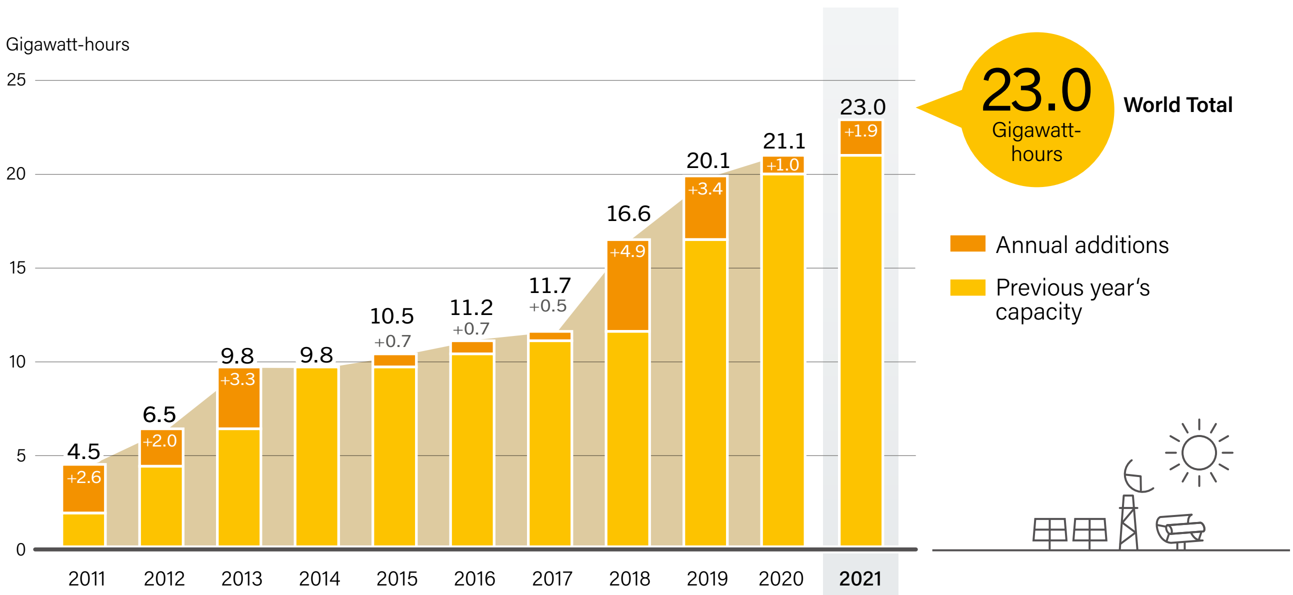
The United States came in second with just over 1.3 GW of commercially operational CSP, or slightly more than 20% of the global capacity.[22] CSP capacity in the country declined in 2021 with the decommissioning of 274 MW across several units of the Solar Energy Generating Systems (SEGS) facility in California.[23] Among the SEGS facilities, the 14 MW SEGS I plant, completed in 1984, was the first utility-scale commercial CSP plant ever built.[24]

By the end of 2021, an estimated 23 GWh of thermal energy storage, based almost entirely on molten salts[ii], was operating in conjunction with CSP plants across five continents.[25] (→ *See Figure 39.*) Only 2 of the 25 CSP plants completed globally since the end of 2014 do not incorporate TES: an integrated solar combined-cycle facility in Saudi Arabia and the Megalim plant in Israel.[26] TES capacity, installed mainly alongside CSP, represents nearly 40% of the global energy storage capacity outside of pumped hydropower.[27]

i Individual TES capacities are calculated by multiplying the reported hours of storage for each facility by their corresponding rated (or net) power capacity in MW.

ii The total TES capacity in MWh is derived from the sum of the individual storage capacities of each CSP facility with TES operational at the end of 2021. More than 95% of global TES capacity in operation on CSP plants is based on molten salt technology. The remainder uses steam-based storage.

FIGURE 39.
Thermal Energy Storage Global Capacity and Additions, 2011-2021



Source: See endnote 25 for this section.

CSP INDUSTRY

Industry activity in the CSP sector continued to focus largely on Africa, the Middle East, and Asia, with Chile emerging as Latin America's first active commercial market.[28] CSP projects that either entered operations or were under construction during 2021 involved lead developers and investors from China, Saudi Arabia and the United States.[29] Contractors were based in China Spain, and the United States.[30] The Saudi company ACWA Power remained the leading CSP project developer in 2021, with 800 MW under construction[i].[31]

CSP costs continued to decline during the year, as evidenced by the record-low CSP bid tariff (USD 34 per MWh) for the 390 MW Likana plant (incorporating 13 hours of TES) in Chile, received during a renewable energy capacity auction.[32] This followed a nearly 70% decrease in average CSP costs during the decade ending in 2020.[33] Multiple factors have contributed to these declines, including technological innovation, improved supply chain competitiveness, and the growing CSP capacity in regions with high solar irradiance (which, along with increased TES capacity, has boosted the overall capacity factor of the global CSP fleet).[34]

The ability for CSP with TES to compete with other power technologies is influenced strongly by the structure of power auctions and procurement processes, and the value placed on specific benefits of these systems in terms of dispatch flexibility and capacity factor.[35] (→ *See Energy Systems chapter.*)

CSP with TES has high potential to enhance power systems that incorporate large volumes of variable renewable power based on solar PV and wind.[36] In many cases, CSP and TES are co-located with solar PV capacity to reduce costs and increase capacity values. The newly completed Cerro Dominador plant in Chile is co-located with 100 MW of solar PV, and the Spanish CSP company Sener announced plans in 2021 to implement a hybrid plant that incorporates CSP with molten salt storage and solar PV.[37]

Other hybrid concepts emerged in 2021, some of which combine CSP and TES with other forms of storage to create longer-duration storage, enhance flexibility or produce clean fuels. Photon Energy (Sweden) and RayGen (Australia) announced plans to implement a 300 MW solar plant with 3.6 GWh of energy storage using CSP, solar PV, TES and long-duration thermal-hydro storage.[38] A demonstration project in California (US) produced green hydrogen using CSP.[39]

In addition to these novel combinations, a range of other research and development (R&D) activities were under way to improve the costs, reliability and flexibility of CSP and TES systems. Many were supported by public funds. For example, the US Department of Energy (DOE) announced USD 39.5 million for R&D on solar PV and CSP, and the DOE's Solar Energy Technologies Office set a cost goal of $50 per square metre for heliostats[ii], with the aim of bringing the CSP price to $0.05 per kilowatt-hour.[40] R&D in TES was focused on high-temperature storage media such as liquid metals.[41]

Global CSP market contracted for **the first time since 1980's**.

i Other notable developers, investors or owners of CSP plants that either entered operations or were under construction during the year included EIG Global Energy Partners (US), Solar Reserve (US), the Shanghai Parasol Renewable Energy Company (China) and the Jiangsu Xinchen CSP Company (China). Some of the leading companies involved in the engineering, procurement and construction of CSP facilities were Abengoa (Spain), Shanghai Electric (China), Acciona (Spain), Brightsource (US) and Gansu No. 1 Construction Engineering Group (China). See endnote 1 for this section.

ii Heliostats are dual-axis tracking reflectors or mirrors grouped in arrays used to reflect sunlight in the collection tower.

KEY FACTS

- **China** remained the world's largest market for solar thermal capacity additions in 2021, followed distantly by India, Turkey, Brazil and the United States.
- **Annual sales** grew at double-digit rates in several large solar thermal markets, including Brazil, France, Greece, India, Italy, Morocco, Poland, Portugal and the United States.
- **Large collector manufacturers** benefited more than small manufacturers from the growing market and continued to consolidate their market positions.
- **Solar industrial heat capacity** under construction was dominated by higher-temperature systems that use concentrating collector technologies.

SOLAR THERMAL HEATING

The global solar heat market grew 3% in 2021 to 25.6 gigawatts-thermal (GW_{th})[i], up from 24.9 GW_{th} in 2020.[1] This reversal, after seven years of decline, was the result of several factors, including rebounded demand (particularly in China) in the wake of COVID-19 related trade and traffic restrictions; increased construction activity in many countries; additional support schemes under national economic recovery policies; and rising fossil fuel and electricity prices.[2] Sales grew at double-digit rates in several large solar thermal markets including Italy (83%), France (70%), Brazil (28%), Portugal (22%), the United States (19%), Greece and India (18% each), Poland (17%) and Morocco (10%).[3]

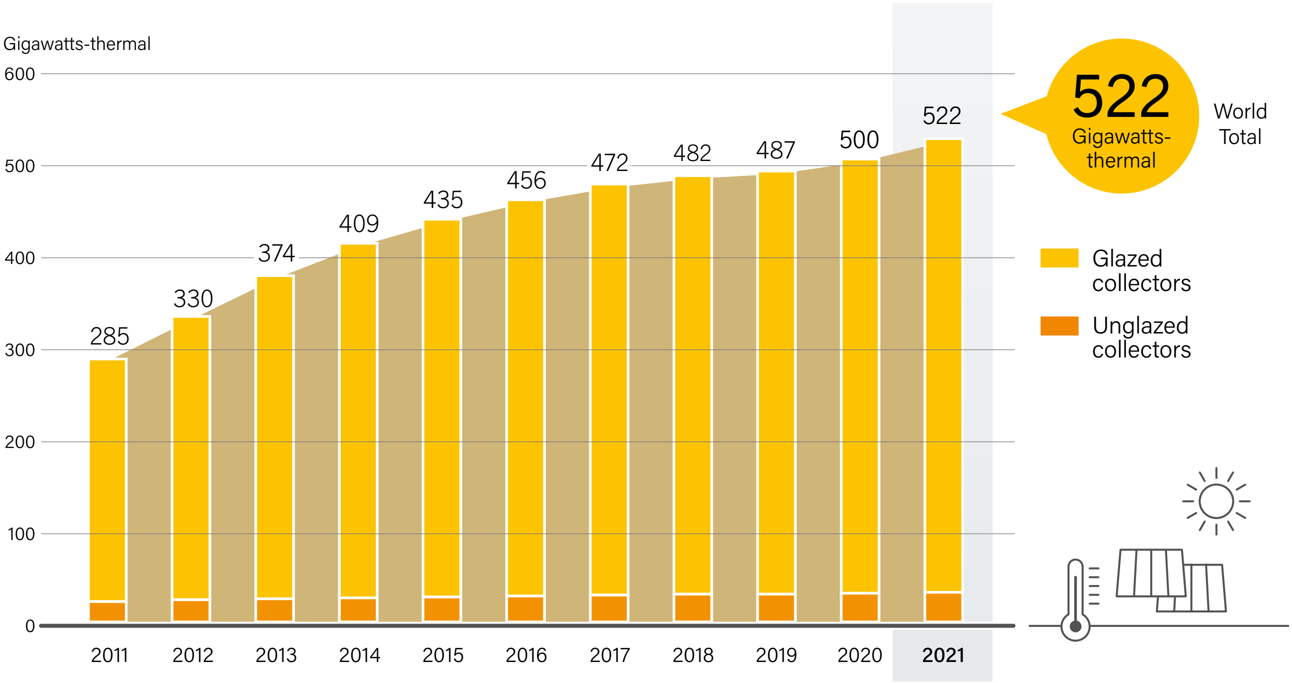
In some large residential markets (such as Australia, Austria, China, France, Germany and Spain), solar thermal solutions continued to face fierce competition from heat pumps and biomass boilers, both of which offer stand-alone solutions for hot water and/or space heating.[4] However, in some markets (such as China, France and Spain), utility and industry demand for large-scale solar heat projects helped offset the slowing household demand for solar water heaters.[5]

The transition continued from small residential solar thermal systems to large central procurement offers for big construction projects and commercial and industrial plants (such as in Austria, China and France). This resulted in consolidation among collector manufacturers globally, as only large producers were able to respond to the new demand structure.[6] Some of the world's largest collector manufacturers further consolidated their market position by receiving new orders from smaller producers that closed their own factories in Europe, in response to years of declining sales, and chose to purchase collectors from large producers.[7] Despite growing sales volumes, the large equipment manufacturers increased their prices for solar collectors and storage tanks and reduced their margins in 2021 to meet the challenge of rapidly rising material costs.[8]

By year's end, millions of residential, commercial and industrial clients in at least 134 countries were benefiting from solar thermal heating and cooling systems.[9] Cumulative global solar thermal capacity in operation reached an estimated 522 GW_{th} in 2021, up 4% from 502 GW_{th} in 2020.[10] (→ *See Figure 40.*) Total global capacity in operation at the end of 2021 was enough to provide around 427 terawatt-hours (1,537 petajoules) of heat annually, equivalent to the energy content of 251 million barrels of oil.[11]

i Global data for annual capacity additions and total capacity in operation in this section include all collector types: glazed (flat plate and vacuum tube collector technology), unglazed, concentrating, air and photovoltaic-thermal (PV-T). In previous editions of the GSR, global additions and totals included only glazed and unglazed collectors. The change is being made because formerly niche applications (concentrating, air and PV-T) are playing a growing role in some national markets and because data availability has increased.

FIGURE 40.
Solar Water Heating Collectors Global Capacity, 2011-2021



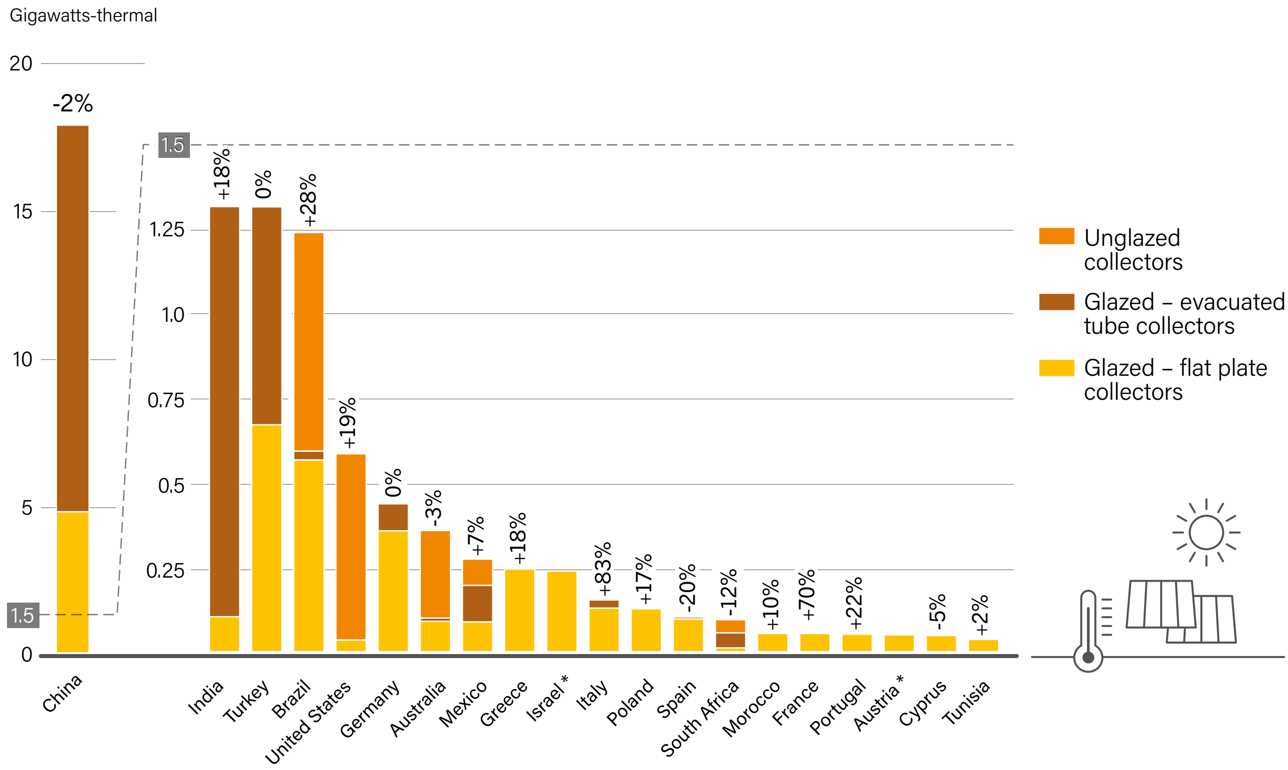
Source: Based on IEA SHC. See endnote 5 for this section.
Note: Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors.

As most residential and commercial solar heat projects include a storage tank unit, solar heat deployment plays an important role in creating a market for thermal energy storage (TES) capacity, which helps to integrate high shares of renewables in buildings and industry. Assuming a minimum storage volume of 50 litres per square metre of collector area in operation, the global solar thermal storage capacity reached an estimated 2,620 gigawatt-hours (GWh) at the end of 2021.[12]

China remained the world's largest national market for solar thermal systems of all types, accounting for 73% of the cumulative world capacity, followed distantly by the United States, Turkey, Germany and Brazil. The top 20 countries for new additions remained more or less the same in 2021, led by China, India, Turkey, Brazil and the United States.[13] (→ *See Figure 41.*)

Europe added
11% more solar thermal capacity
in 2021 than in 2020, due to increased policy support.

FIGURE 41.
Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2021



Source: See endnote 13 for this section.

Note: Additions represent gross capacity added. Numbers atop bars represent the rate of growth in annual sales relative to 2020.
*Additions for Austria and Israel refer to 2020 (latest data available). For Morocco, the share of collector types was not available.

TOP COUNTRY MARKETS

China's solar thermal market ended its downward slide after eight years of continuous decline.[14] Manufacturers installed 17.7 GW_{th} of solar thermal capacity in 2021, around the same as in 2020.[15] The market turnaround was driven by growth in central hot water and space heating projects for the housing industry, spurred by overall economic recovery following the pandemic-related lockdowns.[16]

Across China, newly installed solar thermal capacity for space heating (both district systems and individual buildings) increased 15%, adding a total of 2 GW_{th}.[17] The increase was due largely to "green" heating policies aimed at replacing coal boilers in the country's north to improve air quality.[18] The market also was aided by industry promotional activities: for example, in the leading solar provinces of Shandong and Jiangsu, manufacturers of solar thermal systems offered trade-in options tied to building renovations, which helped stimulate demand, particularly among rural households.[19]

Industry consolidation in China continued in 2021, with only large solar equipment manufacturers bidding on central procurement offers for solar thermal equipment and large solar collector fields.[20] In reaction to the declining market volumes in recent years, Chinese large collector manufacturers continued to expand their portfolios into renewable heating more broadly. By the end of 2021, half of China's producers were offering stand-alone heat pumps and solar heat pump solutions.[21]

Vacuum tube collectors continued to dominate the Chinese solar thermal market, although their share in new additions was down from 87% in 2015 to 72% in 2021.[22] The top three companies for vacuum tube collector production in 2021 were Solareast Group, Linuo Paradigma and Sangle.[23] The long-term transition from vacuum tube to flat plate collectors has been driven by building codes that mandate the use of solar thermal systems in new construction and in major renovations to reduce local air pollution. Such regulations have increased the demand for façade- and balcony-integrated applications, where flat plate collectors have been the preferred solution.[24]

China's flat-plate collector sales again rose slightly (2%) in 2021, to 5 GW_{th} (7.11 million square metres).[25] Since 2015, when the flat plate collector market was 3.9 GW_{th}, manufacturers have met all of the increases in annual demand through improved utilisation rates at existing facilities.[26] In 2021, the seven largest Chinese producers of flat plate collectors increased their combined sales volumes by 11%, growing faster than the total domestic market for this technology.[27] The seven companies were: Solareast Group (including the Sunrain and Micoe brands), followed by Jinheng Solar (with its export brand BTE Solar), Linuo Paradigma, Sangle, Fivestar, Haier and Sunte Solar.[28]

Due to the growing interest in electrification of heating, demand for PV-Thermal increased **45% globally** in 2021.

Across China, the implementation of two new national policies in 2021 spurred investments in solar thermal projects. The "Double Carbon" strategy calls for China to achieve peak carbon emissions by 2030 and carbon neutrality by 2060.[29] As a result, in 2021 preparation was under way for a 77 megawatt-thermal (MW_{th}) solar heat field to provide space heating and snow production at a "green" leisure park in Hebei.[30] In addition, a new national building code (to be enforced in April 2022) mandates that new buildings in China include solar thermal, solar PV or heat pump systems.[31]

Among the other top countries for new solar thermal additions, **India** caught up with Turkey in 2021 to rank second after China. India's market grew 18% relative to 2020, to 1.35 GW_{th}, whereas Turkey's sales remained stable for the third consecutive year, at 1.35 GW_{th}.[32] Neither country had financial support schemes for solar thermal in place, so the Indian industry relied mainly on solar building obligations, and the Turkish industry on the cost competitiveness of solar water heaters.[33]

India's market has been driven by a solar building obligation in place since 2007 in the state of Karnataka, where 70% of the country's new capacity was installed during 2021.[34] India appeared to be on track to meet its target of 14 GW_{th} by the end of 2022 (set by the National Solar Mission in late 2009), reaching a total of 12.7 GW_{th} in operation at the end of 2021.[35]

Vacuum tube collectors accounted for 92% of newly installed capacity in India in 2021, up from 87% in 2020.[36] This was mainly because rising material costs (and hence higher prices) led to a 25% decline in flat plate collector sales.[37]

In **Turkey**, residential solar water heaters remained the backbone of the solar thermal industry, whereas trends for large solar heat applications varied. Demand grew significantly in the Mediterranean coast tourist region, where several large systems were installed.[38] The payback periods for solar thermal in the region are relatively short due to high irradiation and a good match between hot water demand and the high solar-yield season.[39] In contrast, public demand for central solar hot water systems in Turkish hospitals, dormitories and prisons declined in 2021.[40] Altogether, Turkey had 18.9 GW_{th} of solar thermal capacity in operation at year's end, or 4% of the global total.[41]

Among the top five countries, **Brazil** experienced the largest growth in new additions (up 28%), adding 1.27 GW_{th} in 2021.[42] New solar heating systems for swimming pools (unglazed collectors) reached 664 MW_{th} (up 33%) as people spent more time at home during the pandemic and invested in home improvements.[43] Annual installations of solar hot water systems for residential and commercial consumers increased 23%, to 609 MW_{th}, due to growth in the construction sector as well as rising electricity prices caused by drought-induced power shortages and blackouts.[44] Brazil continued to rank fifth globally for total operating capacity, with 14.3 GW_{th} by year's end.[45]

The **United States** ranked fifth for solar thermal sales in 2021 (adding 601 MW_{th}), bringing its total capacity in operation to 18.2 GW_{th}.[46] The country remained the second largest market for unglazed collectors (566 MW_{th}) after Brazil, followed by Australia (266 MW_{th}).[47] As in Brazil, new solar pool heating systems drove the US solar thermal market, helping to increase US additions 19% in 2021.[48]

Whereas in India, Turkey, and Brazil, solar water heaters are cost-effective compared to electricity-driven hot water solutions, in the United States and most European countries financial incentives are still needed to reduce upfront investment costs for solar thermal technology. This is because these latter regions have higher equipment and labour costs, and in some cases lower solar resources.[49]

Europe added 11% more solar thermal capacity in 2021 than in 2020, due to new "green heat" support schemes for buildings and industry to support national targets for climate neutrality.[50] In several European countries, demand also was driven by the growth in new housing units.[51] Altogether, an estimated 1.49 GW_{th} of new solar thermal capacity was added across the region, up 2% from the pre-COVID year of 2019 (1.47 GW_{th}).[52] By the end of 2021,

more than 10 million solar thermal systems, totalling 36 GW_{th}, were in operation across Europe, mostly in households.[53] Most of these systems include storage tanks, with an estimated 180 GWh in combined thermal storage capacity.[54]

The top five European countries for new additions in 2021 were Germany, Greece, Italy, Poland and Spain.[55] Three of these countries – Germany, Italy and Poland – have depended heavily on subsidies in recent years.

In **Germany**, the world's sixth largest solar thermal market, annual sales were similar to 2020 (around 450 MW_{th}), when additions grew by 26%.[56] This was despite a new national support scheme, launched in 2020, to accelerate decarbonisation in buildings.[57] The scheme drove up sales of biomass boilers (41%) and heat pumps (28%) in 2021, but did not affect annual installations of solar thermal systems.[58] The country's solar associations pointed to this unequal growth in heating technologies under the policy and called for solar thermal energy to be included among the "privileged technologies" in German building regulations on outdoor construction[i],[59] By year's end, Germany reached 15 GW_{th} of solar thermal capacity in operation, around 3% of the global total and 42% of the European total.[60]

Greece was the second largest European market, adding more systems than ever before for a newly installed capacity of 251 MW_{th}.[61] The drivers were the same as in previous years: cost-competitive solar thermal systems; a national solar building regulation that mandates a minimum 60% solar hot water for new buildings; and the Energy Savings in Households programme, which provides lowincome families with grants covering 60% of the upfront investment in solar water heaters.[62]

Italy's annual additions rose a record 83% to 158 MW_{th}, enabling the country to pass both Poland and Spain.[63] This strong growth was driven by increased construction activity combined with a new green building policy, the "Superbonus" for energy-efficient buildings.[64] This policy, which entered into force in February 2021, provided homeowners and housing co-operatives with a 110% tax reduction when jumping at least two classes in the building efficiency standard through so-called driving measures, such as thermal insulation and boiler replacement, including with solar thermal systems.[65]

In **Poland**, Europe's fourth largest market, additions increased 17% to 132 MW_{th} newly installed.[66] Although this was more than in 2020, it was below the pre-COVID volume of 201 MW_{th} installed in 2019.[67] Sales of residential solar water heaters continued to dominate new additions, triggered by support from European Union (EU) funds[ii],[68] Increasing investor interest in hybrid systems for space heating, including solar thermal combined with heat pumps, provided hope for rising solar thermal demand in the years to come.[69]

Spain was the only top-five European market where capacity additions fell in 2021. Spain´s solar sales have been driven mainly by the national technical building code (CTE) in recent years, rather than by financial support schemes.[70] However, revision of the CTE in January 2021 resulted in a market decline of 20% for the year, to 107 MW_{th}.[71] Instead of requiring that a minimum share of hot water demand in new buildings be met with solar thermal systems, the revised code calls for a minimum 60-70% of hot water needs to be supplied by renewable energy more broadly.[72] As a result, the share of new solar thermal capacity added that was driven by the CTE declined from 87% in 2020 to 82% in 2021.[73]

By contrast, solar heat in Spain's industry and service sector received substantial support from EU funds, totalling EUR 108 million (USD 122 million) in 2021 for 51 projects (62 MW_{th} in total).[74] A huge increase in commercial and industrial solar heat capacity is expected in 2022-2023, as all projects that received grants must be in operation before June 2023.[75] Industry representatives expect total installed costs to fall due to economies of scale, standardisation of solutions and a general maturing of the technology suppliers.[76]

Across Europe, flat plate collectors have dominated markets for decades, whereas in Asia vacuum tube collectors have represented well over half of annual additions.[77] In 2021, the largest producers of flat plate collectors in Europe were Greenonetec (Austria), Dimas (Greece), Bosch Thermotechnik (Germany) and Papaemmanouel (Greece).[78] The region's 10 largest flat plate collector manufacturers increased their combined sales 21% during the year, faster than the European market overall (11%).[79]

As in China, Europe's large producers profited from market consolidation as smaller manufacturers closed factories and purchased collectors from larger producers instead.[80] Some European technology suppliers also took advantage of the inability of Chinese manufacturers to supply markets in Europe and the Americas due to high transport costs.[81] For example, Greek manufacturers, already successful global exporters, shipped a record 582 MW_{th} of solar thermal capacity in 2021, up 33% from 2020.[82] Greece's export volumes nearly tripled between 2014 and 2021, from 189 MW_{th} to 582 MW_{th}.[83]

i Outdoor construction includes, for example, utility poles and power plants.

ii Funding was allocated from the European Regional Development Fund, whose purpose is to transfer money from Europe's richer regions to invest in the infrastructure and services of underdeveloped regions.

DISTRICT HEATING

Although most of the solar thermal capacity installed globally continued to be for water heating in individual buildings, the use of **solar thermal technology in district heating** also expanded in 2021.[84] (→ *See Figure 42*) Data on completed solar district heating systems were reported only from Europe, however, and the number of plants brought online in the region fell slightly from 10 (totalling 33 MW_{th}) in 2020 to 9 (totalling 23 MW_{th}) in 2021.[85] Reasons for the decline included long planning periods, challenging permitting processes and installation delays due to the pandemic.[86]

The leading solar district heating market was France, with three systems (totalling 7.2 MW_{th}) brought online during the year, followed by two systems in Austria (5.4 MW_{th}).[87] Denmark, Germany, the Netherlands and Sweden each completed one new installation.[88] Solar district heating plants also were likely commissioned in China (as part of the newly added 2 GW_{th} of space heating capacity in 2021), but national statistics do not distinguish between collector fields heating individual buildings and those heating multiple buildings via district networks.[89]

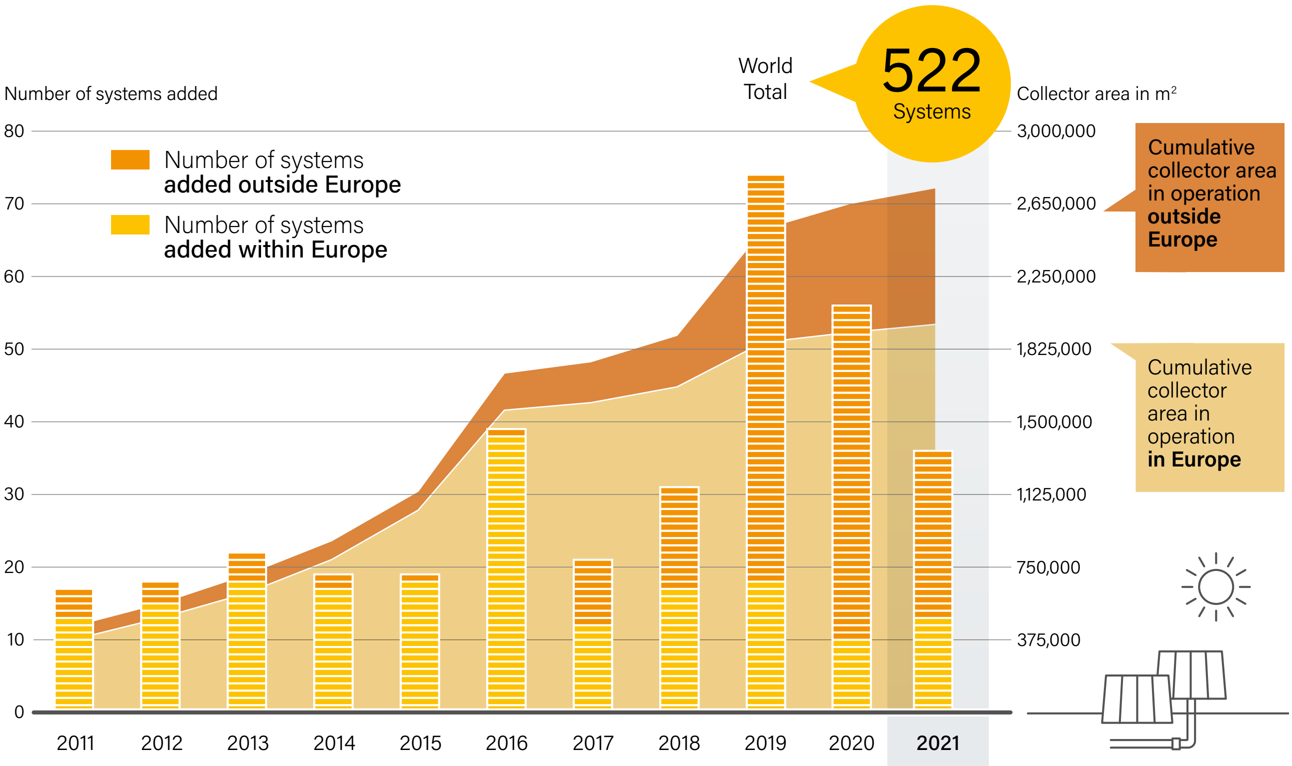
Elsewhere in Europe, air quality problems and rising energy security concerns increased interest in solar district heating, including in the Western Balkan countries, where studies were under way for future projects.[90] The European Bank for Reconstruction and Development, in co-operation with Germany's KfW bank, extended its solar district heating support to additional cities in the region in 2021.[91] By year's end, pre-feasibility studies were completed in Pristina (Kosovo), and in Bor, Pancevo and Novi Sad (all Serbia)[i]; these four cities aim to generate up to a combined 170 GW_{th} of solar heat annually.[92] Three additional pre-feasibility studies were under development to explore the potential for solar district heating plants in Korca (Albania), Nis (Serbia) and Zenica (Bosnia and Herzegovina).[93]

Despite minimal additions in 2021, Denmark remained the world leader in solar district heating capacity, with more than 1 GW_{th} in operation by year's end.[94] The levelised cost of heat for solar district heating plants in the country fell an estimated 32% between 2010 and 2019, from 6.6 US cents per kilowatt-hour (kWh) to 4.5 US cents per kWh.[95] Factors behind the cost reduction included greater developer experience, increased competition among a small number of project developers and economies of scale.[96]

The weighted-average installed cost of the six solar district heating plants newly commissioned in Denmark in 2019 (latest data available) was USD 409 per kilowatt-thermal (kW_{th}), down from USD 573 per kW_{th} in 2010.[97] In comparison, the weighted-average total cost of the 12 solar district heating plants commissioned in Germany between 2018 and 2020 was USD 769 per kW_{th}.[98]

i By year's end, both Pristina and Pancevo had advanced to the feasibility study level.

FIGURE 42.
Large Solar Heat Plants, Global Annual Additions and Total Area in Operation, 2011-2021



Source: Based on IEA SHC. See endnote 84 for this section.

Note: Figure includes plants with collector fields of at least 350 kilowatts-thermal (kWth) (500 m²), either for solar district heating or for solar hot water and/or solar space heating of residential, commercial and public buildings. Data are for solar water collectors and concentrating collectors.

The top markets for solar industrial heat in 2021 were **Mexico, Netherlands and Austria**.

INDUSTRIAL HEAT

In addition to generating heat for buildings, solar thermal technologies provide emission-free heat for a large number of production-related processes. Many industrial companies around the world, including multinational corporations, are turning to green heat solutions – including solar heat technologies – to meet their social and environmental goals.[99] This is important considering that industry is among the most difficult economic sectors to decarbonise, given the long investment cycles for new energy infrastructure.[100]

By the end of 2021, at least 975 **solar industrial heat plants (SHIP)**, totalling more than 826 MW_{th}, were supplying process heat to factories worldwide.[101] This heat is used for processes including boiling, cleaning, distilling, pasteurizing, pulping, malting, dyeing and bleaching.[102] Both the installation and commissioning of SHIP projects were delayed in 2021 due to pandemic-related restrictions and shortages of raw material supplies.[103] In all, 71 SHIP projects with a total capacity of 36 MW_{th} came online during the year, down from 87 projects and 93 MW_{th} in 2020.[104]

The ranking of countries with the highest numbers of newly commissioned projects changed significantly in 2021. China, which led the SHIP world market in 2020 with 30 new plants, reported only 7 new systems and was overtaken by Mexico, with 18 plants, followed by the Netherlands (15 plants) and Austria (11 plants).[105] The global decline in the SHIP market in 2021 is due to this Chinese contraction; outside of China, the market increased from 57 plants in 2020 to 64 plants in 2021.[106] In terms of capacity additions, France (10 MW_{th}) overtook China (8.2 MW_{th}), followed by third place Turkey (3.8 MW_{th}).[107]

Although commissioning was down during 2021, construction of new SHIP plants accelerated, and at least 44 MW_{th} of capacity for 16 projects was in the pipeline by year's end.[108] SHIP capacity under construction was dominated by higher-temperature systems that use concentrating collector technologies: 12 concentrating heat systems totalling 32 MW_{th} were planned to be commissioned in 2022, up sharply from the 9 MW_{th} of concentrating heat capacity commissioned globally in 2021 for both the industrial and service sectors.[109]

China, Mexico and India remained the key markets for SHIP turnkey system providers.[110] The leading companies involved in the engineering and construction of SHIP facilities (ranked by number of projects in operation by the end of 2021) were Modulo Solar (Mexico), Solareast Group (China), Linuo Paradigma (China), Inventive Power (Mexico) and G2Energy (Netherlands).[111]

For the first time, weighted-average data on the levelised cost of heat for a large number of SHIP plants were published in 2021[i]. Costs differ by country due to varying cost structures for materials and labour and differing irradiation levels, among other factors.[112] SHIP plants commissioned in China, Mexico and India between 2010 and 2020 produced heat for around 4 US cents per kWh[ii] on average.[113] This compared to an average of 6.4 US cents per kWh in Southern Europe and 9.2 US cents per kWh in Central Europe.[114] Central Europe shows the widest range in the levelised cost of heat over the period because, as the SHIP market matured, small projects with relatively high costs gave way to large projects with lower costs.[115] The average installed cost of SHIP plants in Europe dropped 68% between 2014 and 2020 (from USD 1,679 per kW_{th} to USD 531 per kW_{th}), due mainly to economies of scale.[116]

While SHIP plants in Mexico are cost competitive with fossil fuels, particularly liquefied petroleum gas, in many other countries achieving competitiveness against oil and natural gas is dependent on public funding.[117] In France, the largest new SHIP plant of 2021 (10 MW_{th}), which came online in September at a malting plant, received EUR 3 million (USD 3.4 million) from the French energy agency Ademe.[118] Based on this subsidy, the project developer Kyotherm (France) was able to offer the malting plant a solar heat price that was below what the client paid previously for gas-produced heat. Kyotherm played a pioneering role in operating as a solar heat energy service company (ESCO).[119]

i The number of projects with cost-performance indicators for SHIP plants within the database for the International Renewable Energy Agency is still small. To compare regional cost differences, values for the levelised cost of heat are averaged over a 10-year period. The values in this paragraph are based on 252 projects, or around 26% of the global SHIP market.

ii The weighted-average levelised cost of heat for SHIP plants in Asia (60 plants, mainly in India and China) was 3.9 US cents per kWh and in Mexico (81 plants) was 4.4 US cents per kWh.

Other SHIP technology suppliers have turned their attention to heat delivery contracts, since the ESCO model reduces the risk of the industrial heat user and speeds business decision making because the engagement is free from capital expenditure and does not burden the equity of the client.[120] During 2021, the Belgium company Atzeq was constructing its fourth ESCO project, a 3.8 MW_{th} parabolic trough collector field that will supply steam to a chemical producer in Belgium.[121] Inventive Power (Mexico) commissioned its first ESCO project, a parabolic trough collector facility with 332 kW_{th} of capacity for a food processor.[122] Modulo Solar (Mexico) financed and installed two plants (totalling 1.7 MW_{th}) with an ESCO model to provide heat for private swimming pools.[123]

The number of multi-MW SHIP plants under engineering or construction continued to grow in 2021, driven by rising fossil fuel prices and by financial support schemes in Europe and the US state of California.[124] The project developer NewHeat (France) took the lead in finding industrial clients.[125] It announced the start of the construction of a 15 MW_{th} SHIP plant for a whey powder factory in France, supported by Ademe, and secured a grant of EUR 4.5 million (USD 5.1 million) from the EU innovation fund for a 20 MW_{th} plant for a malting factory in Croatia.[126] Also in Europe, Simona Alexe – greenixcloud (Austria) carried out a feasibility study for a 25 MW_{th} SHIP plant for a textile company in Austria, and an EU-funded Spanish support scheme awarded a grant to Engie Servicios Energéticos (Spain) for a 30 MW_{th} plant at a brewery.[127] For comparison, the largest SHIP plant already in operation in Europe at year's end was a 10.5 MW_{th} facility for an agricultural business in the Netherlands.[128]

California's Food Production Investment Program, established in 2018 to encourage food producers in the state to reduce greenhouse gas emissions, awarded grants totalling USD 13 million to four SHIP plants with a combined capacity of at least 22.6 MW_{th}.[129] The largest US solar steam producing system (2.3 MW_{th}) was commissioned in early 2021 at an almond processor.[130] At year's end, two other solar steam producing systems for dairies (8.4 MW_{th} and 11.9 MW_{th}) were under construction, and the fourth SHIP plant (also for a dairy) was in the planning phase.[131] The four grants supported the business development of a new generation of US-based concentrating solar heat technology suppliers: Hyperlight Energy, Sunvapor and Skyven Energy.[132]

OTHER DEVELOPMENTS

Leading developers of all types of solar heat plants are using stock markets to gain additional capital to pre-finance project development costs.[133] In 2021, Tigi (Israel) started trading shares in the cleantech sector of the Tel Aviv Stock Exchange, raising around USD 10 million.[134] Heliogen (US) successfully raised USD 415 million in the run-up to its initial public offering in December 2021 by using a special purpose acquisition company.[135] Savosolar (Finland), listed on Nasdaq Nordic since 2015, gained up to EUR 5.4 million (USD 6.1 million) by rights issues in 2021.[136] Prior to 2021, only Savosolar and three other solar thermal manufacturers were listed on stock markets globally.[137]

Due to growing interest in the electrification of heating, demand for photovoltaic-thermal, or hybrid collectors, increased again in 2021. PV-T collectors consist of a thermal absorber below a solar PV module and deliver both electricity and thermal energy that can be used as a flexible energy source for heat pumps in buildings.[138] During the year, 30 manufacturers reported sales of PV-T capacity of at least 88 MW_{th} (connected to 31 MW electric), up 45% from 61 MW_{th} in 2020.[139]

The largest markets for new PV-T additions (by capacity added) were France, the Netherlands, Israel, Germany and Spain.[140] France achieved the highest annual growth with nearly six times more PV-T capacity added in 2021 (68 MW_{th}) than in 2020.[141] Within the country, the popularity increased of both PV-T air solutions for space heating and unglazed PV-T collectors as the heat source for heat pumps.[142] In all key markets, demand among residential and commercial clients has been driven by the ability to produce both heat and electricity from the same roof space, thus generating a higher yield per area.[143]

Innovative business models such as **heat delivery contracts** attracted new customers.

KEY FACTS

- **The global wind power** installed capacity grew by 102 GW in 2021, again led by China. Onshore additions fell relative to 2020 and offshore additions surged to new highs, driven largely by policy changes in China and the United States. Not including China, annual global installations rose more than 14%.
- **The offshore wind sector** attracted increasing attention from governments, project developers, oil and gas majors and other energy providers. By one estimate, the offshore wind power pipeline reached 517 GW by early 2022.
- **Rising costs** due to supply chain constraints, labour shortages, shipping backlogs and rising raw material prices compounded ongoing challenges, including a lack of grid infrastructure and permitting. Outside of China, average turbine prices reached levels not seen since 2015, and the industry is urging greater focus on the system value of wind energy rather than solely on continually declining costs and prices.

WIND POWER

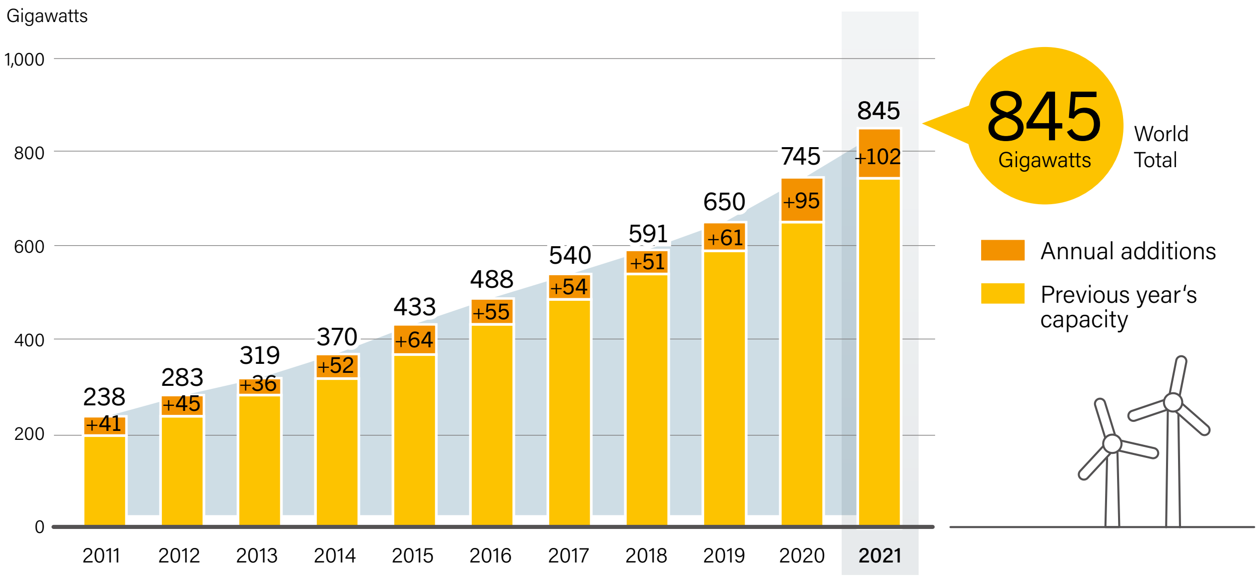
OVERVIEW

An estimated 102 gigawatts (GW)[i] of wind power capacity was installed globally in 2021 – including more than 83 GW onshore and almost 19 GW offshore.[1] Total additions were up around 7% relative to 2020 to the highest level to date, with annual offshore installations almost three times their previous high.[2] By year's end, total global wind power capacity rose 13.5% over 2020 to surpass 845 GW (791 GW onshore and the rest offshore).[3] (→ *See Figure 43.*) Wind power capacity in operation around the world contributed an estimated 7% of total electricity generation in 2021.[4]

Global additions onshore were down relative to 2020 as land-based installations declined in China and the United States; offshore, the explosive increase in capacity added was due largely to a dramatic policy-driven rise off the coast of China.[5] Nearly every region saw record annual additions in 2021.[6] Not including China, global installations were up more than 14% over 2020.[7] New wind farms reached full commercial operation in at least 55 countries, up from 49 in 2020, and at least one country, Saudi Arabia, brought online its first commercial project (0.4 megawatts, MW).[8]

i Additions are gross (although only a few countries decommissioned significant amounts of capacity in 2021) and were not necessarily all grid-connected at year's end. See endnote 1 for this section.

FIGURE 43.
Wind Power Global Capacity and Annual Additions, 2011-2021



Source: Based on GWEC. See endnote 3 for this section.

Note: Totals may not add up due to rounding. Additions in 2021 are gross, but bar heights and numbers above bars reflect year-end totals.

The economics of wind energy continued to be the primary driver for new installations, combined with the need to increase energy security and to mitigate climate change.[9] Outside of China's offshore market (driven by an expiring feed-in tariff, or FIT) and the United States (with tax credits and state renewable portfolio standards), global demand for wind power in 2021 was driven largely by China's onshore grid parity scheme and by other policy mechanisms including auctions (or tendering).[10] Power purchase agreements (PPAs) are playing a growing role thanks to the cost competitiveness of wind energy.[11]

However, the wind sector faces a number of challenges. In the longer term, these include a shortage of sites with good wind resources and proximity to grid connections; the fact that the large scale of today's turbines is pushing the industry to the limits of current turbine design; and the need for turbine manufacturing and installation to scale up dramatically for wind energy to play a significant role in mitigating climate change[i].[12] Massive increases in manufacturing and installation will require not only a large ramp-up in production capacity and trained labour, but also procurement of vast quantities of minerals and other material inputs alongside extensive actions to minimise the associated negative social and environmental consequences.

Other significant challenges are the lack of grid infrastructure, which is unavailable or outdated in many locations, and permitting, which can be an expensive, complex and time-consuming process.[13] One study estimates that the average permitting process globally takes 29 months and, combined with other lengthy administrative processes, results in an average project-planning process of more than five years; this compares with only several months required to construct a wind farm.[14] In some cases, permitting challenges[ii] have begun to deter investment, and there is growing concern that they are a key factor slowing the energy transition.[15]

The shift to auctions and gradual removal of support schemes, which have focused the industry on price reductions, have helped spur technological innovation and efficiencies that reduced costs throughout the wind power value chain over the years, and the cost of capital has declined due to low interest rates and growing investor confidence.[16] These factors have helped make wind energy competitive with fossil fuels.[17] But the race to the bottom on price is disincentivising investment, and price declines are levelling off, with fewer opportunities remaining to reduce costs without further sacrificing profits, even as shifts to more-sustainable business practices could raise some costs.[18] Ever-larger turbines already have driven up associated transport and logistics costs.[19]

In 2021, such challenges were compounded by pandemic-induced supply chain constraints, labour shortages and shipping backlogs, as well as rising prices for major raw material inputs (e.g., steel, aluminum, copper, resins, fibreglass), components, and energy, while project delays affected turbine orders and interest rates began to rise after several years of decline.[20] These forces have added pressure when margins were already tight, with turbine manufacturers squeezed between high costs and developers that want cheaper turbines.[21]

As a result, the largest manufacturers outside of China raised their turbine prices, with 2021 marking the largest price increase in a decade.[22] By contrast, Chinese turbine prices reportedly declined 24% during the year.[23] The decline was due to a combination of fierce domestic competition to gain market share during China's transition to an era of grid parity, and the ease of supply chain control and lower input costs in the world's largest manufacturing hub[iii].[24] Outside of China, average turbine prices rose to levels not seen since 2015, reversing several years of decline[iv].[25] Despite record turbine orders and annual revenue highs in most cases, the margins reported by Nordex Acciona (Germany), Siemens Gamesa (Spain) and Vestas (Denmark) fell an average 7.7 percentage points relative to 2020, and GE (United States) reported heavy losses for the year.[26]

Against such challenges, the industry (at least outside of China) is increasingly expressing the need to focus on the system value that additional wind energy can bring – as well as on factors related to sustainability of projects and citizen participation, and on ensuring that projects are actually realised – rather than focusing solely on continually falling costs and prices.[27]

i For example, annual installations must scale up to 390 GW (310 GW onshore and 80 GW offshore) by 2030 according to the net zero 2050 roadmap of the International Energy Agency. See endnote 12 for this section.

ii In addition to expense and complexity, challenges include the large number of permits required for an individual project, under-resourced permitting authorities, lack of guidance, local opposition and legal challenges, and unclear land ownership titles. See endnote 15 for this section.

iii China leads the world for turbine components and dominates the processing and refining operations of rare earth, copper, nickel and other minerals that are critical for wind turbine manufacture. See endnote 24 for this section.

iv Wind power remained cost competitive with fossil fuels due to rising prices for the latter; in contrast to the wind power industry, however, fossil fuel generators saw record profits in 2021. See endnote 25 for this section.

TOP MARKETS

For the 13th consecutive year, Asia (mostly China) was the largest regional market, representing around 61.4% of added capacity (up from nearly 60% in 2020).[28] Most of the remaining installations were in Europe (15.6%), North America (13.8%) and Latin America and the Caribbean (5.7%).[29] China was followed distantly by the United States, which was well ahead of Brazil, Vietnam and the United Kingdom; these five countries together accounted for more than 77% of annual installations.[30] Other countries in the top 10[i] for total capacity additions were Sweden, Germany, Australia, India and Turkey.[31] To rank among the top 10, annual installations of at least 1.4 GW were required, up from 1.1 GW in 2020.[32] After remaining unchanged since 2014, the list of the 10 leading countries[ii] for cumulative capacity changed in 2021 as Sweden was added and Italy dropped off.[33] (→ *See Figure 44.*)

China's total wind power installations were up nearly 2.8% in 2021 to a new record high, and the country accounted for more than half of global additions.[34] Land-based additions declined more than 18% relative to 2020, following a rush to install onshore projects, which had to be grid-connected before the end of 2020 to receive the expiring national FIT[iii].[35] At sea, an upsurge in additions in 2021 resulted from a race to connect projects before the offshore FIT expired at year's end.[36]

The estimated 55.9 GW (41.4 GW onshore and 14.5 GW offshore) added in 2021 brought China's total wind power capacity to an estimated 346.7 GW.[37] Around 47.6 GW of this was integrated into the national grid, with most of it (61%) in the more populated central, eastern and southern regions, for a total of 338.3 GW[iv] considered officially grid-connected by year's end.[38] Overall, China's utilisation rate of wind power averaged 96.9% in 2021, up slightly from 2020.[39] Wind generation was up 40.5% and accounted for 7.9% of total electricity production (up from 6.1% in 2020 and 5.5% in 2019).[40]

Chinese **turbine manufacturers** account for around half of global manufacturing; most of their turbines continue to be installed domestically, but declining demand onshore in China is causing manufacturers to turn to markets elsewhere, while the competitive pricing and technological improvements of Chinese turbines are attracting increased international interest.[41] MingYang was the first Chinese turbine manufacturer[v] to announce plans to build factories in Europe.[42] By one estimate, six of the world's top 10 turbine producers in 2021 were based in China; the remaining four were Vestas (Denmark), Siemens Gamesa (Spain), GE (US) and Nordex Group (Germany).[43] Outside of China, the top five manufacturers accounted for an estimated record 93-95% of market share, continuing several years of consolidation.[44]

i The top 10 markets in 2020 were China, the United States, Brazil, the Netherlands, Spain, Germany, Norway, France, Turkey and India.

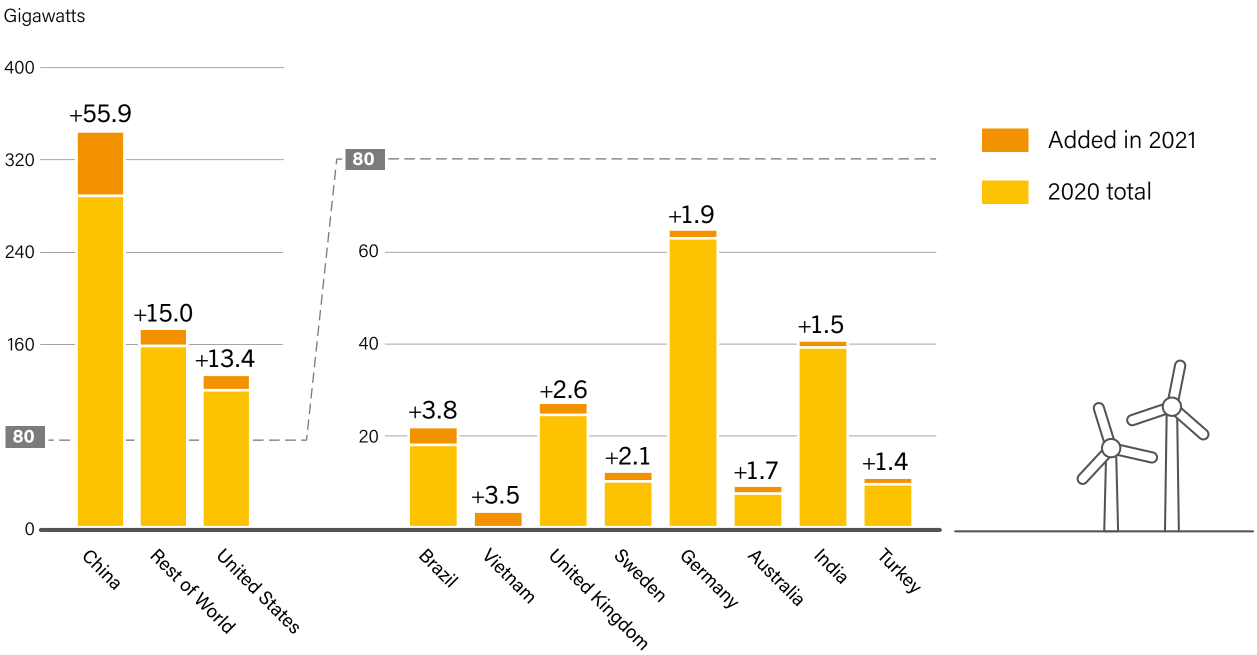
ii The top 10 countries for cumulative capacity at the end of 2021 were China, the United States, Germany, India, Spain, the United Kingdom, Brazil, France, Canada and Sweden, with Brazil moving ahead of France and Sweden replacing Italy.

iii Without the FIT mechanisms, China's wind power projects receive the regulated price for coal-fired generation in each province.

iv Statistics differ among Chinese organisations and agencies as a result of what they count and when. See endnote 38 for this section.

v Note, however, that Goldwind (China) is the majority owner of the German-based company Vensys, which has manufactured turbines outside of China for several years. See endnote 42 for this section.

FIGURE 44.
Wind Power Capacity and Additions, Top 10 Countries, 2021



Source: See endnote 33 for this section.

Note: Numbers above bars are gross additions, but bar heights reflect year-end totals. Net additions were lower for Germany (1.7 GW) and for the United States (12.9 GW), due to decommissioning. Totals may not add up due to rounding; numbers for Rest of World are rounded to nearest GW.

Vietnam
joined the top 10 for the first time as annual installations soared many-fold to nearly 3.5 GW.

The **United States** again ranked second globally for capacity additions and year-end total, with 13.4 GW (net 12.9 GW, all onshore) installed during 2021, for a total of 135 GW.[45] US installations were at their second highest level ever but were down more than 20% relative to the record additions of 2020.[46] Progress was slowed by several factors, including supply chain and trade constraints, logistics challenges, interconnection queues and rising costs, all of which affected the economics of projects.[47] Uncertainty about the policy environment also delayed investment; most significantly, the federal production tax credit (PTC) was extended only at the end of December 2020 for projects that began construction by the last day of 2021[i].[48]

To offset supply chain constraints and cost inflation, and to adjust for the step-down in value of the PTC, developers in the United States sought higher prices; wind PPA prices increased 19.2% on average relative to 2020.[49] By year's end, the US pipeline of new projects included 23.9 GW of capacity onshore and 17.5 GW offshore, with the latter driven mainly by state procurement targets.[50] Wind energy accounted for 9.1% of US utility-scale electricity generation in 2021, up from 8.4% in 2020.[51]

The third ranking country for newly installed capacity was **Brazil**, which represented nearly 66% of additions in Latin America and the Caribbean.[52] Despite challenges during the year due mostly to the COVID-19 pandemic, Brazil's market was up more than 60% relative to 2020, with 3.8 GW installed (all onshore) for a total of 21.6 GW.[53] This growth resulted from several factors, including rising electricity demand (up 4.1% in 2021) and economic recovery.[54] The increased use of private auctions and bilateral PPAs also helped drive the record additions.[55] Wind energy generated more than 72 terawatt-hours (TWh) of electricity (up more than 26%) and was Brazil's second largest source of electricity generation in 2021, after hydropower, accounting for 11.5% of the mix.[56]

Although none of Brazil's capacity to date is operating off the country's 7,500-kilometre coastline, in early 2022 the federal government published laws governing offshore wind power projects; already, several companies including Shell (Netherlands) have plans for a strong presence in Brazil's offshore sector.[57]

Vietnam was among the top 10 markets for the first time, ranking fourth globally in 2021. Driven by the looming expiration of the national FIT, Vietnam's annual installations soared many-fold over 2020 additions (0.1 GW), approaching 3.5 GW (2.7 GW onshore and nearly 0.8 GW offshore), for a year-end total of 4.1 GW.[58] The national government has supported renewable energy (particularly wind power and solar PV) to reduce fuel imports and ensure energy security while also enabling the country to meet rapidly rising electricity demand.[59] As of early 2022, Vietnam's FIT for wind energy was expected to be extended from 2021 to the end of 2023; a draft of the country's Power Development Plan 8 (for 2021-2030), released in 2021, included new capacity targets (18 GW of wind power by 2030) and prioritised improvements in grid infrastructure.[60]

The record installations in Vietnam were achieved despite ongoing challenges including pandemic-related supply chain disruptions, a lack of capital, and weak grid capacity, with some of the country's transmission lines operating at full load or even overloaded (particularly where solar PV capacity is high).[61] In response to such grid constraints, Vietnam's government decided against approving any new wind (or solar PV) capacity in 2022.[62]

After not even making the global top 10 list in 2020, the **United Kingdom** ranked fifth worldwide in 2021, followed by Sweden (sixth globally) and Germany (seventh).[63] The United Kingdom regained its spot as the lead European installer, adding 2.6 GW for a total of 26.8 GW (14.1 GW onshore and 12.7 GW onshore).[64]

i The PTC gives wind energy generators a tax credit of roughly USD 0.024 per kilowatt-hour for electricity fed into the grid. In light of delays and supply chain issues caused by the pandemic, the commissioning deadline for projects that began construction in 2016 and 2017 was extended by one year in 2020 and again in 2021; in December 2020, the PTC was legally extended for a further year at 60% of the full credit rate. Projects had to qualify for the tax credit by 31 December 2021; those that did have a four-year safe harbour window to commission. As of early 2022, the PTC had expired but negotiations were ongoing in the US Congress regarding further extension.

Although UK additions were up more than four-fold relative to 2020, they were well below the 2017 high of 4.5 GW.[65] Most new capacity was put into operation offshore (see later discussion); onshore additions (0.3 GW) were nearly triple those in 2020 but represented the second lowest UK onshore additions since 2005.[66] Onshore deployment has stalled in recent years due to a lack of policy support, with all commissioned projects deployed through PPAs or on a merchant basis.[67] However, after excluding onshore wind power from the Contracts for Difference (CfD)[i] auctions for several years, in December 2021 the UK government launched the fourth CfD round to expand investment in renewable energy, including both onshore and offshore wind.[68]

Europe as a whole placed second after Asia for regional share of new global installations, with nearly 16 GW added (up more than 18% over 2020) for a total of 225 GW.[69] Commissioning of new projects across Europe continued to be delayed by global supply chain issues and permitting bottlenecks.[70] The top five European countries for capacity additions – the United Kingdom, Sweden, Germany, the Netherlands (1.3 GW) and France (1.2 GW) – accounted for almost 58% of the region's total (down from 60.6% for the top five in 2020).[71] While representing relatively small portions of total installations, Croatia, Denmark, Finland and the Russian Federation each added record amounts of new capacity.[72]

Most new capacity in Europe outside of the United Kingdom was installed in the European Union (EU), where 11 GW came online, mostly onshore (10 GW, or 91%), for a year-end total of 188.9 GW (173.3 GW onshore and 15.6 GW offshore).[73] Across the EU-27, 18 countries added capacity during 2021, compared with 17 the previous year.[74] However, total installations were up only slightly over the 10.5 GW added in 2020.[75] According to one estimate, the EU needs to install 32 GW annually to achieve the region's target to meet 40% of its final energy consumption with renewable sources by 2030.[76]

Sweden led the EU for new installations in 2021, up from fifth place regionally in 2020, and ranked sixth globally.[77] A record 2.1 GW came online, more than double the previous year's installations, for a total of 12.1 GW (all onshore).[78] Wind energy generated 27.4 TWh in 2021, accounting for around 16.5% of Sweden's total electricity generation.[79] There is evidence that wind energy is reducing average annual electricity rates in the country's south.[80] However, challenges to further growth include the need to modernise and expand Sweden's electric grid and to simplify the permitting process.[81]

As in 2020, **Germany** ranked third in Europe for newly installed capacity; globally, the country fell from sixth to seventh place, despite an increase in annual installations.[82] Germany's additions rose more than 15%, to 1.9 GW (1.7 GW net, all onshore), for a year-end total of 63.8 GW (56.1 GW onshore and 7.7 GW offshore).[83] Onshore installations were up in 2021 thanks to a slight improvement in the permitting situation, but continued to be far below the volumes added during 2012-2017, as well as below government commitments for the decade.[84] The additional capacity was not enough to make up for poor wind conditions during the year; wind energy generation (113.8 TWh) was down 14% relative to 2020, and accounted for 20% of Germany's electricity generation.[85]

Throughout the year, Germany's auctions for new onshore capacity were undersubscribed, due largely to state-level permitting challenges, as well as a decline in diversity of actors and investors.[86] However, a mid-year auction was the country's first onshore wind tender since December 2017 to award more than 1 GW.[87] Other EU countries (including Denmark, France, Italy and Poland) have seen undersubscription in wind-specific auctions and strong competition from solar PV in technology-neutral auctions for a variety of reasons, including low ceiling prices and permitting challenges.[88]

In early 2022, the German government announced[ii] targets to increase offshore wind power capacity to 30 GW by 2030, 40 GW by 2035 and 70 GW by 2045; onshore, the government plans to add 10 GW of new capacity annually starting in 2025.[89] To achieve the onshore target, the plan calls for increasing the number of auctions, streamlining permitting procedures and dedicating 2% of Germany's land area to wind generation.[90] In addition, community wind power projects up to 18 MW will be exempt from the auction scheme.[91] At the state level, there are efforts to increase local participation in project earnings to improve public acceptance of new wind farms.[92]

At year's end, Germany continued to lead Europe for total wind power capacity, followed by Spain (28.2 GW), the United Kingdom (26.8 GW), France (19.1 GW) and Sweden (12.1 GW).[93] These countries together accounted for nearly 67% of the region's total.[94] For the EU and United Kingdom combined, wind energy met around 15% of electricity demand[iii], with far higher shares in Denmark (44%) and Ireland (31%), and 20% or more in Portugal, Spain, Germany and the United Kingdom.[95]

Australia installed enough capacity in 2021 to join the global top 10 for the first time, ranking eighth. For the third consecutive year, Australia saw records for both installations and output, adding 1.7 GW for a total of 9.1 GW (all onshore).[96] Wind power remained Australia's largest source of renewable electricity, producing 26.8 TWh (up 18.5% from 2020), or 11.7% of the country's total generation.[97] The relative increase in capacity additions was due at least in part to the commissioning of projects that were under construction for some time and had faced delays.[98] Despite pandemic-related uncertainties and relatively low wholesale electricity prices, corporate PPAs with buyers that have set sustainability targets continued to represent an important source of investment for new projects.[99]

i The CfD is the UK government's primary mechanism for supporting renewable electricity generation. Developers that win contracts at auction are paid the difference between the strike price (which reflects the cost of investing in the particular technology) and the reference price (a measure of the average market price for electricity).

ii Proposed changes were first announced in January and an expanded package was approved in April 2022.

iii The share of electricity demand met by wind energy across the EU and the United Kingdom in 2021 was about the same as in 2019 and 1.4% below 2020, despite capacity additions, due to a resurgence in electricity demand (following the pandemicrelated decline in 2020) and lower generation in several countries. The lowest average generation occurred in September, coinciding with a steep increase in electricity prices; some blamed the price increase on wind power but, according to one source, evidence shows it was mostly due to high gas prices. See endnote 95 for this section.

However, several factors have slowed new investment in Australia's wind sector, including grid congestion and a need for more transmission infrastructure, local resistance, a drop in wholesale electricity prices in recent years and declining availability of premium wind sites.[100] There also has been an ongoing lack of clarity at the federal level regarding relevant regulations and climate change policy.[101] State governments, however, have moved ahead with plans to establish renewable energy zones – encompassing new grid infrastructure alongside wind, solar and storage projects – which have provided optimism for future investment.[102] In addition, Australia passed national legislation in 2021 to allow for the installation and operation of wind turbines offshore; as of early 2022, nearly 20 projects had been announced.[103]

India also ranked among the world's top 10 countries for additions in 2021, rising one step to place ninth. Nearly 1.5 GW was installed, representing a 30% increase over 2020 additions, for a total approaching 40.1 GW (all onshore).[104] As in Australia, India's increase was due largely to the commissioning of previously delayed projects.[105] COVID-19 had significant impacts across the Indian economy, with supply chain and labour challenges affecting wind power installations; a temporary decline in electricity consumption also stalled some deployment.[106]

Wind-only tenders in India saw strong competition, with all capacity awarded and the lowest bid prices in some tenders down relative to 2020.[107] However, since installations peaked in 2017 (4.1 GW) and India shifted from FITs to tendering via "reverse auctions[i]", the country has tracked well behind national targets for annual installations, while the number and diversity of local investors in India's wind power sector has declined and installations have become more concentrated geographically.[108] As of early 2022, only around a quarter of the capacity awarded under auctions since 2017 had been commissioned, and several companies that had been awarded PPAs through auctions surrendered capacity due mainly to low tariffs and rising costs[ii].[109] India continues to target 60 GW of wind power capacity by 2022 and 140 GW by 2030.[110]

Other longer-term challenges to deployment in India include the high cost of capital as well as challenges related to grid connection, permitting and land acquisition for projects.[111] As in several other countries, many of India's best wind sites are already in use, and the country is seeing increasing conflicts over land – large wind (and solar) power projects require large parcels, often leading to development on common land used previously by local communities, for example.[112] Land rights issues are on the rise elsewhere around the world as well.[113]

Ranking tenth globally was **Turkey**, which added a record 1.4 GW (just above the previous high in 2016) for a total of 10.8 GW, all operating onshore.[114] Wind power contributed more than 9.8% of total electricity generation and accounted for half of Turkey's new power generating capacity in 2021.[115] Market growth was reportedly due to a rush to qualify for the country's foreign currency-based incentive scheme (YEKDEM), which expired at year's end.[116]

Turkey is working to expand its renewable energy capacity to lessen its heavy reliance on imported fuels, create jobs and reduce the country's carbon footprint, all while meeting rapidly rising energy demand.[117] Over the past decade, Turkey has developed a strong industry supply chain, including production facilities of both domestic and foreign manufacturers, while increasing wind power capacity 10-fold.[118] By late 2021, the cost of new installations in Turkey averaged 32% lower than five years earlier, and generation from new wind power capacity was cheaper than that from existing (imported) coal, even excluding a carbon price.[119]

Wind turbines operating offshore accounted for more than

18.2%

of all newly installed global wind power capacity in 2021.

i An auction in which suppliers that meet certain minimum criteria can submit non-negotiable price bids, and the buyer selects winners based on lowest-priced bids first.

ii Turbine manufacturers operating in India are shifting their focus overseas while developers are moving away from auctions and long-term PPAs to options that fetch better energy prices – through direct sales to commercial and industrial customers and sales via the Indian Energy Exchange. See endnote 109 for this section.

OFFSHORE WIND

In the offshore wind power segment, four countries in Europe and three in Asia added a record 18.7 GW in 2021, well above the 6.9 GW connected in 2020, increasing cumulative global offshore capacity to 54.8 GW.[120] Wind turbines operating offshore accounted more than 18% of all newly installed global wind power capacity in 2021 (up from 6.5% in 2020 and the previous high of 10% in 2019) and represented nearly 6.5% of total capacity at year's end (4.7% in 2020).[121] China led the sector for the fourth year running, home to more than 77% of new capacity, and Europe and Vietnam installed nearly all the rest.[122]

China added 14.5 GW in 2021, nearly four times its record offshore additions of 2020, as developers rushed to commission projects before the national FIT expired at year's end.[123] Total offshore capacity more than doubled to nearly 25.4 GW, propelling the country well ahead of the long-term leader the United Kingdom.[124] China's offshore industry has become an important driver of regional economic growth.[125] Other countries in Asia that added capacity were Vietnam (0.8 GW, intertidal), propelled by an expiring FIT to rank third worldwide for offshore additions, and Chinese Taipei (0.1 GW).[126]

Europe connected 3.3 GW of new capacity to the grid, bringing the regional total to 28.3 GW.[127] Most of these installations were in UK waters (2.3 GW), including the world's largest operational floating wind farm, the 48 MW Kincardine project off the coast of Scotland.[128] UK installations jumped sharply following a slow year in 2020[i]; however, there was concern that changes to the country's bidding system, which requires investors to pay upfront "option fees" for the right to develop projects, will raise future costs of offshore wind energy.[129] Annual installations will need to rise significantly to meet an accelerated UK target (50 GW by 2030) set in April 2022 as part of a national energy security strategy.[130]

Denmark followed with a record 0.6 GW; the only other European countries to add offshore capacity were the Netherlands (0.4 GW) and Norway, which commissioned a 3.6 MW TetraSpar floating demonstration project.[131] At year's end, five countries continued to host nearly all of Europe's offshore capacity: the United Kingdom (45%), Germany (27%), the Netherlands (10.5%), Denmark and Belgium (each 8%).[132]

Also in 2021, construction began on the first commercial wind projects in several European countries (France, 976 MW; Italy, 30 MW; Norway, 88 MW floating project) as well as off the coast of Japan (140 MW).[133] The United States broke ground on its first commercial-scale project, the 0.8 GW Vineyard Wind Farm, followed in early 2022 by another large project, and had a record year for solicitations (8.4 GW); as of early 2022, nine US states had set offshore procurement targets totalling 44.6 GW.[134]

By year's end, 18 countries (12 in Europe, 5 in Asia and 1 in North America) had offshore wind capacity in operation, unchanged from 2019 and 2020.[135] China led the world for total capacity (25.4 GW), followed distantly by the United Kingdom (12.7 GW), Germany (7.7 GW), the Netherlands (3 GW), Denmark and Belgium (both around 2.3 GW).[136] Asia (mostly China) was home to around 48.6% of global offshore capacity, and Europe hung onto the regional lead with 51.3% of the total (down from 70% in 2020).[137]

Although the offshore segment accounts for a relatively small portion of global wind power capacity, it is attracting significant attention due to new government targets and other commitments driven by energy security and climate change concerns.[138] During 2021, new targets were set and projects planned in existing markets in Asia, Europe and North America[ii], and in new markets (e.g., Australia and Brazil).[139] According to one analysis, the global pipeline for offshore wind reached 517 GW as of early 2022.[140] Several countries also launched roadmaps in 2021 and early 2022, including Colombia, the Philippines and Turkey.[141]

An increasing number of governments and developers are turning to floating offshore turbines. Floating turbines[iii] can go where nearshore waters are too deep for fixed-bottom machines and can take advantage of stronger, more consistent winds farther from shore, rather than being sited where the sea floor topography is suitable, meaning that public resistance is lower and capacity factors are higher.[142] They require fewer construction materials than fixed-bottom turbines and need no marine engineering expertise for assembly.[143] Most projects to date have been prototypes or pilots, but the industry is considered ready to scale, with development in the pre-commercial phase.[144]

i The low level of installations in 2020 was due to a gap in execution of projects under the first and second rounds of the UK CfD. See endnote 129 for this section.

ii Although the target is not set in law, the Biden administration announced in early 2021 that it aimed for the United States to achieve 30 GW of offshore wind power capacity by 2030. In addition, new official targets were set at the state level in 2021 and early 2022. See endnote 139 for this section.

iii By one estimate, the use of floating turbines can triple the size of the potential market. See endnote 142 for this section.

During 2021, governments around the world were looking to develop floating technology and projects, and leading international offshore developers and investors were launching projects.[145] China's first floating machine, a 5.5 MW pilot anti-typhoon turbine, was commissioned during the year, Japan held a tender for its first floating project, and the United Kingdom announced funding to support technology development and set a target for 1 GW[i] of floating capacity by 2030.[146] Also in 2021, the Republic of Korea announced plans to build a 6 GW project by 2030, and the United States announced plans to deploy floating turbines in waters off the US west coast.[147] The top five countries for cumulative capacity at the end of 2021 were the United Kingdom, Portugal, Japan, Norway and China.[148]

Oil and gas majors, fossil fuel service providers and utility companies have shown increasing interest in offshore wind power, particularly floating technologies and projects.[149] They are driven in part by growing pressure to reduce their carbon emissions and are attracted by the potential for hydrogen production, while also being able to deploy their existing skills and experience.[150] The potential for wind energy (generated both offshore and onshore) to produce hydrogen also is sparking interest among other large energy consumers, including the metal manufacturing and mining industries.[151] (→ *See Snapshot Argentina.*)

TECHNOLOGY AND INFRASTRUCTURE

Manufacturers of turbines for use onshore and offshore continued to focus on technology innovation in 2021. The industry has been compelled to continuously reduce costs and achieve the lowest possible levelised cost of energy (LCOE) in response to the transition to auctions as well as rising material costs and other pressures.[152] The industry also is innovating to address challenges associated with scaling up production, transport and other logistical issues as well as to enhance the value of wind energy while further improving its environmental and social sustainability.[153]

Turbine size continued to increase (e.g., capacity, rotor diameter, hub height) in order to optimise cost and performance.[154] In 2021, the average size of turbines delivered to market passed the milestone of 3.5 MW, 27% larger than in 2020 (2.81 MW).[155] Further, new machines with power ratings ranging from 6 MW to more than 7 MW were introduced for use onshore, while several European and Asian manufacturers announced new offshore turbines in the 11-16 MW range.[156]

Larger, higher-efficiency turbines mean that fewer turbines, foundations, converters and cables, and less labour and other resources, are required for the same output, translating into faster project development, reduced risk, lower costs of grid-connection and operation and maintenance (O&M), and overall greater yield, all important for the offshore sector in particular.[157] Between 2010 and 2020, global weighted average capacity factors rose by nearly a third (to 36%) for onshore wind, while driving down the LCOE.[158] Offshore, average capacity factors during 2021 of UK projects in the North Sea ranged from 33.5-36% for projects commissioned in 2010, to 50% and higher for projects that began operations during 2018-2020.[159]

As turbines get larger, they are pushing the limits of what is possible in terms of voltage, manufacturing, and logistics of transport and installation.[160] Increasingly, there is a focus on using medium- (rather than low-) voltage converters to deal with higher currents of large offshore machines.[161] Manufacturers also are moving towards production of modular and customisable designs: in 2021, for example, Vestas announced a modular nacelle to ease turbine siting, transport, project construction and O&M.[162] Such modularity can enable increases in the ratings of very large machines without installing new ones, reducing associated costs and environmental impacts.[163]

i This target was increased to 5 GW in early 2022, as part of the United Kingdom's 50 GW by 2030 offshore wind power target. See endnote 146 for this section.

Offshore, as machine sizes grow and projects move farther to sea and into deeper waters, and as the number and locations of developments increase, more and larger vessels are required to transport and install wind turbines.[164] As of early 2021, only around 50 vessels were equipped for installing offshore turbines, with most located off mainland China and the rest mainly in northern Europe.[165] Several companies announced plans during the year to build new vessels or modify existing ships to handle larger machines.[166]

Also in 2021, the United Kingdom and the EU announced plans to increase investments in specially designed ports to handle ever-larger offshore turbines and to accelerate manufacturing capacity for domestic and export markets.[167] China saw significant improvements in transport and installations for the offshore sector, and, at year's end, all of the country's coastal provinces had five-year plans to develop industrial parks and advance the supply chain for deployment of turbines offshore.[168] In the United States, which continues to lag behind Europe and parts of Asia in offshore supply chains and associated infrastructure (e.g., manufacturing facilities, dedicated ports, service vessels, rail links and grid connections), a number of private entities as well state and federal governments committed to developing the necessary infrastructure, particularly along the Atlantic coast.[169]

Innovation in the industry also continued to focus on making wind energy fully sustainable, and in a way that is cost-effective in order to remain competitive.[170] Initiatives to reduce emissions associated with turbine production and installation have included redesigning the logistics network and shifting to cleaner sources of energy for production.[171] Substantial effort also has been focused on turbine blades.

Great progress has been made over the years to ensure the efficiency of blade operation, but there was little emphasis until recently on their life-cycle impacts; unlike the other 85-90% of a wind turbine's mass[i], blades are difficult to recycle and often end up in landfill.[172] Among advances in 2021, Siemens Gamesa produced for commercial use its first fully recyclable offshore blades, made with a new resin that can be separated efficiently from other components at the end of a blade's working life, and the Zero wastE Blade ReseArch (ZEBRA) consortium produced the first prototype of its 100% recyclable blade made from thermoplastic resin.[173] Public-private international collaborations focused on a variety of possible solutions, such as the recycling of existing glass fibre products, the development of recyclable thermoplastics combined with three-dimensional blade printing, and the development of longer, lighter-weight, modular and more-recyclable blades made with fabric.[174]

The industry also is working to improve the sustainability of forestry, extraction and trade of balsa wood (a key component of blade cores) and to develop alternative materials.[175] Industry demand for balsa wood has surged in recent years, causing supply problems and raising prices, which has intensified illegal logging and forest degradation in the Amazon, with adverse impacts on local indigenous people.[176] To reduce balsa wood imports and relieve shortages, scientists in China are experimenting with plantations, while some blade manufacturers are using a lightweight, strong plastic (polyethylene terephthalate) in place of balsa wood.[177]

Several companies made new or expanded blade-related sustainability pledges in 2021. GE's LM Wind Power (Denmark) announced plans to produce zero-waste blades (manufacturing process only) by 2030; Vestas pledged to develop a fully recyclable blade by 2030 and zero-waste turbines by 2040; and Ørsted (Denmark) committed to reuse, recycle or recover all blades in its projects once decommissioned.[178]

→ *See Sidebar 6* on the following pages for a summary of the main renewable energy technologies and their costs.[179]

Innovation in the industry continued to focus on reducing costs, scaling up production, and enhancing the value of wind energy while improving environmental and social sustainability.

i Approximately 85-90% of a wind turbine's mass comprises easily recyclable materials (such as steel, cement, copper, electronics and gearing), but the composite materials that make blades relatively light and aerodynamic are difficult and costly to recycle.

SIDEBAR 6. Renewable Electricity Generation Costs in 2021

Renewables have become the default source of least-cost new power generation globally, following a 10-year trend of cost declines. Despite supply chain challenges and rising commodity costs in 2021, the costs of electricity from utility-scale solar PV and onshore and offshore wind power all fell during the year, while the cost of concentrating solar thermal power (CSP) rose slightly. Renewables not only are competing with fossil fuels but are significantly undercutting them, when new electricity generation capacity is required. In 2018, the global weighted-average levelised cost of electricity (LCOE) of onshore wind power fell below the level of the cheapest fossil fuel-fired generation option, while solar PV achieved that feat in 2020.

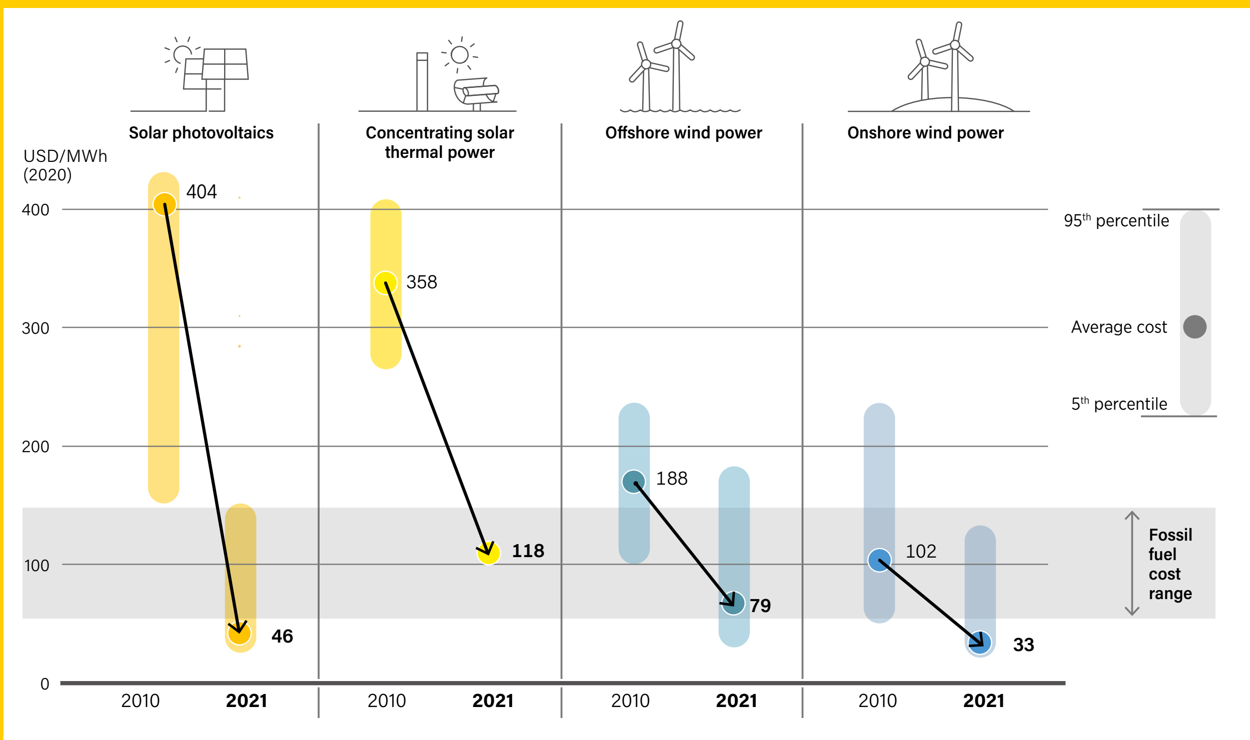
Solar PV has experienced the most rapid cost reductions since 2010, with the global weighted-average LCOE of newly commissioned utility-scale projects falling 89% between 2010 and 2021, from USD 0.40 per kilowatt-hour (kWh) to USD 0.046 per kWh. (→ *See Figure 45.*) This represented a steep decline, from solar PV being more than twice as costly as the most expensive fossil fuel-fired power generation option to undercutting the bottom of the range for new fossil fuel-fired capacity in 2021 by USD 0.008 per kWh[i].

This reduction has been driven primarily by declines in module prices, which have fallen 91% since 2010 (despite the recent uptick). Utility-scale solar PV capacity factors also have risen over time. Initially, this was driven mainly by growth in new markets with better solar resources, but in recent years the more extensive use of one-axis trackers and bi-facial modules has been important.

For onshore wind power projects, the global weighted-average cost of electricity fell 64%, from USD 0.102 per kWh in 2010

i The fossil fuel-fired power generation cost range by country for the Group of 20 (G20), and fuel, is estimated to be between USD 0.054 per kWh and USD 0.167 per kWh. This assumes that the current high fossil fuel prices do not cause a fundamental shift in 30-year natural gas price expectations. If long-term US gas price expectations rose to USD 5 per gigajoule at the Henry Hub, the lower bound would rise to USD 0.064 per kWh.

FIGURE 45.
Global Weighted-Average LCOEs from Newly Commissioned, Utility-scale Renewable Power Generation Technologies, 2010-2021



Note: These data are for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The LCOE is calculated with project-specific installed costs and capacity factors, while the other assumptions are detailed in the Power Generation Costs 2021 report from IRENA. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects. No price range available for CSP. In 2021 there was only one CSP plant comissioned, as many projects have been delayed.

Source: IRENA Renewable Cost Database.

to USD 0.033 per kWh in 2021. These cost reductions were driven by declines in turbine prices and balance of plant costs, as well as by higher capacity factors from today's state-of-the-art turbines. Reductions in operations and maintenance (O&M) costs also have occurred as a result of increased competition among O&M service providers, greater wind farm operational experience, improved preventative maintenance programmes, more reliable turbines and increased availability.

The global weighted-average total installed cost of newly commissioned onshore wind power projects fell 36%, from USD 2,041 per kilowatt (kW) in 2010 to USD 1,315 per kW in 2021. At the same time, continued improvements in wind turbine technology, wind farm siting and reliability have led to an increase in average capacity factors, with the global weighted average increasing from 27% in 2010 to 39% in 2021.

The global weighted average LCOE of newly commissioned offshore wind projects fell from USD 0.188 per kWh in 2010 to USD 0.079 per kWh in 2021, a reduction of 58%.

The decline in the cost of electricity from CSP between 2010-2021 – into the middle of the range of the cost of new capacity from fossil fuels – remains a remarkable achievement, recording a 67% decline in this period.

The global weighted-average LCOE of hydropower rose 26% between 2010 and 2021, from USD 0.039 per kWh to USD 0.049 per kWh. This was still lower than the cheapest new fossil fuel-fired electricity option.

The global weighted-average LCOE of bio-power projects experienced some volatility during 2010-2021 but did not show a notable trend upwards or downwards over the period. However, the global weighted-average LCOE in 2021 of USD 0.067 per kWh was 14% lower than the 2010 value of USD 0.078 per kWh.

The global weighted-average LCOE of geothermal was USD 0.068 per kWh in 2021, 34% higher than in 2010 but well within the range seen between 2013 and 2021, of USD 0.054 per kWh to USD 0.071 per kWh. Annual new capacity additions remain modest, and one project with an atypically low capacity factor of 42% dragged down the global weighted-average capacity factor for newly commissioned projects in 2021 to 77%.

Note: The rising strength of the USD currency during the year has reduced prices in USD terms in some of the major markets. For wind power technology, most of the price increase for turbines made outside of China is expected to be felt in 2022. Solar PV modules prices increased by 4-7% in 2021 compared to 2020, while prices in 2022 are expected to vary depending on module technology. For details on methodology, see International Renewable Energy Agency, *Power Generation Costs 2021*, June 2022.

Source: See endnote 179 for this chapter.

04

SNAPSHOT. CHAD

Solar PV for Electricity Access

Chad, a landlocked country in north-central Africa, has one of the lowest electricity access rates in the world. Only 8% of the population had access to electricity in 2019, with a significant gap between rural (1%) and urban (20%) areas. Apart from a 1 megawatt (MW) wind power plant in the eastern town of Amdjarass, electricity is supplied only by generators, which break down regularly. Oil, used to run clusters of generators, is expensive and highly polluting. This precarious energy situation hinders socio-economic development and affects quality of life, especially in Chad's second largest city, Abéché. With 80,000 inhabitants, Abéché is not connected to the national grid and has struggled to develop its infrastructure due to security challenges.

In this unfavourable context, the French renewable energy firm InnoVent is developing Chad's first solar power plant in Abéché. The pilot phase of the plant (1 MW) was built between mid-2020 and November 2021, with soldiers providing security for both personnel and equipment. In December 2021, the first electricity was delivered to the grid of the national power company, Société Nationale d'Electricité (SNE). Ultimately, the solar plant will have a total capacity of 5 MW. Plans for 2022 include installing and commissioning 2.5 MW of battery storage and building the second phase of the plant (4 MW), with the aim of having the facility fully operational by early 2023.

Source: See endnote 3 for this chapter.

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

KEY FACTS

- **As of 2021, 770 million people** lacked access to electricity, and 2.6 billion lacked access to clean cooking.
- **Achieving the target for universal access** to clean cooking by 2030 may fall 30% short.
- **An estimated 1.09 billion people** annually are exposed to significant risk due to a lack of access to cooling, as inadequate refrigeration and storage lead to large wastage of food production.
- **In 2021, 7.43 million off-grid solar lighting products** were sold, one-third through "pay-as-you-go" and two-thirds via cash.
- **Solar mini-grid capacity** totalled 365 megawatts (MW) in 2019, including 60 MW in Asia, 54 MW in Sub-Saharan Africa and 12 MW in Latin America and the Caribbean.
- **The top 10 companies** account for 80% of the annual investment in off-grid solar, while for clean cooking the top 7 companies account for 90% of the investment.

In 2021, an estimated 770 million people worldwide did not have **access to electricity**.[1] The number of people without access fell significantly in the last decade, from 1,153 million in 2010 to 759 million in 2019.[2] However, the COVID-19 pandemic slowed global progress in reaching universal electricity access, as a decline in new grid and off-grid connections led to a 2% increase in the population without access in 2021.[3] (→ *See Snapshot: Chad.*) The greatest change occurred in Asia, where the gap in electricity access shrank four-fold over the decade (while it increased slightly in sub-Saharan Africa).[4]

Most world regions enjoy electricity access rates above 94%.[5] Sub-Saharan Africa remains the region with the lowest access rate, at 46% in 2019, representing 570 million people who lack access.[6] Most of the gap in electricity access can be attributed to 20 countries where population growth has outpaced the electrification rate, including the Democratic Republic of the Congo (DRC), Ethiopia and Nigeria.[7] Access remains lower in rural areas (640 million without access) than in urban areas (116 million).[8]

In 2019, around 2.6 billion people worldwide did not have **access to clean cooking**.[9] Annual growth in access is slow, averaging 1% for the decade, and the target for universal access to clean cooking by 2030 may fall short by 30%.[10] In 2019, for the first time, sub-Saharan Africa was home to more people without access to clean fuels and clean cooking technologies than any other region.[11] More than 80% of the access gap in clean cooking is concentrated in 20 countries, with the largest gaps (access rates of 5% or below) in the DRC, Ethiopia, Madagascar, Mozambique, Niger, Tanzania and Uganda.[12]

Between 2019 and 2021, during the COVID-19 pandemic, the number of people without access to clean cooking increased by around 30 million, or 1%.[13] In developing regions of Asia, many people who recently had gained access to clean cooking fuels reverted to traditional fuels for financial reasons.[14] A similar reversal was observed in sub-Saharan Africa, where the number of people without access to clean cooking is expected to have increased to an estimated 4% above pre-pandemic levels.[15]

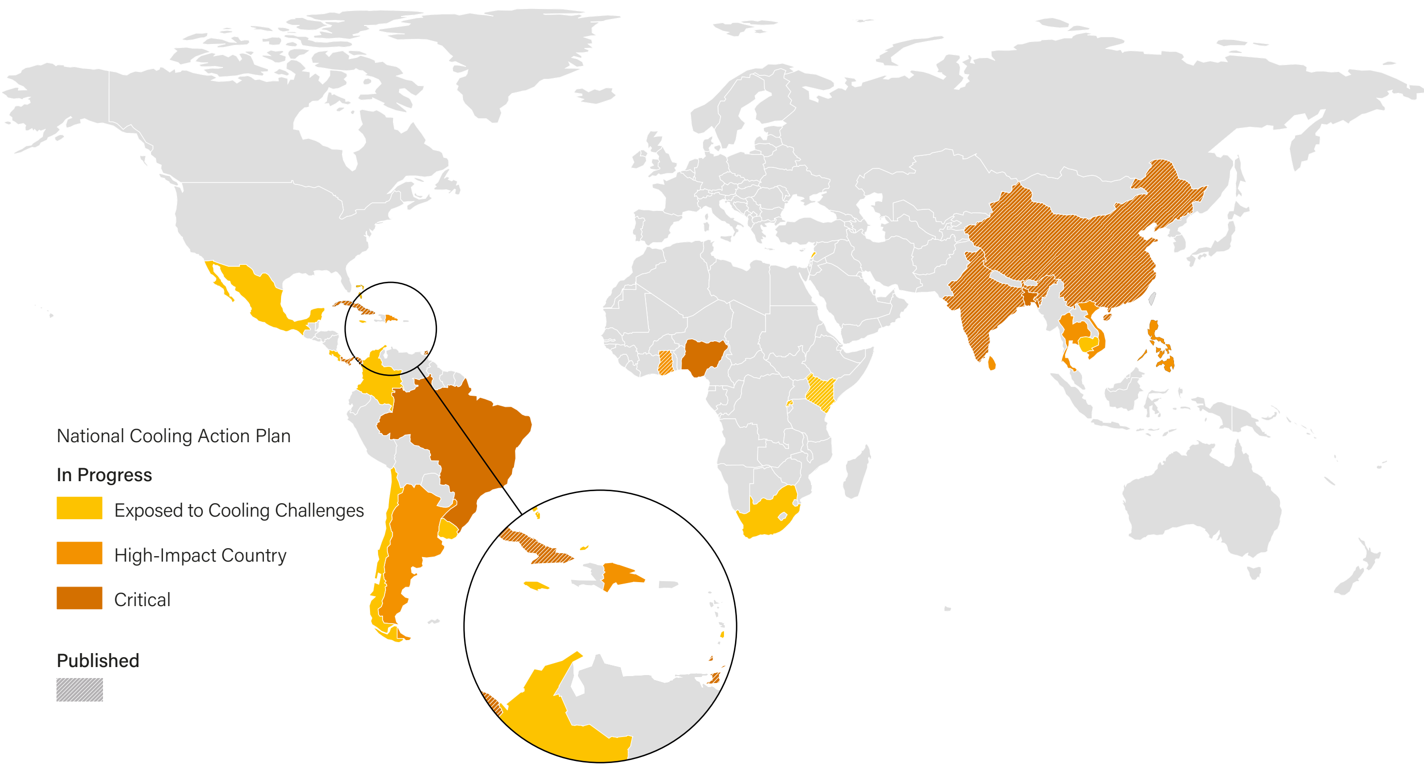
Globally, lack of **access to cooling** is impacting an estimated 1.1 billion people, especially in Bangladesh, India and Nigeria.[16] In these countries, an estimated 40% of the total food produced is wasted due to inadequate refrigeration and storage.[17] Increasingly, countries such as India, Kenya and Nigeria are deploying solar-powered cold rooms, using various business solutions to provide value to small farmers.[18] By the end of 2021, 6 countries had developed national cooling action plans – which include assessments of risk and cooling demand as well as detailed interventions to advance the deployment of cooling technologies – and 23 countries were developing them.[19] (→ *See Figure 46.*)

Around 450 million people across Africa, including more than 70% of the continent's rural population, lack **access to (sustainable) mobility**[i] due to limited transport infrastructure.[20] (→ *See Transport Section in Global Overview Chapter.*) "Micro-mobility" solutions such as electrified bikes, scooters, and three-wheelers, as well as battery charging services, are emerging as an opportunity to expand transport access, including through the use of renewables.[21] In Kenya and Uganda, where motorcycle taxis (boda-bodas) and tuk-tuks are popular for transporting goods and services (and provide employment for young people), possibilities exist for converting to electric solutions.[22]

Lack of access to cooling is impacting an estimated **1.1 billion people.**

i The provision of services and infrastructure for the mobility of people and goods – advancing economic and social development to benefit today's and future generations – in a manner that is safe, affordable, accessible, efficient, and resilient, while minimising carbon and other emissions and environmental impact.

FIGURE 46.
Countries Developing National Cooling Action Plans for Cooling Access, as of End-2021



Source: SEforALL. See endnote 19 for this chapter.

RENEWABLE-BASED ENERGY ACCESS FOR RESILIENCE

The distributed nature of renewable energy technologies can help increase community resilience in the face of extreme weather, political instability and other unexpected events. The world's leastdeveloped countries comprise 9 out of the 10 countries globally[i] most affected by weather-related losses.[23] In Asia, natural disasters directly impacted 57 million people in 2021 – particularly in Bangladesh, China, India, the Philippines and Thailand – and millions were displaced to makeshift locations, lacking access to health care, food supplies and communications infrastructure.[24] In many cases, modular and transportable distributed renewables for energy access (DREA) technologies were deployed to enable emergency response teams to quickly provide recovery assistance to those in need.[25]

In urban affected areas, DREA solutions such as rooftop solar photovoltaics (PV) and water heaters can provide immediate back-up power and heat.[26] Larger-scale solutions such as solar parks and wind farms – either combined with battery storage or hybridised and connected to the distribution grid – can power critical infrastructure like desalination plants and water distribution pumps when shortages occur. In Mombasa, Kenya, a recently built solar-powered desalination project, a partnership between WaterKiosk and Boreal Light GmbH, provides clean water to 23 local hospitals.[27] DREA systems in disaster-prone areas should be designed to withstand adverse events to ensure long-term value.[28]

Solar-powered greenhouses and hydroponic vertical farms – where vegetables and staple foods can be grown using minimal land, water and soil – also have proliferated. In 2013, a vertical farm was piloted in Kenya (which has been suffering from acute rainfall shortages) and has since been replicated by homes and businesses across the country as well as in Nigeria, Tanzania and Uganda.[29]

Electricity access for public infrastructure such as health centres, schools and government offices is critical. A lack of access (or uneven access) hampers institutional effectiveness and community development and weakens the links between remote areas and the central government. DREA solutions support essential rural healthcare services such as vaccine preservation, diagnostic equipment operation and air filtration. In sub-Saharan Africa, distributed renewables could power the 1.75 million health centres and schools that lack access to electricity.[30] (→ *See Box 10.*) In times of drought, DREA can support irrigation, water pumping, ice-making and freezing for food preservation.[31]

i Afghanistan, the Bahamas, Bolivia, India, Japan, Malawi, Mozambique, Niger, South Sudan and Zimbabwe.

BOX 10. Energy Access in the Health Sector

Renewable energy solutions have supported the provision of health care and other essential services, especially since the start of the COVID-19 pandemic. Solutions range from small-scale off-grid installations for unelectrified rural clinics, to larger, steady power delivery services for urban clinics that house crucial medical devices but are subject to unreliable grids. During the pandemic, there has been a particular focus on cold chains to keep COVID-19 vaccines chilled from production to delivery. These cold storage facilities require 24/7 power supply, which has come from hybrid solar/diesel, battery/inverter systems or direct-drive solar refrigerators.

During 2020 and 2021, a variety of initiatives included mini-grids and microgrids in the health sector:

- Nigeria's Rural Electrification Agency developed several solar mini-grids for use at hospitals and other healthcare facilities as an emergency response to COVID-19. Health facilities also were a focus of several other donor-driven mini-grid initiatives.
- The Multilateral Energy Compact for Health Facility Electrification, launched in 2021, targets providing 25,000 health facilities worldwide with access to clean and reliable power sources. Aimed primarily at health facilities that are experiencing a significant energy gap, the compact will contribute to the replacement of existing fossil-based capacity with renewable energy solutions.
- The Green Climate Fund's Clean Cooling facility aims to support reliable and climate-friendly vaccine cold chains – as well as clean cooling in health facilities – in El Salvador, São Tomé and Príncipe and Somalia.
- Power Africa, funded by the US Agency for International Development, directed USD 4.1 million in grants to off-grid companies in 2020 to electrify health clinics in rural and peri-urban areas, including through mini-grids. In Lesotho, OnePower and SustainSolar aim to supply seven containerised solar mini-grids under Power Africa to electrify several clinics.

Source: See endnote 30 for this chapter.

RENEWABLE-BASED ENERGY ACCESS FOR GENDER EQUALITY

Energy access and gender equality are strongly interlinked and are at the crossroads of two of the United Nations Sustainable Development Goals (SDG 5 and SDG 7).[32] Across Sub-Saharan Africa, as well as in Asia, women are more likely to be responsible for chores such as cooking, cleaning, and collecting wood and water, particularly in rural communities.[33] The use of traditional wood fuel for cooking is a leading cause of mortality from indoor air pollution, attributed to 7 out of 100,000 deaths worldwide in 2019.[34] However, the links between energy access and gender depend on local circumstances, and in some cases perceived barriers to gender equity result from gaps in financing and training.[35]

Solutions such as electric cook stoves, energy-efficient solar water pumps, and cooling technologies can improve the lives of women and others living in remote areas.[36] In addition to decreasing exposure to harmful indoor air pollutants, such technologies create opportunities for women and girls to attend school and enter the labour force; reduce acceptance of gender-based violence; and change social norms through access to information.[37] Electricity access using off-grid renewable energy solutions can enhance women's economic power through gender-inclusive development of nascent industries for these technologies.[38] Yet even though women traditionally are responsible for most tasks that use energy and appliances, they tend to have limited decision-making power regarding these purchases.[39]

Many developing countries have adopted policy solutions to address women's energy needs, acknowledging that women often are the primary energy users and income generators and serve as agents of change.[40] Evidence from sub-Saharan Africa shows that involving women in energy access programmes and projects leads to both greater energy access and increased gender equality.[41] In 2021, the Economic Community of West African States (ECOWAS) adopted a gender mainstreaming policy to address barriers hindering women's participation in energy access, and Burkina Faso and Nigeria both have adopted gender action plans developed under the auspices of the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE).[42]

Several countries in Asia are considering using gender budgeting for new policies and programmes, which involves auditing the extent to which gender equality is integrated into plans.[43] Pakistan has built on past efforts to use gender-focused institutional budgeting in institutions such as the Ministry of Women's Development and the Punjab Finance Department, with the Ministry of Energy and several think tanks now in the process of forming national-level energy and gender mainstreaming policies.[44]

Despite this policy ambition, gender-centric energy access projects in developing countries remain scarce and typically are embedded as a capacity building or awareness component in access programmes. Exceptions exist, however – such as Solar Sister and Tata Power – driven mainly by nongovernmental efforts and corporate social responsibility programmes.[45] (→ *See Snapshot: Africa.*)

SNAPSHOT. AFRICA

Gender-Integrated Energy Access Programmes

Solar Sister, a network of women entrepreneurs operating across several countries in Africa, has provided 3 million people with access to clean energy as of April 2022. The social enterprise is unique because of its focus on empowering women to build sustainable businesses in their communities. The programme recruits, trains, and supports women entrepreneurs, and supplies them with off-grid solar products (such as solar lighting) and clean cook stoves to sell.

Solar Sister provides support to rural communities, generates revenue for women entrepreneurs and increases access to clean energy sources. As of early 2022, the network had sold more than 613,000 clean energy products, generating additional income for over 8,600 households and supporting some 6,800 women entrepreneurs. Products sold by the Solar Sister entrepreneurs have avoided the emission of more than 946,763 metric tonnes of CO_2.

Source: See endnote 45 for this chapter.

SMALL-SCALE OFF-GRID SOLAR

MARKET TRENDS

In 2021, the off-grid solar sector continued to experience impacts from the COVID-19 pandemic, although signs of recovery were apparent. Sales of off-grid solar products totalled 7.4 million units for the year, with around two-thirds of the devices purchased in cash and one-third using the "pay-as-you go" (PAYGo)[i] model.[46] In total, more than 100 million people were benefiting from improved energy access from these products (including 14 million people accessing Tier 2[ii] services), saving an estimated USD 12.5 billion in energy expenditures and generating USD 6.7 billion in income.[47]

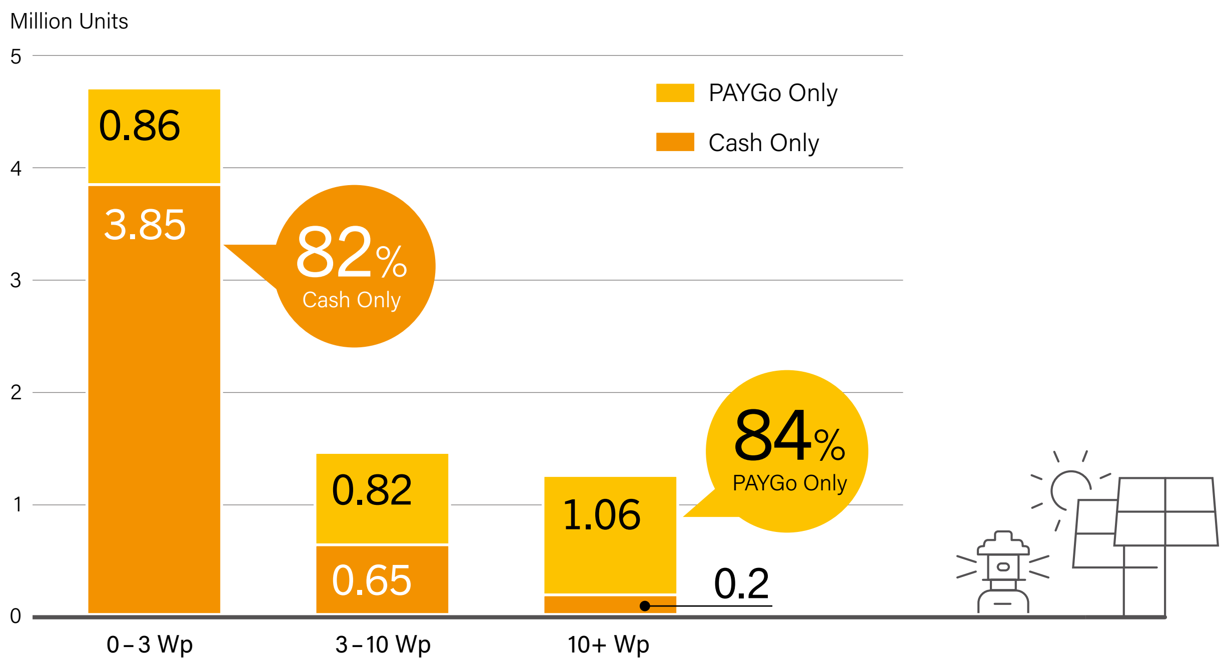
The bulk of the sales (6.1 million units) were portable lanterns (0-3 watt peak, Wp) and small solar devices such as phone chargers (3-10 Wp), which together represent 83% of all off-grid solar products.[48] In addition, nearly 1.3 million solar home systems (above 10 Wp) were sold during the year, representing 17% of total sales.[49] The vast majority of the solar home systems (more than 84%) were sold under the PAYGo model, whereas the vast majority of portable lanterns were sold as cash products.[50] (→ *See Figure 47.*)

PAYGo companies providing solar home systems traditionally have focused on basic services such as lighting and phone charging. Increasingly, however, companies are expanding their offerings to bigger systems that power a broader range of key appliances, such as televisions, fans, refrigeration units and solar water pumps. Sales of these appliances in the first half of 2021 totalled 421,000 units, the lowest level since 2018, as the industry has been affected by supply issues, shortages and price increases.[51]

i The emergence of smart devices is the main breakthrough for making business models viable. By monitoring consumption, these technologies allow a shift from upfront device purchase (which is out of reach for many customers) towards termbased payment per use (PAYGo).

ii Tier 2 energy provision is 50 to 500 watts of power for 4 to 8 hours daily.

FIGURE 47.
Volume of Off-grid Solar Products Sold, by Size and Type of Sale, 2021



Source: GOGLA. See endnote 50 for this chapter.

Market dynamics vary across regions and countries.[52] (→ *See Figure 48.*) East Africa was the leading market globally in 2021, with nearly 4 million units of off-grid solar products sold, dominated by Kenya (1.7 million) and Ethiopia (439,103).[53] While Kenya's sales have been relatively steady since 2019, Ethiopia's have fallen continuously since 2019 due to a combination of the COVID-19 pandemic, conflict and monetary devaluation.[54] Elsewhere in the region, sales grew substantially in Zambia (up 77%), Rwanda (30%) and Tanzania (9%).[55] For key solar-powered appliances, demand fell in most countries except Mozambique and Zambia, where sales were up 29% and +101%, respectively.[56]

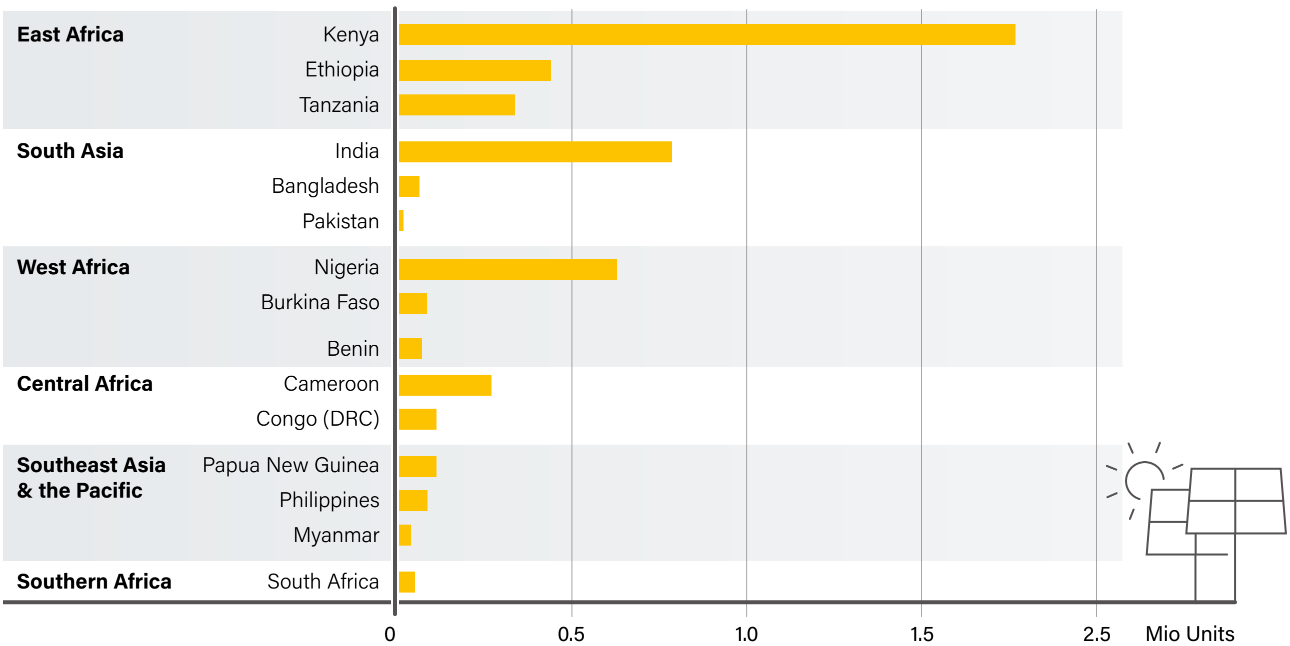
The West African market is much smaller (around the same size as Kenya's market) but has shown solid growth, ranking second globally with around 1 million off-grid solar products and devices sold in 2021.[57] Nigeria is the region's largest market, with sales totalling 628,000.[58] The market has shown strong, steady growth since 2019, with sales up 77% between the first and second quarters of that year.[59] Burkina Faso is West Africa's second largest market for off-grid solar products (85,113 devices sold in 2021), followed by Benin (71,240 devices) and Senegal, which recently enforced a value-added tax (VAT) exemption on solar products.[60] While these markets are in a growth phase, others in the region – including in Côte d'Ivoire, Liberia and Ghana – are shrinking, with low demand.[61]

The Nigerian market for off-grid solar products is co-ordinated by the Rural Electrification Agency, which aggregates various programmes including the Renewable Energy Fund (which delivered 6,805 solar home systems as of 2020), the Nigeria Electrification Project and Power Africa[i].[62] As a result of these efforts, Nigeria recorded high sales (240,000 units) in 2021, with a significant increase in PAYGo sales.[63] The country also is the largest market in West Africa for solar appliances, which grew 38% in 2021 compared to the second half of 2020.[64] In other African regions, the largest market for Central Africa is Cameroon, with 430,358 off-grid solar products sold in 2021.[65]

South Asia was the third largest market globally, with 869,833 off-grid solar products sold in 2021.[66] India dominated the region with 785,711 devices sold, although sales were down 66% compared to 2019.[67] Due to ongoing grid-connection efforts in the country, the Indian market is moving away from off-grid solar products to grid-connected products. East Asia and the Pacific have a modest market for off-grid solar, with 258,454 items sold in 2021, mainly in Papua New Guinea (111,616 devices) and the Philippines (86,891 devices).[68] Sales in the region have quadrupled since 2019.[69]

i The Nigerian Electrification Project budget for stand-alone solar home systems and micro small and medium enterprises is very sizeable, at USD 305 million equivalent, of which USD 230 million comes from private sector funding. Meanwhile, the Power Africa Nigeria Power Sector Programme (2018-2023) has a component aiming to develop business and consumer markets for off-grid solutions, focusing on support for solar home systems, mini-grids and microgrids.

FIGURE 48.
Volume of Off-grid Solar Products Sold, PAYGo Only, Selected Countries, 2021



Source: GOGLA. See endnote 52 for this chapter.

BUSINESS MODELS AND FINANCING

To be sustainable, a business model for off-grid solar products depends primarily on the consumer's ability to access financing and to secure income, rather than on the vendor's capacity to sell hardware products. This requires having the capability for lending, supported by a payment platform that the consumer is able to access through a mobile phone or other smart device – essentially, the company is a software platform bundled to a solar solution. In some cases, the business might use an "energy as a service" approach, providing productive appliances and functions. While some business models rely on a direct relationship with the end customer, which entails organizing distribution networks, other models rely on accredited distributors (which handle sales, installation and/or maintenance).

So far, the **pico**[i] **solar** and solar home systems markets have been regulated as markets for goods. However, the advanced monitoring software platforms that these companies offer are bundling large fleets of systems into a common monitoring tool, which can track customers individually as well as aggregating generation and demand. From the point of view of the system operator, this approach is increasingly similar to that of a "distributed" energy service supplier, which opens possibilities for convergence with electricity regulations in the future. The following are examples of dominant companies in the off-grid solar field and their offerings:

- M-KOPA, which operates in East Africa, uses a PAYGo approach to offer three sizes of solar home systems and solar fridges for small businesses, as well as smartphones. For customers who have made reliable payments on a PAYGo product, the company also offers services such as clean biomass cookstoves, entertainment packages, and financial services such as cash loans and hospital packages.[70]
- Green Planet/Sun King is primarily a retail and maintenance company that manufactures solar home systems and also offers appliances. Its service centres are based in India, but the company is looking for distributors in Africa.[71]
- Zola offers a hardware solution with modular and versatile solar power, storage and inverter packages at several scales. In addition, it offers a software solution that generates data for both the customer and the distributor to monitor the fleet of operational devices. The company is looking for distributors in Africa.[72]
- d.light uses its PAYGo Atlas platform to enable customer management and payment processing for a range of smart solar appliances connected to the platform. It also provides access to mobile phones, which host the mobile payment solution and can be recharged through the solar appliances. The company relies on distribution partners that operate local sales networks.[73]

Access to finance is a major barrier to universal energy access, and locally owned companies face barriers to harvesting funding opportunities. The off-grid solar sector is highly concentrated, with the top 10 recipients of investment receiving 80% of the total.[74] In 2021, GET.invest launched a Finance Readiness Support mechanism to help micro- to medium-sized companies raise funds.[75] Meanwhile, product affordability remains a challenge, particularly in remote rural areas. In 2020, Bboxx launched an offering of 20-watt solar panels and improved batteries targeted at low-income rural households, with the goal of initially servicing the DRC, Kenya, Rwanda and Togo before expanding elsewhere.[76]

PAYGo solutions also exist in agriculture, with the aim of improving agricultural productivity and boosting rural incomes. In Kenya, examples include Boreal Light's solar water pumping solution, which provides drinking water for 3,000 residents, and SunCulture, which provides solar-powered irrigation systems for smallholder farmers and also is expanding to Ethiopia, Togo and Uganda. Other leading actors in small-scale solar solutions for agriculture are Cooperative Bank in Kenya (greenhouse farming), Gham Power in Nepal (irrigation), Offgrid Sun in Zimbabwe (water and irrigation), Tesvolt in Brazil (irrigation), Pahseaun (milk chilling and storage) and Seawater Greenhouse (desalination).[77]

Access to finance is a major barrier to **universal energy access**.

i See glossary.

MINI-GRIDS

MARKET TRENDS

As of 2019, an estimated 47 million people were connected to 19,000 mini-grids worldwide, and another 7,500 systems were in the planning stages, mostly in Africa (4,000), South Asia (2,200) and East Asia and Pacific (900).[78] Most of the operating mini-grids were based in Asia (60%), with the rest mainly in sub-Saharan Africa (39%).[79] In total, around 6,900 mini-grid systems are found in East Asia and the Pacific, and around 1,500 in Africa.[80] The main countries with existing mini-grids are Afghanistan (4,980), Myanmar (3,988), India (2,800), Nepal (1,519) and China (1,184).[81]

Of the identified 5,544 mini-grids tracked by the Mini-Grids Partnership as of March 2020 (with a total capacity of 2.37 gigawatts, GW), 87% were based on renewable energy.[82] Although most renewablebased mini-grids are powered with diesel and hydropower, other solutions include solar-diesel hybrid systems as well as, more recently, solar PV and battery systems, driven by the falling costs of both technologies. Solar PV has been the fastest growing mini-grid technology, incorporated into 55% of mini-grids in 2019 compared to only 10% in 2009.[83] The installed capacity of solar mini-grids totalled an estimated 365 MW in 2019, including 60 MW in Asia, 54 MW in sub-Saharan Africa and 12 MW in Latin America and the Caribbean.[84]

In 12 sub-Saharan African countries, the number of renewable-based mini-grid connections installed by private developers grew from just 2,000 in 2016 to more than 41,000 in 2019, mostly in East Africa.[85] Across sub-Saharan Africa, around 42,000 household mini-grid connections (including diesel systems) serve more than 200,000 people, as well as businesses, schools and health facilities.[86] Other countries in West and East Africa also have initiated mini-grid developments.[87]

In West Africa, Nigeria has one of the world's largest mini-grid support programmes under the Nigeria Electrification Project (NEP) and aims to electrify 300,000 households and 30,000 local enterprises through private sector-driven solar-hybrid mini-grids by 2023.[88] With funding from the World Bank and the African Development Bank, the project offers minimum-subsidy tenders and performance-based grants.[89] Nigeria's Rural Electrification Authority commissioned several installations in 2020, including two solar-hybrid mini-grids (totalling 135 kilowatts, kW) developed by Renewvia Energy and a 234 kW solar-hybrid mini-grid installed by a local developer to power nearly 2,000 households.[90] In 2021, the Authority signed agreements with Husk Power to build seven mini grids providing over 5,000 new connections.

In 2022, Sierra Leone plans to complete the installation of 94 mini-grids, primarily under the Rural Renewable Energy Project.[91] A competitive process was used to select three operators, and the presence of health centres and **productive uses**[i] was considered in the selection of eligible locations.[92] In 2021, Togo's Rural Electrification and Renewable Energy Agency announced the first 129 locations to be electrified by its mini-grid programme, which has been supported by an extensive ground survey, geospatial analysis and system modelling.[93] Also that year, Senegal's Rural Electrification Agency launched a tender to electrify 117 villages through solar mini-grids.[94] In 2020, Benin selected 11 companies to build solar mini-grids serving 128 locations under its Off-Grid Clean Energy Facility.[95]

> An estimated 47 million people were connected to **19,000 mini-grids worldwide.**

In East Africa, Kenya has been the most active mini-grid market with nearly 200 sites in operation in 2019.[96] In 2021, Renewvia Energy commissioned another three solar mini-grids (87.6 kW total) in the country's Turkana and Marsabit counties, serving two communities and a refugee camp, with support from the EnDev results-based financing facility.[97] Kenya Power launched a tendering process in 2021 to hybridise 23 older diesel mini-grids, mostly with solar.[98] Overall, the country's draft mini-grid regulations, released in 2021, indicated 280 new mini-grids planned and under construction, with the expectation of having a total of 391 projects in operation across Kenya by the end of 2022.[99] Most of these are being developed under the Kenya Off-Grid Solar Access Project (KOSAP) financed by the World Bank.[100]

In Central Africa, a 1.3 MW solar-hybrid mini-grid installed by Nuru in the city of Goma, DRC, entered into service in early 2020.[101] In November 2021, Uganda inaugurated a mini-grid in the district of Lamwo, where 25 mini-grid projects are planned.[102] The country undertook a master planning exercise and identified sites for mini-grids powering 62,000 residents in 10 service territories.

In Asia, India is seeking full grid connection of its electricity supply, although the supply remains unreliable, which has led to the deployment of "under the grid"[ii] solutions.[103] Bangladesh's 170 kW BREL solar mini-grid project came online in early 2020; the project was financed by the Infrastructure Development Company Limited (IDCOL) as part of its solar mini-grid initiative for islands and other remote areas, which has brought online a total of 27 projects with a combined capacity of 5.6 MW.[104]

In Brazil, the Universal Access programme achieved 3.5 million connections and benefited 16 million people as of 2021.[105] To encourage productive uses of electricity, it includes the creation of Community Production Centres (CCP) that address the production, processing and marketing of local products.[106] The More Light for Amazon sub-programme, established in 2020, seeks to promote electricity access in remote regions of the Amazon states, targeting 70,000 families to be supplied with solar PV systems.[107] However, challenges in locating and consistently accessing these communities throughout the year could impede the collection of payments.[108]

i See glossary.

ii Such developments consist in building a mini-grid in areas where the distribution networks are present. It occurs in communities that are within the territory of distribution companies but receive unreliable, inconsistent, and/or low-quality power or no power at all.

BUSINESS MODELS AND FINANCING

Many mini-grids are owned by national utilities, whereas others are under private, community or hybrid ownership.[109] Mini-grid development traditionally has been driven by utilities and nongovernmental organisations, but in recent years private developers also have entered the space.[110] So far, there is no universally proven business model that works everywhere and is completely commercially viable without donor or public support.[111] National governments have provided fiscal and regulatory support to the sector through VAT exemptions and policies, such as Kenya's new minigrid regulation in 2021.[112]

Most of the growth in the mini-grid sector has been supported by donor programmes, such as Nigeria's NEP and Kenya's KOSAP.[113] The World Bank alone claims to account for 25% of global investment in the sector.[114] Additionally, the Mini-grid Funder's Group, which represents 30 funders and financiers that co-ordinate efforts and share lessons, has reported a total committed investment of around USD 1.8 billion in mini-grids globally (USD 1.4 billion in Africa).[115] The largest programmes are in Burundi, the DRC, Mali, and Nigeria, with other sizeable efforts (above USD 10 million) in Kenya, Lesotho, Liberia, Malawi, Mozambique, Niger and Tanzania.[116]

One issue is the capacity of institutions and the private sector to absorb the funds at their disposal.[117] Of the USD 2.1 billion in financing approved by donors of the Mini-Grid Funder's Group since 2007, only 14% had been disbursed as of 2020.[118] A key challenge on the private sector side is the lack of maturity of the sector, as most mini-grid developers are small companies or vertically integrated startups that face difficulties in scaling up operational and financial capacity and mobilising equity. At the project level, some developers struggle to find suitable commercial arrangements with anchor loads, without which the mini-grids may not be viable over the long term.[119] On the institutional side, there are challenges in awarding licences and robust contracts. Most companies have yet to reach scale; large players have small equity stakes in the market, and impact funds are stimulating the market.

In 2020, Husk Power was the first company globally to install 100 community mini-grids, and it serves 5,000 business customers.[120] The company operates in India without the need for subsidies, relying on a diversified business model that addresses both the supply side (solar mini-grids for access, small and medium enterprises) and the demand side (the retail of productive appliances and microfinance). Husk believes that its model is scalable, and in early 2022 it announced a target of 5,000 mini-grids in Africa and Asia for a total of 1 million connections.[121] The company has been engaged since November 2021 in building six mini-grids in Nigeria's Nasarawa state under the NEP.[122]

PowerGen supports more than 120 communities in over 8 African countries through micrograms and is also expanding in the commercial and industrial sector.[123] The company announced a partnership with CrossBoundary Energy Access in 2021 to electrify 55,000 households in Nigeria.[124] Other large international corporations, such as EDF, Enel, ENGIE, Iberdrola, Shell and Tokyo Electric, also have joined the mini-grid market, generally by taking over or investing in smaller companies.[125] Impact funds such as the Schneider Electric Energy Access Fund, the Energy Access Ventures Fund and Schneider Electric Energy Access Asia support the development of start-ups for energy access.[126]

Moving forward, large-scale portfolio approaches (such as in the DRC, Nigeria and Sierra Leone) are expected to support large project pipelines, as they are able to attract global risk-mitigation facilities and unlock private equity.[127] The Scaling Mini-Grid project in the DRC, Africa's largest at USD 400 million, plans to equip 21 provincial capitals with 200 MW of capacity through solar mini-grids, bringing the national electricity access rate from 19% to 30% by 2024.[128]

In 2021, the Multilateral Investment Guarantee Agency (MIGA), a World Bank subsidiary, issued guarantees of up to USD 37.1 million to cover investments in the solar home systems provider Bboxx in several African countries.[129] The guarantee was issued through a special purpose fund to cover equity and quasi-equity shareholder loan investments in Bboxx subsidiaries in the DRC, Kenya and Rwanda for a maximum term of 10 years.[130] MIGA also issued a guarantee of USD 5.9 million to cover investments in Bboxx through the Energy Inclusion Facility Off-Grid Energy Access Fund, a USD 100 million financing facility created by the African Development Bank to finance electrification in Africa through off-grid solutions.[131]

The emergence of geospatial analysis software, used to develop electrification plans that define areas for mini-grids, is enabling wider application of a portfolio approach to deployment.[132] Prospecting project pipelines for mini-grid developments requires resource-intensive field studies, and partial automation can help streamline the process and trigger economies of scale. Village Data Analytics software has been used in more than 15 countries in Africa and Asia to delineate mini-grid developments in rural areas, combining satellite data, on-the-ground data surveys and the Internet of Things to develop a village profile and propose an optimised mini-grid design.[133] Both Ethiopia and Nigeria use least-cost geospatial integrated energy plans to delineate opportunities for mini-grid extension.[134]

BUILDING SUSTAINABLE BUSINESS MODELS FOR DREA

MINI-GRID MODELS FOR PRODUCTIVE USES

One strategy to sustain mini-grid companies is to increase the average revenue per user, maintaining a controlled financial risk. Key to this is engaging with communities that demonstrate stable income and growth potential for productive uses of the energy. The stakes are high, as an increase in productive uses can reduce the levelised cost of electricity for the mini-grid by 25% or more.[135]

Of the 37 mini-grid projects financed by the Energy and Environment Partnership Trust Fund (EEP Africa), the most common productive uses that customers engage in are illumination and service provision (30%), light manufacturing (such as welding or carpentry) (24%), agri-processing (22%) and cold storage (13%).[136] EEP Africa approved funding in 2020 to support several innovative mini-grid business models that include productive uses.[137] In Rwanda, it is supporting East African Power in developing a hydropower plant and mini-grid that will service households, community buildings, an agricultural centre of excellence and a women's aquaculture business.[138] In Uganda, EEP Africa is supporting efforts by Equatorial Power and ENGIE to deploy four solar-hybrid mini-grids (with an industrial park as an anchor client) as well as an incubation programme that enables local women entrepreneurs to access asset financing for productive use appliances.[139]

Some companies involve local communities in identifying mini-grid needs and ways to grow demand. Miowna SA, a joint venture of PowerGen and Sunkofa Energy, won a competitive tender run by the Benin Off-Grid Clean Energy Facility in 2020 to electrify 40 villages in Benin.[140] Miowna worked with communities and other local stakeholders to identify innovative value propositions through productive uses that will help boost local incomes and make mini-grids viable.[141] In Uganda, Equatorial Power and ENGIE are building a solar mini-grid to bring power to 15,000 people in the Lake Victoria area, including through productive uses such as electric mobility (including boats and e-motorcycles) and an agriprocessing hub to deliver water purification, ice making, fish drying and other value-added agricultural services.[142]

Providing energy as a service through productive uses tends to bridge the unregulated market for solar home systems and the regulated mini-grid market, especially in terms of service quality. OKRA Solar uses the strategy of offering flexible, scalable interconnected solar home systems that can be progressively interconnected to form a mini-grid; this has the advantage of being able to adapt the system configuration to the actual load and to secure investments. In Cambodia, OKRA Solar electrified 140 households with its adaptable solution, at a total cost that the company claims is 40% lower than a traditional mini-grid set-up featuring a centralised solar and storage system and a low-voltage distribution network.[143]

Another area of potential growth is delivering renewable energy solutions to the mining sector.[144] This includes supplying reliable power to ensure continuous operations, as national grids often are unable to provide such services because grids are remote, may lack reliability or have high power costs. Globally, the global mining sector currently sources around 5 GW of renewable energy capacity, driven by the need to reduce both greenhouse gas emissions and operational costs (62% of the energy used in mining comes from fossil fuels).[145] Options include replacing heavy fuel oil generators with solar PVbattery hybrid on isolated grids.[146]

ENERGY AS A SERVICE

The productive uses segment is possibly a market on its own, which requires working with developers and communities as a trusted partner to deliver, maintain and finance productive appliances. For example, the start-up EnerGrow seeks to improve the profitability of electricity distribution companies (both grid-connected and off-grid) by financing consumer assets that increase energy consumption, ability to pay and economic output.[147] EnerGrow serves as an asset-based, de-risking partner that delivers the goods and provides a guarantee during the loan period, while monitoring income and impact. The company is active in Uganda and seeks to replicate its business model in conjunction with the most active energy access programmes, such as in the DRC, Kenya and Nigeria.[148]

Although most of the productive use programmes focus on businesses, the bulk of grid connections and associated costs are in the household segment. Significant potential lies in electric cooking (through electric pressure cookers or induction), especially in urban and peri-urban areas, where cooking relies largely on charcoal and where these technologies can provide both an additional load and revenue to grid operators as well as savings to end-customers.[149] Cooking devices may be eligible for carbon certificates, representing an additional income source for retailers. (→ *See Clean Cooking section in this chapter.*)

For the agriculture sector, various productive uses can support an increase in productivity and valueadded. Sustainable cooling solutions can be integrated alongside energy access, energy efficiency, agriculture and healthcare interventions in rural areas.[150] DREA technologies allow for solar applications in irrigation, drying, post-harvest cooling (including to improve the production and preservation of milk and dairy products) and water pumping (including to improve the supply of water and feed for dairy cows). In East Africa, there are needs for solar-based irrigation, cooling and processing for horticulture and dairy.[151] Across sub-Saharan Africa, the market for off-grid solar cold storage solutions is an estimated USD 6.25 billion, with 5 million potential customers in Kenya alone.[152]

Under its sustainable cooling project portfolio, Private Financing Advisory Network (PFAN) evaluated 35 project applications with a total investment ask of USD 150 million.[153] PFAN reports a cluster of projects related to solar PV-powered cold storage facilities for aquaculture and agricultural applications.[154] The projects involve small, modular cold rooms powered primarily by off-grid solar PV. Several of these projects reportedly are supported by digital platforms delivered via mobile phone technology that include the device in the larger supply chain management process.[155]

In Kenya, SokoFresh has developed two different models: a flat monthly lease per cold storage for larger contract farmers (business-to-business) and a rental fee per kilogram stored per day (coolingas-a-service) for smallholder farmers and co-operatives in off-grid areas.[156] In India, Inficold provides solar-based cold storage solutions to reduce perishable waste, with an estimated USD 1.6 billion market in the milk and dairy sector and a further USD 900 million market opportunity in cold storage for fish, meat and eggs.[157] ColdHubs in Nigeria provided cold room utility to more than 5,200 smallholder farmers, retailers, and wholesalers in 2021, storing more than 40,000 tonnes of food.[158]

CONSUMER PROTECTION

A key challenge facing the productive appliance sector is the price competition with poorly manufactured, less-efficient products, which are sub-standard in advanced markets and tend to be redistributed to sub-Saharan Africa. For most consumers in the energy access sector, price is the leading driver of purchases. However, few developing countries have adopted regulations on minimum energy performance standards (MEPS), which promote high-performing, durable appliances.

The VeraSol initiative, launched in 2020 and led by CLASP and the Schatz Energy Research Center at Humboldt State University, is an extension of the Lighting Global initiative to encompass productive uses and component-based solar home systems.[159] VeraSol offers methods, testing capabilities, and baseline levels of product quality for consumer protection, among others. It features a database of certified products including solar energy kits, electric pressure cookers, televisions, fans, refrigerators and solar water pumps. Such frameworks offer governments and donors the possibility to incentivise and support companies and initiatives that rely on efficient appliances for energy access.[160]

Kenya's 2016 energy regulations include technology-specific MEPS for refrigerators, air conditioners, lighting, motors and (magnetic) ballasts.[161] In Burkina Faso, ANEREE (Agence Nationale des Énergies Renouvelables et de l'Efficacité Énergétique) has adopted energy efficiency certifications for many appliances, as well as labelling for energy performance, which enables equipment to be excluded from the VAT.[162] Key challenges facing the country include the prevalence of low-quality appliances and minimal capacity to enforce the certifications and standards; additionally, developing productive uses requires delivering, selling, maintaining and supporting the financing of appliances relevant to the community.

By early 2021,
67 countries
had included household energy or clean cooking goals in their NDCs under the Paris Agreement.

CLEAN COOKING

Of the 4 billion people who lacked access to "modern energy cooking services" (MECS[i]) as of 2021, an estimated 1.25 billion were in the process of transitioning from having "no" or "limited" access to having "high quality" access.[163] The shift is occurring most rapidly in East Asia and in Latin America and the Caribbean, whereas sub-Saharan Africa has the lowest rate of people transitioning to high-quality access.[164] However, rapid urbanisation in Africa is bringing consumers closer to cleaner cooking sources such as electricity.

By early 2021, 67 countries had included household energy or clean cooking goals in their NDCs under the Paris Agreement.[165] Rwanda seeks to provide 80% of its total population (and 50% of its urban population) with access to modern efficient cookstoves by 2030.[166] Nepal announced a target to have 25% households using electric stoves by 2030.[167]

i The level of access to MECS is tracked by ESMAP's multi-Tier framework, which nuances access along the dimensions of exposure to pollutants, efficiency, safety, affordability, availability and convenience.

Over the past two decades, the primary fuel mix for cooking has diversified away from wood biomass and liquefied petroleum gas (LPG). Although the global population using wood biomass for cooking increased from 1.8 billion in 2000 to 2 billion in 2010, it fell back to 1.8 billion between 2015 and 2019.[168] In 2019, the number of people using gaseous fuels (e.g., LPG, natural gas and biogas) for cooking surpassed the number of people using fuelwood, to reach a total of 1.9 billion.[169] Electricity also gained traction, with 546 million people using electric cookstoves in 2019, an increase of 360 million in less than a decade.[170]

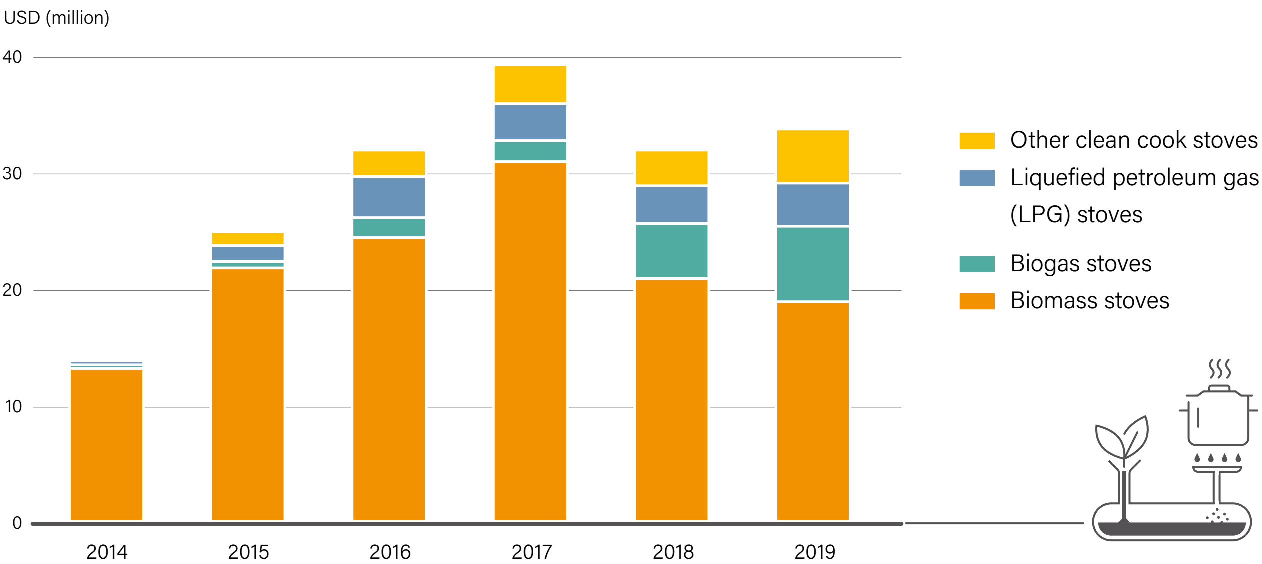
The distribution and sale of new cookstoves has increased, spurred by the emergence of new and competent supply chain participants such as manufacturers and last-mile distributors in the clean cooking markets. Although cookstove sales stalled between 2017 and 2019, with a recorded USD 41 million in revenue in 2019, sales in 2020 were nearly double those in 2019.[171] Of stove sales using the PAYGo model, 62% were sold in Zambia, 17% in Uganda and 14% in Kenya.[172]

Despite high sales of clean cookstoves in 2020, the COVID-19 crisis disrupted supply chains and tempered demand. Of 111 companies surveyed by the Clean Cooking Alliance, 30% reported a temporary cessation of operations, and two-thirds reported moderate-to-severe disruptions in activities during the year.[173] Non-biomass models accounted for a record 42% of the clean cookstoves purchased in 2019, continuing the five-year shift away from biomass cookstoves towards cleaner ones.[174] (→ *See Figure 49.*) In 2020, sales of biomass cookstoves grew 5% relative to 2019.[175]

The range of technologies available in the clean cooking sector reflects the diversity of customer types[i] and is supported by a variety of business models (mainly PAYGo, carbon credits, results-based financing and grants). LPG and ethanol are used mainly in urban areas, where population density, higher incomes and established distribution networks allow these fuels to compete favourably with traditional options such as charcoal and kerosene.[176] In rural areas, biogas is a proven alternative to charcoal and harvested wood; its use has grown steadily since 2010, particularly in Africa.[177] (→ *See Figure 50.*) In India, the use of biogas for cooking fell 18% (by nearly 2 million people) over the decade, whereas in China it was up 4% (by 4.5 million people).[178]

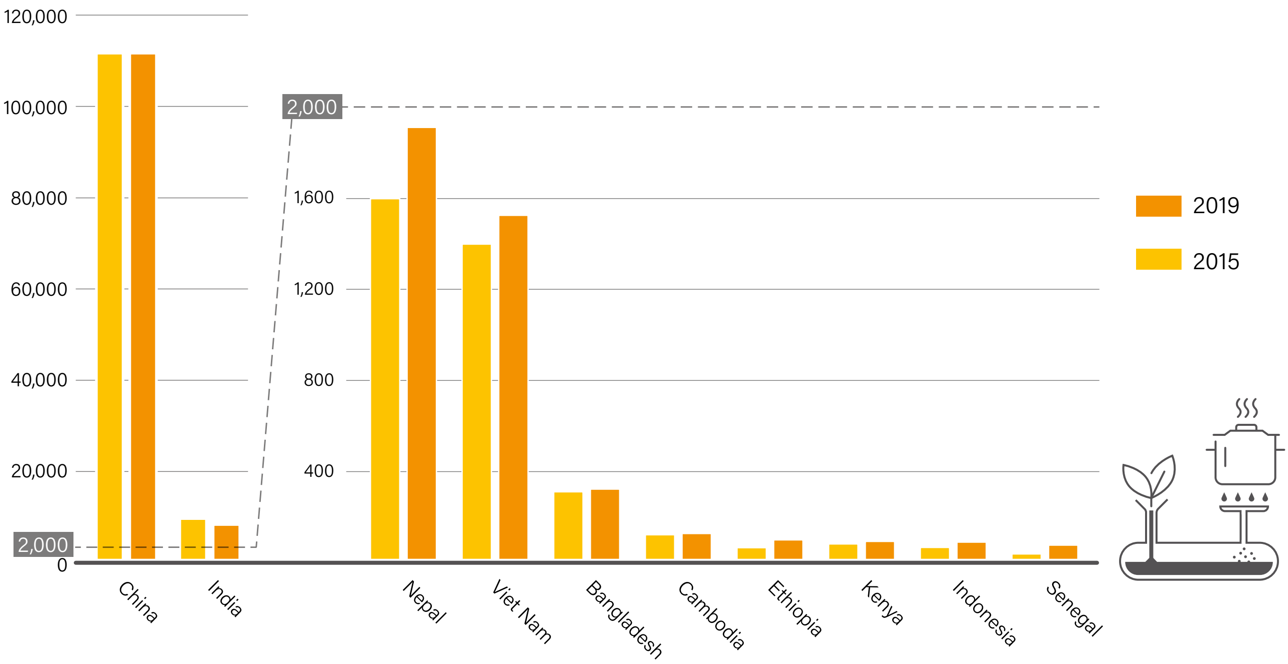
i These depend, for example, on cooking practices and fuel availability, with each technology solution addressing different needs.

FIGURE 49.
Cookstove Sales by Type, 2014-2019



Source: Clean Cooking Alliance. See endnote 188 for this chapter.

FIGURE 50.
Number of People Using Biogas for Cooking, Top 10 Countries in Africa and Asia, 2015 and 2019



Source: IRENA. See endnote 191 for this chapter.

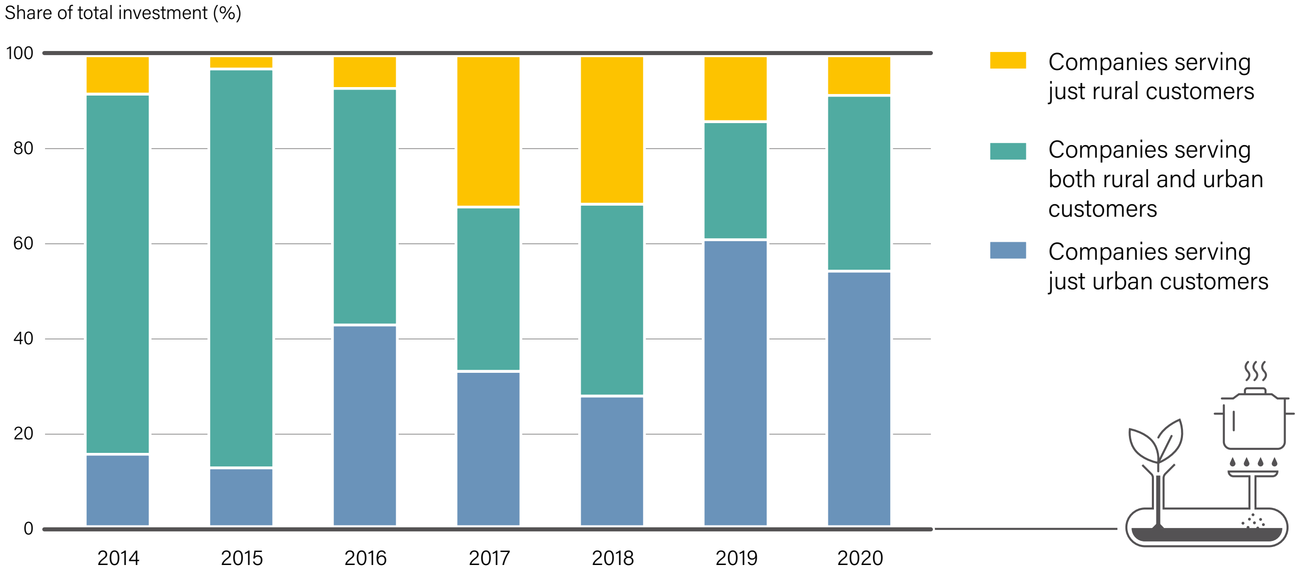
Technology use depends on the availability of locally sourced feedstock and processing facilities. If either of these is not available in sufficient quantities, this can make clean cooking technologies less competitive with traditional alternatives.[179] The use of wood pellet fuels also has increased.[180]

The affordability of clean cooking appliances and fuels is critical. At recent price levels[i], these technologies have not been able to compete with no-cost fuel solutions when external factors such as safety, health and economic potential are not internalised.[181] The main market potential for clean cooking lies with consumers who are currently paying for wood or charcoal, mainly in urban and periurban areas.[182] In recent years, member companies of the Clean Cooking Alliance that serve only urban consumers raised more capital than companies with rural customers, due to the need to secure return on equity from customers with higher incomes located in urban settings.[183] (→ *See Figure 51.*)

i Today, upfront expenditures are in the range of USD 50 to USD 100 for LPG and electric stove kits, USD 75 to USD 100 for gasifier stoves, and USD 500 to USD 1,500 for biogas, which suggests the need for pay-per-use models.

The **affordability of clean cooking appliances and fuels** is critical.

FIGURE 51.
Investment Raised by Clean Cooking Companies Based on Customer Location, 2014-2020



Note: The data rely on self-reporting by the companies and have been supplemented with publicly available investment data. The number of companies reporting has varied between 39 and 51 during the years 2014 to 2020.
Source: Clean Cooking Alliance. See endnote 197 for this chapter.

The policy landscape for clean cooking stalled in 2021, due in part to the impacts of the pandemic. Rising oil prices also posed challenges for large-scale LPG programmes in some countries, such as Nigeria and India, where the prices for LPG canisters nearly doubled during 2021.[184] Among policy developments, the Go Electric campaign launched in India in February 2021 aims to raise national awareness of the benefits of electric mobility and cooking.[185] Kenya committed to including 100% access to clean cooking by 2028 in its Bioenergy Strategy 2020-2027.[186]

As the shift to biogas progresses, the use of LPG and natural gas for cooking likely will continue to grow, and electric cooking also has significant growth potential.[187] A recent study identified Bangladesh, China, India, Indonesia, Kenya, Malaysia, Nigeria, Peru and Uganda, among others, as strong growth countries for mini-grid and stand-alone electric cooking.[188] Notably, some of the countries identified in the study (including India, Indonesia, Kazakhstan, Mexico, Malaysia and Thailand) have renewable energy shares of less than 40% in their electricity mix, suggesting the need for strong policies to decarbonise the electricity supply.

Adoption is a major hurdle for the sector. In many countries with a high penetration of clean primary fuels, users of clean stoves continue to use traditional fuels and stoves.[189] A study in Nigeria revealed how cultural preferences such as food taste, fuelling practices and cook pan size have impeded the adoption of cleaner cookstove designs, despite high awareness.[190]

BUSINESS MODELS

The clean cooking supply chain, although growing stronger, remains nascent, as it has not yet achieved the scale required for the size of market it should serve.[191] Companies are manufacturing mainly in small batch series, and most are pre-profitable.[192] Despite improving sales volumes and consumers, only a minority of companies have realised sales revenues above USD 1 million.[193]

For consumers, paying for a service through PAYGo is equivalent to purchasing solid fuels on a regular basis; this enables clean cooking solutions to compete with traditional fuels in areas where fuel is not free. Smart devices also can open avenues for broad uptake of carbon finance to fund stove programmes.[194] In addition, smart devices have unlocked possibilities for PAYGo technology in the biogas sector.[195]

Small LPG start-ups, such as KopaGas and PayGo Energy, dominate the use of PAYGo in clean cooking. However, in 2020 ENGIE Africa announced a new partnership with the PAYGo gas company PayGas in South Africa to support two new LPG refilling stations that can service 4,000 homes.[196] PayGas plans to scale its operations to other African countries.[197]

In rural areas, pre-fabricated "smart" biodigesters are being tested that bundle productive uses in their offer, which includes PAYGo. ATEC offers the option in Cambodia of either upfront payment or a monthly fee for delivering services such as organic fertiliser, free cooking gas and waste management services.[198] Globally, Sistema.bi offers a prefabricated biodigester bundled with several productive appliances and services, such as biogas for thermal energy, biogas and biofertiliser.[199]

Another emerging trend is the bundling of electricity and clean cooking services, with both solar home systems and mini-grid operators entering this space. In a pilot in six mini-grid locations in Tanzania, households exposed to electric pressure cookers found the technology to be time efficient and convenient and said they may continue using the service.[200] Some stove producers are looking to enter the market for low-level electricity access services, such as small lighting appliances; a key example is Africa Clean Energy's ACE One product, which combines cooking, lighting and electricity.[201]

Business models appear to be converging for companies that increasingly serve as software and lending platforms, with the hardware component adapting to fit various market segments through energy as a service. In Rwanda, Bboxx offers a package combining PAYGo solar with PAYGo cooking solutions.[202] Meanwhile, Biolite – a charcoal and wood stove producer and solar lighting start-up that is active in 17 countries and operates a network of 30 distributors – announced that it would start distributing off-grid solar solutions, leveraging the Angaza retail network.[203] Other hybrid models include ACE Drive, which delivers a biomass cookstove with a smartphone, charger and LED lighting.[204]

Ethanol is used minimally as a renewable cooking fuel but has potential because it is relatively easy to distribute.[205] The traditional model has been bottling and bulk distribution, but in 2019 KOKO Networks launched a decentralised distribution model in Nairobi, Kenya with the fuel infrastructure company Vivo Energy.[206] Customers can pre-pay digitally for the ethanol canisters, as alternatives to other fuels, which are generally cheaper (40% for charcoal and 10% for kerosene), and then top them off at around 700 ethanol vending machines (KOKO Points) in corner shops around the city.[207] The company sells its own ethanol stoves, manufactured in India, and was serving 50,000 households by August 2020.[208] In June 2020, it received results-based financing under the Dutch SDG 7 programme for a further 250,000 connection points.[209]

Business models
for electricity and clean cooking tend to converge through the PAYGo model.

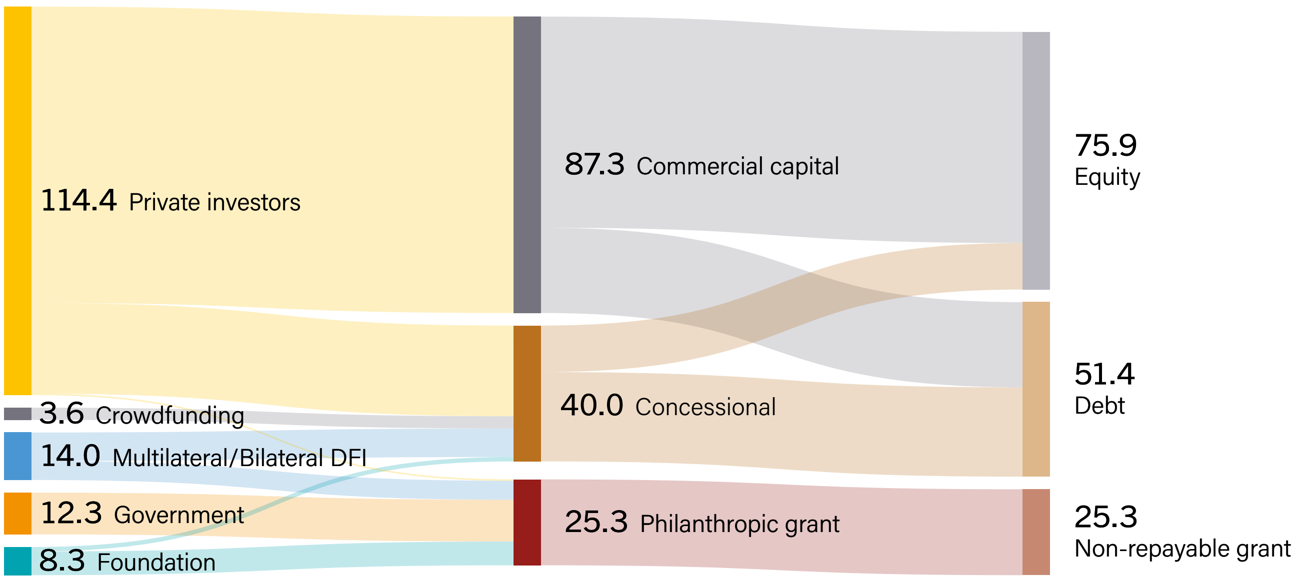
INVESTMENT AND FINANCING

Financing for the clean cooking sector is shifting from grants to corporate equity. The Clean Cooking Alliance recorded USD 70 million in transactions in 2019, up 75% from 2017.[210] Most of these transactions (60%) were equity and only 11% were grants (versus 40% and 25%, respectively, in 2017).[211] This investment is highly concentrated: in 2020, just seven companies accounted for more than 90% of the total investment tracked by the Clean Cooking Alliance.[212] Just four companies accounted for half of the capital raised: Circle Gas (Kenya, PAYGo LPG), Sistema.bio (Central America, biogas), KOKO Networks (Kenya, ethanol) and Biolite (Kenya, biomass stoves).[213] Data from the Clean Cooking Alliance records USD 60.7 million in 2020. Compound annual growth of 20% annually was reported for the period 2014-2020, well below the estimated USD 4.5 billion annual investment required for universal access to clean cooking.[214]

For the 51 companies surveyed by the Clean Cooking Alliance, nearly 80% of the capital raised during 2017-2019 (a total of USD 144 million) came from private investors, while 20% came from multilateral finance institutions, development finance institutions and governments.[215] (→ *See Figure 52.*) The funds went primarily to LPG (26%), biomass stoves (25%) and biogas systems (19%), followed by ethanol (14%), processed biomass (12%) and electric systems (3%).[216] Companies targeting populations in urban areas raised twice as much capital as those addressing rural areas over the period.[217]

Uptake of crowdfunding models for energy access also has occurred. Despite the COVID-19 pandemic, crowdfunding platforms for clean cooking have posted notable growth, raising a cumulative USD 8 million in investments between 2014 and 2020.[218] Crowdfunding vehicles have included peer-to-peer (P2P) business lending, P2P micro-lending, equity, donations, rewards and initial coin offerings (ICOs).[219] Of these models, P2P transactions and ICOs hold opportunity for the immediate- and medium-term scale-up of the sector. Although P2P business lending inflows comprise 99% of the clean cooking crowdfunding, cryptocurrencies are at an early stage of adoption, and ICOs could be integral in the future in providing quick alternative options for securing much-needed financing for scale-up.[220]

FIGURE 52.
Clean Cooking Capital Raised by Source and Type, 2017-2019



All values in million USD

Investment Source

- **Private investors**
  Includes private commercial funds, impact funds, angel investors and founders
- **Crowdfunding platforms**
  Online platforms that typically provide equity and debt to companies by collecting small amounts of money from a large group of people
- **Multilaterals/Bilateral Development Financial Institutions (DFIs)**
  Includes financial institutions typically set by governments or charitable organizations that provide risk capital on concessional terms. The source of capital for DFIs may be public or private
- **Government**
  Includes programs that typically provide non-return seeking capital such as grants to support industries and companies
- **Foundations**
  Includes non-profit organizations or charitable institutions that provides grants or concessionary capital for charitable or catalytic purposes. Foundations may raise capital through private or public sources

Investment Type

- **Commercial capital**
  Defined here as capital seeking purely a financial return
- **Concessionary capital**
  Defined here as capital that seeks sub-commercial financial returns along with impact returns
- **Philanthropic grant**
  Defined here as a type of capital as distinct from "non-repayable grants," used as a capital instrument

Investment Instrument

- **Non-repayable grant**
  Grant is defined as non-financial return seeking capital typically made for charitable purposes

Source: Clean Cooking Alliance.
See endnote 228 for this chapter.

Companies progressively are incorporating carbon finance in their revenue models; such financing increased from USD 0.5 million in 2017 to USD 5 million in 2019, primarily from biomass stove manufacturers under the Clean Development Mechanism.[221] Carbon financing has great potential, particularly with the emergence of carbon accounting methodologies that rely on continuous monitoring though smart devices. In October 2021, the Gold Standard released a new methodology for metered energy cooking devices that applies to LPG, electric, ethanol, and biogas stoves, which could provide solid ground for rapid growth in the carbon revenue model.[222]

Varying financing instruments have been deployed to support enterprise growth and attract private equity. The BIX Fund provides debt, equity and mezzanine capital and triggers innovative financing, such as debt instruments based on carbon uptake and result-based financing.[223] SPARK+ Africa provides debt and quasi-equity and also blends senior debt from large and institutional financers, equity provided by development finance institutions and impact investors, and first loss provided by impact investors and donor facilities. As the world's largest impact investment fund focused on clean cooking and the fuel value chain, SPARK+ Africa has raised at least USD 40 million for new projects across sub-Saharan Africa.[224]

The sector is also supported by non-financing programmes, such as the Venture Catalyst Programme for the Clean Cooking Alliance to support technical assistance and grants to improve business models and support scale-up.[225]

ELECTRIC MOBILITY

Electric transport is growing strongly globally, including in India and several countries in Sub-Saharan Africa.[226] In India, of the 87,659 electric vehicles procured through government-backed incentives in 2021, 97.5% were two- and three-wheelers and buses (a total of 6,265 e-buses).[227] The number of government-supported programmes that promote micro-mobility in rural communities – including connections to mini-grids as part of a strategy to increase productive uses – is increasing.[228]

Some African countries have integrated electric mobility into national climate action plans, such as their Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.[229] Rwanda's Green Growth and Climate Resilience Strategy is mobilising USD 900 million for electric vehicles and associated charging infrastructure.[230] Kenya set a target for 5% of its registered vehicles to be electric by 2025.[231]

International programmes such as the Global Electric Mobility Programme sponsored by the Global Environment Facility (GEF) also hold promise for the sector. In mid-2021, the GEF announced support for pilot projects and policy development initiatives in 29 additional countries, bringing the total number of countries with GEF-funded electric mobility to 50.[232] Electric motorcycle demonstration projects are operating in Kenya and Uganda as part of the UN Environment Programme's global emobility programme, which supports projects for electric two- and three-wheelers in 16 countries, light-duty vehicles in 25 countries and electric buses in 14 countries.[233] The start-up Sokowatch has deployed electric tricycles to address the logistical challenge of restocking, and microgrid developers are boosting network demand by selling electric bikes coupled with a battery-as-a-service approach.[234]

At the crossroads of transport and access, Powerhive in Kenya is testing a business model for battery charging as a service with its solar-powered mini-grids in the country's west.[235] Through the pilot service, subscribers can swap out the batteries of their converted Bajaj bikes for newly charged ones when they become depleted, paying for the difference in the state of charge.[236] India's common service centres launched a rural electric mobility programme in 2021, and Guraride in Rwanda is improving its green public bikeshare system, which includes e-bikes.[237]

Kenya and Uganda are thriving markets for electric mobility, and the potential remains significant. Uptake of conventional motorcycles is surging, with motorcycle imports increasing three-fold compared to car imports over the last two decades.[238] In Kenya, the company Opibus, in partnership with Uber, is aiming to deploy 3,000 electric motorcycles by 2022, and the start-up company Stimaboda is providing a charging service for electric moto-taxis, beginning in Nairobi.[239]

Electric transport
is growing strongly globally, including in India and several countries in Sub-Saharan Africa.

05

SNAPSHOT. NEW ZEALAND

Funding Renewable Energy via Green Banks

In 2019, the government of New Zealand established New Zealand Green Investment Finance (NZGIF) with initial capital of NZD 100 million (USD 68.3 million). This "green bank" is mandated to reduce greenhouse gas emissions by enabling capital flows and increasing direct investment (in the form of equity and debt) in target sectors such as transport, process heat, energy efficiency, agriculture, distributed energy resources, plastics and waste. In 2021, the bank received a further NZD 300 million (USD 205 million) in capital investment, quadrupling its initial pool in only two years, to NZD 400 million (USD 273.3 million). So far, the investments have resulted in lifetime emission reductions of around 250,000 to 300,000 tonnes of CO_2.

For example, NZGIF invested in the SolarZero project, which provides households in New Zealand with cleaner and cheaper renewable energy at a flat rate for 20 years. As of early 2022, the project had expanded its distributed energy network to more than 4,800 residential clients and generated a total of 16.9 GWh of solar electricity, with the energy savings averaging 40-50% of a household's electricity consumption. In 2021, it equipped 800 customers and installed 500 batteries. Customers can save NZD 230 (USD 157 million) annually and avoid 15 tonnes of CO_2 emissions on average during the 20-year period. Since the project's launch, residents have saved around NZD 2.3 million (USD 1.5 million) on their power bills.

As part of the SolarZero project, NZGIF is committed to providing NZD 10 million to NZD 30 million (USD 6.8 million to USD 20.5 million) in debt facilities to corporations to generate large-scale solar power at their facilities. The project also aims to expand renewable energy in schools through an NZD 8 million (USD 5.4 million) debt facility and NZD 10 million (USD 6.8 million) in reserve. In addition, NZGIF has invested in electrifying vehicle fleets through the company Sustainable Fleet Finance, which relies on an NZD 10 million (USD 6.8 million) credit facility as well as an NZD 10 million (USD 6.8 million) facility provided by New Zealand Post.

Source: See endnote 161 for this chapter.

05 INVESTMENT FLOWS

KEY FACTS

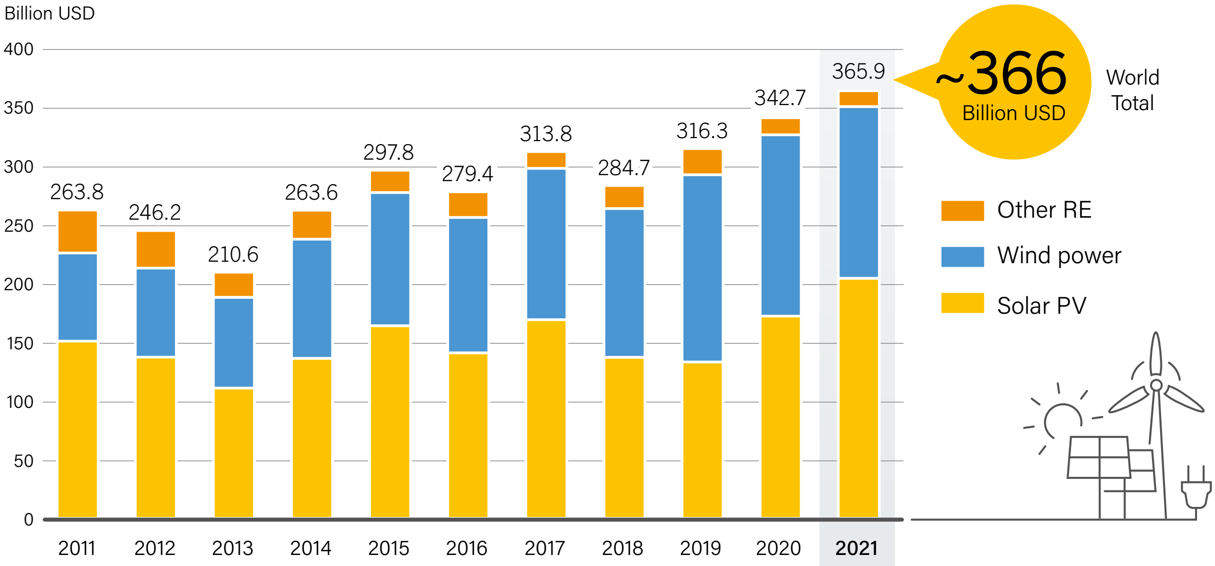
- Global new investment in renewable power and fuels reached an estimated **USD 366 billion in 2021**, a record high, despite impacts from the COVID-19 pandemic.
- Solar PV and wind power continued to dominate new renewable energy investment, with **solar PV accounting for 56%** of the 2021 total and **wind power for 40%**.
- China again accounted for the **largest share of global investment** in renewable power and fuels, with **37% of the total**.
- Renewable power installations continued to attract far more investment than did fossil fuel or nuclear generating plants, with **renewables accounting for 69% of the total amount committed to new power** generating capacity in 2021.
- The divestment trend continued in 2021 with more than 1,400 institutional investors and institutions worth **more than USD 39 trillion in assets committing to partially or fully divesting from fossil fuels**.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 megawatts, MW) reached a record high in 2021, at an estimated USD 366 billion[i,1] This was a 6.8% increase over 2020, due largely to the global rise in solar photovoltaic (PV) installations.[2] Investment in renewable power and fuels has exceeded USD 250 billion annually for eight consecutive years.[3] (→ *See Figure 53*.) These estimates do not include investment in renewable heating and cooling technologies, for which data are not collected systematically.

Solar PV and wind power continued to dominate new investment in renewables, with solar PV accounting for 56% of the 2021 total, and wind power for 40%.[4] The strong growth in solar PV investment in 2020 expanded further in 2021, rising nearly 19% to reach USD 205 billion.[5] Wind power investment fell 5% to USD 147 billion, reflecting a sharp decline in offshore wind power investment (down 45%) and a smaller increase in onshore wind power investment (up 16%).[6] Investment in other renewable energy technologies, including biomass, waste-to-energy, geothermal power, and small hydropower, declined overall.[7]

i Data are from BloombergNEF and include the following renewable energy projects: 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.

FIGURE 53.
Global Investment in Renewable Power and Fuels, 2011-2021



Source: Based on BloombergNEF. See endnote 3 for this chapter.

Note: Figure does not include investment in hydropower projects larger than 50 MW. BNEF data for previous years have been revised since the publication of last year's Global Status Report.

Investment in electric vehicles and associated charging infrastructure was up 77% to USD 273 billion in 2021.[8] This reflected the increased policy support for electrification in core auto markets, new battery technologies, lower expected costs and rising consumer adoption despite the COVID-19 pandemic.[9] Investment in energy storage also reached a new record of USD 7.9 billion in 2021, which may reflect falling technology costs and growing political incentives and targets.[10]

INVESTMENT BY ECONOMY

Investment in renewable power and fuels varied by region, rising in China, India, and the Middle East and Africa, but falling in the Americas (due largely to a decrease in the United States) and in Europe and Asia (excluding China and India).[11] (→ *See Figure 54.*) China continued to account for the largest share of global investment in renewables (excluding hydropower larger than 50 MW), at 37%, followed by Europe (22%), Asia-Oceania (excluding China and India; 16%) and the United States (13%).[12] All other world regions accounted for 4% or less of the total.[13]

China's overall investment in renewables increased 32% to USD 137 billion in 2021.[14] This was due largely to a bump in solar PV investment, which grew 115% to USD 79 billion, a high not seen since 2017.[15] Investment in all other renewable technologies in China fell, including wind power (down 9% to USD 58 billion).[16] Renewable energy investment in China is driven in part by the country's long-term decarbonisation goals and by the growing demand for power, which is high in comparison with countries in the Organisation for Economic Co-operation and Development (OECD).[17]

Investment in solar PV in China was boosted by large-scale projects undertaken co-operatively by local and national governments.[18] The decline in wind power investment reflects the comparatively lower price of Chinese wind turbines as well as the shift in the national feed-in tariff (FIT).[19] Beginning on 1 January 2021, the FIT rewarded onshore wind power projects with the same remuneration as coal-fired power plants.[20] Financial support for offshore wind power was scheduled to stop in 2022.[21]

Investment in European renewable energy projects fell 5% to USD 79.7 billion in 2021.[22] Although solar PV investment grew nearly 8% to USD 34.1 billion, investment declined in all other renewable energy technologies in Europe, including wind power.[23] Despite ambitious national targets for wind power development in many countries, complex permitting rules and procedures together with disrupted supply chains were partly to blame for the drop in wind power investment across the continent.[24]

In Asia-Oceania (excluding China and India), investment in renewables fell 11% to USD 56.8 billion.[25] Contrary to the trends in most other regions, solar PV investment declined 17%, whereas the other renewable energy technologies saw moderate investment increases.[26] The drop in solar PV investment is attributed largely to declines in Vietnam and to a lesser extent in Japan.[27] Vietnam, which became a major solar PV market in 2019 and 2020, had a commissioning deadline for its national FIT in 2020, after which investment in solar PV was less attractive.[28] In Japan, recent amendments to the national FIT negatively impacted investment.[29] Outside of these two countries, solar PV investment in the region was more stable.[30]

In India, total new investment in renewables increased 70% to USD 11.3 billion.[31] Investment in all renewable energy technologies increased in the country in 2021, with notable jumps

For the second year in a row, solar PV is the only renewable technology to have an **increase in investment**.

in solar PV (up 68% to USD 7.5 billion) and wind power (up 92% to USD 3.4 billion).[32] Investment in solar PV and wind power in India has been greatly supported by the implementation of auctions, which have been widely successful and have resulted in comparatively cheap renewable power purchase agreements for stateowned utilities.[33]

In the United States, which attracted the most renewable energy investment among developed economies, investment fell nearly 17% to USD 46.7 billion in 2021.[34] Countering the trends in China and Europe, solar PV investment plummeted 29% to USD 26.1 billion, and investment in wind power remained unchanged, whereas investment in all other renewable energy technologies increased.[35] The drop in investment in the United States is attributed largely to supply chain challenges, combined with permitting and grid connection difficulties, the fall-off in available federal tax credits, and continued uncertainty about tariffs and other trade measures that impact module imports.[36]

Brazil's total investment in renewables was up 27% to USD 11.6 billion in 2021, surpassing for the first time the high of 2008, when the country's biofuel boom was in full swing.[37] Solar PV and wind power saw notable investment increases of 27% and 31%, respectively, whereas investment in all other technologies declined.[38] Solar PV investment was supported in part by low interest rates resulting from the COVID-19 pandemic as well as skyrocketing electricity prices exacerbated by the country's worst drought in nearly a century.[39] Auctions, which were not held in 2020 due to the pandemic, resumed in 2021, helping to support the investment boom in both wind power and solar PV.[40] Importantly, a revision of a law (5829) set to pass in 2022 will introduce grid-access charges for residential and commercial system owners after a 12-month grace period, which has created a rush in solar PV development.[41]

Outside Brazil and the United States, renewable energy investment in the Americas totalled USD 9.7 billion in 2021, up 7% from the previous year but still well below the highs in 2012, 2017 and 2019.[42] Solar PV investment fell substantially (24%), whereas investment increased for wind power (up 34%) and the other renewable energy technologies.[43] The decline in solar PV investment in the region is due largely to drops in both Argentina and Mexico, where auctions for renewable energy that had once driven investment were placed on hold in 2021.[44] Chile's market remained strong in 2021 with USD 3.4 billion in renewable investment, although its total was not as high as in recent years.[45] Colombia, still a nascent market for renewables, is showing promising investment growth and reached a new high in 2021 of USD 750 million, most of which was in wind power.[46]

Investment in renewables in the Middle East and Africa increased 19% to USD 12.8 billion.[47] Although wind power investment fell substantially, solar PV investment grew 41% to an all-time high of USD 10.9 billion.[48] Investment in the other renewable energy technologies also saw notable increases.

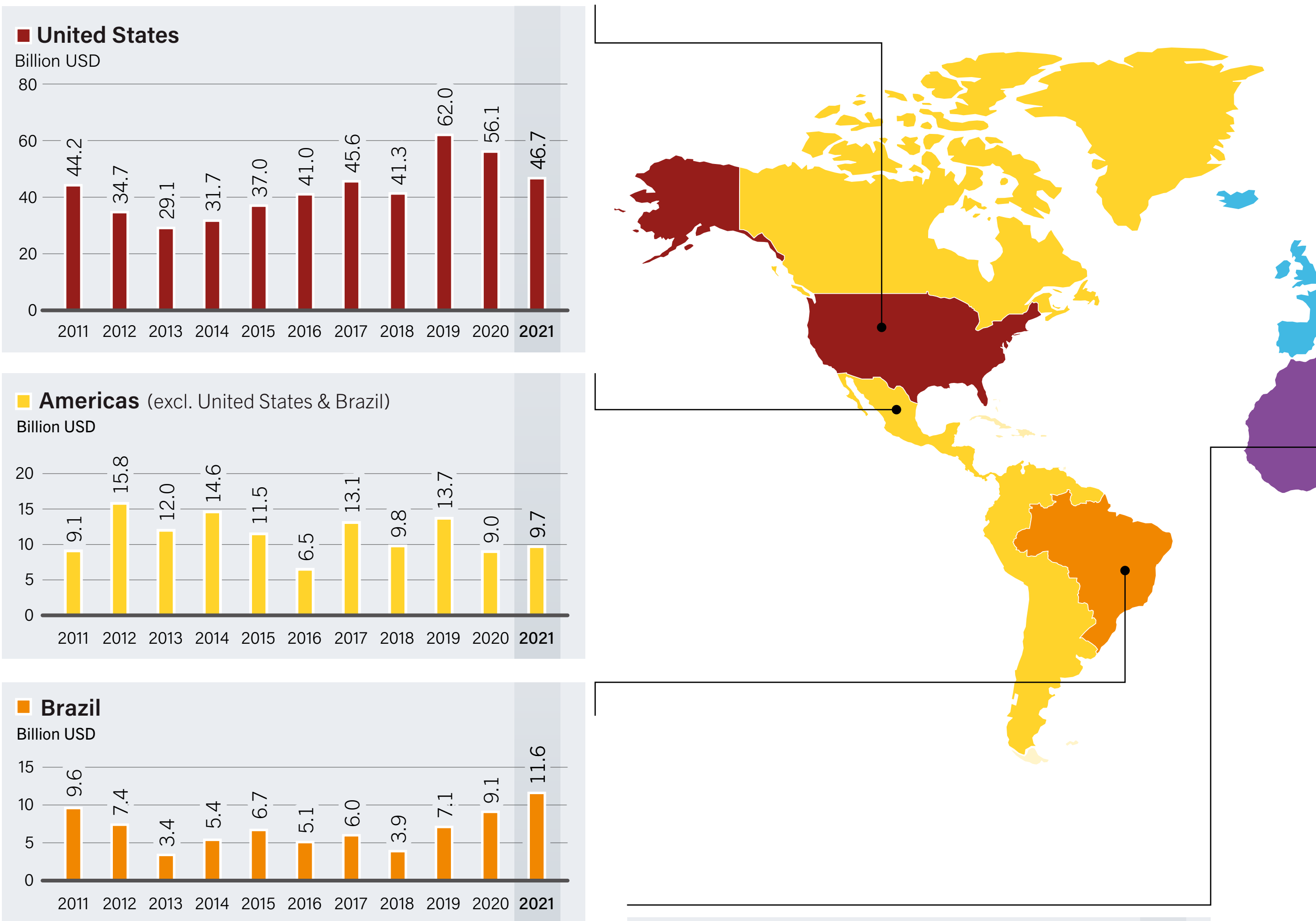
Developing and emerging economies face unique challenges to financing renewable energy projects compared to the developed world. Investment in these countries is complicated by political instability, macroeconomic uncertainty (related to inflation and exchange rates), policy and regulatory issues, institutional weaknesses and a lack of transparency.[49] Country-related risks and underdeveloped local financial systems also can directly affect the cost of capital.[50] For example, nominal financing costs can be up to seven times higher in emerging and developing countries than in developed countries, such as in Europe and the United States.[51]

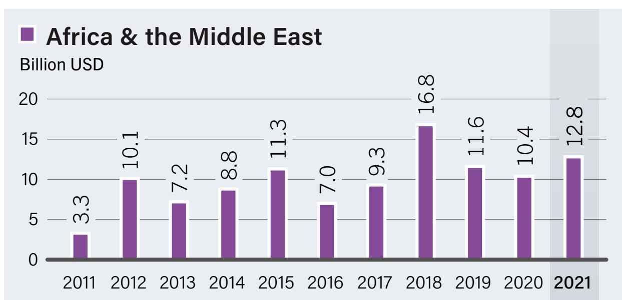
IMPACTS OF COVID-19

Investment in new renewable energy projects showed remarkable resilience despite impacts from the COVID-19 pandemic.[52] In the face of uncertain economic recovery, major commercial banks were cautious about lending and more reluctant to invest, leading to higher rates on loans, tighter loan standards for borrowers and lower chances of attracting the requisite project funding.[53] Banks were more interested in renewable energy projects proposed by developers that had a track record of successful project completion than in projects by first-time investors, such as community solar initiatives.[54] The reduction in energy demand that resulted from pandemic lockdowns also impacted renewable energy investment, which was further complicated by disruptions in global supply chains.[55]

Governments, as part of their broader response to the COVID-19 pandemic, in many cases allocated dedicated funds to support investment in renewables. As of October 2021,

FIGURE 54.
Global Investment in Renewable Power and Fuels, by Country and Region, 2011-2021





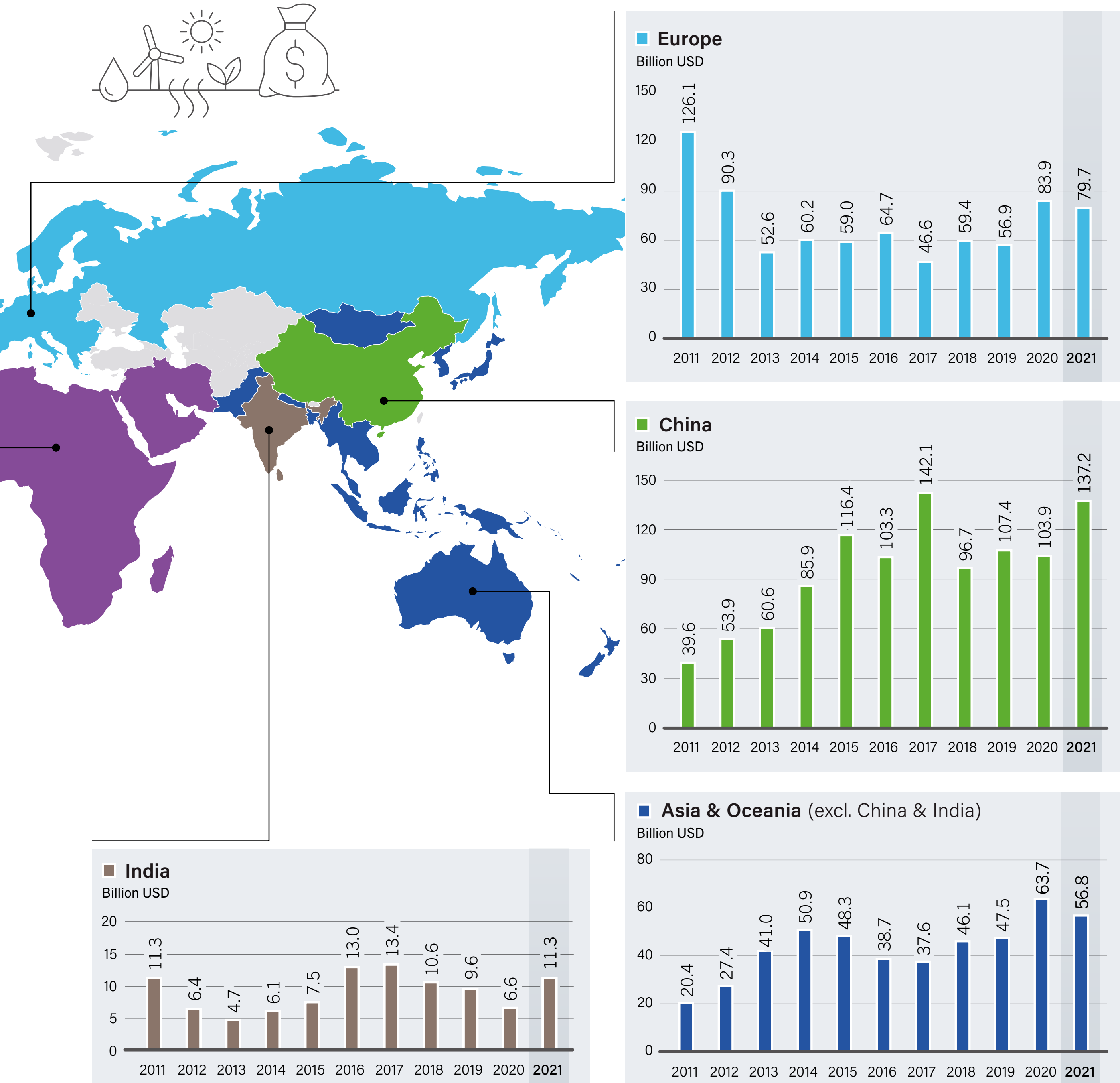
Source: Based on BloombergNEF. See endnote 11 for this chapter.

Note: Figure does not include investment in hydropower projects larger than 50 MW. BNEF data for previous years have been revised since the publication of last year's Global Status Report.

recovery programmes related to clean energy[i] totalled USD 470 billion, although this represented only 2.8% of the total USD 16.9 trillion in fiscal support mobilised to respond to the pandemic.[56] These energy-related funds were largely in developed countries and were channelled mainly through existing programmes such as energy efficiency grants, public procurement, utility plans and support for electric transport.[57] In a notable exception, China allocated around USD 12 billion to renewables as part of its response effort.[58]

Since 2011, more than
two thirds
of global investment in renewable power and fuels are concentrated among China, Europe and the United States.

i Here, the International Energy Agency defines clean energy to include low-carbon electricity (renewable and nuclear power), fuels and technology innovation (hydrogen, carbon capture and storage, biofuels and more), low-carbon and efficient transport (electric and efficient vehicles and others), energy-efficient buildings and industry, electricity networks including smart-grid investment and people-centred transitions such as access to clean cooking.



Energy-related spending spanned the sectors of renewable power, heating and cooling, and transport. Support for renewable power included Italy's pledge of USD 2.5 billion in investment for the installation of around 2,000 MW of primarily solar PV plants in small municipalities.[59] The Australian government added USD 1.03 billion to an existing fund that invests directly in new renewable electricity, clean hydrogen production and similar resource projects.[60] In the heating and cooling sector, in Poland USD 11 million was allocated to a research and development programme dedicated to transitioning heating plants away from coal and towards at least 80% renewable sources.[61] In the transport sector, Latvia, within its COVID-19 recovery framework, dedicated USD 10 million to installing biofuel production capacity, in line with its goal to achieve 7% renewables in the transport sector by 2030.[62]

Governments also are dedicating COVID-19 related funds to tackling energy poverty, which has increased in the wake of the energy crisis.[63] Spending dedicated to limiting energy poverty has had mixed effects on the environment.[64] While some governments have promoted renewables and energy efficiency, the most immediate measures include tax and direct support to fossil fuels for transport and heating.[65] (→ *See Snapshot: Spain.*)

SNAPSHOT. SPAIN

Investing in Renewables to Tackle Energy Poverty

Globally, the COVID-19 pandemic and energy crisis have increased energy poverty and exacerbated the risk to households of becoming energy poor. Spain is among the European countries most adversely affected by this risk, as it has some of the highest electricity prices in the region. In 2020, energy poverty impacted an estimated 17% of the population, and 10.9% of inhabitants could not properly heat their homes.

To tackle energy poverty, regional and local governments have implemented renewable energy projects to reduce the energy burden of households. In 2021, the European project PowerUp kicked off in the Spanish city of Valencia, with a budget of EUR 200,000 (USD 226,480). The project lifts administrative and regulatory barriers and offers tax subsidies to support local solar PV energy communities. In the city of Zaragoza, the Barrio Solar project spearheaded the installation of 100 kilowatts-peak of solar PV plants for collective selfconsumption, supported by EUR 350,000 (USD 396,340) in public and private funds. Small businesses and households will benefit from the electricity produced from the project, with 20 low-income households receiving electricity for free.

In the wake of energy price hikes in late 2021, the Spanish government implemented several tax and direct support measures, most of which promote the continued use of fossil fuels. Meanwhile, part of the electricity bill reductions are financed by capping the revenues of renewable energy producers. Two measures adopted in 2021 – a rate reduction in the value-added tax (VAT) (from 21% to 10%) on electricity bills for most power consumers, and suspension of the 7% generation tax – were extended to June 2022. In 2021, the government allocated EUR 202 million (USD 229 million) to support the household heating expenses of Spain's most vulnerable consumers, with discounts covering up to 70% of a household's bill. Transport fuels receive the largest support: a minimum bonus of 20 cents per litre of fuel for all consumers, while freight and passenger transport companies receive additional direct aid.

Source: See endnote 65 for this chapter.

RENEWABLE ENERGY INVESTMENT IN PERSPECTIVE

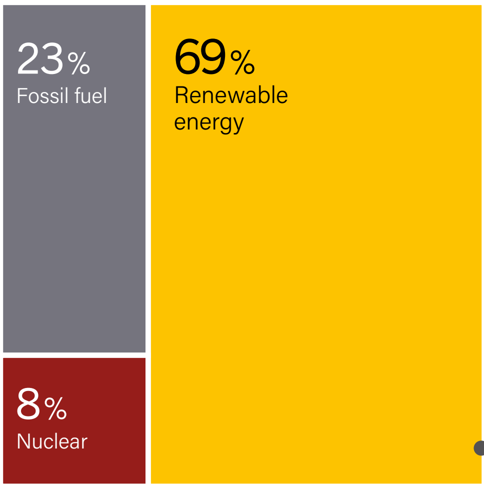
Renewable power installations continued to attract far more investment in 2021 than did fossil fuel based or nuclear generating plants. Maintaining the shares of the past few years, investment in new renewable power capacity accounted for 69% of the total investment committed to new power generating capacity (including fossil fuels and nuclear).[66] (→ *See Figure 55.*)

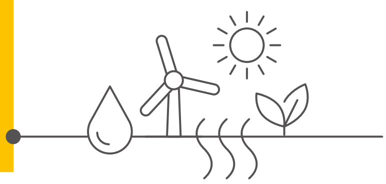
Most scenarios that limit the increase in global mean temperature are accompanied by a nearcomplete phase-out of fossil fuel power generation (without carbon capture and storage) by 2100.[67] These scenarios show dramatic increases in renewable energy deployment.[68] Thus, to meet climate change mitigation targets, investment in new fossil fuel power capacity needs to plummet.

Despite this imperative, banks and investors have continued to channel massive sums of money to fossil fuel industries such as coal, oil and natural gas.[69] (→ *See Sidebar 7.*) During 2020-2021, financial institutions in six countries (Canada, China, India, Japan, the United Kingdom and the United States) were responsible for more than 80% of coal financing.[70] Commercial banks provided USD 363 billion in loans to the coal industry during this period and channelled USD 1.2 trillion to coal companies through underwriting[i].[71] Commercial banks also play a key role in financing tar sands oil (with USD 23.3 billion in 2021); arctic (USD 8.2 billion), offshore (USD 52.9 billion) and fracked (USD 62.1 billion) oil and gas; and liquefied natural gas (USD 22.9 billion).[72] These investments have persisted despite the risk of stranded assets that would accompany transitions related to climate change mitigation.[73] (→ *See Box 11.*)

i Underwriting refers to the process of raising capital for companies by issuing bonds or shares on their behalf and selling them to investors.

FIGURE 55.
Global Investment in New Power Capacity, by Type, 2021





Between 2020-2021 the **coal industry** received as much investment as renewable power and fuels in 2021.

Source: Based on IEA. See endnote 66 for this chapter.

BOX 11. Investment in Potential Fossil Fuel Stranded Assets

The transition away from widespread fossil fuel use is critical to avert some of the worst impacts of global climate change. Among the implications of this energy transition for business-as-usual behaviour is the likelihood of "stranded assets", or assets that turn out to be worth less than expected as a result of economic changes related to the transition.

While assets can become **physically** stranded – for example, because of rising sea levels – the term generally is used in the context of **economic** stranding, where fossil fuel assets fail to deliver expected returns over their lifetime as a result of changes in relative costs and commodity prices. This also encompasses the impacts of **regulatory** stranding.

Long-term demand for oil, natural gas and coal will be impacted both by policy action on climate as well as by the rapid deployment of low-carbon technologies such as renewable energy, battery storage and hydrogen. This weakening of demand creates transition risks for companies, governments, and investors, as prices are likely to fall over the long term, even if they remain volatile in the short term because of imbalances between supply and demand.

The development of oil and gas projects is predicated on anticipated cash flows over many years or often decades. Thus, changes to long-term prices will impact the return that companies – and ultimately their investors – derive from these investments. Assets become stranded when, prior to the end of their anticipated economic life, they are unable to meet a company's return threshold. They may, however, continue to operate – the commodity price may exceed the marginal cost of operations – but this does not mean that the assets will deliver the expected return.

Carbon Tracker has quantified the risk of stranded assets for companies engaged in oil and gas production (both listed and state-owned), in terms of the capital expenditure that is at risk under a low-carbon scenario. Globally, the analysts have identified around USD 1 trillion in capital for new upstream oil and gas projects that could proceed under a business-as-usual scenario, but that ultimately are not needed if the world follows a pathway aligned with meeting the goals of the Paris Agreement. This reduction in need is driven by either policy action or technological development, or a combination of both. Other parts of the fossil fuel value chain are also exposed to such risks, including coal-fired power generation assets that are still being built in some regions.

Given the risks as well as the urgency of reducing fossil fuel emissions, this capital would be better deployed elsewhere, potentially financing the development and deployment of new energy technologies (such as wind and solar) and delivering stable, long-term returns for investors while helping to accelerate the energy transition. It is critical that investors and policy makers alike recognise the risks of continuing to invest in assets that could become stranded, exercising capital discipline to protect both their investments and the climate.

Source: See endnote 73 for this chapter.

DIVESTMENT

Since 2011, institutions worldwide increasingly have divested from, or sold off their financial interests in, fossil fuel companies. By late October 2021, around 1,485 institutions spanning 71 countries had committed to fossil fuel divestment[i], with estimated total assets of around USD 39.2 trillion.[74] Most early commitments to divestment were in the United States, but by 2021 nearly 70% of institutions committed to divesting were outside that country, demonstrating the global shift of the movement.[75] Large insurance companies, pension funds and universities with massive endowments have driven the biggest increases in assets committed to divestment.[76] As of October 2021, faith-based organisations led in commitments, accounting for 35% of total divestments, followed by educational institutions (15%), philanthropic foundations (12.6%), pension funds (12%) and governments (11.4%).[77]

Several important divestment-related announcements were made across sectors during 2021. In the lead-up to the United Nations climate talks in Glasgow in November, 72 faith-based institutions from 6 continents, with more than USD 4.2 billion in combined assets, announced their commitment to divest from fossil fuels.[78] Harvard University pledged to pull its USD 41.9 billion endowment from any company that explores or develops fossil fuels.[79] La Banque Postale in France committed to divest its USD 894 billion in assets from oil and gas companies by 2030.[80] The Ford Foundation also announced that its USD 17 billion in assets would no longer be invested in any fossil fuel-related industries.[81]

In the public sector, China announced in 2021 that it would build no new coal-fired plants outside the country.[82] That November, more than 20 countries and 5 development institutions committed to end international public finance of coal, oil and gas projects by the end of 2022, and to steer funds to clean energy instead.[83] Together, these developments mark the end of nearly all major international public finance of coal.[84] In another partnership announced in the lead-up to Glasgow, the governments of Indonesia and the Philippines joined with the Asian Development Bank to establish a mechanism that will use blended finance to accelerate the retirement of new coal power plants and develop renewable

i Through fossil fuel divestment, an institution makes a binding commitment to exclude any fossil fuel company (coal, oil and natural gas) from either all or part of its managed asset classes, or to selectively exclude companies that derive a large portion of their revenue from coal and/or tar sands companies. Organisations also may commit to some form of an exclusion policy based on different criteria, such as whether the company is aligned with the goals of the Paris Agreement.

energy to replace it.[85] In addition, Durban became South Africa's second city to commit to divestment, pulling USD 130 million from its two pension funds out of fossil fuels.[86] (→ *See Cities chapter.*)

The broader divestment movement has been called insignificant by some, based on the argument that only a small portion of investors will divest their holdings and divested shares will be bought by other investors.[87] Nonetheless, it has been shown that the divestment movement has been accompanied by an overall reduction in capital flows to domestic oil and gas companies.[88] This reduction is less prevalent in countries that heavily subsidise oil and gas, underlining the need to remove fossil fuel subsidies if climate change mitigation targets are to be met.[89] The value of these subsidies fluctuates from year to year depending on reform efforts, consumption of subsidised fuels, international fossil fuel prices, exchange rates and general price inflation.[90] Some estimates for 2020 were in the range of USD 5.9 trillion, although wide disagreement remains on how to accurately calculate fossil fuel subsidies.[91]

Funds divested from fossil fuel companies are not necessarily re-invested in companies associated with renewables.[92] However, the global network DivestInvest links the two by providing guidance to organisations and individuals during the divestment process and encouraging them to establish climate-friendly criteria for their investments (for example, by investing in renewable energy companies, low-carbon transport, or sustainable agriculture and forestry options).[93]

HSBC, in its phase-out policy for coal announced in late 2021, included requirements for its impacted clients to establish transition plans to clean energy, ultimately aiming to provide between USD 750 billion and USD 1 trillion in sustainable finance and investment to support the transition to net zero emissions.[94] The European Commission and other governments announced a partnership to decommission and repurpose South Africa's coal-fired power plants and invest in new low-carbon generation technologies such as renewables.[95] (→ *See Snapshot: South Africa.*)

SNAPSHOT. SOUTH AFRICA

Linking Divestment with Clean Energy

South Africa is the largest coal producer and consumer in Africa. Coal contributes more than 70% of the country's energy supply and accounts for 86% of its electricity generation. However, during the UN climate talks in Glasgow in 2021, the South African government took a major step towards divesting from coal by announcing the Just Energy Transition Partnership, or "South Africa Deal", in conjunction with the EU and the governments of France, Germany, the United Kingdom and the United States.

The partnership aims to support decarbonisation efforts in South Africa by providing USD 8.5 billion in financing through grants and loans over a five-year period. The three stated goals are to retire current coal plants, aid clean energy sources and provide transition support to coal-dependent regions of the country. The partnership will also assist the national power utility, Eskom, in transitioning from coal to renewables, a shift that is anticipated to require USD 27 billion in investment.

The Just Energy Transition Partnership will support South Africa's efforts to speed decarbonisation while preventing up to 1.0 to 1.5 Gt of emissions over the next two decades. The partnership will help the country build a climate-resilient economy while supporting vulnerable communities and promoting employment. As a pilot project, it will likely spark interest among other countries – such as India, Indonesia and the Philippines – that are seeking external climate finance to reduce their coal reliance.

Source: See endnote 95 for this chapter.

SHIFTING FRAMEWORKS FOR INVESTMENT IN RENEWABLES

Investors wishing to address climate change and support renewables are increasingly turning their attention to sustainable finance options, in consideration of regulatory requirements, risk management imperatives, and/or changes in demand and asset allocation strategies. Three frameworks are increasingly relevant for renewable energy finance and investment: 1) the development of sustainable finance taxonomies at the national and regional levels to provide information on the environmental and/or social performance of enterprises and financial products; 2) systems rating the performance of enterprises according to environmental, social and governance (ESG) criteria to help assess the suitability of a company, activity or fund for investment; and 3) green bonds, the proceeds of which may go to renewable energy.[96]

Innovative financing options such as peer-to-peer trading models based on blockchain technology also have begun to emerge.[97] By connecting renewable energy producers with potential buyers via a decentrally managed transaction, such platforms can finance projects that otherwise may not be funded.[98] (→ *See Box 12.*)

BOX 12. Using Blockchain for Renewable Energy Financing

Digital technologies are being proposed as a tool to help achieve many of the United Nations (UN) Sustainable Development Goals, including SDG 7 on Affordable and Clean Energy. By improving the flexibility of power systems and energy services, digital and smarter electricity networks can allow for greater integration of renewable electricity sources. Digital technologies enable new linkages and interactions between energy supply and demand, support improved energy planning and real-time monitoring, and facilitate the use of distributed and decentralised energy resources.

At the same time, innovative approaches to renewable energy financing are crucial to reduce emissions and accelerate the energy transition. Renewable energy projects typically face a mismatch between capital supply and needs, and investors perceive high investment risks due to large transaction costs during financing and to a lack of liquidity and bankable projects in developing countries. Distributed ledger technologies[i] have a seemingly large potential to overcome many of these challenges by enabling smart energy systems and clean energy financing.

Blockchain technology can unlock new approaches to financing, including investment marketplaces that connect project developers, investors and purchasers to collaborate on a common platform. Sun Exchange, based in South Africa, is using a blockchain-based micro-leasing marketplace to democratise renewable energy financing through crowdfunding. The platform allows individual and corporate investors to buy solar cells that provide electricity to businesses and organisations and earn money from the clean power generated. By April 2022, Sun Exchange had enabled more than 40 solar projects.

Blockchain technology also offers solutions to make power purchase agreements (PPAs) more efficient and transparent. PPAs are used to secure payment streams for renewable energy projects and often are crucial to help developers obtain the initial investment. However, PPA structures, processes and standards are fragmented across countries and markets, and this complexity is a barrier to raising project funds. To ease such challenges, smart contracts on a blockchain-based marketplace can enable transparent transactions between power producers, purchasers and investors on a common shared ledger. For example, Mojo Power in Australia uses a blockchain platform provided by WePower to facilitate PPAs for solar PV retail at a competitive rate and with full transparency.

These new approaches can help build robust pipelines of renewable energy projects for which various investors can mobilise capital. The blockchain platforms that enable such approaches remove frictions and allow complex marketplace interactions to scale without compromising trust – contributing to low-carbon power generation and a pathway towards net zero carbon emissions.

i Distributed ledger technologies comprise digital infrastructure and protocols that immutably enable simultaneous access, validation and record-keeping across a network. Among these, blockchain is a type of software in which digital transactions are grouped together into blocks. See UN Innovation Network, "A Practical Guide to Using Blockchain Within the United Nations," May 21, 2020, https://atrium.uninnovation.network/guide.

Source: See endnote 98 for this chapter.

SUSTAINABLE FINANCE TAXONOMIES

Sustainable finance taxonomies provide a classification of economic activities with the aim of clarifying which investments and/or activities may be defined as sustainable or "green".[99] Such taxonomies can be relevant for renewables in two main ways: 1) for companies producing or manufacturing renewable energy technologies; and 2) for the owners or operators of renewable energy assets (such as a utility that operates a wind farm as part of its broader portfolio).[100] Such stakeholders would be eligible for the technological screening of the taxonomy and thereby be pre-screened for interested investors.[101]

Whereas some taxonomies are binary ("green"/"not green"), others are more transition-oriented and have specific aims to advance sustainable investment.[102] Here, colour scales commonly are used to indicate the extent to which activities adhere to given principles.[103] For example, renewables-related economic activities may be coded "green", while fossil fuel-based activities that adhere to certain standards may be coded "yellow" or "amber", while yet other activities may be "red", similar to traffic light systems.[104]

The number of sustainable finance taxonomies in use or under development has increased rapidly since the Paris Agreement was signed in 2015.[105] (→ *See Figure 56.*) This expansion continued in 2021, particularly in the lead-up to the UN climate talks in Glasgow.[106]

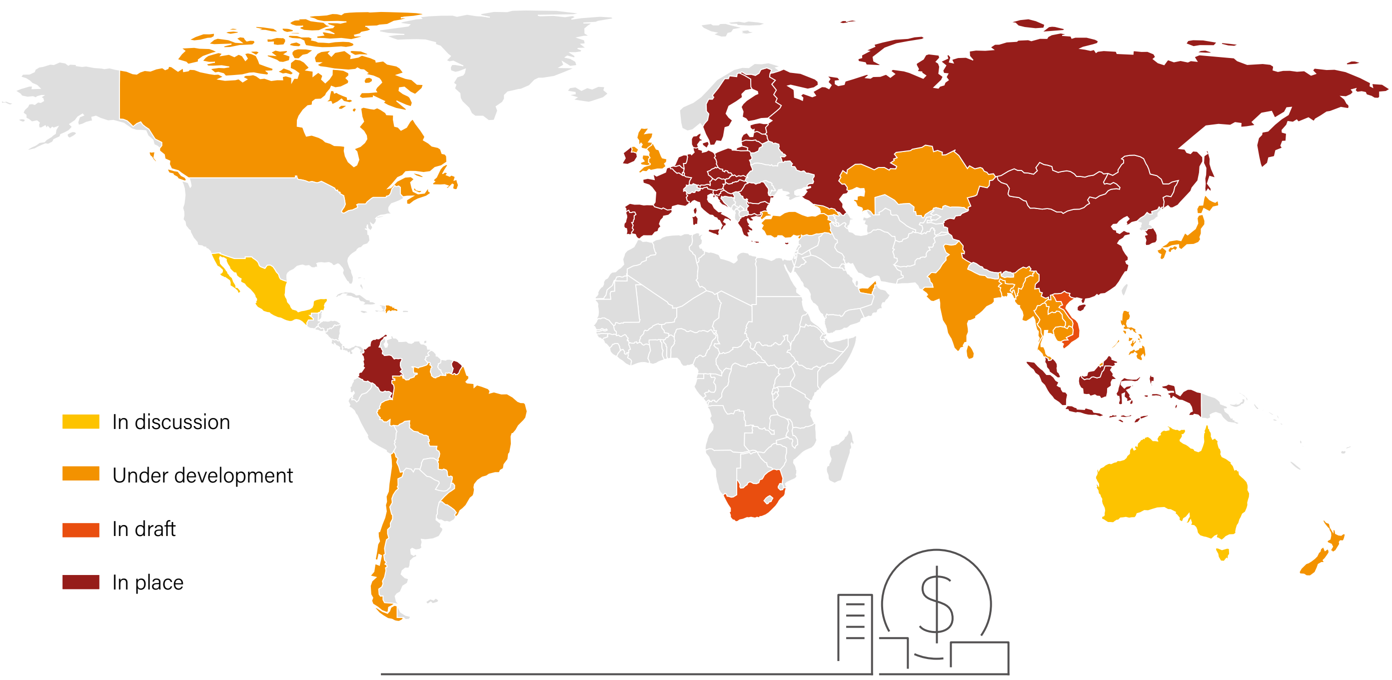
In Asia, taxonomies are already in use in China, Indonesia, Malaysia, Mongolia, and the Republic of Korea and are in various stages of development in Bangladesh, India, Japan, Kazakhstan, the Philippines, Singapore, Sri Lanka, Thailand and Vietnam.[107] The Association of Southeast Asian Nations (ASEAN)[i] released the first version of its taxonomy in 2021, classifying economic activities based on their grade of alignment, thus establishing a framework within which member states can develop national taxonomies.[108] The national taxonomies in Indonesia, Malaysia and Singapore were issued in alignment with this guidance.[109]

The EU Taxonomy was published in 2020, with its first stage of mandatory compliance beginning in 2022.[110] The taxonomy is a binary classification system for economic activities that substantially contribute to at least one of six environmental objectives established in the EU regulation, while not significantly harming any of the others.[111] Large companies (of 500 employees or more) in the EU are required to provide information to capital markets about the environmental performance of their assets and economic activities, as defined in the taxonomy, as well as their investment plans to reach taxonomy-specified targets and criteria.[112] Disclosure requirements pursuant to the EU Taxonomy Regulation also apply to financial products (→ *see ESG section below*).

In 2021, the United Kingdom announced its requirements for reporting under a green taxonomy to support sustainable investing in the country.[113] The Russian Federation also announced the official adoption of its Green Taxonomy during the year.[114]

i Member countries include Brunei, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam.

FIGURE 56.
Sustainable Finance Taxonomies Worldwide, in Place, Under Development and in Discussion, Early 2022



Source: Based on International Platform on Sustainable Finance. See endnote 105 for this chapter.

In view of the rapid deployment of sustainable finance taxonomies, the Group of Twenty (G20) countries suggested in October 2021 that jurisdictions should "consider developing sustainable finance taxonomies using the same language, voluntary use of reference or common taxonomies, and regional collaboration."[115] In July 2020, China and the EU already had begun to develop a Common Ground Taxonomy through a working group of the International Platform on Sustainable Finance, identifying commonalities and differences in their respective approaches.[116] The cross-border integration of taxonomies was a major discussion topic during the Glasgow talks in 2021.[117] However, the vested interests in each country's definitions make creating a harmonised taxonomy across jurisdictions challenging.[118]

ENVIRONMENTAL, SOCIAL AND GOVERNANCE (ESG)

ESG has shifted from being a niche focus to becoming a component of mainstream finance in many OECD countries.[119] Net inflows of investment into exchange-traded funds with ESG traits totalled USD 128 billion in 2021, up 57% from USD 81.3 billion in 2020.[120] Despite this growth, there is no universally accepted standard framework for companies to report on ESG metrics, and the ESG market itself has mushroomed into several different types of structures[i].[121] ESG financing is further complicated by a lack of reliable data and by data inconsistencies.[122]

The categorisation of an organisation or its activities as ESG may be based on a risk perspective (e.g., how environmental risks may affect a company) and/or by an impact perspective (e.g., the impact that a company or activity has on the outside world).[123] Companies that rate and value ESG funds more from a risk perspective have been criticised for using methodologies that ignore the larger (environmental) impact of a company on the planet.[124] As the impact perspective becomes increasingly relevant to investors aiming for net zero carbon or clean energy goals, a "double-materiality concept" is arising, which incorporates both the risk and impact perspectives.[125] This approach may have more relevance for renewables.[126] Relatedly, ESG products increasingly are being used to assess a company's commitments and actions to transition to renewable energy.[127]

Regulators worldwide are faced with questions of how to define what should and should not be considered under the ESG label, in addition to the types of disclosure required and how to track and audit sustainability-related statements.[128] Relevant for the "environmental" pillar of ESG, in 2017 the Task Force on Climate-Related Financial Disclosures (TCFD) provided a voluntary framework for reporting on climate-related risks and opportunities.[129] Here, renewable energy is considered in the classification of climate-related opportunities; for example, utilities may report on the share of renewables in their total electricity generation.[130] Since the inception of such voluntary disclosure frameworks, a global trend has developed towards mandatory disclosure.[131] Brazil, Japan, New Zealand and the United Kingdom are among countries that have aligned their regulatory reporting frameworks with the TCFD guidelines.[132]

Europe's Sustainable Finance Disclosure Regulation (SFDR), which applies primarily to the sale of sustainable financial products, uses key resource efficiency indicators (such as the use of renewables) to help appropriately label a given product.[133] In June 2021, the Group of Seven (G7) countries[ii] agreed to mandate climate-related financial reporting in line with the recommendations of the TCFD.[134] During the Glasgow talks in November, the International Sustainability Standards Board was established to create a comprehensive global baseline of sustainability disclosures for capital markets, possibly building on the TCFD.[135]

Seven countries and the EU have **sustainable finance taxonomies** in place.

Despite the flurry of activity in developing disclosure recommendations and regulations, asset managers and asset owners have largely lagged in publishing consistent climate-related metrics and targets.[136] Disclosure in its own right has been insufficient to redirect capital to low-carbon assets such as renewable energy companies.[137] Relying on improvements in the information that is available to market players (such as through standards, labels and disclosure requirements) does not necessarily nudge the reallocation of capital.[138] This is especially true if the granularity, methodology and focus of the different data providers are not coherent.

Central banks are uniquely positioned to counter this lack of movement by supplementing this information or disclosure-based regulation and helping to channel funding into sustainable projects. Some central banks, largely in emerging and developing countries, have developed policy tools based on incentives or target quantities, often in line with sustainable development goals.[139] In Bangladesh, additional liquidity is provided to commercial banks that lend to green projects such as renewables.[140] The Reserve Bank of India requires banks to allocate 40% of their credits to priority sectors, including renewable energy.[141] The Bank of Lebanon differentiates reserve requirements, reducing a commercial bank's obligatory reserve requirements by 100-150% of the loan value for a project.[142]

Central banks in the developed world typically have more narrow mandates and thus have not implemented the same levels of incentive-based support.[143] A notable exception is in Japan, where banks are offered more favourable refinancing terms based on their lending to sustainable projects.[144]

i These structures include sustainability-linked derivatives (SLDs), credit-default-swap indexes, exchange-traded derivatives on listed ESG-related equity indexes and emissions trading derivatives.

ii Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.

GREEN BONDS

Although various instruments are available to finance renewable energy projects, green bonds in particular have become prominent in recent years.[145] Green bonds differ from traditional bonds in that the proceeds are earmarked for qualifying investments in renewable technologies or in various forms of climate adaptation and mitigation. Investors obtain a certain interest rate over a stipulated time period, and the funds must be used for the purposes for which the bond was issued. This provides investors with greater visibility over the actual use of the funds than is the case for traditional bonds.

The COVID-19 pandemic impacted issuance of all bond types in 2020. In 2021, however, more than USD 522 billion in green bonds was issued, a record high and well above the USD 298 billion issued in 2020.[146] Europe accounted for the majority of green bond issuance in 2021 – more than half of the global total – followed by Asia (led by China, Japan and Singapore).[147] By country, the United States maintained its lead in issuing green bonds, increasing its volume 63% to USD 81.9 billion in 2021.[148]

In some instances, sustainable finance taxonomies have been developed for green bonds.[149] Such taxonomies typically are applied on a voluntary basis (e.g., the Green Bond Standard in the EU), although more uniform efforts have been developed (e.g., in China).[150] China's Green Bond Endorsed Catalogue, released in 2015 and updated in 2021, lists projects and sectors eligible for green bond issuance and includes in its qualifications "recycling, processing and utilisation of renewable resources" as well as "new energy and clean energy equipment manufacturing".[151] The United Kingdom's green bond framework of June 2021 lists renewable energy as one of six eligible project categories.[152]

RENEWABLE ENERGY AND CLIMATE FINANCE

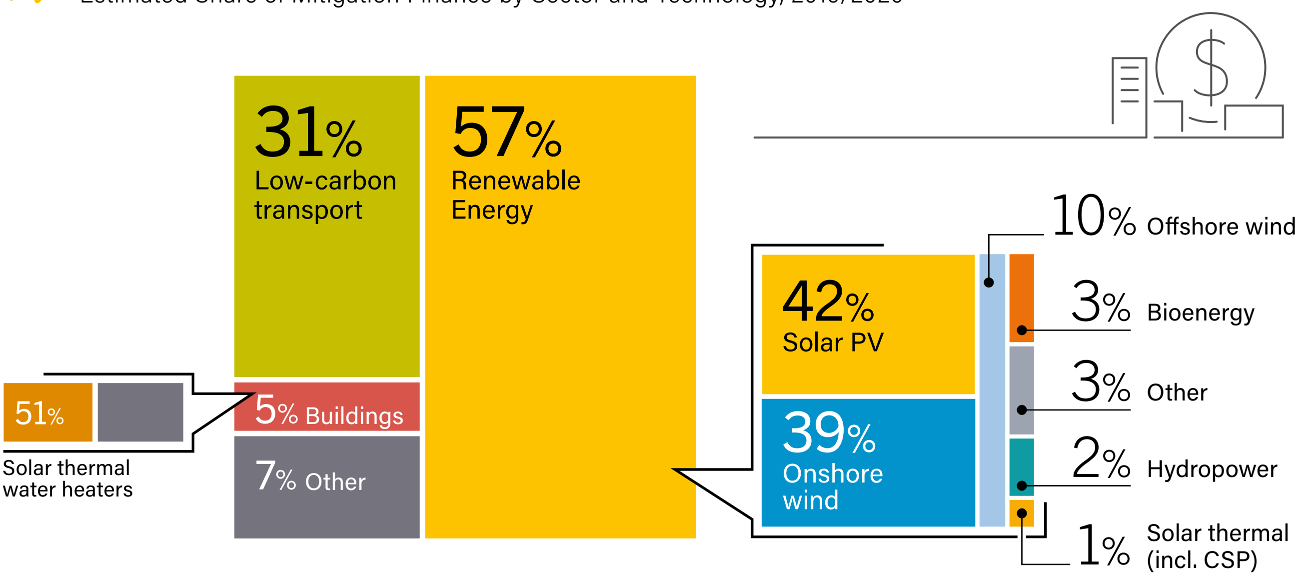
Climate finance is any financing that seeks to support either climate change mitigation actions (for example, renewable energy generation, energy efficiency or low-carbon transport) or adaptation actions (for example, disaster risk management, waste and water, or resilient infrastructure). A total of USD 632 billion in climate finance was allocated in 2019/2020[i], up 10% from the previous two-year period, reflecting a steady rise over the past decade.[153] This increase continued despite the impacts of the COVID-19 pandemic, which affected both the demand for and delivery of climate finance in 2020.[154]

Climate finance flows were concentrated mainly in East Asia and the Pacific (46% of the total, led by China), followed distantly by Europe (17%) and the United States and Canada (13%).[155] Mitigation activities represented roughly 90% of the total flows, or around USD 571 billion.[156] A majority (57%) of mitigation finance was investment in renewables, dominated by solar PV and onshore wind energy.[157] (→ *See Figure 57.*) Finance for low-carbon transport accounted for another 31% of total mitigation finance, much of which was allocated to battery electric vehicles and charging stations.[158]

The landscape of climate finance flows is multi-faceted, interconnected and evolving. As of 2019/2020, public finance – including funds provided by development finance institutions, governments and climate funds – supplied around 51% of total climate finance, at USD 321 billion, while private finance supplied the remainder.[159] Renewable energy attracted higher shares of private finance than other sectors, with around 69% coming from private sources in 2019/2020, reflecting the commercial viability

i Value is the most recent available and is an average of 2019 and 2020 data, expressed in nominal (current) USD.

FIGURE 57.
Estimated Share of Mitigation Finance by Sector and Technology, 2019/2020



Source: Based on CPI. See endnote 157 for this chapter.

and increasing competitiveness of renewable technologies.[160] (→ *See Market and Industry chapter.*) Commercial financial institutions provided most of the private capital for renewables (around USD 104 billion per year), followed by corporations and households (such as for residential solar PV systems).

Public support came mostly from state-owned financial institutions (USD 45 billion per year) – including green banks[i] – followed by national development finance institutions (USD 28 billion).[161] (→ *See Snapshot: New Zealand.*) Support for renewables from state-owned financial institutions increased sharply, while support from national development finance institutions was down compared to 2017/2018.[162]

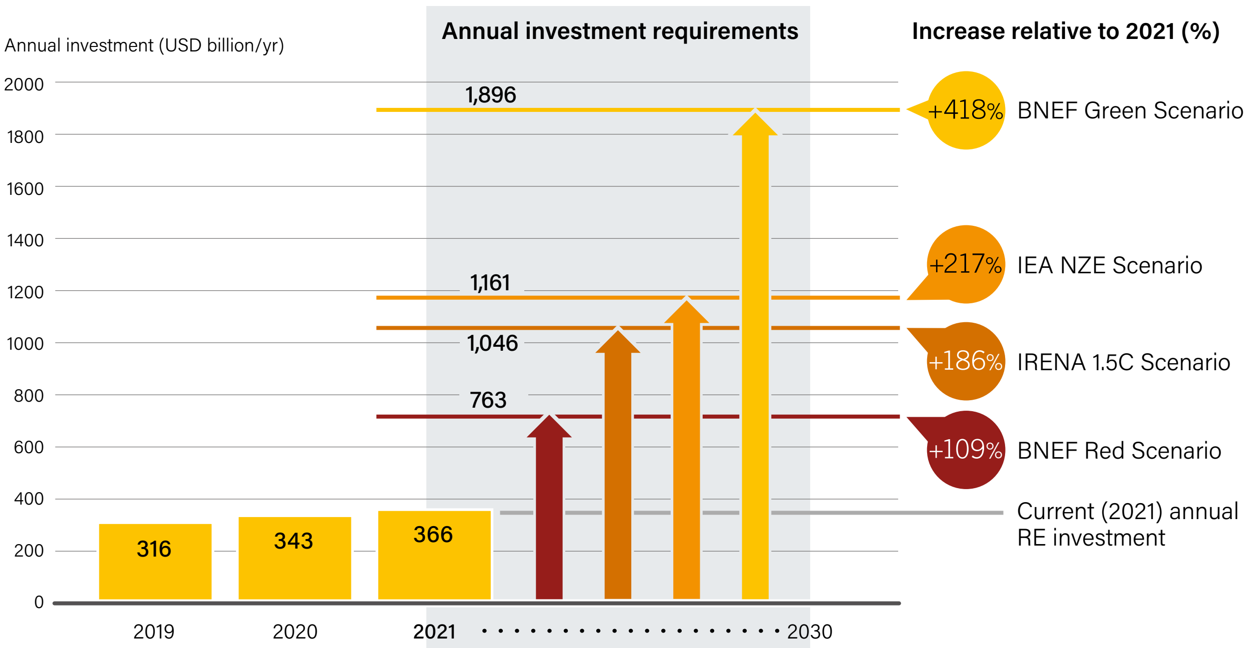
The Paris Agreement (Article 2.1c) highlights the need to make finance flows consistent with the goal of limiting global temperature rise to 1.5 degrees Celsius.[163] Achieving this goal would require significant growth in the overall investment in renewables compared to the last decade, which totalled around USD 300 billion annually.[164] Estimates of the renewable energy investment needed to achieve the goals of the Paris Agreement range from USD 763 billion to USD 1.8 trillion annually to 2030, beginning in 2021.[165] (→ *See Figure 58.*)

Investment needs to increase between **2–5 times** to reach climate change mitigation scenarios.

In April 2021, the Glasgow Financial Alliance for Net Zero (GFANZ) was launched to bring together existing and new net zero finance initiatives.[166] As part of the GFANZ coalition, 450 financial firms in 45 countries, responsible for combined assets exceeding USD 130 trillion, have committed to mobilising private capital for emerging markets and developing economies through private sector investments and public-private collaboration.[167]

i Green banks function as banks only in terms of being financial intermediaries – they do not fall under traditional banking regulations and are typically set up as a public financing authority that leverages limited public funds to attract additional private capital for renewable and other related technologies. See C40 Cities, "Establishing a City Green Bank, Best Practice Guide" (London: 2020), https://www.c40knowledgehub.org/s/article/Establishing-a-City-Green-Bank-Best-Practice-Guide.

FIGURE 58.
Range of Annual Renewable Energy Investment Needed in Climate Change Mitigation Scenarios Compared Against Recent Investments



Note: These scenarios quantify renewable energy differently than the BloombergNEF historical basis used in this chapter. The BloombergNEF scenario estimates here include only investment needed in wind power and solar PV, while the International Energy Agency and International Renewable Energy Agency estimates include only investment needed in renewable power technologies.

Source: Based on BloombergNEF and CPI. See endnote 165 for this chapter.

SIDEBAR 7. Oil and Gas Industry Investments in the Renewable Energy Transition

The oil and gas industry rebounded in 2021 as the global economy began to recover from the COVID-19 pandemic. At the same time, many individual and institutional investors – including governments, financial institutions, universities and others – stepped up their efforts to divest from fossil fuels. By year's end, the total assets worldwide committed to fossil fuel divestment reached USD 39.2 *trillion*, up from only USD 52 billion in 2014. Investors of all kinds are pressuring oil and gas suppliers to move out of high-carbon activities and to transition their energy production to renewables.

As public opinion has shifted away from fossil fuels, oil and gas conglomerates have attempted to rebrand themselves simply as "energy companies", although in most cases they continue to pursue plans to extract and produce oil and gas. This rebranding is especially visible in Europe, where companies have made increasing renewable energy commitments. Plenitude, a subsidiary of Eni (Italy), aims to offer all of its retail customers renewable electricity by 2030. TotalEnergies (France), which has diversified its portfolio, achieved 500 gigawatt-hours of biomethane production capacity in 2021 and is targeting 2 terawatt-hours annually by 2025 through an agreement with resource management group Veolia.

Oil and gas companies have used several strategies to signal their transition to renewables, in an effort to maintain investor support and diversify revenue streams. Most big industry players have set intermediate targets for installed renewable energy capacities by 2030, while at least two companies have set longer-term targets: Royal Dutch Shell (UK) aims to install 60 GW of renewable capacity by 2050, and Eni aims to install 230-450 GW. In 2021, Repsol (Spain) updated its target for renewable generation capacity to 60% by 2030. Other producers have already successfully pivoted to renewables, including Denmark's Ørsted, which now ranks among the largest developers of offshore wind energy.

Some companies have installed solar PV capacity to power their oil field operations and to address their Scope 1[i] emissions (those resulting directly from company operations). However, Scope 3 emissions make up the vast majority of emissions from the industry; these include embedded emissions as well as those released by the end-users of company products, for example through activities like transport. In 2021, facing pressure from shareholders, Chevron (US), ExxonMobil (US) and TotalEnergies began disclosing potential estimates of their Scope 3 emissions. TotalEnergies has taken a step further and plans to reach carbon neutrality for its Scope 1, 2 and 3 emissions by 2050 or sooner, aiming for net zero across its supply chain, energy purchases and end-use emissions.

i Scope 1 corresponds to greenhouse gas emissions from owned or controlled sources (company operations, etc.). Scope 2 corresponds to indirect emissions from the generation of energy (electricity, steam, heat or cooling) consumed by the company. Scope 3 corresponds to indirect emissions along the value chain, including from company products.

SIDEBAR 7. Oil and Gas Industry Investments in the Renewable Energy Transition (continued)

Several companies have started to decrease their production of oil and gas, including Shell, TotalEnergies and BP (which plans to cut production 40% in the next decade). However, most US companies have trended towards using carbon offsets to meet their emission reduction goals, rather than directly curbing hydrocarbon production or shifting to renewables. To lower the carbon intensity of their operations, Chevron and ExxonMobil (as well as Shell) have incorporated strategies such as carbon capture and storage and reductions in gas flaring (a leading source of methane emissions). Chevron has pledged to reduce flaring 60% by 2028. Occidental Petroleum is relying on enhanced oil recovery as a pillar of its net zero goal for 2050; the company is investing in solar projects and injecting captured carbon to offset the additional oil extraction. Ultimately, the net zero strategies of both Chevron and ExxonMobil have strengthened the companies' investments in oil and gas production for the near future.

Some oil and gas majors have acquired existing renewable energy companies or projects to diversify their portfolios. In 2021, Chevron acquired Renewable Energy Group (REG) for more than USD 3.1 billion, and BP purchased 9 GW worth of solar projects for USD 220 million from renewable developer 7X Energy. Among Shell's recent acquisitions are Inspire Energy and Savion LLC (utility-scale solar and storage developers) and Sprng Energy (one of India's largest renewable companies), which it purchased for USD 1.6 billion.

Eni has started using financial instruments to fund its energy transition activities. In 2021, it issued a EUR 1 billion (USD 1.1 billion) sustainability-linked bond that was earmarked to achieve sustainability targets related to the company's Scope 2 and 3 emissions (production and extraction segments) and installed renewable capacity.

State-run oil and gas companies, meanwhile, have unique and integral links to their respective countries' energy security, economic stability and resource management. Historically, these companies have relied on hydrocarbon production to bring in government revenue; however, several have begun shifting to renewables to help meet national energy transition targets and to diversify away from diminishing oil and gas resources. In 2021, Malaysia's Petronas and Colombia's Ecopetrol were the first state-run oil companies on their respective continents to announce net zero targets. Petronas committed to dedicating 9% of its capital expenditure to renewables through 2025 and to quadruple its renewable energy capacity to 3 GW by 2024. Ecopetrol earmarked 7-8% over the next two years to low-carbon energy and plans to install 400-450 MW of renewables, mostly solar PV, by 2024.

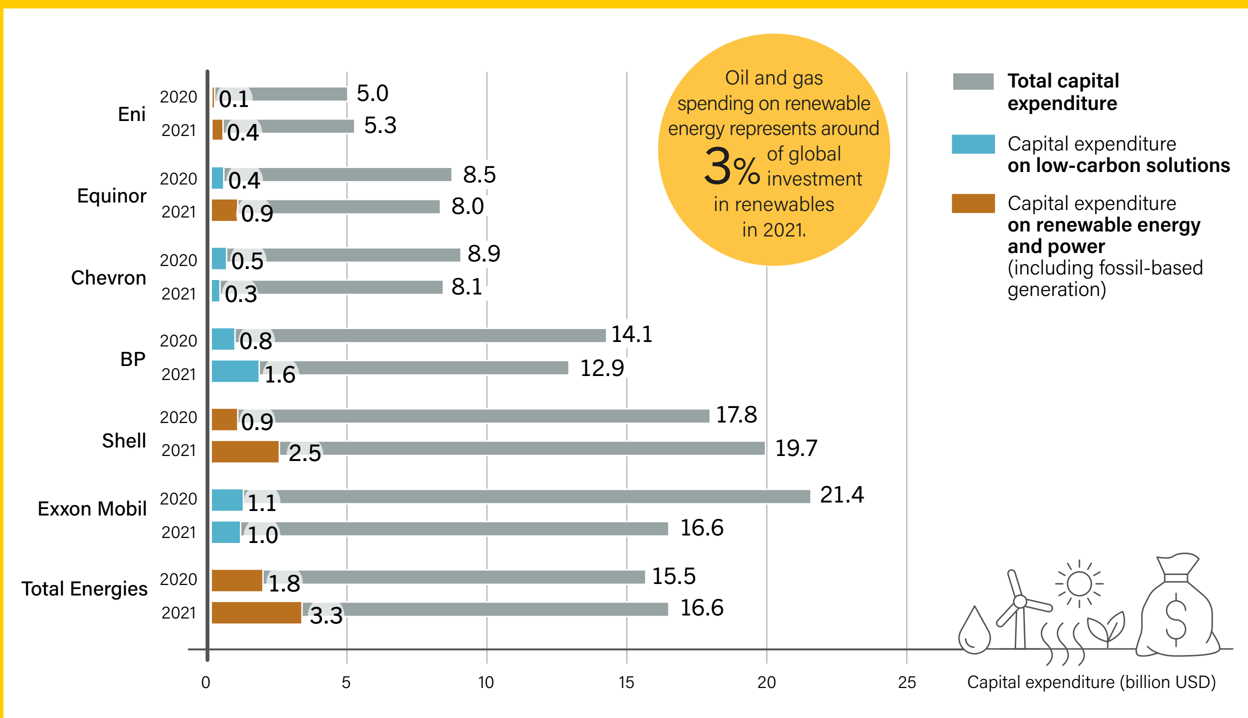
While several oil and gas companies experienced declines in their total capital expenditures in 2021, Eni, Shell and TotalEnergies reported increases. Company investments in renewables and low-carbon solutions increased sharply during the year (with the exception of Chevron and ExxonMobil), although in most cases this investment represented less than 15% of a company's total capital expenditure. (→ *See Figure 59.*) Overall, oil and gas industry spending on renewables worldwide represented only around 3% of the total global investment in renewable power and fuels in 2021.

To push for greater accountability, investors have called for executive compensation at companies such as Chevron and Marathon (US) to be tied to environmental, social and governance (ESG) metrics (but not directly to renewables). However, at several major US oil and gas companies – including Occidental, Phillips 66 and Valero – top executives received increases in compensation for several years even as the companies lagged in emission reductions compared to industry averages. At Repsol, in contrast, capital discipline drove the company to cut dividends 40% while aiming to increase low-carbon investment to 30% by 2025.

Despite mounting pressure to shift to renewables, oil and gas companies have sought to stymie policies aimed at slowing fossil fuel production. In the United States, ExxonMobil lobbied to oppose a 2021 federal budget bill that included cuts to US emissions, even as the company simultaneously announced a net zero target for 2050. BP pushed back on European Union legislation aimed at lowering emission limits by supporting the inclusion of natural gas in the EU Taxonomy, and Eni criticised the Taxonomy's emission threshold for power plants as being too restrictive. In an open letter to the European Commission, other European oil and gas suppliers, such as Repsol and TotalEnergies, expressed support for replacing coal with natural gas, rather than focusing on the shift to renewables.

Source: See endnote 69 for this chapter.

FIGURE 59.
Renewable Energy Spending as a Share of Total Capital Expenditure, Selected Oil and Gas Companies, 2020 and 2021



Note: Values cannot be compared to the previous year GSR, data has been updated based on companies annual report and available data.

Source: See endnote 69 for this chapter.

06

SNAPSHOT. USA, HAWAII

Using Energy Storage to Optimise Delivery of Renewables

The US state of Hawaii has experienced rapid uptake of renewables in recent years, with some islands producing up to 300% of their local electricity demand from solar and wind power. Traditionally the most expensive state for electricity, Hawaii is benefiting from its renewable energy abundance to drive policy change and reduce both curtailment and fossil fuel use during peak hours. Hawaii was the first state to set a 100% renewable portfolio standard (by 2045) and reached 29.8% renewable generation in 2019.

The decommissioning of the largest fossil fuel plant on the island of Oahu has prompted the state's electric utility to work with customer-owned energy advocates on a programme to pay households upfront cash plus a monthly credit to install a battery alongside their rooftop solar. Policies supporting feed-in tariffs have fluctuated in recent years, but households are now paid to store excess solar production throughout the day and to release it to the grid for two hours during the evening at premium electricity rates.

Hawaii's utility also introduced pilot programmes to provide bus owners with no-cost charging infrastructure for electric buses and special rates for daytime charging when renewables are producing the most. Special time-of-use rates for EV charging also are available for medium- to large-sized commercial customers on the islands of Hawaii, Maui and Oahu, helping them save anywhere from 7% to 58% on electricity rates during these periods.

Source: See endnote 15 for this chapter.

06 RENEWABLE-BASED ENERGY SYSTEMS

KEY FACTS

- **The foundations** of fully renewable-based energy systems are currently being laid, spurred by advancements in wind and solar power, storage technologies, sector coupling and demand-side flexibility.
- **Innovations in storage technologies,** supported by plummeting storage costs, are making it possible to deploy energy storage more widely, improving reliability while helping to balance out the fluctuations of variable renewables.
- **Demand response and demand-side flexibility** are making it possible to shape demand more rapidly and more easily than in the past, providing stakeholders in the energy system with a new set of tools to balance supply and demand while helping to sustain high shares of renewables over longer periods.

Throughout history, countries and regions have met varying portions of their energy needs with renewable energy sources. Renewables derived from the sun, water and wind long provided the backbone of energy supply to feed livestock used to transport goods, power sawmills, pump water and grind grain.[1] Until relatively recently, humans relied almost exclusively on locally harvested biomass resources (mainly firewood) to meet heating needs, and still today these resources play a dominant role in the energy mix of many countries, particularly in sub-Saharan Africa.[2]

In the late 19th and early 20th centuries, industries frequently powered their operations using hydroelectricity generated from nearby rivers and streams; even now, many regions of the world continue to meet the bulk of their electricity needs with hydropower.[3] The dominance of renewables in human energy use started to change, however, as fossil fuels in the form of coal, oil, and gas were harvested in growing quantities, making renewable-based energy systems the exception in much of the world.

More recently, many regions of the world have started to re-invent renewable energy systems, propelled by improvements and cost reductions in technologies such as wind power and solar photovoltaics (PV), combined with the urgency to rapidly reduce carbon emissions.[4] While no examples exist of fully renewable-based energy systems that span the electricity, heating, cooling, and transport sectors, the foundations of such systems are now being laid, including the technologies, infrastructure and markets.[5] (→ *See Sidebar 8.*)

SIDEBAR 8.
Where Are 100%-plus Renewable Energy Systems a Reality Today?

Certain regions of the world are demonstrating the possibility of fully renewable-based power systems, including systems that rely exclusively on variable renewable energy sources such as solar and wind power. Development has been concentrated largely in the power sector, although efforts to increase the share of renewables in transport, as well as in heating and cooling, are gaining momentum.

Electricity
As of the end of 2021, six countries relied on 100% renewable electricity: **Costa Rica, Denmark, Norway, Iceland, Paraguay** (hydropower) and **Uruguay**. At the sub-regional level, these were joined by four provinces/states: **South Australia** (Australia), **Hawaii** (US), **Quebec** (Canada) and **Qinghai** (China). Islands using 100% renewable-based power included **Ta'u** (American Samoa), **Eigg** (Scotland), **El Hierro** (Spain), **Graciosa** (Portugal) and **King Island** (Australia).

Heating and Cooling
Iceland's heating needs are largely met with geothermal energy distributed through the country's several district heating networks, or directly via renewably produced electricity. The province of **Quebec** (Canada) meets the bulk of its heating needs with electricity produced from 100% renewable energy sources (mostly hydropower).

Transport
Fully renewable-based transport is occurring on a vehicle-by-vehicle basis as a growing number of charging stations (whether based at home, at work, or from service providers such as EVgo) are being supplied by 100% renewable electricity. However, this is not yet occurring in a widespread or systematic fashion. Some transport systems are becoming largely electric and increasingly renewable, led by local governments (e.g., in Waiheke, New Zealand). Biofuels, while renewable, remain marginal, with most fuels limited to 5-10% shares.

Source: See endnote 5 for this chapter.

Due in part to declining renewable power costs, the share of variable renewable energy (VRE) sources in the global electricity mix has grown rapidly, exceeding 10% for the first time in 2021.[6] Some countries have seen far higher shares. Variable renewables such as wind and solar power accounted for more than 30% of electricity production in Denmark (53%), Uruguay (35%), Spain (32%), Portugal (32%) and Ireland (31%) in 2021.[7] (→ *See Figure 60.*) These countries and others achieved even higher daily maximum levels of VRE penetration, with generation exceeding 40% of consumer demand.[8]

Several factors are converging to make energy systems based on renewable energy (particularly variable renewables) possible.

First, several different forms of **energy storage** are either already mature (such as pumped storage) or becoming less expensive and rapidly expanding (such as battery storage technologies). Other emerging storage technologies include mechanical and gravitational storage, chemical storage (including the production of hydrogen[i] or of synthetic fuels such as methanol) and thermal storage, providing more options for better balancing the fluctuations of VRE sources.

Second, industry and market players are starting to expand **sector coupling**. This refers to greater integration between the electricity, heating, cooling, and transport sectors, largely through electrification and the production of renewable fuels. Sector coupling is making it possible to meet energy needs that previously were supplied by fossil fuels – such as heating and transport – with supply from cleaner alternatives like renewable electricity, thereby increasing the share of renewables in the energy mix.

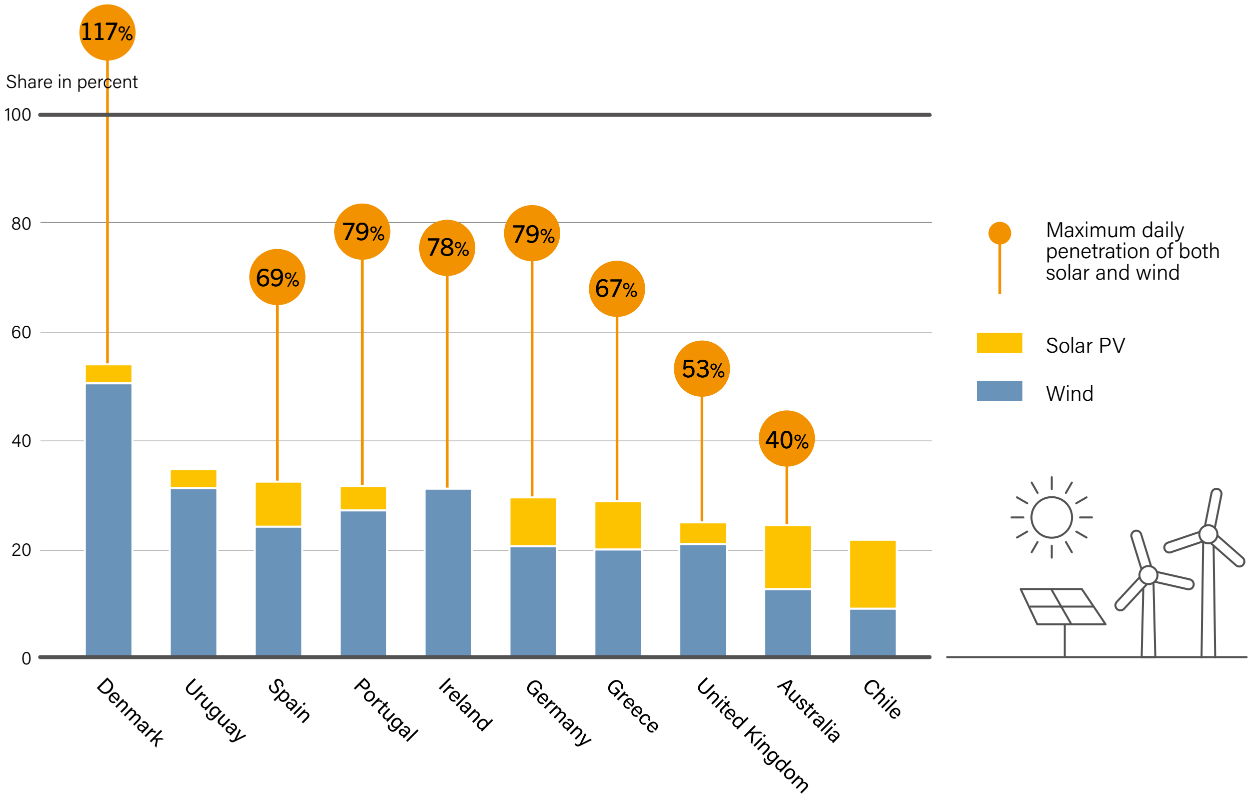
Third, **demand response** is becoming an important accelerator of energy system transformation across all sectors of energy use. It is being facilitated by the rise of digital technologies, low-cost data measurement and transmission, and a widening array of smart appliances such as controllable thermostats and electric heat pumps.[9] Demand response – whether from households, institutional buildings, businesses or industries – is making energy demand more flexible, responding in real-time to system constraints (including congestion, undersupply and oversupply) as well as to price signals.

Finally, energy systems integration is being facilitated by the **expansion of transmission and distribution networks**, including transmission grids, district heating and cooling networks, and pipelines to facilitate the transmission of green gases such as ammonia and synthetic methane.[10] It also is being supported by ongoing improvements in forecasting.

As these changes gain momentum, the transition to a fully renewable-based energy system is entering a dynamic new phase. As in past years, progress towards renewables in 2021 occurred largely in the power sector, although the pace of change in the heating and transport sectors has picked up as sector coupling spreads. Advancements in the power sector also have helped accelerate change in other sectors, fuelling growth in a range of applications including the electrification of heating and transport and the production of renewable fuels from electricity.

i In this chapter, all references to hydrogen refer to renewable (or "green") hydrogen produced from renewable energy sources.

FIGURE 60.
Top Countries for Share of Variable Renewable Electricity Generation, and Maximum Daily Penetration, 2021



Note: Figure shows countries among the top 10 according to the best available data at the time of publication. Several smaller countries with low total generation and/or high imports are excluded from this list.

Maximum penetration refers to the maximum daily share of production from variable renewable electricity divided by daily electrical load. Data for Chile and Uruguay were not available.

Source: See endnote 7 for this chapter.

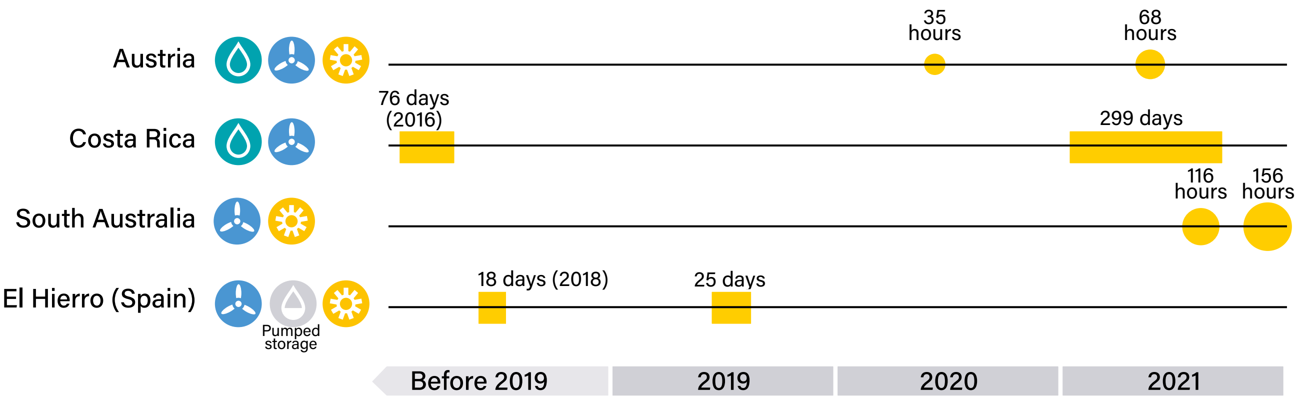
Examples of 100% (or near-100%) renewables in the power sector are relatively widespread: during the second half of 2020 and early 2021, Costa Rica met its electricity demand for an uninterrupted 300 days entirely with renewable electricity sources, mainly hydropower (80-85%) and geothermal (roughly 12%), with a small share of wind power.[11] The province of Quebec (Canada) supplies more than 100% of its electricity needs with hydropower and a few large wind power projects, exporting its surplus to neighbouring jurisdictions in the United States and Canada.[12] Paraguay supplements its hydropowerbased electricity mix with a small contribution from biomass, and Iceland meets virtually all its electricity needs with a combination of hydropower and geothermal energy.[13] In 2020, Scotland met just under 100% of its gross electricity demand almost exclusively from wind power.[14]

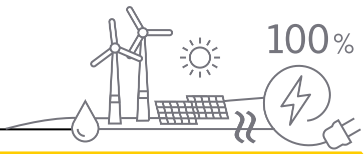
Shares exceeding 100% renewables have been achieved elsewhere in the world, with a growing number of jurisdictions now regularly generating surplus renewable electricity. Several options are available to deal with this surplus: export it to neighbouring regions; convert it to another form of energy (such as thermal storage, battery storage or synthetic fuels); activate residential, commercial or industrial demand to soak up the surplus; or curtail it. In the US state of Hawaii, solar power has exceeded daytime electricity demand on parts of the electric grid since 2016, requiring the surplus power to flow to other areas of the network; this trend that has led to tighter rules on customers investing in solar PV and to surging investment in battery storage.[15] (→ *See Snapshot: Hawaii.*)

The entire state of South Australia was powered by renewable electricity for an uninterrupted 156 hours in the final weeks of 2021, supplied primarily by wind and rooftop solar power.[16] (→ *See Figure 61 and Snapshot: South Australia.*) To reduce curtailment and make greater use of its renewable electricity supply, South Australia is scaling up efforts to encourage both demand response and storage, while the network

Three states or countries – South Australia, Scotland and Denmark – had met more than **100%** of their total electricity demand with wind and solar as of April 2022.

FIGURE 61.
Longest Uninterrupted Stretch with 100%-plus Renewable Electricity, Selected Countries or Regions





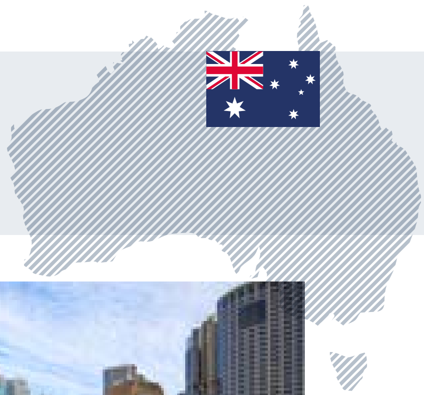
	Population served	Technology	Year	Duration
Quebec (Canada)	8 million	Hydro, Wind	since 2012	Continuously
Paraguay	7 million	Hydro	since 2019	Continuously
Norway	5 million	Hydro, Wind, Solar	since 2019	Continuously
Uruguay	3.5 million	Wind, Hydro, Bioenergy		88% on an annual basis
Iceland	366,000	Hydro, Geothermal		Continuously
Graciosa (Portugal)	4000	Wind, Solar, Storage	2020	128 days
King Island (Tasmania)	~2,000	Solar, Wind, Storage	2015	33 hours
Ta'u (American Samoa)	790	Solar, Storage	since 2016	Continuously
Eigg (Scotland)	87	Hydro, Wind, Solar	since 2008	Continuously

Source: See endnote 16 for this chapter.

operator is expanding its interconnections with neighbouring states so that it can export more of its surplus electricity.[17] In 2018, Qinghai Province in China operated fully on renewable electricity for nine days in a row (216 hours), due in part to the development of a communication platform that monitors renewable energy generation in real-time and co-ordinates it with data on power consumption.[18]

Historically, high shares of renewables have been most common in regions with abundant hydropower potential.[19] However, the rise of increasingly cost-effective energy storage combined with greater demand-side flexibility and the expansion of grid infrastructure is making it possible for regions with widely differing resource endowments to transition to fully renewable-based energy systems.[20]

SNAPSHOT. SOUTH AUSTRALIA



Solar Sponge Tariff

As renewables start supplying larger portions of the electricity mix, cities and states are finding non-storage-based solutions to meet the challenges of integrating variable renewable energy sources such as wind and solar. In 2021, the state of South Australia briefly set a record by producing 143% of its electricity demand from local renewables. While battery storage absorbs some of the excess generation, South Australia uses additional strategies to distribute the surplus while also building more wind and solar parks.

The record production lasted only a few minutes, but throughout 2021 as a whole South Australia registered a full 180 days during which solar and wind power generation exceeded the state's electricity demand. Investments in transmission lines have allowed South Australia to reduce curtailment of excess renewable electricity by exporting this power to neighbouring Victoria. Newly installed synchronous condensers[i] also have helped counteract the swings of variable renewable energy moving through the grid, reducing the state's reliance on natural gas as a stabiliser during high renewables generation.

A time-of-use tariff, known regionally as the "solar sponge" tariff, incentivises energy use during daytime hours. The cost of distributing electricity falls 25% during times when solar is most abundant (10 a.m. to 3 p.m.) and rises 125% during peak hours (6 a.m. to 10 a.m. and 3 p.m. to 1 a.m.). The state offers subsidies for residential battery storage, and there are plans to build higher-capacity batteries to further support local renewable generation – among the many options for addressing the variable nature of renewables.

Source: See endnote 16 for this chapter.

i Synchronous condensers are used for several reasons, including managing minor fluctuations of variable renewable energy by absorbing and producing reactive power. They provide system strength and inertia usually supplied by conventional energy sources such as natural gas. The use of synchronous condensers had declined due to new technologies but has since resurged due to their compatibility with intermittency and variable energy sources such as wind and solar.

ENERGY STORAGE

Energy storage systems are being deployed at a range of scales around the world. These systems can store electric or thermal energy to enable reliable, around-the-clock energy supply. Forms of energy storage (and key technologies) include mechanical (pumped storage, flywheels), electro-chemical (batteries, including lithium-ion and lead-acid), chemical (hydrogen) and thermal (molten salt storage, hot water tanks). Energy storage infrastructure can help stabilise the grid across time scales from minutes to days, providing a range of benefits to the energy system while supporting decarbonisation.

Storage solutions can be distinguished between distributed solutions (typically sited directly at a customer's premises) and centralised or grid-scale solutions. Another sub-sector that grew in prominence in 2021 is long-duration[i] energy storage, supported by the launch at the November climate talks of the Long Duration Energy Storage Council.[21] These technologies aim to bridge longer-term variations in energy supply, particularly seasonal fluctuations.[22]

Pumped storage remained the largest source of energy storage during 2021, with more than 160 GW installed.[23] This mature technology represents more than 90% of the global stationary storage capacity, including 93% of the capacity in the United States at the end of 2020, and an estimated 97% of the total capacity installed in the European Union (EU).[24] Pumped storage capacity is heavily concentrated, with more than 80% of the capacity in 2021 installed in just four markets: China (36 GW), Japan (27.6 GW), the United States (21.9 GW) and the EU (52.2 GW).[25]

Despite its stronghold on the market, pumped storage growth has been slow, increasing less than 7% between 2012 and 2021.[26] New developments in 2021 included a major project starting commercial operation in China, projects entering construction in the United States, and the first pumped hydro storage to reach financial close in Australia in more than 40 years.[27] As jurisdictions around the world look beyond pumped storage, other types of energy storage projects have picked up steam, based on technologies such as lithium-ion batteries, flow-batteries, gravitational storage, thermal energy storage, compressed air storage and power-to-fuels.[28]

Battery storage technologies have grown rapidly from less than 1 GW globally in 2012 to more than 17 GW by the end of 2020, and the United States alone installed a further 4.2 GW in 2021.[29] Rapid cost declines have helped propel the market, making battery storage competitive for a growing number of end-use applications.[30] Battery storage costs fell roughly 90% within a decade, from more than USD 1,200 per kilowatt-hour (kWh) in 2010 to around USD 130 per kWh near the end of 2021.[31] By year's end, the global stationary battery storage market was valued at USD 31.2 billion.[32]

The wide use of batteries in mobile devices and electric vehicles has contributed to the spread of battery technologies and made it possible to deploy them cost effectively to meet a range of power system needs. Battery storage systems operating around the world now provide ancillary[ii] services including frequency response and voltage support to power systems, gradually replacing many of the services traditionally provided by large conventional generation plants.[33] A procurement process launched by Scotland's national grid operator resulted in 5 battery storage contracts for the supply of ancillary services to help increase grid stability.[34] In May 2022, a 25 megawatt (MW)/25 megawatthour (MWh) battery storage project in south-eastern France entered into commercial operation, following a larger 61 MW/61 MWh project in northern France in December 2021.[35]

Hydrogen and synthetic fuels such as methanol, as well as ammonia, have gained momentum in the more than two dozen countries worldwide that have adopted hydrogen strategies.[36] If produced with renewable electricity, these **power-to-fuels** (or power-to-X) projects can provide another means to increase the share of renewables used in hard-to-decarbonise sectors such as steel production. More than 300 hydrogen projects have been deployed in Europe to improve the system integration of renewables and support decarbonisation, and at least 100 more are under way in Asia, Australia and the Americas.[37]

The largest renewable hydrogen project (using a 150 MW alkaline electrolyser) entered commercial operation in China in early 2022, powered by a 200 MW solar PV plant.[38] A 20 MW project (producing hydrogen via electrolysis powered by hydroelectricity) came online in 2021 in Canada, along with a

i The terminology used to categorise energy storage by duration or discharge period varies widely. The GSR considers "short-duration" storage to be energy storage for less than around 10 hours, and "long-duration" refers to periods of around 10 to 100 hours. "Long-term" or "seasonal" storage describes energy storage for periods in excess of 100 hours, typically for weeks, months and years. Pumped storage is a mature and widely commercialised form of long-term storage.

ii Ancillary services (e.g., frequency control and voltage control) provide valuable support to the grid through operational adjustments that help maintain a continuous flow of electricity to consumers.

50 MW solar-powered project in the Netherlands.[39] In Germany, grid operator Amprion is partnering with Open Grid Europe to develop a large hydrogen-based power-to-gas project, which involves building a 100 MW electrolyser and reconfiguring the natural gas grid to transport hydrogen.[40] Stationary hydrogen storage tanks are being built at the facility, increasing the total volume of hydrogen that can be produced while also increasing the volume of renewable energy that can be processed.[41]

Elsewhere in Europe, the island of Utsira (Norway) has expanded its renewable energy plans beyond wind and hydrogen to include a battery storage unit, a smart power management and control system, and the electrification of vessels that travel to and from the island; these investments are making it possible to transition the energy supply used by ships in the area to renewables.[42] During 2021, a hybrid project in Oxford (UK) using lithium-ion and flow batteries was connected to the grid, bringing 50 MW (100 MWh) of new battery storage online, and in California (US) a tender for long-duration energy storage was awarded to a project using a 69 MW (552 MWh) lithium-ion battery.[43] The world's largest flow battery started construction in China in September 2021, a 100 MW (500 MWh) project that will be used to help meet peak loads and to bridge dips in renewable energy output.[44]

Compressed air energy storage facilities that make use of underground caverns have been connected to the grid in recent years in Hebei Province (China) and Ontario (Canada), and several projects in California were in various stages of planning and development.[45] Among the California initiatives under construction is a 500 MW (5 GWh) project by Hydrostor that relies on purpose-built caverns, enabling the facilities to be sited in a wider range of locations.[46]

Thermal energy storage technologies are widely used to store heat energy in hot water tanks, molten salts, open pit storages, borehole storages and other mechanisms. Europe's more than 10 million solar thermal systems total an estimated 187 GW of thermal energy storage capacity, while China's solar thermal storage capacity is estimated to be even larger.[47] Thermal energy storage frequently is used in conjunction with (solar) district heating systems, storing the surplus energy in hot water tanks or pits.[48]

Among the emerging thermal energy storage technologies is Sunamp's recently launched "heat battery" for residential applications, which makes use of phase change materials that can absorb and release thermal energy more efficiently than other forms of thermal storage such as water.[49] Such technologies are improving the integration of VRE by consuming electricity during times of oversupply, while also helping save customers money by "charging" when the cost of electricity is lower.[50]

The use of molten salt storage, notably at concentrating solar thermal power (CSP) plants, has also expanded. Projects include a 110 MW facility in Chile that entered commercial operation in March 2022 and has 17.5 hours of thermal energy storage, enabling constant renewable electricity supply.[51]

Battery storage costs have

fallen 90%

since 2010.

SECTOR COUPLING

Sector coupling refers to the integration of energy supply and demand across electricity, heat, and transport applications, which may occur through co-production, combined use, conversion and substitution.[52] Sector coupling has taken hold in the two main end-use sectors – heating and transport – in two primary ways:

- linking the power and heating/cooling sectors by using electricity to meet thermal needs such as through electric heat pumps or other forms of electric heating; and
- linking the power and transport sectors through the electrification of mobility, including two- and three-wheeled vehicles, cars, trucks, delivery vehicles, buses, trains, trams and even aviation.[53]

By providing pathways for renewable electricity to supply energy in heating and transport, sector coupling is facilitating higher shares of renewables.[54] A growing array of digital technologies are making it possible to activate and de-activate individual appliances and to control electric vehicle charging patterns, among other digital controllable loads.[55] Smart technologies also are being used to control hot water tanks and other household appliances such as air conditioners and thermal energy storage systems, enabling power demand to be controlled more flexibly and dynamically.[56] Such developments are enabling previously separate end-use sectors to become increasingly interconnected, accelerating the pace of energy system transformation and unlocking important co-benefits including emission reductions, lower energy prices, improved resilience and greater energy security.[57]

Heating (and cooling) represents roughly 50% of global final energy consumption. (→ *See Global Overview chapter.*) Although cooling needs already are met mostly with electricity, heating needs continue to rely largely on the direct use of fossil fuels. Transitioning the heating sector to renewables can be done in a variety of ways, including through biomass direct-use or biogas installations, through the use of geothermal and solar heat, and through the efficient use of electric heat in end-use appliances. Heat pumps have emerged as a key technology in this regard, as each unit of electricity used to operate the heat pump can generate the equivalent of 3 to 5 units of thermal energy for space or water heating.[58] (→ *See Heat Pumps section in Market and Industry chapter.*)

Digital technologies are making it easier to integrate electric heat into homes and businesses in a flexible, system-responsive way. In the United Kingdom, the company Mixergy has started to roll out adaptive water heaters that are Internet-linked and able to draw on different sources of renewable heat, including renewable electricity, on-site solar hot water and heat pumps.[59]

"Smart technologies" allow users to optimise their own on-site consumption of self-produced electricity (such as from rooftop solar PV) to supply appliances in real-time, before the energy generated on-site gets exported to the grid. Such on-site optimisation is becoming attractive in regions where electricity prices are higher than the cost of on-site production, such as Germany, California and Australia.[60] Using the renewable power directly on-site reduces losses while enabling customers to shift the electricity that they demand from the grid to periods when prices are lower.[61]

In countries and regions with relatively high electricity prices – such as Australia, Germany and parts of the United States – a growing number of companies are offering optimised self-consumption linked to smart meters and appliances as part of their solar installations.[62] New software-as-a-service (SaaS) companies in the country are enabling electricity customers to tap into low electricity prices, providing them with software that automatically activates on-site loads in response to low prices to provide cheaper electric vehicle charging and more cost-effective heating and cooling.[63]

In early 2022, German network operator TenneT and heat pump manufacturer Viessmann launched a pilot project to link heat pump use to the availability of wind and solar power, using controllable thermostats and on-site thermal storage tanks to help minimise VRE curtailment.[64] Through the project, heat pump owners receive a lower electricity tariff in exchange for enabling the local distribution network operator to remotely control operation of the units.[65]

Sector coupling is helping achieve **higher shares of renewables.**

The spread of district heating and cooling networks is enabling the wider use of renewable heating and cooling. Ninety percent of households in Iceland use geothermal heat, mostly piped through district networks, and hundreds of conventional district heating networks exist throughout Europe, the United States, the Republic of Korea and China.[66] To transition these networks to renewables, some operators are incorporating biomass energy and solar hot water, while increasing the use of renewables in combined heat and power (CHP) plants.[67] The district heating network in Copenhagen (Denmark) is rapidly phasing down coal and using surplus electricity to provide heat directly to the network via electric boilers and heat pumps.[68] Some operators have opened their networks to prosumers[i], enabling different thermal energy sources at various temperatures to contribute to meeting heating needs.[69]

The district heating system being built in Hamburg (Germany) as of 2021 will use surplus wind power (both onshore and offshore) to generate heat for households and businesses.[70] The heat will be fed into the local district heating network and help better integrate wind power when it is abundant. The project has established a "heating marketplace" that allows the real-time trading of heat among different heat providers on the network (including individual households).[71] Power-to-heat systems based on the use of surplus electricity that otherwise would be curtailed were operating in Berlin (Germany) and under construction in Neubrandenburg, Parchim, Rostock and Stralsund.[72]

In an innovative example of sector coupling, a renewable-based power-to-gas installation in Lingen (Germany) aims to recycle the waste heat from the electrolysis facility by injecting it into the local district heating network.[73] In Herning (Denmark), surplus heat from the production of green hydrogen is being used to serve a local district heating network.[74]

Energy use for **transport** accounts for around 32% of final energy demand, virtually all of which is met by fossil fuels. (→ *See Global Overview chapter.*) However, the rise of electric vehicles has made it possible for growing numbers of users to meet their transport needs with renewably generated electricity.[75] As with heat pumps in the heating sector, electric vehicles are emerging as a key enabling technology in the transition to a renewable-based transport system. (→ *See Sidebar 4 in Global Overview chapter.*)

New digital technologies are enabling greater interactivity with end-use appliances, particularly larger loads such as electric vehicle chargers, pool pumps, air conditioners, thermostats and heat pumps.[76] Austin Energy in Texas (US) offers a higher upfront subsidy for customers that install residential electric vehicle charging stations that are Wi-Fi-equipped to enable greater interactivity and communication with the grid.[77] In 2020, California updated its inverter standards to enable greater interactivity between distributed energy resources (such as solar PV and energy storage systems) and the grid.[78] Shenzhen (China) is using its growing electric vehicle and e-bus fleets as a flexible energy resource to help stabilise and improve the efficiency of the power system, co-ordinating the vehicles' charging patterns by relying on signals sent from power suppliers.[79]

Some jurisdictions are mandating that electric vehicles be charged strictly with renewables. The private charging station operator EVgo now offers 100% renewable electricity at its charging stations across the United States, including for operators of fleet vehicles, and all public charging stations in Austin (Texas) are powered by 100% renewable electricity through the utility's green power programme.[80] In Germany, upfront subsidies for home-based electric vehicle charging stations are contingent on customers' enrolment in a 100% renewable energy option, similar to rules adopted in Austria.[81]

Several island regions have moved to fully electrify their transport systems. The island of Waiheke off the coast of New Zealand has begun to transition its passenger vehicle fleet, as well as buses and waste collection vehicles, to run on electricity.[82] In 2021, Greece announced plans to transition its islands to renewably powered electric transport, with islands such as Astypalea and Chalki being equipped with solar power and on-site battery storage to supply a growing fleet of electric vehicles.[83] Similar plans were launched in Barbados, the Madeira islands (Portugal) and New Caledonia (France).[84]

i 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.

DEMAND RESPONSE

A central part of adapting the energy system to the integration of renewables is making energy demand more flexible – particularly energy demand for electricity, heating and cooling, and transport. With the transition to renewables, the power system is evolving from one in which grid operators forecast demand and schedule supply, to one in which supply is forecast and demand is scheduled to match.[85]

Demand response can entail decreasing flexible loads (such as heat pumps, electric vehicles, water heaters, or commercial and industrial loads such as refrigeration) during times of low renewable energy supply, and increasing them during times when supply is abundant and prices are low.[86] Although it has been used for decades (mainly in collaboration with industrial electricity customers), demand response increasingly is a central component of many strategies to achieve high shares of variable renewables. While current capacity is limited to only a few countries and regions today, the demand response market is growing rapidly.[87] (→ *See Table 7.*)

As the share of variable renewables in power systems increases, more utilities are experiencing periods in which supply exceeds demand at certain times of the year, whether due to high rainfall (in the case of hydropower) or to days with abundant wind or sunshine.[88] While heavy rains typically can be stored (to some degree) in a dam's reservoir, surplus wind and solar power must be either curtailed, exported to neighbouring regions or stored. Due to the weather-dependent nature of many renewable energy technologies, such periods of surplus are occurring more frequently.[89] (→ *See Figure 61.*)

The recurrence of grid surpluses is accelerating efforts to make power demand more flexible. Several transmission system operators in Europe recently joined forces to establish a blockchain[i]-based data platform, the Equigy Crowd Balancing Platform, to enable millions of households to participate in providing flexibility to the system, by increasing or decreasing either their electricity production or energy demand in response to system needs.[90] A similar project to increase flexibility from demandside resources from households was launched in Switzerland.[91] (→ *See Sidebar 8.*)

An expanding web of digital appliances and sensors is linking previously non-networked appliances such as water heaters, dryers, refrigerators, and thermostats, enabling these units to respond automatically to price signals. Such appliances can be activated when solar or wind generation in the network is high, and turned off when solar or wind output declines. Connecting such appliances is enabling electricity demand to be shaped in various ways based on system needs.[92] (→ *See Figure 62.*)

In 2021, Europe was home to an estimated 14.9 million heat pumps and more than 4 million electric vehicles, creating the potential for a deep pool of demand-side flexibility in the system.[93] Efforts to increase system flexibility also were under way in Thailand, with the national electric utility developing smarter energy management systems to tap into demand-side flexibility.[94] In 2018, the island of Tilos (Greece), which uses demand response technologies combined with wind, solar, and battery storage technologies, was approaching the ability to meet nearly all of its electricity needs with renewables.[95]

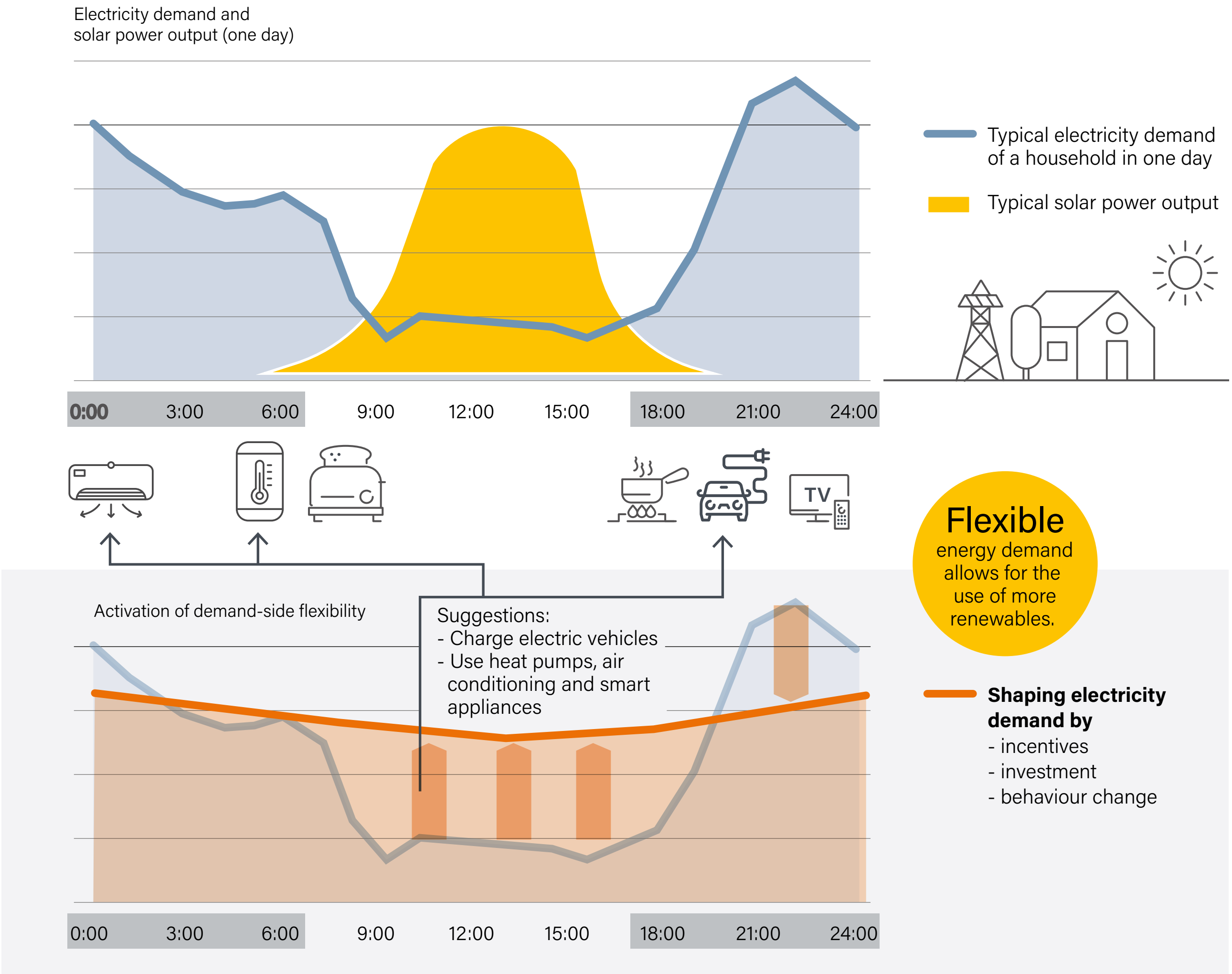
i See Glossary for definition.

TABLE 7.
Estimated Demand Response Capacity in Selected Jurisdictions in Recent Years

Jurisdiction	Available demand response capacity (estimated)
United States (nationwide)	31 GW, with roughly half from residential programmes (end-2019)
Japan	5.8 GW (end-2020)
China	More than 4 GW (end-2020)
Italy	4 GW (end-2020)
United Kingdom	More than 1.5 MW (end-2020)
France	1.5 GW (end-2020)
Hydro Quebec (Canada)	157 MW (first quarter 2022)
National Energy Market (Australia)	40 MW (end-2021)

Source: See endnote 87 for this chapter.

FIGURE 62.
Illustration of Demand-side Flexibility at the Household Level



Source: Based on RMI. See endnote 92 for this chapter.

Under new grid management rules rolled out in Germany in late 2021 and early 2022, smaller sources of both supply and demand are now allowed to participate in providing balancing services.[96] The threshold for participation was reduced from 10 MW to 100 kW, making it possible for small groupings of demand-side appliances such as heat pumps to take part.[97] In the United States, new rules adopted in 2020 enable distributed energy resources (both supply and demand sources) to be aggregated together and to participate directly in the country's bulk electricity markets; during 2021 and 2022, system operators across the country submitted strategies detailing how they plan to comply.[98]

A programme in California successfully signed up more than 450,000 electricity customers (including 115,000 active users) to provide demand response to the network, using low-cost data collection and smart appliances to enable residential customers to play a greater role in providing flexibility.[99] By responding to real-time signals rapidly and effectively, operators were able to alleviate pressures on the grid while improving reliability.[100] In 2021, German grid operator 50 Hertz made use of small-scale loads such as heat pumps and electric vehicles to support system balancing, enabling the loads to be aggregated to respond in real time to congestion and price signals on the wholesale power market.[101]

While demand response typically is voluntary, some utilities and regions have introduced standards and regulations to expand participation, in some cases requiring new appliances to be demand response-enabled. In 2021, Australia was in the final stages of implementing a nationwide demand response standard covering appliances including solar PV systems, air conditioners, pool pumps, electric hot water storage heaters, battery storage systems and electric vehicle storage infrastructure.[102] Upon its entry into force (in 2023 for water heaters and 2024-2026 for other appliances), the standard requires that a set of household appliances be able to respond to remote communications to either increase or decrease the electricity they draw from the network.[103]

In the EU, the rules governing the participation of demand-side flexibility improved in several Member States in 2021, although significant differences within the region remain.[104] Slovenia joined France in allowing demand-side flexibility resources to be aggregated across all components of the electricity market (day-ahead, intra-day and balancing markets), and Finland, Italy and Romania have set clear rules for the market-based procurement of ancillary services.[105] To ensure a level playing field, Finland, France, Italy and Slovenia adopted rules prohibiting[i] distribution system operators from owning and managing electric vehicle charging infrastructure as well as energy storage infrastructure.[106]

Related developments have emerged to facilitate the growth of aggregators, sometimes called **virtual power plants**[ii] (VPPs). As VPPs have spread in recent years, they have moved beyond simply incorporating supply sources such as wind, solar, hydropower, and biogas facilities, to also control demand sources such as heat pumps, electric vehicles, battery systems, pumps and air conditioners.

As of early 2022, more than 30 GW of renewable energy capacity was connected within VPPs around the world, up from less than 100 MW in 2012.[107] (→ *See Table 8.*)

Real-time **price signals** (including time-of-use electricity tariffs) are useful to help balance supply and demand and maintain reliability.[108] Developments in energy pricing combined with smarter metering and inverter technologies are starting to make it possible to ease supply constraints and mitigate demand spikes dynamically.[109] This can be done either through behavioural change, or through changes in the pre-programmed settings used to operate solar home systems, thermostats, vehicle charging and appliances. Introducing variable electricity pricing can help discourage consumption during hours of peak demand while encouraging it when the VRE supply is abundant.[110]

With the electrification of transport, there is a greater need to ensure near-real-time interactivity between vehicle charging and the grid.[111] Because periods of low prices tend to correlate with periods of high renewable electricity output, charging station operators increasingly are offering customers time-varying rates to encourage charging during periods when supply is abundant.[112] Such "smart charging" approaches help increase the amount of renewable electricity that can be integrated into the grid, providing cost savings to customers while reducing curtailment.[113]

i Without such prohibitions, distribution system operators could use the revenues derived from network tariffs to crosssubsidise such infrastructure, arguably providing them an unfair competitive advantage, in contravention of the EU's Internal Electricity Market Directive. See endnote 106 in this chapter.

ii A virtual power plant is 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.

TABLE 8.
Networked Capacity of Selected VPP Operators Worldwide, as of Early 2022

VPP Operator	Total networked capacity
Statkraft	14,000 MW
NextKraftwerke	9,800 MW
Enel	7,400 MW
OhmConnect	550 MW
AGL	More than 200 MW

Source: See endnote 107 for this chapter.

Virtual Power Plants grew to
over 30 GW
in 2021, up from less than 100 MW in 2012.

In Hawaii, the utility HECO offers lower rates for electric bus operators that charge their fleets during the daytime, when renewable energy is abundant, as well as overnight when power demand is lower.[114] For residential and commercial customers, special electric vehicle (EV) charging rates are being rolled out across Oahu, Maui and Hawaii's main island that are between 7% and 58% cheaper than the current rates.[115] A similar approach in the United Kingdom relies on time-of-use rates that encourage drivers to charge their electric vehicles during low-demand periods, while offering them payments to feed power back into the network when supplies are tight and prices are high.[116] The UK's national standards for such "vehicle-to-grid" policies are scheduled to come into force in April 2023.[117]

Such dynamic pricing also is being deployed in the power and heating and cooling sectors. In 2021, Duke Power in South Carolina (US) issued a revamped net metering policy that incentivises customers to switch to controllable thermostats and includes time-of-use rates of up to USD 0.35 cents per kWh for any solar power that customers feed to the grid during peak times.[118] A similar policy in Hawaii offers near-zero compensation (i.e., a near-zero reduction to their electricity bill) for owners of PV systems who export their surplus to the network during the daytime (with premium pricing for exports during the peak evening hours of 5 p.m. to 8 p.m.), combined with an upfront cash bonus for customers that install battery storage systems.[119] In Spain, a dynamic time-of-use tariff for customer-sited solar PV projects was introduced to encourage greater responsiveness by prosumers to price signals.[120]

In July 2021, South Australia Power Networks started implementing "solar sponge" tariffs designed to encourage electricity customers to shift more of their demand to during the daytime when solar power is abundant.[121] In the UK, utility company Octopus Energy began offering "plunge tariffs" that adjust on a half-hourly basis depending on wholesale market prices, enabling customers to benefit from times of high renewable energy supply and low (or negative) wholesale market prices.[122] The Australian company Fronius helps customers that have on-site solar PV systems optimise their self-consumption, linking their solar output to a smart energy management system to improve the economics of the system, enable faster payback and reduce power bills.[123]

ENERGY INFRASTRUCTURE

A further factor enabling the transition to renewable-based energy systems is the push to build and strengthen the **interconnectedness** of different regions across larger geographic areas, through either transmission grids or renewable gas networks. Interconnections enable regions with renewable electricity generating capacity (or synthetic gas or green hydrogen production) to export energy to other regions when supply is abundant. Denmark regularly exports surplus wind power to Germany and other European countries while importing large volumes of electricity, mainly hydropower from Norway and Sweden.[124] Scotland often sends its surplus wind power southward.[125] Interconnections enable regions to develop and integrate higher shares of renewables than would otherwise be possible.

Building out power grids also enables the variability of wind and solar output to be balanced out over larger geographic areas, with cloud cover or dips in wind speeds in one region being offset by fluctuations in output elsewhere on the network[i]. Such smoothing effects make it easier to maintain system reliability, while helping to reduce forecasting errors.[126]

Benefits of accurate **forecasting** include better planning of reserve capacity, more efficient dispatching of generation assets (both renewable and conventional) and smarter scheduling of maintenance.[127] Better forecasting techniques allow for more accurate predictions of the output of weather-dependent renewables. In windy Denmark and Scotland, artificial intelligence and deep learning are helping to more accurately predict both future wind power output and future electricity prices, improving the operation and profitability of wind farms.[128]

i A similar effect is observed in electricity demand, with power demand exhibiting less short-term variability when considered over progressively larger geographic areas.

07

SNAPSHOT. BELGRADE, SERBIA

Decarbonising Transport and Boosting Renewables

In 2021, the City of Belgrade announced its climate action plan, earmarking EUR 5.2 billion (USD 5.8 billion) through 2030 to reduce greenhouse gas emissions in an effort to combat climate change and improve local air quality. This strategy is part of efforts to reduce growing climate risks, such as extreme heat, heavy precipitation and drought.

The Green City Action Plan, focusing on broader environmental benefits, lays out interdisciplinary approaches for a more sustainable Belgrade. To improve air and water quality, the city plans to extend its train and tram lines, bringing estimated savings of 684,861 tonnes of CO_2 annually. Most of the remaining EUR 1.2 billion (USD 1.3 billion) budget for transport will go towards electrifying 20% of private vehicles, 40% of buses, and 80% of taxis and commercial vehicles, in addition to switching all city-owned vehicles to electric by 2030. To reduce the city's car dependence, Belgrade plans to expand bike lanes and walkways while minimising sprawl.

The plan gives considerable attention to renewables and energy efficiency. Around EUR 3 billion (USD 3.4 billion) of the overall blueprint goes to retrofitting buildings, improving heating networks and integrating renewables into the natural gas distribution network, among others. To wean the city off natural gas and petroleum, Belgrade plans to advance local renewable generation. Several sites have been identified to install a total of 111 MW of wind energy, in addition to a waste incinerator producing 30.2 MW of electricity and 56.5 MW of heat, and a landfill gas plant generating 3.1 MW of electricity and 1.8 MW of heat. Public-private partnership models will finance most of the projects, with private investments expected to comprise 36% of the total.

Source: See endnote 112 for this chapter.

07 RENEWABLES IN CITIES

KEY FACTS

- By the end of 2021, around **1,500 cities had renewable energy targets** and/or policies, collectively covering more than 1.3 billion people.
- **Over 1,100 city governments have announced net zero targets.** Yet, exact measures are still under discussion or no status information on targets is available, highlighting the importance of master plans, including the deployment of renewables.
- Regulatory mechanisms such as **building codes typically apply only to new buildings**, although some cities also require this during retrofits and renovations. For existing buildings, financial and fiscal incentives such as grants, rebates and tax credits often are used to encourage renewables.
- By the end of 2021, **270 cities had established low-emission zone**s and 20 had passed bans and restrictions on certain (fossil) fuels or vehicle types.

In 2021, climate and energy action in cities was shaped by tumultuous global events. COVID-19 restrictions remained in place throughout the year, keeping most cities (as well as countries) focused on rebuilding the economy and protecting public health. At the same time, concerns about rising energy prices and their effects on city budgets and municipal utilities elevated the importance of a stable and affordable energy supply on the policy agenda.[1] Driven by these trends – as well as by growing climate concern, rising air pollution and public pressure – cities increased their commitments towards net zero emissions[i] and renewable energy action, particularly in advance of the November 2021 UN climate talks in Glasgow (Scotland).[2]

City governments used a broad range of targets, policies and actions to show local commitment to renewables. By the end of 2021, around 1,500 cities had renewable energy targets and/or policies, up from around 1,300 the previous year.[3] This meant that, collectively, more than 1.3 billion people – around 30% of the urban population – were living in a city with a renewable energy target and/or policy (up from 25% in 2020).[4] (→ *See Figure 63.*) City governments also have taken action that indirectly supports the shift to renewables, such as setting net zero targets and targets for electrifying heating, cooling and transport.[5]

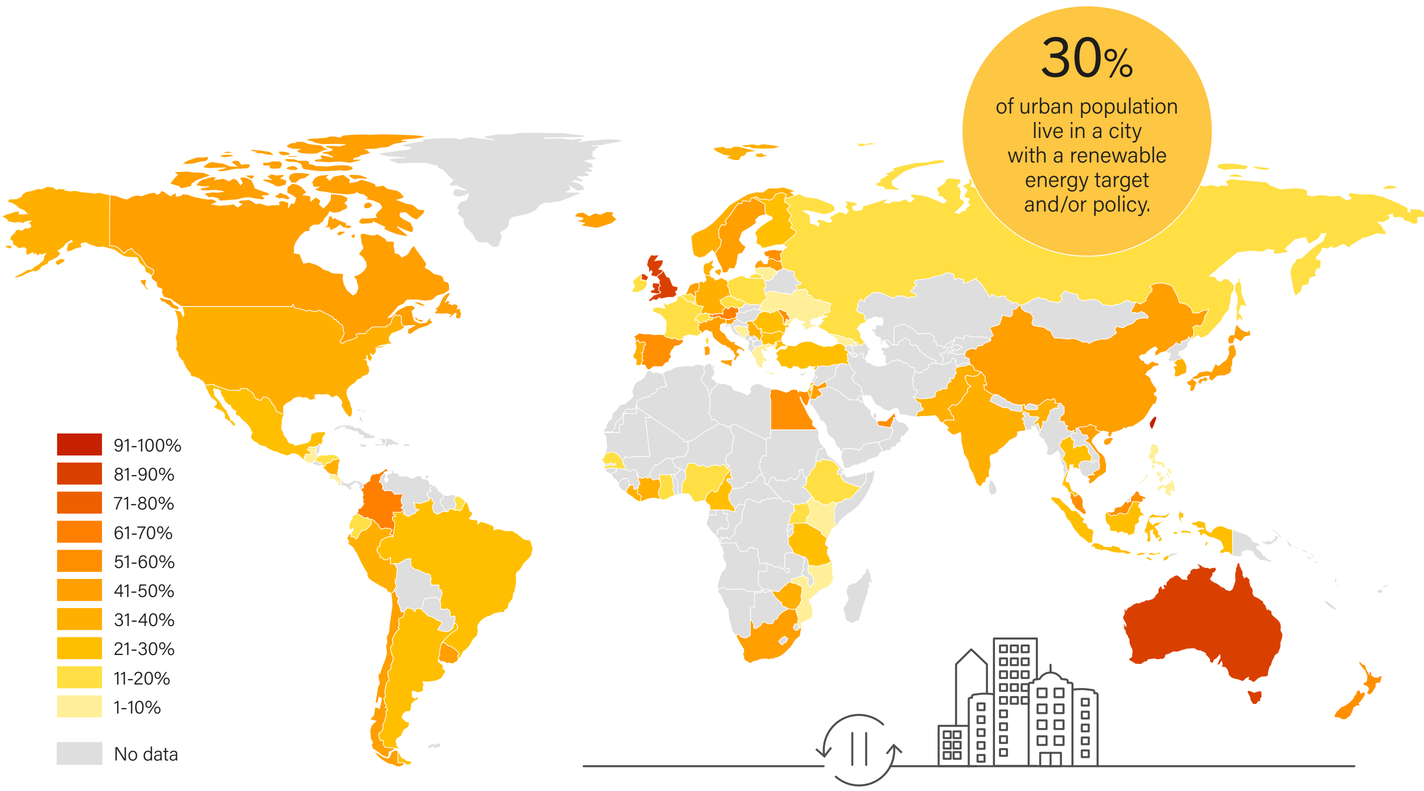
i Net zero emissions can be achieved, for example, by using natural sinks, such as reforesting land or adopting agricultural best practices, or through a technological solution, such as carbon capture and storage. Net zero targets also are referred to as "climate neutral", "carbon neutral" or "zero emission" targets, although technically these differ. Carbon neutrality refers to net zero emissions of only carbon dioxide (CO_2), whereas climate neutrality indicates a broader focus on all greenhouse gases. There is no agreed definition, and implementation of these targets also varies broadly. See glossary.

Such local action has been key in supporting both national decarbonisation efforts and efforts to achieve global goals such as the Paris Agreement. Cities are home to around 55% of the world's population, and energy use in cities accounts for three-quarters of global final energy use (and a similar share of energy-related CO_2 emissions).[6] Energy demand in cities continues to grow, particularly in Africa and Asia, due mainly to urban population growth (including urbanisation) and economic development.[7] As city governments move towards electrifying transport as well as heating and cooling in buildings, electricity demand also is expected to grow.[8] Municipal buildings and transport account for only a small share of urban energy demand – the bulk of the energy consumed city-wide is used in residential and commercial buildings, and for private transport.[9]

Energy use in cities accounts for **three-quarters** of global final energy use.

City governments have played a role in expanding sustainable energy access and reducing energy poverty for inhabitants. Around 1 billion urban and peri-urban dwellers live in rapidly growing slums and informal settlements, often located on the periphery of cities.[10] Many inhabitants continue to lack access to energy and to other urban services and infrastructure. City action on sustainable and reliable energy access has been key to improving living conditions for the urban poor and to efforts to achieve Sustainable Development Goal 7 (on sustainable energy for all) and interlinked goals.[11]

FIGURE 63.
Share of Urban Population with a Renewable Energy Target and/or Policy, 2021



Note: Calculations based on population in cities with renewable energy targets and/or policies and their share of the national population. Excludes cities with energy efficiency, electric vehicle and/or net zero targets. Data not available for some countries. See Reference Table R3 in GSR2022 Data Pack.

Source: See endnote 4 for this chapter.

To support vulnerable communities, the Race to Resilience campaign was launched in mid-2021 to boost the resilience of some 4 billion people by 2030, with a focus on transforming urban slums into healthy, clean and safe environments.[12] Renewables have played a role in many local resilience efforts: for example, the Sunnyside project in Houston (Texas, US) powered around 5,000 low-income homes with solar energy in 2021, with the aim of reducing energy costs and creating jobs.[13]

Many challenges remain for cities to take climate and energy action. The degree to which national governments grant their city counterparts regulatory power and access to financial markets is decisive in cities' abilities to advance renewables.[14] Cities also are subject to market rules and energy regulations set at higher levels of government – and to the political dynamics that shape these instruments.[15] For example, persistent fossil fuel subsidies adopted at the national level may contribute to a clash in priorities and a lack of coherence between national and local policies.[16]

In 2021, state lawmakers in Ohio (US) enacted a law that allows counties to veto renewable energy projects and that bans local governments from restricting natural gas use; these developments could impede the city of Columbus in achieving its 100% renewable electricity target.[17] In Florida, a 2021 law prohibits local governments from any action restricting a utility's energy choices, hampering St. Petersburg's progress on its 100% renewable energy target and delaying Tampa's passing of a target.[18]

Other factors affecting cities' ability to advance renewables include the lack of institutional and human capacities as well as insufficient awareness of how cities can contribute to the energy transition.[19] In general, city voices remain underrepresented in global energy and climate debates, and their role in supporting national decarbonisation plans often is not reflected in countries' Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.[20] Although city governments play no official role in the ongoing UN climate negotiations, the Glasgow Climate Pact, for the first time, emphasised the urgency of multi-level, co-operative action to achieve the Paris goals.[21]

In response to the diverse challenges they face, some local governments have collaborated with higher-level national governments to realise renewable energy projects, while others have initiated and/or supported legal challenges to remove legislative barriers to climate and energy action. City engagement in global and regional city networks seeking to tackle rising emissions – such as the Global Covenant of Mayors for Climate & Energy, ICLEI–Local Governments for Sustainability and C40 Cities – also has grown.[22]

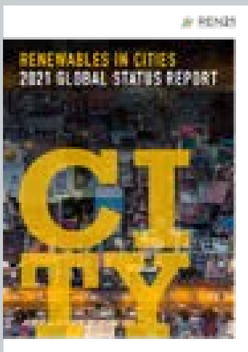
DRIVERS FOR RENEWABLES IN CITIES

Renewable energy developments vary by city and depend on the local context, available resources, and community values and needs. As such, the drivers[i] for renewables are influenced by a city's broader economic, social and environmental priorities. Because city governments have close ties to their citizens, they are motivated to seek solutions that meet local energy demand while fostering healthy, resilient and liveable communities – often in line with efforts towards a socially inclusive and just energy transition.[23] For cities that have reported renewable energy actions under the CDP-ICLEI Unified Reporting System, the co-benefits of renewables have included job creation, resource security, economic growth, social inclusion and improved public health.[24]

With the COVID-19 pandemic entering its second year in 2021, continued lockdowns and distancing requirements had a major impact on urban priorities and the drivers for renewables. Efforts to ensure public health and well-being while supporting local economic recovery and resilience were top priorities.[25] This affected cities' abilities to pursue renewable energy projects. For example, in Houston, COVID-19 decreased the internal capacity to address energy and sustainability issues.[26] In Thailand, where a national policy required local governments to prioritise the pandemic, the town of Nongsamrong postponed renewable energy activities due to limited staff availability.[27] Grand Rapids (Michigan, US) similarly delayed municipal solar photovoltaic (PV) projects, citing lost tax revenues.[28]

BOX 13. Renewables in Cities at REN21

REN21's *Renewables in Cities Global Status Report* (REC), published in 2019 and 2021, provides an overview of the status, trends and developments of renewable energy in cities, using the most up-to-date information and data available. The report aims to inform decision makers, raise interest around the urban renewable energy story and inspire continued action. The present chapter provides an update on key trends in anticipation of the full *Renewables in Cities 2023* Global Status Report, scheduled for release in early 2023. See ren21.net/cities for further information.



i For a detailed discussion of drivers, see REN21's *Renewables in Cities 2019 Global Status Report*, available at www.ren21.net/cities.

After the annual UN climate talks were postponed in 2020 due to the pandemic, public pressure on governments to take climate action increased in 2021 in the lead-up to the Glasgow meetings. Climate emergency declarations continued to spread, although more slowly than in previous years as attention shifted to the net zero movement. By late 2021, around 2,050 local governments had declared a climate emergency[i] (up from 1,853 in 2020), dominated by localities in Canada, the Republic of Korea, the United Kingdom and the United States.[29] Many local governments have used these declarations to emphasise their net zero commitments, but it is not yet clear whether and how they will be used to support renewables.[30]

Another priority in cities has been reducing local air pollution (and carbon emissions) from the burning of fossil fuels in road transport, buildings and industry.[31] COVID lockdowns that curtailed traffic and cleared the air increased pressure on city governments to prioritise active transport modes such as cycling and walking, as well as public transport.[32] In September 2021, the World Health Organization updated its Air Quality Guidelines, slashing by half the guideline limit for the most damaging air pollution.[33]

In the face of rising energy costs towards the end of 2021 – a trend that continued in early 2022 following the Russian invasion of Ukraine – municipal agendas have prioritised keeping these costs manageable, including for municipal utilities. Due to spiking energy prices, several private energy providers went out of business during this period, throwing consumers back to be served by municipal utilities.[34] In Germany alone, 39 providers had ceased operations by early 2022.[35] This has strained the ability of municipal utilities to provide their customers with reliable service.

CITY ENERGY AND CLIMATE TARGETS

Local energy and climate action continued to grow in 2021, with many city governments prioritising renewables on their policy and planning agendas.[36] City governments have given direct support to renewables deployment and investment by setting specific **renewable energy targets**, either for municipal operations (their own buildings and transport fleets) or to shift city-wide energy use.[37]

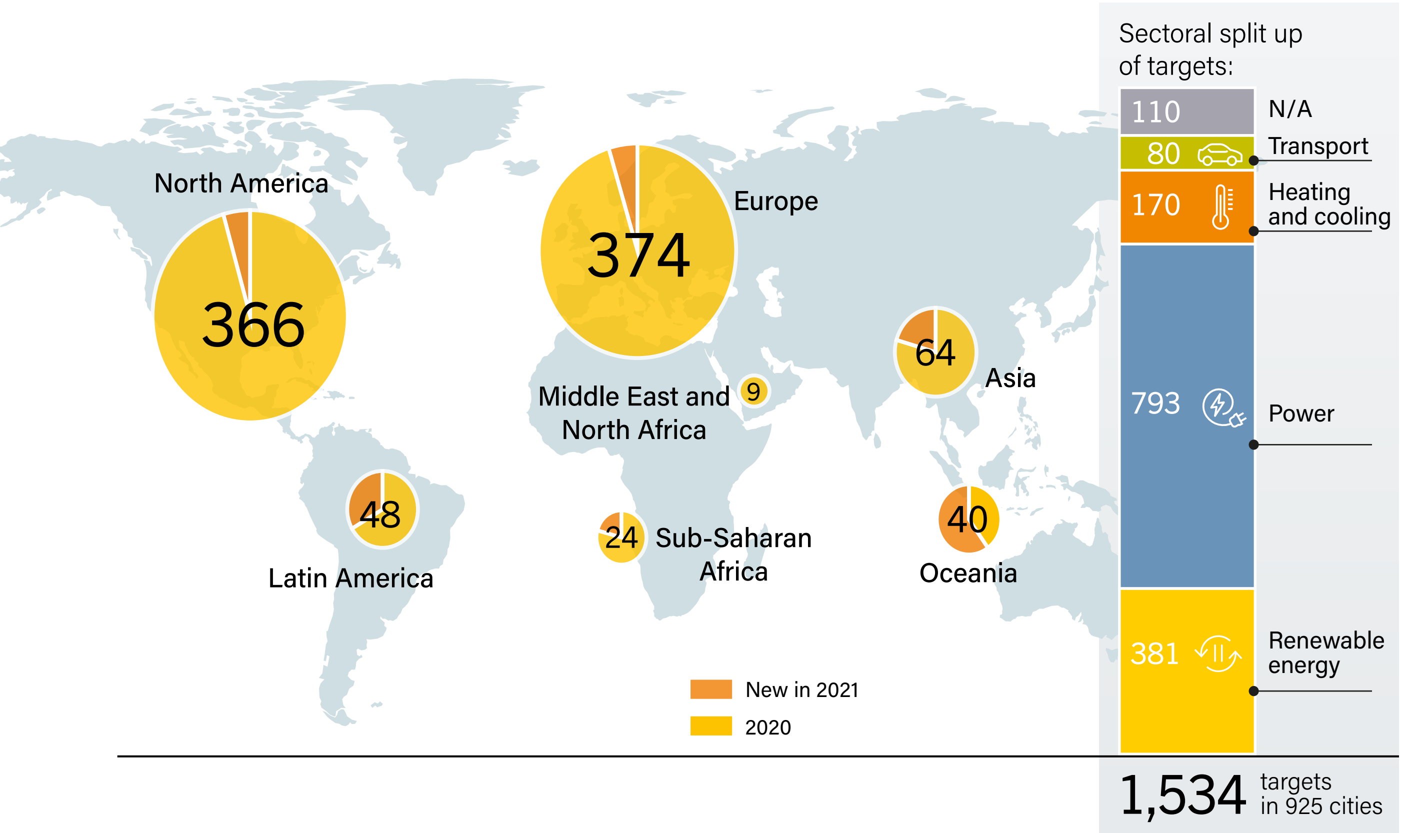
Such targeting has taken diverse forms, ranging from aspirational pledges and announcements, to participation in initiatives and campaigns, to setting binding targets, to anchoring renewables in policy documents and supporting measures. These efforts have sent signals to citizens, industry and service providers about the prioritisation of renewables and have set an example through the creation and testing of new policies, thus pressuring higher levels of governments to follow suit.[38]

By year's end, more than 920 cities in 73 countries had set a renewable energy target in at least one sector (power, heating and cooling, or transport), up from around 830 cities in 2020.[39] (→ *See Figure 64.*) Most city targets are in highincome countries (which can better access financial resources), such as Australia, France, Germany, the United Kingdom and the United States.[40] Nonetheless, targets have emerged around the world, including in Argentina, India, Malaysia and South Africa.[41] Targets remain dominant in small and medium-sized cities (up to 500,000 people) but also are present in larger cities and megacities, with New York and Los Angeles (both US) and Johannesburg (South Africa) all adding targets in 2021.[42]

More than
920 cities in 73 countries
set a renewable energy target.

i This includes city governments that have passed a binding motion declaring a climate emergency. Following such a declaration, jurisdictions typically set up a process to develop an action plan and report back within three to six months.

FIGURE 64.
Number of Cities with Renewable Energy Targets, by Region and Sector, 2020 and 2021



Note: The figure includes cities with renewable energy targets either for municipal operations or for city-wide energy use, or for both. Some cities have more than one renewable energy target. Energy efficiency targets are not included in the calculations. For more information, see Reference Table R14 in GSR2022 Data Pack.

Source: See endnote 39 for this chapter.

Over
1,100 city governments
announced net zero targets.

Urban renewable energy targets (and policies) often apply to either the buildings or transport sector (or both), with only a few cities having comprehensive system-wide renewable energy targets.[43] Targets to shift to renewables in **buildings** are the most prevalent, as well as commitments to increase energy efficiency and expand the net zero building stock. Almost 700 cities had such targets by the end of 2021, most of which were for renewable power, although heating and cooling targets and targets for renewables in buildings in general also are increasing.[44]

In September, mayors from 15 cities, such as Buenos Aires (Argentina), Lagos (Nigeria), Lisbon (Portugal) and Seoul (Republic of Korea), were the initial signatories of the C40 Renewable Energy Declaration[i], committing to 100% renewable electricity by 2050 and to decarbonising heating and cooking.[45] Also in 2021, the Los Angeles City Council voted to transition to 100% clean energy by 2035 (a decade earlier than originally planned and in line with US national goals) by replacing the city's natural gas-powered electricity with wind and solar power and battery storage.[46]

Momentum also is growing for dedicated targets to decarbonise the heating of buildings and to expand access to clean cooking fuels, particularly as electrification of the heat sector accelerates.[47] In early 2022, London adopted a target to have 2.2 million electric heat pumps city-wide by the end of 2030, as well as a district heating network serving nearly half a million buildings, as part of the city's pathway to achieve net zero; these plans are more ambitious than the UK's national Heat and Buildings Strategy.[48]

Targets for scaling up renewables in **transport** are gaining ground only slowly. Most targets for biofuels are established at higher levels of government, although some cities have set targets for the production of biogas and biomethane (usually from waste-to-energy plants) that are aimed specifically at the (public) transport sector.[49] Only a few cities, such as Adelaide (Australia) and Buenos Aires (Argentina), have targets for the procurement of biofuel buses.[50]

In line with global trends, most city-level renewable transport targets focus on **electric vehicles**[ii] (EVs), with around 100 cities having such targets in place.[51] For example, Bengaluru (India), Bogota (Colombia) and Chengdu (China) agreed to procure only electric buses starting in either 2021 or 2022; often, such targets are part of a plan to achieve a certain number or share of electric buses in circulation by a certain year.[52] Some EV targets are linked directly to the use of renewable power, as in Mumbai (India) and Seattle (Washington, US), which aim for a 100% electrified bus fleet powered entirely by renewables.[53]

Although targets for renewable **hydrogen**[iii] in cities are unusual, interest in hydrogen buses for public transport is emerging, particularly in China and the Republic of Korea (although typically without specifications for renewable hydrogen).[54] Beijing aims to have more than 10,000 fuel cell vehicles on the road and to build 37 hydrogen filling stations by 2025.[55] In 2021, Los Angeles became the first big US city to commit to renewable hydrogen, with the L.A. Department of Water and Power aiming to transition its 4,300 megawatts (MW) of fossil fuel power plants partly to renewable hydrogen by 2025 and fully by 2030, in addition to expanding hydrogen storage.[56] Lancaster (California, US) outlined similar plans.[57]

The global momentum towards **emission reduction targets** in cities further accelerated in 2021. By year's end, over 1,100 city governments – in addition to regional and national governments – had announced targets for **net zero** emissions, which reflects a balance between CO_2 emissions and removals.[58] Some cities have made net zero pledges on their own, while many others have joined global networks, such as Race To Zero[iv].[59] Thanks to these pledges, by the end of 2021 almost 1 billion people were living in a city with a net zero target.[60] City net zero targets are most prevalent in Europe (led by France, Romania and the United Kingdom) and Latin America and the Caribbean (led by Argentina), followed by East Asia and North America.[61]

Only a few city governments have anchored their net zero pledges in policy documents or developed a plan for achieving this goal. In most cities, exact measures are still under discussion or no status information on targets is available, highlighting the importance of master plans that outline specific actions and strategies towards net zero, including the deployment of renewables.[62] (→ *See Figure 65.*)

Although most net zero targets are not explicitly linked with renewable energy, nearly all scenarios that aim for net zero emissions highlight the need to shift from fossil fuels to renewables to achieve this goal.[63] (→ *See Snapshot: Helsinki, Finland.*) Targets can stimulate the uptake of renewables indirectly by mandating the phase-out of fossil fuels and supporting the scale-up of renewables, alongside energy efficiency measures. Yet many net zero announcements lack a direct link to renewables. In an analysis of cities with more than 250,000 inhabitants, only 161 of the 504 cities that had net zero targets also had a renewable energy target as of 2021.[64] (→ *See Figure 66.*)

A variety of platforms and partnerships have been developed to help cities report on their progress in achieving renewable energy and climate targets. However, many cities lack the resources to accurately track these advances.[65] By late 2021, a

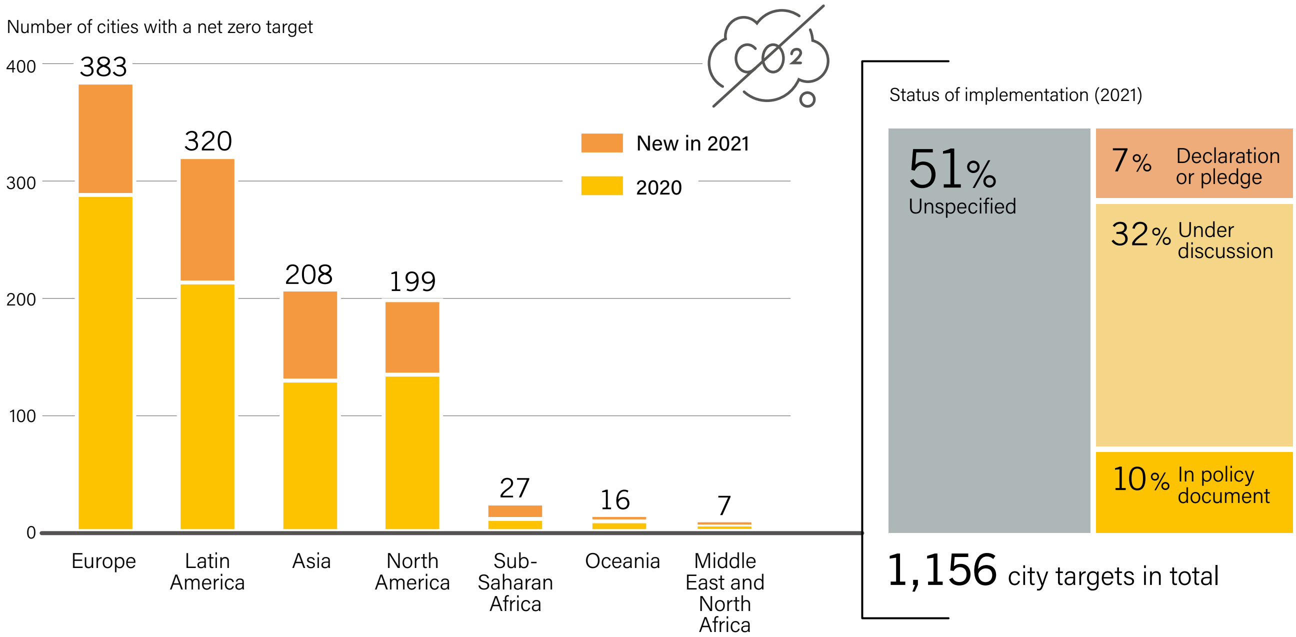
i The C40 Declaration offers three pathways for city action, which cities can pursue depending on their unique needs and circumstances. The declaration does not include transport.

ii This chapter relies on the terminology that cities generally use when setting targets and policies to decarbonise transport. This includes calls for "carbon-neutral", "zero-emission" or "clean" vehicles, which typically refer to electric vehicles and are not necessarily linked with renewable energy.

iii Also called green hydrogen. See Glossary for definition

iv In the lead-up to the Glasgow climate talks, more than 1,050 local governments (also including regions) pledged to reach net zero as part of Race To Zero, with the target year being 2050 and interim targets set for 2030.

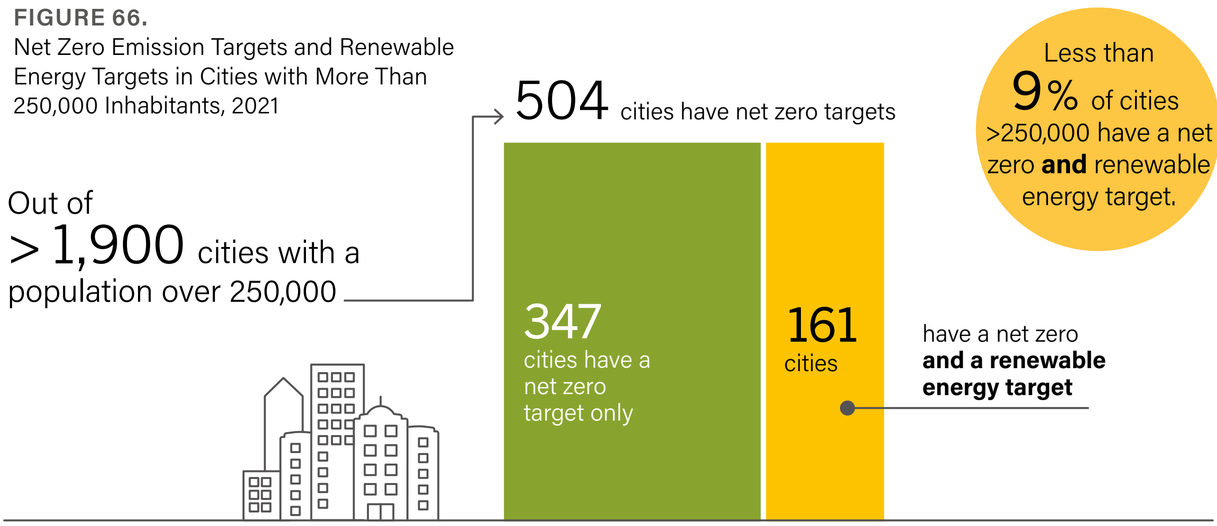
FIGURE 65.
Cities with Net Zero Emission Targets and Status of Implementation, by Region, 2020 and 2021



Note: Calculations include the following: targets reported by the UNFCCC as either targets under discussion or in policy documents; emission reduction targets of 80% and more; net zero buildings targets; and other targets including climate neutrality and zero-carbon targets in buildings. Calculations exclude targets for 1.5°C, fossil-free targets and 100% energy self-sufficiency targets. See Reference Table R15 in GSR2022 Data Pack.

Source: Based on C40 Cities. See endnote 62 for this chapter.

FIGURE 66.
Net Zero Emission Targets and Renewable Energy Targets in Cities with More Than 250,000 Inhabitants, 2021



Note: The figure covers only cities with populations over 250,000 inhabitants. In addition, hundreds of smaller cities have also passed net-zero emission and/or renewable energy targets. See reference table R15 in GSR2022 Data Pack.

Source: See endnote 64 for this chapter.

record 1,128 local governments from 85 countries were reporting their data through the CDP-ICLEI Unified Reporting System.[66] More than 880 city governments reported actions related to renewables.[67] So far, the data indicate that most cities are not on track to reach their targets. For example, as of 2021 Portland (Oregon, US) had yet to set performance standards and to issue an equity plan for its 2018 Portland Clean Energy Community Benefits Fund, more than three years after its launch.[68]

FINANCING RENEWABLES

City governments have used a variety of mechanisms to finance renewable energy projects, which can be grouped broadly into: using their own capital and/or assets to develop projects; raising funds through bonds, development finance and bank loans; and leveraging funds provided by higher levels of government. Asheville (North Carolina, US) has worked with the county and state governments to advance its 100% renewable energy target by co-funding renewables projects.[69] Cornwall Council (UK), with support from several national departments and ministries, secured around GBP 6 million (USD 8.1 million) to finance the retrofitting of more than 700 homes and the installation of solar PV.[70] Another financing option is to collaborate with the private sector on energy purchasing through public-private partnerships.[71] (→ *See Snapshot: Durban, South Africa.*)

The available solutions depend on the context, including existing rules and regulations, ownership rights for infrastructure, the availability of capital, the ability of municipalities to collect fiscal revenue and borrow money, and the potential to mobilise private sector partners. City governments are responsible for only part of the investment within a city; private finance and household spending also play a role and have their own priorities, planning horizons and constraints.[72]

SNAPSHOT. HELSINKI, FINLAND

Revamping District Heating

In Finland's capital Helsinki, more than half of all district heat is produced from coal, resulting in the heating sector contributing well over half of the city's greenhouse gas emissions. Pushed by the national ban on coal in energy production as well as Helsinki's goal to become carbon neutral by 2030 (moved up from 2035), the city launched a global competition to revamp its district heating system. As part of this Helsinki Energy Challenge, the city announced a USD 1 million prize competition for the submission of master plans that eliminate coal-based heat without increasing the share of heat from biomass.

More than 250 teams from 35 countries submitted proposals during 2020. That December, 10 finalists were invited to refine their plans, and by March 2021 four winners were selected, demonstrating feasible, localised plans. The winning proposals suggested a diverse set of solutions: 1) a market-based strategy, using carbon-neutral heating auctions; 2) a mixture of novel thermo-chemical energy storage with already commercially available technologies; 3) a continually evolving plan that integrates new technologies while using existing technologies such as heat pumps and electric boilers in the interim; and 4) taking advantage of the nearby Baltic Sea to install inflatable hot seawater reservoirs that can double as leisure attractions.

Although formal plans have not yet been announced to implement the winning proposals, Helsinki has set a precedent showing that collaboration and innovation are possible and necessary for making the future of heating carbon-free. As part of this challenge, the city also announced that it would share winning proposals and solutions with other city governments to inspire them on how to decarbonise their heating systems.

Source: See endnote 63 for this chapter.

Due to the spectrum of actors involved, tracking renewable energy finance in cities remains difficult. Existing reporting on urban climate finance flows shows that most public and private capital spending for climate mitigation goes to sustainable transport (including public transport and EVs), followed by buildings infrastructure, energy efficiency, and on-site renewable power and heat – with only a small share allocated to utility-scale renewable generation.[73] Public and private urban climate finance flows averaged USD 384 billion annually in 2017 and 2018 (latest estimates available), of which USD 4 billion was dedicated to renewable energy generation.[74]

City governments, alongside other actors, also have begun divesting their assets from fossil fuels; in some cases, this money was re-invested directly in more sustainable options. By the end of 2021, more than 170 city and local governments, as well as some city pension funds, had divested from all or selected fossil fuels.[75] Ahead of the Glasgow climate talks, six cities including Auckland (New Zealand), Glasgow and Rio de Janeiro (Brazil) announced commitments to divest from fossil fuel companies, raising the total number of cities participating in C40's divestment campaign (launched in 2020) to 18[i].[76]

SNAPSHOT. DURBAN, SOUTH AFRICA

Using Tenders to Finance 100% Renewable Electricity

In mid-2021, Durban (eThekwini) in South Africa passed its Transition Policy, building on the city's 2020 Climate Action plan, which targets 40% electricity from low-carbon technologies by 2030 and 100% by 2050. As part of this plan, the city launched a tender in 2021 to procure up to 400 MW of additional electric capacity from independent power producers in South Africa. This is the first tender of its kind for Durban, made possible by a landmark decision granted in late 2020 that enables South African municipalities to procure new power generation capacity outside of the state utility Eskom and to develop their own capacity.

These developments were driven by the need to establish an integrated municipal energy system with a diversified generation mix, in order to provide affordable and reliable energy for residents and businesses, improve energy security and create jobs along the energy supply chain. By procuring 400 MW from a diverse mix of sustainable, dispatchable and reliable generation technologies, the city hopes to enhance energy trade, stimulate competition and reduce the effects of load shedding on the local economy. The city called for all potential private developers, investors and experienced energy infrastructure organisations to submit proposals to support divestment from fossil fuels and investment in renewable sources.

Source: See endnote 71 for this chapter.

i In 2021, Auckland, Copenhagen, Glasgow, Paris, Rio de Janeiro and Seattle signed on to C40's Divesting from Fossil Fuels, Investing in a Sustainable Future campaign, joining Berlin, Bristol, Cape Town, Durban, London, Los Angeles, Milan, New Orleans, New York City, Oslo, Pittsburgh and Vancouver. See endnote 75 for this chapter.

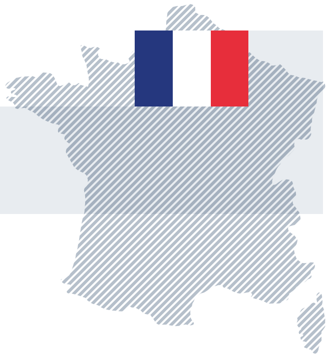
BUILDINGS

To achieve their renewable energy targets, municipal governments have taken steps to decarbonise their building stock, with a focus on transforming how buildings are powered, heated and cooled. Broadly, these measures vary depending on whether they apply to buildings under municipal control (e.g., local government buildings, schools, hospitals, social housing), or to residential, commercial and industrial buildings that account for city-wide energy use. Measures also differ between new and existing buildings, with many being applied initially to new buildings before expanding in coverage.

ON-SITE GENERATION

By shifting to renewable power in municipal buildings, many city governments have been able to showcase the feasibility and business case of renewables.[77] City governments have used their building assets to install stand-alone renewable energy systems on rooftops, façades and alongside buildings. So far, most of the focus has been on solar PV (sometimes with battery storage) and solar thermal, although modern biomass boilers also have been deployed. In 2021, George municipality (South Africa) installed a 300 kilowatt solar PV plant to cover the electricity use of its main building.[78] Denver

SNAPSHOT. PARIS, ROUEN AND LE HAVRE, FRANCE



Co-operation on Renewables

The French cities of Paris, Rouen and Le Havre recently pooled their resources and approved the creation of Axe Seine Energies Renouvelables, a local mixed-economy company, in early 2022. The company aims to develop 50 renewable energy projects by 2030, including biomass, solar PV, and wind, in addition to heat recovery and hydrogen projects along the Seine River. An important aspect of this initiative is that it will facilitate the ability to pool human and financial resources around renewable energy projects.

The 50 projects potentially represent an installed renewable capacity of 250 MW. The mayors of the three cities had indicated in October 2021 the desire to transform the Seine into the first valley of decarbonisation in France. The initiative is seen as a keen step towards this goal. To fund the partnership, Le Havre and Rouen each will finance one-quarter of the investment capital (at USD 2.2 million each), a French public sector financial institution (the Caisse des dépôts et consignations) will finance another quarter, and the remaining funds will come from the City of Paris and the Greater Paris Metropolis, which will add USD 1.1 million each.

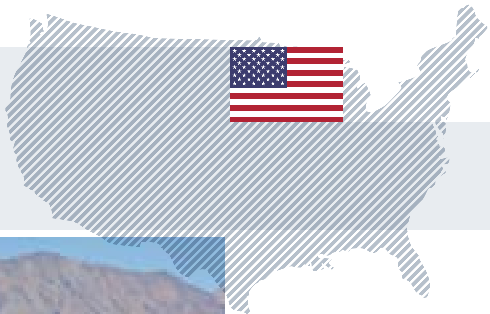
Source: See endnote 85 for this chapter.

City Council (Colorado, US) moved forward with a USD 26 million investment in more than a dozen solar projects to cover municipal power needs, while also adding solar charging infrastructure for EVs.[79]

The electrification of heating is expanding in cities as well, providing an opportunity to use renewable electricity to operate appliances such as heat pumps.[80] In 2021, Salford (UK) installed 12 air-source heat pumps in addition to solar PV on its municipal buildings, as part of its decarbonisation plans.[81] In some cases, city governments also have tapped into local wind, biomass, geothermal and hydropower resources – whether for electricity, for direct thermal heat, for co- and tri-generation of power and heat, or to support the use of renewables in district energy networks.[82]

Policies differ between new and existing buildings.

SNAPSHOT. US CITIES



Community Choice Aggregation

Power distribution in the United States operates under a natural monopoly system: due to high upfront costs, power utilities have exclusive coverage territories where they alone generate, distribute and transmit electricity. To expand the options, cities and municipalities across the country have started to use Community Choice Aggregation (CCAs) to procure renewable electricity on behalf of residents. By bundling demand and acting as a large energy buyer, a CCA can create large contracts, demanding cheaper rates and a cleaner energy mix.

California has emerged as the leader of community choice, as more than 160 towns, cities and counties have joined some 25 CCAs across the state, procuring more than 24 TWh from 2011 to 2018. Large cities such as San Diego and San Francisco have made CCAs the standard. However, smaller cities also have united in regional CCAs – for example, Silicon Valley Clean Energy, which services 13 smaller cities in the San Jose area.

Other US cities have followed suit. Boston, Massachusetts launched its Community Choice Electricity program in February 2021 and packages between 18% and 100% of local renewable energy to residents. In Ohio, one of the first US states to adopt CCAs (back in 2000), the City of Columbus voted overwhelmingly in favour of a green energy aggregation plan. Seven other states have enacted laws enabling CCAs, making it easier for residents to choose cheaper and cleaner energy.

Source: See endnote 90 for this chapter.

PURCHASE AGREEMENTS AND PARTNERSHIPS

In cases where city governments have insufficient space to install renewables, or face other constraints, they have signed agreements to buy the electricity from off-site projects (such agreements are used for on-site generation as well). The most common option is a power purchase agreement (PPA) for municipal energy use (or, in some cases, for city-wide use).[83] In early 2022, Cape Town (South Africa) announced a tender to procure 300 MW of renewable energy from independent power producers.[84] Some cities have pooled their resources to negotiate more favourable terms.[85] (→ *See Snapshot: Paris, Rouen and Le Havre, France.*) In 2021, 24 local governments in the state of Maryland (US) jointly purchased enough renewables to power more than 246,000 homes a year.[86]

In the United States, off-site PPAs between cities and developers of large-scale projects accounted for the vast majority of new renewable power capacity from 2015 to 2021.[87] During the period from 2020 to 2021, local governments in at least 21 states signed over 140 PPAs for off-site projects, totalling more than 7,500 MW of capacity (3,500 MW in 2020 and nearly 4,000 MW through 2021); most of this was solar PV, with the rest being wind and geothermal power.[88]

To overcome limited resources or rules set at higher levels of jurisdiction, city governments have partnered with stakeholders – including utilities and community energy projects – to advance local renewable energy generation and distribution. In 2021, Albury City (Australia) opened applications for an AUD 100,000 (USD 72,500) community energy fund, inviting local groups to launch projects; similar funds exist in Bristol, Camden, Islington and London (all UK).[89] Cities also have launched community choice aggregation programmes to increase the renewable share in the electricity mix.[90] (→ *See Snapshot: US Cities.*) In 2021, Rochester (New York, US) announced that all 57,000 residents would be auto-enrolled in the Community Solar Program, with an option to opt-out.[91]

MUNICIPAL ENERGY INFRASTRUCTURE

Many city governments have shaped their energy infrastructure to support the integration of sectors and to better accommodate renewables. This includes upgrading and expanding district energy networks – including through the integration of local renewables – and commissioning new networks.[92] In 2021, Africa's largest district cooling plant was commissioned in Egypt's New Administrative Capital to serve the government and financial districts and another 180 buildings.[93] Sarajevo (Bosnia and Herzegovina) signed an agreement with the European Bank for Reconstruction and Development for a EUR 16 million (USD 18 million) loan and a EUR 1.2 million (USD 1.4 million) grant to convert its district heating network from oil to geothermal to reduce air pollution.[94]

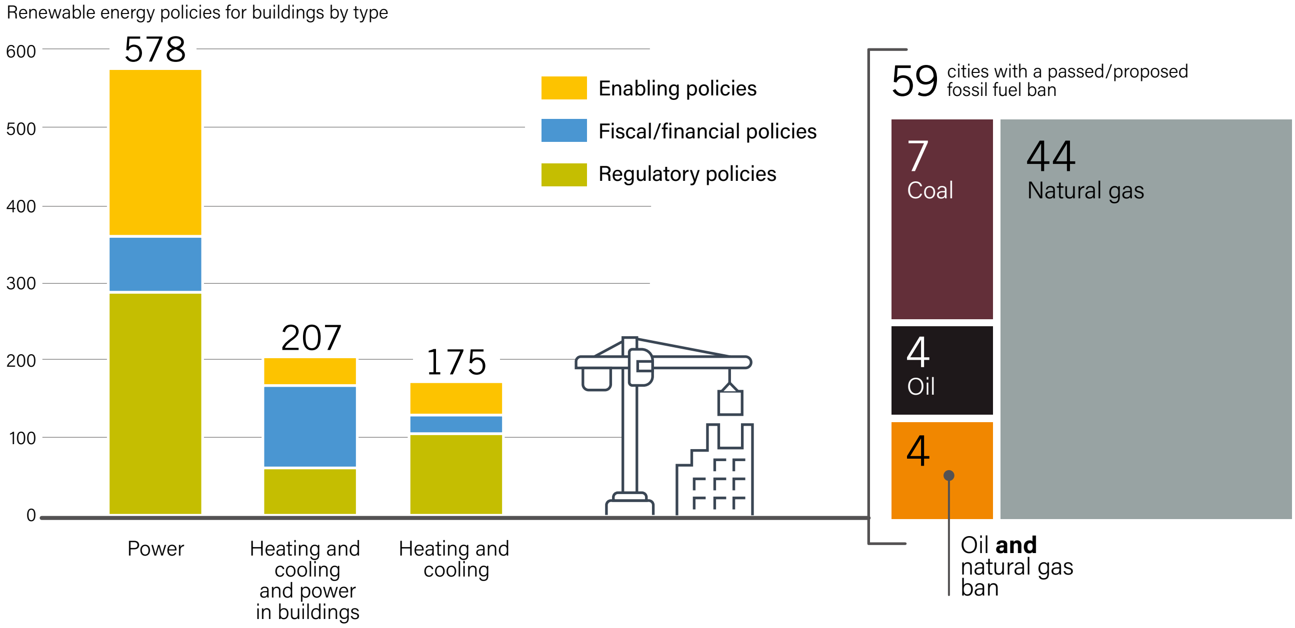
City governments also are linking energy supply with other urban activities and services, such as using waste and wastewater streams to produce biofuels.[95] In 2021, Columbus City Council (Ohio, US) announced a USD 30 million project to use sewage treatment plants to produce biogas for electricity and heat.[96] Similar projects exist in Barcelona (Spain) and Vancouver (Canada).[97]

ALL CITY BUILDINGS

Because municipal buildings account for only a small share of the total urban building stock, the success of meeting local renewable energy targets and contributing to nationwide decarbonisation also depends on energy use in buildings city-wide. To encourage wider uptake of renewables, city governments have used their role as regulators and policy makers to expand policy portfolios.[98] By the end of 2021, over 920 municipal governments had implemented direct regulatory policies, financial and fiscal incentives, and indirect support policies aimed at decarbonising buildings through renewable power and/or renewable heating.[99] (→ *See Figure 67.*) Most measures focus on rooftop renewables (mainly solar PV, and/or solar thermal), although policies supporting the electrification of space and water heating (with heat pumps) also are gaining ground.

Most urban policy makers apply different tools for new versus existing building stocks. Typically, regulatory mechanisms such as building codes that mandate on-site generation of renewables for electricity and/or heating apply only to new buildings, although some cities also require this during retrofits and renovations.

FIGURE 67.
Urban Renewable Energy Policies in Buildings, by Type, 2021



Note: Data should not be compared with previous years, due to revisions and adjusted methodology. Fossil fuel bans are categorised as enabling policies. See Reference Table R16 in GSR2022 Data Pack.

Source: See endnote 99 for this chapter.

59 cities
passed or proposed a ban or restriction on fossil fuels.

Such mechanisms are increasingly common in US and European cities in particular. In 2021, Berlin joined other German cities such as Heidelberg and Konstanz in requiring solar PV and/or solar thermal installations for new residential buildings and during big roof renovations; the law will go into effect in 2023 as part of the goal to reach 25% local renewables.[100]

Industry players have pushed back against such developments. In 2021, the consortium that oversees model building codes for much of the United States and parts of Latin America and the Caribbean stripped local governments of their right to vote on future building codes, a move that has been attributed to the influence of the construction and natural gas industries.[101]

For existing buildings, financial and fiscal incentives such as grants, rebates and tax credits often are used to encourage renewables.[102] In 2021, Bonn, Essen and Ratingen (all Germany) and St. Gallen (Switzerland) launched financial support schemes for solar PV on all type of buildings.[103] (→ *See Snapshot: Essen, Germany.*) Some schemes also extend to heat pumps: in late 2021, London rolled out an energy efficiency and renewable energy fund that grants up to GBP 20,000 (USD 27,000) for lowincome households to install insulation, heat pumps, or solar PV panels, to combat rising fuel poverty.[104] To achieve zero emissions, Ithaca (New York, US) aims to electrify all buildings, offering grants and rebates to commercial owners and households (including a special fund for low-income residents) to undertake energy efficiency upgrades and install heat pumps.[105]

To improve local air quality, reduce energy dependence, and indirectly support renewables, some city governments have introduced bans and/or restrictions on the use of fossil fuels, many of these since 2019.[106] By the end of 2021, a total of 59 in 13 countries (up from 53 cities in 2020) had either passed or proposed a ban or restriction on the use of natural gas, oil or coal for space and water heating and for cooking; cities in California lead in this movement.[107] Some cities have updated their building codes with electrification requirements for new construction, effectively banning fossil fuels.[108] In late 2021, New York became the biggest city to restrict fossil fuel use in new commercial and residential buildings starting in 2023, and in all buildings by 2027.[109]

Some of these measures have met with resistance. Berkeley (California, US) was taken to court by the restaurant industry over its 2019 natural gas ban in new buildings; the court dismissed the lawsuit in late 2021, opening the door for more cities to pursue such restrictions.[110]

SNAPSHOT. ESSEN, GERMANY

Solar Subsidies

Essen, Germany has launched both a solar programme and a green roof programme in the city. Based on a council decision in June 2021, the municipality started in January 2022 to provide financial subsidies for households and businesses to install solar PV and solar thermal systems. This is part of Essen's target to deploy more than 2,200 new solar PV installations by 2026, which would double the number of existing installations.

Under the new regulation, the city will subsidise solar PV systems of up to 40 kW, with the subsidy amount dependent on the system size. Additional funding is provided for systems that couple solar PV with a green roof or are installed on building façades. The policy also supports community energy projects at multi-family residences, with a higher financial incentive for existing buildings. Solar thermal systems receive a subsidy as well, with the amount varying depending on whether the system is used for hot water or heating purposes.

The project has an annual budget of EUR 500,000 (USD 566,200). In addition, Sparkasse bank in Essen supports the initiative by providing a low interest rate to individuals for project loans of up to EUR 20,000 (USD 22,650). Implementation of the funding programme and possible further adjustments were to be evaluated in summer 2022.

Source: See endnote 103 for this chapter.

TRANSPORT

Pushed by the need to improve local air quality and protect public health and well-being, city governments have undertaken efforts to decarbonise urban transport. Such measures often are embedded in wider urban planning strategies that aim to reduce the need for personal motorised transport by expanding walking and biking infrastructure and creating secure, reliable and affordable public transport systems.[111]

PUBLIC TRANSPORT AND MUNICIPAL FLEETS

City governments have made great strides in decarbonising their municipal fleets and public transport systems. In line with global trends, most city efforts have focused on the **electrification** of municipal service fleets and public buses as well as the expansion of metro and light rail systems.[112] (→ *See Snapshot: Belgrade, Serbia.*) In 2021, more than 740 new electric buses were delivered in Qatar (where they will operate as part of the Soccer World Club), Mexico City (Mexico) and St. Louis (Missouri, US).[113] St. Louis also joined other US cities such as Albuquerque, Charlotte and Sacramento in adopting "electric first" purchasing policies that require departments to prioritise electric over conventional vehicles where operationally feasible and cost effective.[114]

To power their public transport systems, some city governments have installed dedicated renewable electricity capacity or signed PPAs for this purpose. In Sydney (Australia), new electric buses were rolled out in 2021 that include solar PV charging at the depot.[115] Utrecht (Netherlands) installed more than 2,000 solar panels over a parking lot, along with 250 bi-directional chargers that will enable electric cars to feed their stored solar power back to the grid.[116]

Many cities have continued to use **biofuels** in transport, with some tapping into urban waste and wastewater resources as inputs for biofuel production. In 2021, Barcelona (Spain) launched a pilot project to produce biomethane from sewage sludge, which is then used to fuel city buses.[117] **Hydrogen**-powered city buses are still in their infancy, but in 2021 a few entered operation in Birmingham and London (both UK) and Zhangjiakou (China); most hydrogen bus projects do not specify the use of renewable hydrogen.[118] Montpellier (France) dropped its order for 51 hydrogen buses in 2021, deeming that electric buses would be more cost effective.[119]

Generally, city governments have relied on public procurement and direct investment to source renewable fuels for their fleets. In cases where public transport systems are not owned by the city itself, collaboration with private companies and national governments has played an important role.[120]

POLICIES FOR PRIVATE TRANSPORT

Because private vehicles account for most of the energy demand and emissions from urban transport, at least 360 city governments have implemented policies encouraging the shift to renewable-based options.[121] (→ *See Figure 68.*) Only a few cities have implemented regulatory policies for renewables in transport: for example, Bogota (Colombia) and San Francisco (California, US) have procurement requirements for the local use of biofuels.[122]

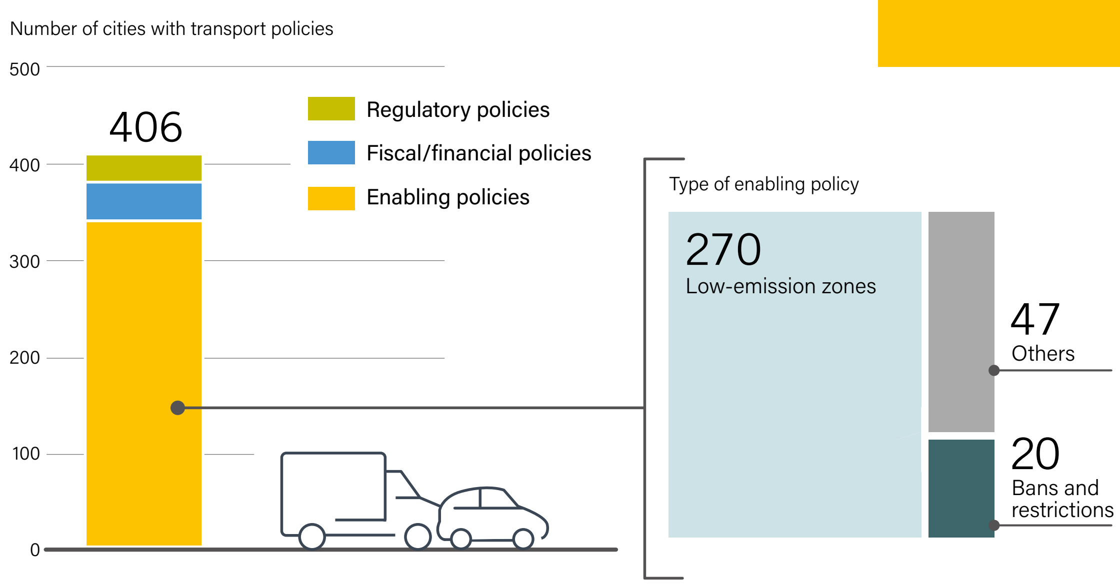
As the momentum to electrify transport grows, mandates requiring EV chargers in new buildings have become more widespread, often as part of building energy codes. In some cases, "EV ready" codes are coupled with "solar ready" codes, requiring vehicles to be charged with renewable electricity. In August 2021, Orlando (Florida, US) passed an EV readiness code, which entered into force in January 2022, for new developments and enlargements of commercial and industrial buildings, requiring a certain amount of parking spaces to be equipped with EV chargers.[123]

Some municipal governments have provided fiscal and financial support for the purchase of biofuel or electric vehicles, in some cases targeted at taxi fleets and delivery companies. For example, several of China's major cities are providing a direct purchase subsidy for zero-emission vehicles, in addition to lower parking fees and subsiding the use of charging infrastructure.[124] Such policies were implemented in Chongqing, Guangzhou, Shenzhen, Shijiazhuang and Zhengzhou during 2020 and 2021.[125]

The most widespread policy support is measures that enable wider transport decarbonisation, such as low-emission zones, bans and restrictions, improving access to charging infrastructure as well as preferential parking. By the end of 2021, 270 cities had established low-emission zones (up from 249 cities in 2020) and 20 had passed bans and restrictions on certain (fossil) fuels or vehicle types (up from 14 in 2020).[126] As of early 2022, heavy vehicles are banned from entering downtown Gateshead and Newcastle (both UK) and Hamilton (Canada).[127] In 2021, Petaluma (California) became the first US city to ban the construction of new gas stations, driven by its carbon neutral goal and a desire to tackle air pollution and environmental concerns.[128]

Only **Barcelona, Bristol, Shanghai and Stuttgart** have implemented LEZs and passed vehicle bans.

FIGURE 68.
Urban Renewable Energy Policies in Transport by Type, 2021



Source: See endnote 121 for this chapter and Reference Table R16 in GSR2022 Data Pack.

ENERGY UNITS AND CONVERSION FACTORS

METRIC PREFIXES

kilo	(k)	=	10^3
mega	(M)	=	10^6
giga	(G)	=	10^9
tera	(T)	=	10^{12}
peta	(P)	=	10^{15}
exa	(E)	=	10^{18}

VOLUME

1 m^3	=	1,000 litres (l)
1 US gallon	=	3.785412 l
1 Imperial gallon	=	4.546090 l

Example: 1 TJ = 1,000 GJ = 1,000,000 MJ = 1,000,000,000 kJ = 1,000,000,000,000 J

ENERGY UNIT CONVERSION

Multiply by:	GJ	Toe	MBtu	MWh
GJ	1	0.024	0.948	0.278
Toe	41.868	1	39.683	11.630
MBtu	1.055	0.025	1	0.293
MWh	3.600	0.086	3.412	1

Toe = tonnes (metric) of oil equivalent

1 Mtoe = 41.9 PJ

Example: 1 MWh x 3.600 = 3.6 GJ

BIOFUELS CONVERSION

Ethanol: 21.4 MJ/l

Biodiesel (FAME): 32.7 MJ/l

Biodiesel (HVO): 34.4 MJ/l

Petrol: 36 MJ/l

Diesel: 41 MJ/l

SOLAR THERMAL HEAT SYSTEMS

1 million m^2 = 0.7 GW_{th}

Used where solar thermal heat data have been converted from square metres (m^2) into gigawatts thermal (GW_{th}), by accepted convention.

Note on Biofuels:

1) These values can vary with fuel and temperature.
2) Around 1.7 litres of ethanol is energy equivalent to 1 litre of petrol, and around 1.2 litres of biodiesel (FAME) is energy equivalent to 1 litre of diesel.
3) Energy values from http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Tonnes_of_oil_equivalent_(toe) except HVO, which is from *Neste Renewable Diesel Handbook*, p. 15, https://www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf.

DATA COLLECTION AND VALIDATION

REN21 has developed a unique renewable energy reporting culture, allowing it to become recognised as a neutral data and knowledge broker that provides credible and widely accepted information. Transparency is at the heart of the REN21 data and reporting culture, and the following text explains some of the GSR's key processes for data collection and validation.

DATA COLLECTION

Production of REN21's GSR is a continuous process occurring on an annual basis. The data collection process begins following the launch of the previous year's report with an Expression of Interest form to mobilise REN21's GSR contributors. During this time, the GSR team also prepares the questionnaires that will be filled in by contributors. The questionnaires are updated each year with emerging and relevant topics as identified by the REN21 Secretariat. The data collection process involves the following elements:

1. **Open data collection.** In the open data collection questionnaire, contributors from around the world submit data on renewable energy in their respective countries or countries of interest. This covers information on annual developments in renewable energy technologies, market trends, policies and local perspectives. The questionnaire also collects data related to energy access from respondents – with a focus on developing and emerging countries – on the status of electrification and clean cooking as well as policies and programmes for energy access and markets for distributed renewables. Each data point is provided with a source and verified independently by the REN21 GSR team. Data collection with the country questionnaire typically begins in October.
2. **Regional contributors.** For some world regions, REN21 appoints one principal data contributor to provide specific renewable energy data across different sectors and to share an overview of general trends and developments of renewables in the specific region.
3. **Peer review.** To further collect data and project examples and to ensure that significant developments have not been overlooked, GSR contributors and reviewers participate in an open peer review process that takes place twice during each report cycle. For GSR 2022, the first round occurred in January and included an overview of the annotated outline, while the second round was held in March/April and included a review of the full draft report. Peer review is open to all interested experts.
4. **Expert interviews.** REN21's global community consists of a wide range of professionals who provide their expert input on renewable energy trends in the target year through interviews and personal communication with the REN21 GSR team and chapter authors. The vast majority of the information is backed up by primary sources.
5. **Desk research.** To fill in remaining gaps in the GSR and to pursue new topics, the REN21 GSR team and chapter authors conduct extensive desk research. Topics of research vary widely between GSR years and depend on emerging topics, important trends and annual availability of formal or informal data in the target sector.
6. **Policy database (national, sub-national, cities).** The REN21 GSR team compiles data on policy-specific indicators, especially targets and policies. This is collected from regional contributors and through desk research. For the city-level data, this builds also on existing consolidated datasets at the global or regional level.
7. **Data-sharing agreements.** REN21 holds several data-sharing agreements with some of the largest and most reliable data providers/aggregators in the energy sector. These formal data are used exclusively in some cases or, in others, form the foundation of calculations and estimations presented in the GSR.

DATA VALIDATION

REN21 ensures the accuracy and reliability of its reports by conducting data validation and fact-checking as a continuous process. Beginning during the first submission of the country questionnaires, data are continually verified up through the design period and until the final report is published. **All data provided by contributors, whether written or verbal, are validated by primary sources, which are published alongside the full report.**

METHODOLOGICAL NOTES

This 2022 report is the 17th 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 2021 data for national and global capacity, output, growth and investment provided in this report are preliminary. Where necessary, information and data that are conflicting, partial or older are reconciled by using reasoned expert judgment. Endnotes provide additional details, including references, supporting information and assumptions where relevant.

Each edition draws from thousands of published and unpublished references, including: official government sources; reports from international organisations and industry associations; input from the GSR community via hundreds of questionnaires submitted by country, regional and technology contributors as well as feedback from several rounds of formal and informal reviews; additional personal communications with scores of international experts; and a variety of electronic newsletters, news media and other sources.

Much of the data found in the GSR is built from the ground up by the authors with the aid of these resources. This often involves extrapolation of older data, based on recent changes in key countries within a sector or based on recent growth rates and global trends. Other data, often very specific and narrow in scope, come more-or-less prepared from third parties. The GSR attempts to synthesise these data points into a collective whole for the focus year.

The GSR endeavours to provide the best data available in each successive edition; as such, data should not be compared with previous versions of this report to ascertain year-by-year changes.

NOTE ON ESTABLISHING RENEWABLE ENERGY SHARES OF TOTAL FINAL ENERGY CONSUMPTION (TFEC)

Assumptions Related to Renewable Electricity Shares of TFEC

When estimating electricity consumption from renewable sources, the GSR must make certain assumptions about how much of the estimated gross output from renewable electricity generating resources actually reaches energy consumers, as part of total final energy consumption.

The International Energy Agency's (IEA) *World Energy Statistics and Balances* reports electricity output by individual technology. However, it does not report electricity consumption by technology – only total consumption of electricity.

The difference between gross output and final consumption is determined by:

- The energy industry's own-use, including electricity used for internal operations at power plants. This includes the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants, and other uses such as electricity use in coal mining and fossil fuel refining.
- Transmission and distribution losses that occur as electricity finds its way to consumers.

Industry's own-use. The common method is to assume that the proportion of consumption by technology is equal to the proportion of output by technology. This is problematic because logic dictates that industry's own-use cannot be proportionally the same for every generating technology. Further, industry's own-use must be somewhat lower for some renewable generating technologies (particularly non-thermal renewables such as hydropower, solar PV and wind power) than is the case for fossil fuel and nuclear power technologies. Such thermal power plants consume significant amounts of electricity to meet their own internal energy requirements (see above).

Therefore, the GSR has opted to apply differentiated "industry own-use" by generating technology. This differentiation is based on explicit technology-specific own-use (such as pumping at hydropower facilities) as well as on the apportioning of various categories of own-use by technology as deemed appropriate. For example, industry own-use of electricity at coal mines and oil refineries is attributed to fossil fuel generation.

Differentiated own-uses by technology, combined with global average losses, are as follows: solar PV, ocean energy and wind power (8.2%); hydropower (10.1%); concentrating solar thermal power (CSP) (14.2%); and bio-power (15.2%). For comparison, the undifferentiated (universal) combined losses and industry own-use would be 16.7% of gross generation. Estimated technology-specific industry own-use of electricity from renewable sources is based on data for 2019 from IEA, World Energy Balances, 2021 edition.

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 2019 from IEA, *World Energy Balances*, 2021 edition.

NOTES ON RENEWABLE ENERGY IN TOTAL FINAL ENERGY CONSUMPTION, BY ENERGY USE

GSR 2022 presents an illustration of the share of renewable energy in total final energy consumption by sector in 2019. (→ *See Figure 3 in Global Overview chapter.*) The share of TFEC consumed in each sector is provided as follows: thermal (51%), transport (32%) and electricity (17%). There are three important points about this figure and about how the GSR treats end-use TFEC in general:

1. Definition of Heating and Cooling and Thermal Applications

In the GSR, the term "heating and cooling" refers to *applications of thermal energy* including space and water heating, space cooling, refrigeration, drying and industrial process heat, as well as any use of energy other than electricity that is used for motive power in any application other than transport. In other words, thermal demand refers to all end-uses of energy that cannot be classified as electricity demand or transport.

2. Sectoral Shares of TFEC

In Figure 3, each sectoral share of TFEC portrays the energy demand for all end-uses within the sector. The shares of TFEC allocated to thermal and to transport also account for the electricity consumed in these sectors – that is, electricity for space heating and space cooling, industrial process heat, etc., and electricity for transport. These amounts have been reallocated from final demand in the electricity sector. Therefore, the share of TFEC allocated to the electricity sector comprises all final end-uses of electricity that *are not used for heating, cooling or transport*. This was a methodological change in GSR 2019 that was intended to strengthen the accuracy of the representation. In total, the final energy consumption of all electrical energy accounted for 21.7% of TFEC in 2019.

3. Shares of Non-Renewable Electricity

Figure 3 illustrates the share of *non-renewable electricity* in thermal and in transport to emphasise that electricity demand is being allocated to each sector. The share of non-renewable electricity is not critical to the figure content, so the percentage value of non-renewable electricity in each sector is not explicitly shown, but it is included in this note. In 2019, all electricity for heating and cooling met 7.8% of final energy demand in the sector (2.2% renewable and 5.6% non-renewable electricity). All electricity for transport met 1.2% of final energy demand in the sector (0.3% renewable and 0.9% non-renewable electricity).

NOTES ON RENEWABLE ENERGY CAPACITIES AND ENERGY OUTPUT

A number of issues arise when counting renewable energy capacities and energy output. Some of these are discussed below:

1. Capacity versus Energy Data

The GSR aims to give accurate estimates of capacity additions and totals, as well as of electricity, heat and transport fuel production in the focus year. These measures are subject to some uncertainty, which varies by technology. The Market and Industry chapter includes estimates for energy produced where possible, but it focuses mainly on power or heat capacity data. This is because capacity data generally can be estimated with a greater degree of confidence than generation data. Official heat and electricity generation data often are not available for the target year within the production time frame of the GSR.

2. Constructed Capacity versus Connected Capacity and Operational Capacity

Over a number of years in the past decade, the solar PV and wind power markets saw increasing amounts of capacity that was connected to the grid but not yet deemed officially operational, or constructed capacity that was not connected to the grid by year's end. Therefore, since the 2012 edition the GSR has aimed to count only capacity additions that were grid-connected or that otherwise went into service (e.g., capacity intended for off-grid use) during the previous calendar (focus) year. However, it appears that this phenomenon is no longer an issue, with the exception of wind power installations in China, where it was particularly evident over the period 2009-2019. For details on the situation in China and on the reasoning for capacity data used in this GSR, see endnote 24 in the Wind Power section of the Market and Industry chapter.

3. Retirements and Replacements

Data on capacity retirements and replacements (re-powering) are incomplete for many technologies, although data on several technologies do attempt to account for these directly. It is not uncommon for reported new capacity installations to exceed the implied net increase in cumulative capacity; in some instances, this is explained by revisions to data on installed capacity, while in others it is due to capacity retirements and replacements. Where data are available, they are provided in the text or relevant endnotes.

4. Bioenergy Data

Given existing complexities and constraints, the GSR strives to provide the best and latest data available regarding bioenergy developments. The reporting of biomass-fired combined heat and power (CHP) systems varies among countries; this adds to the challenges experienced when assessing total heat and electricity capacities and total bioenergy outputs.

Wherever possible, the bio-power data presented include capacity and generation from both electricity-only and CHP systems using solid biomass, landfill gas, biogas and liquid biofuels. Electricity generation and capacity numbers are based on national data for the focus year in the major producing countries and on forecast data for remaining countries for the focus year from the IEA.

The methodology is similar for biofuels production data, with data for most countries (not major producers) from the IEA; however, data for hydrotreated vegetable oil (HVO) are estimated based on production statistics for the (relatively few) major producers. Bio-heat data are based on an extrapolation of the latest data available from the IEA based on recent growth trends. (→ *See Bioenergy section in Market and Industry chapter.*)

5. Hydropower Data and Treatment of Pumped Storage

Starting with the 2012 edition, the GSR has made an effort to report hydropower generating capacity without including pure pumped storage capacity (the capacity used solely for shifting water between reservoirs for storage purposes). The distinction is made because pumped storage is not an energy source but rather a means of energy storage. It involves conversion losses and can be fed by all forms of electricity, renewable and non-renewable.

Some conventional hydropower facilities do have pumping capability that is not separate from, or additional to, their normal generating capability. These facilities are referred to as "mixed" plants and are included, to the extent possible, with conventional hydropower data. It is the aim of the GSR to distinguish and separate only the pure (or incremental) pumped storage component.

Where the GSR presents data for renewable power capacity not including hydropower, the distinction is made because hydropower remains the largest single component by far of renewable power capacity, and thus can mask developments in other renewable energy technologies if included. Investments and jobs data separate out large-scale hydropower where original sources use different methodologies for tracking or estimating values. Footnotes and endnotes provide additional details.

6. Solar PV Capacity Data[i]

The capacity of a solar PV panel is rated according to direct current (DC) output, which in most cases must be converted by inverters to alternating current (AC) to be compatible with end-use electricity supply. No single equation is possible for calculating solar PV data in AC because conversion depends on many factors, including the inverters used, shading, dust build-up, line losses and temperature effects on conversion efficiency. The difference between DC and AC power can range from as little as 5% (conversion losses or inverter set at the DC level) to as much as 40% (due to grid regulations limiting output or to the evolution of utility-scale systems), and most utility-scale plants built in 2019 have ratios in the range of 1.1 to 1.6.[ii]

The GSR attempts to report all solar PV capacity data on the basis of DC output (where data are known to be provided in AC, this is specified) for consistency across countries. Some countries (for example, Canada, Chile, India, Japan, Malaysia, Spain, Sweden and the United States) report official capacity data on the basis of output in AC; these capacity data were converted to DC output by data providers (see relevant endnotes) for the sake of consistency. Global renewable power capacity totals in this report include solar PV data in DC; as with all statistics in this report, they should be considered as indicative of global capacity and trends rather than as exact statistics.

7. Concentrating Solar Thermal Power (CSP) Data

Global CSP data are based on commercial facilities only. Demonstration or pilot facilities and facilities of 5 MW or less are excluded. Discrepancies between REN21 data and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals. The GSR aims to report net CSP capacities for specific CSP plants that are included. In certain cases, it may not be possible to verify if the reported capacity of a given CSP plant is net or gross capacity. In these cases net capacity is assumed.

8. Solar Thermal Heat Data

Starting with GSR 2014, the GSR includes all solar thermal collectors that use water as the heat transfer medium (or heat carrier) in global capacity data and the ranking of top countries. Previous GSRs focused primarily on glazed water collectors (both flat plate and evacuated tube); the GSR now also includes unglazed water collectors, which are used predominantly for swimming pool heating. Since the GSR 2018, data for concentrating collectors are available. These include new installations overall as well as in key markets and total in operation by year's end. The market for solar air collectors (solar thermal collectors that use air as the heat carrier) and hybrid or PV-thermal technologies (elements that produce both electricity and heat) is small, and the data are rather uncertain. All three collector types – air, concentrating and hybrid collectors – are included where specified.

NOTES ON RENEWABLE ENERGY IN TOTAL FINAL ENERGY CONSUMPTION FOR SELECTED COUNTRIES

Country-level estimates of the renewable share of total final energy consumption are provided in GSR 2022 for more than 80 countries. These estimates were prepared from IEA *World Energy Balances and Statistics 2021* data via an analysis framework using the Python programming language. This framework applied the same methodological principles and calculations described above by processing the data using a Python package called pandas.

Processing the data in this manner introduced two major assumptions for the country-level estimates.

The first is regarding the import/export of electricity. Since the calculations return a share of renewables in TFEC, an estimate of the technological share of electricity consumption is necessary. IEA data provide shares of production by technology, but not consumption. This is further complicated as countries import and export electricity, sometimes in vast quantities. For many countries, the electricity consumption share can be assumed to be roughly equivalent to the share of electricity production, thus no adjustment is needed. For others, this assumption can be misleading, notably when the country produces far more electricity than it produces (Paraguay, for example, exports around three times as much hydropower as it uses). Despite this limitation, a full accounting for the electricity imports and exports was beyond the scope of this analysis framework and it was thus assumed that production share is equivalent to consumption share. After experimenting with several options for estimating the imports and exports, it was determined that this assumption produces the most realistic results (with the exception of a few heavily exporting countries).

The second assumption is regarding the share of renewable electricity used for heating. On a global level, this estimate has been provided by the IEA. However, these data do not exist at the country level in a consolidated form. Some estimates were prepared using data from the IEA's Energy Efficiency Extended Indicators database. In other countries, global average estimates of 11.8% of building heat demand and 4.2% of industrial heat demand were applied for 2019. These values were incremented through the years by adjusting the share of renewable electricity for heat based on the growth of renewable electricity between the two years.

OTHER NOTES

Editorial content of this report closed by 31 May 2022 for technology data, and by 15 May 2022 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 2021 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 See Solar PV section of the Market and Industry chapter for sources on capacity data.

ii See IEA Photovoltaic Power Systems Programme (PVPS), *Trends in Photovoltaic Applications 2019*, p. 9, and IEA PVPS, *Snapshot of Global PV Markets 2020*, p. 11.

GLOSSARY

Absorption chillers. Chillers that use heat energy from any source (solar, biomass, waste heat, etc.) to drive air conditioning or refrigeration systems. The heat source replaces the electric power consumption of a mechanical compressor. Absorption chillers differ from conventional (vapour compression) cooling systems in two ways: 1) the absorption process is thermochemical in nature rather than mechanical, and 2) the substance that is circulated as a refrigerant is water rather than chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), also called Freon. The chillers generally are supplied with district heat, waste heat or heat from co-generation, and they can operate with heat from geothermal, solar or biomass resources.

Adsorption chillers. Chillers that use heat energy from any source to drive air conditioning or refrigeration systems. They differ from absorption chillers in that the adsorption process is based on the interaction between gases and solids. A solid material in the chiller's adsorption chamber releases refrigerant vapour when heated; subsequently, the vapour is cooled and liquefied, providing a cooling effect at the evaporator by absorbing external heat and turning back into a vapour, which is then re-adsorbed into the solid.

Agrivoltaic. Simultaneous use of agricultural land both for growing crops and for installing a solar photovoltaic (PV) energy system. With the agrivoltaic system, certain types of agricultural products can be grown in conjunction with the electricity generation, often cultivated beneath the solar panel installation.

Auction. See Tendering.

Bagasse. The fibrous matter that remains after extraction of sugar from sugar cane.

Behind-the-meter system. Any power generation capacity, storage or demand management on the customer side of the interface with the distribution grid (i.e., the meter). (Also see Front-of-meter system.)

Biodiesel. A fuel produced from oilseed crops such as soy, rapeseed (canola) and palm oil, and from other oil sources such as waste cooking oil and animal fats. Biodiesel is used in diesel engines installed in cars, trucks, buses and other vehicles, as well as in stationary heat and power applications. Most biodiesel is made by chemically treating vegetable oils and fats (such as palm, soy and canola oils, and some animal fats) to produce fatty acid methyl esters (FAME). (Also see Hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA).)

Bioeconomy (or bio-based economy). Economic activity related to the invention, development, production and use of biomass resources for the production of food, fuel, energy, chemicals and materials.

Bioenergy. Energy derived from any form of biomass (solid, liquid or gaseous) for heat, power and transport. (Also see Biofuel.)

Biofuel. A liquid or gaseous fuel derived from biomass, primarily ethanol, biodiesel and biogas. Biofuels can be combusted in vehicle engines as transport fuels and in stationary engines for heat and electricity generation. They also can be used for domestic heating and cooking (for example, as ethanol gels). Conventional biofuels are principally ethanol produced by fermentation of sugar or starch crops (such as wheat and corn), and FAME biodiesel produced from oil crops such as palm oil and canola and from waste oils and fats. Advanced biofuels are made from feedstocks derived from the lignocellulosic fractions of biomass sources or from algae. They are made using biochemical and thermochemical conversion processes, some of which are still under development.

Biogas/Biomethane. Biogas is a gaseous mixture consisting mainly of methane and carbon dioxide produced by the anaerobic digestion of organic matter (broken down by microorganisms in the absence of oxygen). Organic material and/or waste is converted into biogas in a digester. Suitable feedstocks include agricultural residues, animal wastes, food industry wastes, sewage sludge, purpose-grown green crops and the organic components of municipal solid wastes. Raw biogas can be combusted to produce heat and/or power. It also can be refined to produce biomethane.

Biomass. Any material of biological origin, excluding fossil fuels or peat, that contains a chemical store of energy (originally received from the sun) and that is available for conversion to a wide range of convenient energy carriers.

Biomass, traditional (use of). Solid biomass (including fuel wood, charcoal, agricultural and forest residues, and animal dung), that is used in rural areas of developing countries with traditional technologies such as open fires and ovens for cooking and residential heating. Often the traditional use of biomass leads to high pollution levels, forest degradation and deforestation.

Biomass energy, modern. Energy derived from combustion of solid, liquid and gaseous biomass fuels in high-efficiency conversion systems, which range from small domestic appliances to large-scale industrial conversion plants. Modern applications include heat and electricity generation, combined heat and power (CHP) and transport.

Biomass gasification. In a biomass gasification process, biomass is heated with a constrained amount of air or oxygen, leading to the partial combustion of the fuels and production of a mix of combustion gases that, depending on the conditions, can include carbon monoxide and dioxide, methane, hydrogen and more complex materials such as tars. The resulting gas can either be used for power generation (e.g., in an engine or turbine) or else further purified and treated to form a "synthesis gas". This can then be used to produce fuels including methane, alcohols, and higher hydrocarbon fuels, including bio-gasoline or jet fuel. While gasification for power or heat production is relatively common, there are few examples of operating plants producing gas of high enough quality for subsequent synthesis to more complex fuels.

Biomass pellets. Solid biomass fuel produced by compressing pulverised dry biomass, such as waste wood and agricultural residues. Pellets typically are cylindrical in shape with a diameter of around 10 millimetres and a length of 30-50 millimetres. Pellets are easy to handle, store and transport and are used as fuel for heating and cooking applications, as well as for electricity generation and CHP. (Also see Torrefied wood.)

Biomethane. Biogas can be turned into biomethane by removing impurities including carbon dioxide, siloxanes and hydrogen sulphides, followed by compression. Biomethane can be injected directly into natural gas networks and used as a substitute for natural gas in internal combustion engines without risk of corrosion. Biomethane is often known as renewable natural gas (RNG), especially in North America.

Blockchain. A decentralised ledger in which digital transactions (such as the generation and sale of a unit of solar electricity) are anonymously recorded and verified. Each transaction is securely collected and linked, via cryptography, into a time-stamped "block". This block is then stored on distributed computers as a "chain". Blockchain may be used in energy markets, including for micro-trading among solar PV prosumers.

Building energy codes and standards. Rules specifying the minimum energy standards for buildings. These can include standards for renewable energy and energy efficiency that are applicable to new and/or renovated and refurbished buildings.

Capacity. The rated power of a heat or electricity generating plant, which refers to the potential instantaneous heat or electricity output, or the aggregate potential output of a collection of such units (such as a wind farm or set of solar panels). Installed capacity describes equipment that has been constructed, although it may or may not be operational (e.g., delivering electricity to the grid, providing useful heat or producing biofuels).

Capacity factor. The ratio of the actual output of a unit of electricity or heat generation over a period of time (typically one year) to the theoretical output that would be produced if the unit were operating without interruption at its rated capacity during the same period of time.

Capital subsidy. A subsidy that covers a share of the upfront capital cost of an asset (such as a solar water heater). These include, for example, consumer grants, rebates or one-time payments by a utility, government agency or government-owned bank.

Carbon intensity. Measure of carbon emitted by weight per megajoule of energy produced, or rate of produced greenhouse gas emissions to gross domestic product.

Carbon neutrality. The achievement of a state in which every tonne of carbon dioxide emitted to the atmosphere is compensated by an equivalent tonne removed (e.g., sequestered). Emissions can be compensated for by carbon offsets.

City. No international criteria or standards exist to determine what a city is. Most definitions of "cities" rely on settlement density and/or population numbers, although the criteria vary widely across countries. Generally, the term "urban area" refers to settlement areas that are more densely populated than suburban or peri-urban communities within the same metropolitan area. The term "city", meanwhile, has broader meanings: according to the United Nations, it can connote a political or civic entity, a geographic unit, a formalised economy or an infrastructure bundle. In some instances, local communities, neighbourhood associations, urban businesses and industries may be subsumed under the term "city". Throughout the GSR, municipal and city government refers to the local decision-making bodies and government authorities (the mayor's office, city council, etc.), unless noted otherwise. In addition to municipal governments, key city-level stakeholders include individual citizens, groups of citizens and private enterprises, as well as various civil society groups that are active within the city.

City-wide. Extending or happening in all parts of a city.

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.

Community choice aggregation (CCA). Under a CCA, municipalities themselves (independently or in partnership with an agency running the CCA) aggregate their residents' and businesses' electricity demand and set out to procure electricity for all participating customers city-wide through direct contracts with energy producers or through third-party energy providers. By enabling local communities to procure their own electricity, CCAs can be an attractive option for cities that want more local control over their electricity mix, for instance to increase the share of renewable electricity.

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 degrees Celsius (°C) for industrial applications, laundries and commercial cooking.

Concentrating solar thermal power (CSP) (also called solar thermal electricity, STE). Technology that uses mirrors to focus sunlight into an intense solar beam that heats a working fluid in a solar receiver, which then drives a turbine or heat engine/generator to produce electricity. The mirrors can be arranged in a variety of ways, but they all deliver the solar beam to the receiver. There are four types of commercial CSP systems: parabolic troughs, linear Fresnel, power towers and dish/engines. The first two technologies are line-focus systems, capable of concentrating the sun's energy to produce temperatures of 400°C, while the latter two are point-focus systems that can produce temperatures of 800°C or higher.

Conversion efficiency. The ratio between the useful energy output from an energy conversion device and the energy input into it. For example, the conversion efficiency of a PV module is the ratio between the electricity generated and the total solar energy received by the PV module. If 100 kilowatt-hours (kWh) of solar radiation is received and 10 kWh of electricity is generated, the conversion efficiency is 10%.

Crowdfunding. The practice of funding a project or venture by raising money – often relatively small individual amounts – from a relatively large number of people ("crowd"), generally using the Internet and social media. The money raised through crowdfunding does not necessarily buy the lender a share in the venture, and there is no guarantee that money will be repaid if the venture is successful. However, some types of crowdfunding reward backers with an equity stake, structured payments and/ or other products.

Curtailment. A reduction in the output of a generator, typically on an involuntary basis, from what it could produce otherwise given the resources available. Curtailment of electricity generation has long been a normal occurrence in the electric power industry and can occur for a variety of reasons, including a lack of transmission access or transmission congestion.

Degression. A mechanism built into policy design establishing automatic rate revisions, which can occur after specific thresholds are crossed (e.g., after a certain amount of capacity is contracted, or a certain amount of time passes).

Demand-side management. The application of economic incentives and technology in the pursuit of cost-effective energy efficiency measures and load-shifting on the customer side, to achieve least-cost overall energy system optimisation.

Demand response. Use of market signals such as time-of-use pricing, incentive payments or penalties to influence end-user electricity consumption behaviours. Usually used to balance electrical supply and demand within a power system.

Digitalisation. The application of digital technologies across the economy, including energy.

Digitisation. The conversion of something (e.g., data or an image) from analogue to digital.

Distributed generation. Generation of electricity from dispersed, generally small-scale systems that are close to the point of consumption.

Distributed renewable energy. Energy systems are considered to be distributed if 1) the systems are connected to the distribution network rather than the transmission network, which implies that they are relatively small and dispersed (such as small-scale solar PV on rooftops) rather than relatively large and centralised; or 2) generation and distribution occur independently from a centralised network. Specifically for the purpose of the chapter on Distributed Renewables for Energy Access, "distributed renewable energy" meets both conditions. It includes energy services for electrification, cooking, heating and cooling that are generated and distributed independent of any centralised system, in urban and rural areas of the developing world.

Distribution grid. The portion of the electrical network that takes power off the high-voltage transmission network via sub-stations (at varying stepped-down voltages) and distributes electricity to customers.

Divestment. Removal or selling of an investment from stranded assets, funds, bonds or stocks. Divestment is an opposite action to investment.

Drop-in biofuel. A liquid biofuel that is functionally equivalent to a liquid fossil fuel and is fully compatible with existing fossil fuel infrastructure.

Electric vehicle (EV). Includes any road-, rail-, sea- and air-based transport vehicle that uses electric drive and can take an electric charge from an external source, or from hydrogen in the case of a fuel cell electric vehicle (FCEV). Electric road vehicles encompass battery electric vehicles (BEVs), plug-in hybrids (PHEVs) and FCEVs, all of which can include passenger vehicles (i.e., electric cars), commercial vehicles including buses and trucks, and two- and three-wheeled vehicles.

Energy. The ability to do work, which comes in a number of forms including thermal, radiant, kinetic, chemical, potential and electrical. Primary energy is the energy embodied in (energy potential of) natural resources, such as coal, natural gas and renewable sources. Final energy is the energy delivered for end- use (such as electricity at an electrical outlet). Conversion losses occur whenever primary energy needs to be transformed for final energy use, such as combustion of fossil fuels for electricity generation.

Energy audit. Analysis of energy flows in a building, process or system, conducted with the goal of reducing energy inputs into the system without negatively affecting outputs.

Energy conservation. Any change in behaviour of an energy-consuming entity for the specific purpose of affecting an energy demand reduction. Energy conservation is distinct from energy efficiency in that it is predicated on the assumption that an otherwise preferred behaviour of greater energy intensity is abandoned. (See Energy efficiency and Energy intensity.)

Energy efficiency. The measure that accounts for delivering more services for the same energy input, or the same amount of services for less energy input. Conceptually, this is the reduction of losses from the conversion of primary source fuels through final energy use, as well as other active or passive measures to reduce energy demand without diminishing the quality of energy services delivered. Energy efficiency is technology-specific and distinct from energy conservation, which pertains to behavioural change. Both energy efficiency and energy conservation can contribute to energy demand reduction.

Energy intensity. Primary energy consumption per unit of economic output. Energy intensity is a broader concept than energy efficiency in that it is also determined by non-efficiency variables, such as the composition of economic activity. Energy intensity typically is used as a proxy for energy efficiency in macro-level analyses due to the lack of an internationally agreed-upon high-level indicator for measuring energy efficiency.

Energy service company (ESCO). A company that provides a range of energy solutions including selling the energy services from a (renewable) energy system on a long-term basis while retaining ownership of the system, collecting regular payments from customers and providing necessary maintenance service. An ESCO can be an electric utility, co-operative, non-governmental organisation or private company, and typically installs energy systems on or near customer sites. An ESCO also can advise on improving the energy efficiency of systems (such as a building or an industry) as well as on methods for energy conservation and energy management.

Energy subsidy. A government measure that artificially reduces the price that consumers pay for energy or that reduces energy production cost.

Energy sufficiency. Entails a change or shift in actions and behaviours (at the individual and collective levels) in the way energy is used. Results in access to energy for everyone while limiting the impacts of energy use on the environment. For example, avoiding the use of cars and spending less time on electrical devices.

Environmental, social and governance (ESG) criteria, also known as "sustainable investing". A collection of standards for measuring key sustainability factors in a firm or industry's green investment. Environmental criteria relate to the quality and functioning of the natural environment and natural systems, and also may include pollution, energy use, climate change, greenhouse gas emissions, changes in land use and waste management. Social criteria refer to well-being, human rights, human capital, labour standards in the supply chain, child, slave and bonded labour, workplace health and safety, freedom of association and expression, diversity, relations with local communities, activities in conflict zones, health and access to medicine, and consumer protection. Governance criteria relate to the governance of companies and other investee entities, such as disclosure of information, business ethics, bribery and corruption, internal controls and risk management, and relationships between a company's management, shareholders and stakeholders.

Ethanol (fuel). A liquid fuel made from biomass (typically corn, sugar cane or small cereals/grains) that can replace petrol in modest percentages for use in ordinary spark-ignition engines (stationary or in vehicles), or that can be used at higher blend levels (usually up to 85% ethanol, or 100% in Brazil) in slightly modified engines, such as those provided in "flex-fuel" vehicles. Ethanol also is used in the chemical and beverage industries.

Fatty acid methyl esters (FAME). See Biodiesel.

Feed-in policy (feed-in tariff or feed-in premium). A policy that typically guarantees renewable generators specified payments per unit (e.g., USD per kWh) over a fixed period. Feed-in tariff (FIT) policies also may establish regulations by which generators can interconnect and sell power to the grid. Numerous options exist for defining the level of incentive, such as whether the payment is structured as a guaranteed minimum price (e.g., a FIT), or whether the payment floats on top of the wholesale electricity price (e.g., a feed-in premium).

Final energy. The part of primary energy, after deduction of losses from conversion, transmission and distribution, that reaches the consumer and is available to provide heating, hot water, lighting and other services. Final energy forms include, among others, electricity, district heating, mechanical energy, liquid hydrocarbons such as kerosene or fuel oil, and various gaseous fuels such as natural gas, biogas and hydrogen.

(Total) Final energy consumption (TFEC). Energy that is supplied to the consumer for all final energy services such as transport, cooling and lighting, building or industrial heating or mechanical work. Differs from total final consumption (TFC), which includes all energy use in end-use sectors (TFEC) as well as for non-energy applications, mainly various industrial uses, such as feedstocks for petrochemical manufacturing.

Fiscal incentive. An incentive that provides individuals, households or companies with a reduction in their contribution to the public treasury via income or other taxes.

Flywheel energy storage. Energy storage that works by applying available energy to accelerate a high-mass rotor (flywheel) to a very high speed and thereby storing energy in the system as rotational energy.

Front-of-meter system. Any power generation or storage device on the distribution or transmission side of the network. (Also see Behind-the-meter system.)

Generation. The process of converting energy into electricity and/or useful heat from a primary energy source such as wind, solar radiation, natural gas, biomass, etc.

Geothermal energy. Heat energy emitted from within the earth's crust, usually in the form of hot water and steam. It can be used to generate electricity in a thermal power plant or to provide heat directly at various temperatures.

Green bond. A bond issued by a bank or company, the proceeds of which will go entirely into renewable energy and other environmentally friendly projects. The issuer will normally label it as a green bond. There is no internationally recognised standard for what constitutes a green bond.

Green building. A building that (in its construction or operation) reduces or eliminates negative impacts and can create positive impacts on the climate and natural environment. Countries and regions have a variety of characteristics that may change their strategies for green buildings, such as building stock, climate, cultural traditions, or wide-ranging environmental, economic and social priorities – all of which shape their approach to green building.

Green energy purchasing. Voluntary purchase of renewable energy – usually electricity, but also heat and transport fuels – by residential, commercial, government or industrial consumers, either directly from an energy trader or utility company, from a third-party renewable energy generator or indirectly via trading of renewable energy certificates (such as renewable energy credits, green tags and guarantees of origin). It can create additional demand for renewable capacity and/or generation, often going beyond that resulting from government support policies or obligations.

Heat pump. A device that transfers heat from a heat source to a heat sink using a refrigeration cycle that is driven by external electric or thermal energy. It can use the ground (geothermal/ground-source), the surrounding air (aerothermal/air-source) or a body of water (hydrothermal/water-source) as a heat source in heating mode, and as a heat sink in cooling mode. A heat pump's final energy output can be several multiples of the energy input, depending on its inherent efficiency and operating condition. The output of a heat pump is at least partially renewable on a final energy basis. However, the renewable component can be much lower on a primary energy basis, depending on the composition and derivation of the input energy; in the case of electricity, this includes the efficiency of the power generation process. The output of a heat pump can be fully renewable energy if the input energy is also fully renewable.

Hydropower. Electricity derived from the potential energy of water captured when moving from higher to lower elevations.

Categories of hydropower projects include run-of-river, reservoir-based capacity and low-head in-stream technology (the least developed). Hydropower covers a continuum in project scale from large (usually defined as more than 10 megawatts (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 the GSR, new investment in renewable energy refers to investment in: technology research and development, commercialisation, construction of manufacturing facilities and project development (including the construction of wind farms and the purchase and installation of solar PV systems). Total investment refers to new investment plus merger and acquisition (M&A) activity (the refinancing and sale of companies and projects).

Investment tax credit. A fiscal incentive that allows investments in renewable energy to be fully or partially credited against the tax obligations or income of a project developer, industry, building owner, etc.

Joule. A joule (J) is a unit of work or energy equal to the work done by a force equal to one newton acting over a distance of one metre. One joule is equal to one watt-second (the power of one watt exerted over the period of one second). The potential chemical energy stored in one barrel of oil and released when combusted is approximately 6 gigajoules (GJ); a tonne of oven-dry wood contains around 20 GJ of energy.

Levelised cost of energy/electricity (LCOE). The cost per unit of energy from an energy generating asset that is based on the present value of its total construction and lifetime operating costs, divided by total energy output expected from that asset over its lifetime.

Long-term strategic plan. A strategy to achieve energy savings over a specified period of time (i.e., several years), including specific goals and actions to improve energy efficiency, typically spanning all major sectors.

Mandate/Obligation. A measure that requires designated parties (consumers, suppliers, generators) to meet a minimum – and often gradually increasing – standard for renewable energy (or energy efficiency), such as a percentage of total supply, a stated amount of capacity, or the required use of a specified renewable technology. Costs generally are borne by consumers. Mandates can include renewable portfolio standards (RPS); building codes or obligations that require the installation of renewable heat or power technologies (often in combination with energy efficiency investments); renewable heat purchase requirements; and requirements for blending specified shares of biofuels (biodiesel or ethanol) into transport fuel.

Market concession model. A model in which a private company or non-governmental organisation is selected through a competitive process and given the exclusive obligation to provide energy services to customers in its service territory, upon customer request. The concession approach allows concessionaires to select the most appropriate and cost-effective technology for a given situation.

Merit order. A way of ranking available sources of energy (particularly electricity generation) in ascending order based on short-run marginal costs of production, such that those with the lowest marginal costs are the first ones brought online to meet demand, and those with the highest are brought on last. The merit-order effect is a shift of market prices along the merit-order or supply curve due to market entry of power stations with lower variable costs (marginal costs). This displaces power stations with the highest production costs from the market (assuming demand is unchanged) and admits lower-priced electricity into the market.

Micromobility. A form of transport that includes modes such as electric sidewalk/"kick" scooters and dockless bicycles (both electric and traditional), as well as electric moped-style scooters and ride-hailing and car-sharing services. Many micromobility service companies have committed to sustainability measures, including the use of renewable electricity for charging vehicles as well as for operations.

Mini-grid/Micro-grid. For distributed renewable energy systems for energy access, a mini-grid/micro-grid typically refers to an independent grid network operating on a scale of less than 10 MW (with most at very small scale) that distributes electricity to a limited number of customers. Mini-/micro-grids also can refer to much larger networks (e.g., for corporate or university campuses) that can operate independently of, or in conjunction with, the main power grid. However, there is no universal definition differentiating mini- and micro-grids.

Molten salt. An energy storage medium used predominantly to retain the thermal energy collected by a solar tower or solar trough of a concentrating solar power plant, so that this energy can be used at a later time to generate electricity.

Monitoring. Energy use is monitored to establish a basis for energy management and to provide information on deviations from established patterns.

Municipal operations. Services or infrastructure that are owned and/or operated by municipal governments. This may include municipal buildings and transport fleets (such as buses, policy vehicles and refuse collection trucks).

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

Net metering/Net billing. A regulated arrangement in which utility customers with on-site electricity generators can receive credits for excess generation, which can be applied to offset consumption in other billing periods. Under net metering, customers typically receive credit at the level of the retail electricity price. Under net billing, customers typically receive credit for excess power at a rate that is lower than the retail electricity price. Different jurisdictions may apply these terms in different ways, however.

Net zero. Net zero emissions refers to achieving an overall balance between greenhouse gas emissions produced and greenhouse gas emissions emitted from the atmosphere. The concept involves equating the quantity of gases such as carbon dioxide, methane, nitrous oxide that are released into the atmosphere due to human-induced activities and cause the greenhouse effect, with the quantity of greenhouse gases that are naturally absorbed by the earth.

Net zero carbon building/Net zero energy building/Nearly zero energy building. Various definitions have emerged of buildings that achieve high levels of energy efficiency and meet remaining energy demand with either on-site or off-site renewable energy. For example, the World Green Building Council's Net Zero Carbon Buildings Commitment considers use of renewable energy as one of five key components that characterise a net zero building. Definitions of net zero carbon, net zero energy and nearly zero energy buildings can vary in scope and geographic relevance.

Non-motorised transport (NMT). Walking, cycling, and their variants; also called "active transport" or "human-powered travel".

Ocean power. Refers to technologies used to generate electricity by harnessing from the ocean the energy potential of ocean waves, tidal range (rise and fall), tidal streams, ocean (permanent) currents, temperature gradients (ocean thermal energy conversion) and salinity gradients. The definition of ocean power used in the GSR does not include offshore wind power or marine biomass energy.

Off-take agreement. An agreement between a producer of energy and a buyer of energy to purchase/sell portions of the producer's future production. An off-take agreement normally is negotiated prior to the construction of a renewable energy project or installation of renewable energy equipment in order to secure a market for the future output (e.g., electricity, heat). Examples of this type of agreement include power purchase agreements and feed-in tariffs.

Off-taker. The purchaser of the energy from a renewable energy project or installation (e.g., a utility company) following an off-take agreement. (See Off-take agreement.)

Pay-as-you-go (PAYGo). A business model that gives customers (mainly in areas without access to the electricity grid) the possibility to purchase small-scale energy-producing products, such as solar home systems, by paying in small instalments over time.

Peaker generation plant. Power plants that run predominantly during peak demand periods for electricity. Such plants exhibit the optimum balance – for peaking duty – of relatively high variable cost (fuel and maintenance cost per unit of generation) relative to fixed cost per unit of energy produced (low capital cost per unit of generating capacity).

Pico solar devices/pico solar systems. Small solar systems such as solar lanterns that are designed to provide only a limited amount of electricity service, usually lighting and in some cases mobile phone charging. Such systems are deployed mainly in areas that have no or poor access to electricity. The systems usually have a power output of 1-10 watts and a voltage of up to 12 volts.

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

Power. The rate at which energy is converted into work, expressed in watts (joules/second).

Power purchase agreement (PPA). A contract between two parties, one that generates electricity (the seller) and one that is looking to purchase electricity (the buyer).

Power-to-gas (P2G). The conversion of electricity, either from renewable or conventional sources, to a gaseous fuel (for example, hydrogen or methane).

Primary energy. The theoretically available energy content of a naturally occurring energy source (such as coal, oil, natural gas, uranium ore, geothermal and biomass energy, etc.) before it undergoes conversion to useful final energy delivered to the end-user. Conversion of primary energy into other forms of useful final energy (such as electricity and fuels) entails losses. Some primary energy is consumed at the end-user level as final energy without any prior conversion.

Primary energy consumption. The direct use of energy at the source, or supplying users with unprocessed fuel.

Product and sectoral standards. Rules specifying the minimum standards for certain products (e.g., appliances) or sectors (industry, transport, etc.) for increasing energy efficiency.

Production tax credit. A tax incentive that provides the investor or owner of a qualifying property or facility with a tax credit based on the amount of renewable energy (electricity, heat or biofuel) generated by that facility.

Productive use of energy. Often used in the context of distributed renewables for energy access to refer to activities that use energy to generate income, increase productivity, enhance diversity and create economic value. Productive uses of energy may include local activities such as agriculture, livestock and fishing; light mechanical works such as welding, carpentry and water pumping; small retail and commercial activities such as tailoring, printing, catering and entertainment; and small and medium-scale production such as agro-processing (grinding, milling and husking), refrigeration and cold storage, drying, preserving and smoking.

Property Assessed Clean Energy (PACE) financing. Provides access to low-interest loans for renewable energy and energy efficiency improvements that can be repaid through increases on property taxes. It was originally conceived of in the United States and now is beginning to expand worldwide.

Prosumer. An individual, household or small business that not only consumes energy but also produces it. Prosumers may play an active role in energy storage and demand-side management.

Public financing. A type of financial support mechanism whereby governments provide assistance, often in the form of grants or loans, to support the development or deployment of renewable energy technologies.

Pumped storage. Plants that pump water from a lower reservoir to a higher storage basin using surplus electricity, and that reverse the flow to generate electricity when needed. They are not energy sources but means of energy storage and can have overall system efficiencies of around 80-90%.

Regulatory policy. A rule to guide or control the conduct of those to whom it applies. In the renewable energy context, examples include mandates or quotas such as renewable portfolio standards, feed-in tariffs and technology/fuel-specific obligations.

(Re-)Municipalisation. Legal process by which municipalities assume control of their electricity procurement and distribution assets, generally through purchase from private entities.

Renewable energy certificate (REC). A certificate awarded to certify the generation of one unit of renewable energy (typically 1 MWh of electricity but also less commonly of heat). In systems based on RECs, certificates can be accumulated to meet renewable energy obligations and also provide a tool for trading among consumers and/or producers. They also are a means of enabling purchases of voluntary green energy.

Renewable hydrogen. Hydrogen produced from renewable energy, most commonly through the use of renewable electricity to split water into hydrogen and oxygen in an electrolyser. The vast majority of hydrogen is still produced from fossil fuels, and the majority of policies and programmes focused on hydrogen do not include a focus on renewables-based production.

Renewable natural gas (RNG). Gas that is produced through the anaerobic digestion of organic matter and processed to remove the carbon dioxide and other gases, leaving methane that meets a high specification and that can be interchangeable with conventional natural gas. See Biomethane.

Renewable portfolio standard (RPS). An obligation placed by a government on a utility company, group of companies or consumers to provide or use a predetermined minimum targeted renewable share of installed capacity, or of electricity or heat generated or sold. A penalty may or may not exist for non-compliance. These policies also are known as "renewable electricity standards", "renewable obligations" and "mandated market shares", depending on the jurisdiction.

Reverse auction. See Tendering.

Sector integration (also called sector coupling). The integration of energy supply and demand across electricity, thermal and transport applications, which may occur via co-production, combined use, conversion and substitution.

Smart energy system. An energy system that aims to optimise the overall efficiency and balance of a range of interconnected energy technologies and processes, both electrical and non-electrical (including heat, gas and fuels). This is achieved through dynamic demand- and supply-side management; enhanced monitoring of electrical, thermal and fuel-based system assets; control and optimisation of consumer equipment, appliances and services; better integration of distributed energy (on both the macro and micro scales); and cost minimisation for both suppliers and consumers.

Smart grid. Electrical grid that uses information and communications technology to co-ordinate the needs and capabilities of the generators, grid operators, end-users and electricity market stakeholders in a system, with the aim of operating all parts as efficiently as possible, minimising costs and environmental impacts and maximising system reliability, resilience and stability.

Smart grid technology. Advanced information and control technology that is required for improved systems integration and resource optimisation on the grid.

Smart inverter. An inverter with robust software that is capable of rapid, bidirectional communications, which utilities can control remotely to help with issues such as voltage and frequency fluctuations in order to stabilise the grid during disruptive events.

Solar collector. A device used for converting solar energy to thermal energy (heat), typically used for domestic water heating but also used for space heating, for industrial process heat or to drive thermal cooling machines. Evacuated tube and flat plate collectors that operate with water or a water/glycol mixture as the heat-transfer medium are the most common solar thermal collectors used worldwide. These are referred to as glazed water collectors because irradiation from the sun first hits a glazing (for thermal insulation) before the energy is converted to heat and transported away by the heat transfer medium. Unglazed water collectors, often referred to as swimming pool absorbers, are simple collectors made of plastics and used for lower-temperature applications. Unglazed and glazed air collectors use air rather than water as the heat-transfer medium to heat indoor spaces or to pre-heat drying air or combustion air for agriculture and industry purposes.

Solar cooker. A cooking device for household and institutional applications that converts sunlight to heat energy that is retained for cooking. There are several types of solar cookers, including box cookers, panel cookers, parabolic cookers, evacuated tube cookers and trough cookers.

Solar home system. A stand-alone system composed of a relatively low-power photovoltaic module, a battery and sometimes a charge controller that can provide modest amounts of electricity for home lighting, communications and appliances, usually in rural or remote regions that are not connected to the electricity grid. The term solar home system kit is also used to define systems that usually are branded and have components that are easy for users to install and use.

Solar photovoltaics (PV). A technology used for converting light directly into electricity. Solar PV cells are constructed from semiconducting materials that use sunlight to separate electrons from atoms to create an electric current. Modules are formed by interconnecting individual cells. Building-integrated PV (BIPV) generates electricity and replaces conventional materials in parts of a building envelope, such as the roof or facade.

Solar photovoltaic-thermal (PV-T). A solar PV-thermal hybrid system that includes solar thermal collectors mounted beneath PV modules to convert solar radiation into electrical and thermal energy. The solar thermal collector removes waste heat from the PV module, enabling it to operate more efficiently.

Solar-plus-storage. A hybrid technology of solar PV with battery storage. Other types of renewable energy-plus-storage plants also exist.

Solar water heater (SWH). An entire system consisting of a solar collector, storage tank, water pipes and other components. There are two types of solar water heaters: pumped solar water heaters use mechanical pumps to circulate a heat transfer fluid through the collector loop (active systems), whereas thermosyphon solar water heaters make use of buoyancy forces caused by natural convection (passive systems).

Storage battery. A type of battery that can be given a new charge by passing an electric current through it. A lithium-ion battery uses a liquid lithium-based material for one of its electrodes. A lead-acid battery uses plates made of pure lead or lead oxide for the electrodes and sulphuric acid for the electrolyte, and remains common for off-grid installations. A flow battery uses two chemical components dissolved in liquids contained within the system and most commonly separated by a membrane. Flow batteries can be recharged almost instantly by replacing the electrolyte liquid, while simultaneously recovering the spent material for re-energisation.

Sustainable aviation fuel (SAF). According to the International Civil Aviation Organization, such fuels are produced from three families of bio-feedstock: the family of oils and fats (or triglycerides), the family of sugars and the family of lignocellulosic feedstock.

Target. An official commitment, plan or goal set by a government (at the local, state, national or regional level) to achieve a certain amount of renewable energy or energy efficiency by a future date. Targets may be backed by specific compliance mechanisms or policy support measures. Some targets are legislated, while others are set by regulatory agencies, ministries or public officials.

Tender (also called auction/reverse auction or tender). A procurement mechanism by which renewable energy supply or capacity is competitively solicited from sellers, who offer bids at the lowest price that they would be willing to accept. Bids may be evaluated on both price and non-price factors.

Thermal energy storage. Technology that allows the transfer and storage of thermal energy. (See Molten salt.)

Torrefied wood. Solid fuel, often in the form of pellets, produced by heating wood to 200–300°C in restricted air conditions. It has useful characteristics for a solid fuel including relatively high energy density, good grindability into pulverised fuel and water repellency.

Transmission grid. The portion of the electrical supply distribution network that carries bulk electricity from power plants to sub-stations, where voltage is stepped down for further distribution. High-voltage transmission lines can carry electricity between regional grids in order to balance supply and demand.

Variable renewable energy (VRE). A renewable energy source that fluctuates within a relatively short time frame, such as wind and solar energy, which vary within daily, hourly and even sub-hourly time frames. By contrast, resources and technologies that are variable on an annual or seasonal basis due to environmental changes, such as hydropower (due to changes in rainfall) and thermal power plants (due to changes in temperature of ambient air and cooling water), do not fall into this category.

Vehicle fuel standard. A rule specifying the minimum fuel economy of automobiles.

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

Virtual net metering. Virtual (or group) net metering allows electricity utility consumers to share the output of a renewable power project. By receiving "energy credits" based on project output and their ownership share of the project, consumers are able to offset costs on their electricity utility bill.

Virtual power plant (VPP). A network of decentralised, independently owned and operated power generating units combined with flexible demand units and possibly also with storage facilities. A central control station monitors operation, forecasts demand and supply, and dispatches the networked units as if they were a single power plant. The aim is to smoothly integrate a high number of renewable energy units into existing energy systems; VPPs also enable the trading or selling of power into wholesale markets.

Virtual power purchase agreement (VPPA). A contract under which the developer sells its electricity in the spot market. The developer and the corporate off-taker then settle the difference between the variable market price and the strike price, and the off-taker receives the electricity certificates that are generated. This is in contrast to more traditional PPAs, under which the developer sells electricity to the off-taker directly.

Voltage and frequency control. The process of maintaining grid voltage and frequency stable within a narrow band through management of system resources.

Watt. A unit of power that measures the rate of energy conversion or transfer. A kilowatt is equal to 1 thousand watts; a megawatt to 1 million watts; and so on. A megawatt-electrical (MW_e) is used to refer to electric power, whereas a megawatt-thermal (MW_{th}) refers to thermal/heat energy produced. Power is the rate at which energy is consumed or generated. A kilowatt-hour is the amount of energy equivalent to steady power of 1 kW operating for one hour.

LIST OF ABBREVIATIONS

AfDB	African Development Bank
ASEAN	Association of Southeast Asian Nations
AUD	Australian dollar
CAPEX	Capital expenditure
CCA	Community choice aggregation
CHP	Combined heat and power
CNY	Chinese yuan
CO_2	Carbon dioxide
COP	Conference of the Parties
CSP	Concentrating solar thermal power
DREA	Distributed renewables for energy access
ECOWAS	Economic Community of West African States
EJ	Exajoule
ESCO	Energy service company
ESG	Environmental, Social and Governance
ETS	Emission trading system
EU	European Union (specifically the EU-27)
EUR	Euro
EV	Electric vehicle
FAME	Fatty acid methyl esters
FIT	Feed-in tariff
G20	Group of Twenty
GBP	British pound
GDP	Gross domestic product
GSR	Global Status Report
GW/GWh	Gigawatt/gigawatt-hour
GW_{th}	Gigawatt-thermal
HEFA	Hydrotreated esters and fatty acids
HJT	Heterojunction cell technology
HVO	Hydrotreated vegetable oil
ICE	Internal combustion engine
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ktoe	Kilotonne of oil equivalent
kW/kWh	Kilowatt/kilowatt-hour
kW_{th}	Kilowatt-thermal
LCOE	Levelised cost of energy (or electricity)
LPG	Liquefied petroleum gas
m^2	Square metre
MJ	Megajoule
Mtoe	Megatonne of oil equivalent
MW/MWh	Megawatt/megawatt-hour
MW_{th}	Megawatt-thermal
NDC	Nationally Determined Contribution
O&M	Operations and maintenance
OECD	Organisation for Economic Co-operation and Development
OTEC	Ocean thermal energy conversion
PAYGo	Pay-as-you-go
PJ	Petajoule
PPA	Power purchase agreement
PTC	Production Tax Credit
PV	Photovoltaic
R&D	Research and development
RED	EU Renewable Energy Directive
RPS	Renewable portfolio standard
SAF	Sustainable aviation fuel
SDG	Sustainable Development Goal
SHIP	Solar heat for industrial processes
TCFD	Task Force on Climate-Related Financial Disclosures
TES	Thermal energy storage
TFEC	Total final energy consumption
TW/TWh	Terawatt/Terawatt hour
UK	United Kingdom
UN	United Nations
US	United States
USD	United States dollar
VAT	Value-added tax

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POLICY LANDSCAPE

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GEOTHERMAL POWER AND HEAT

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WIND POWER

1 Global additions in 2021 are gross and are based on the following: 93,605 MW (72,499 MW onshore and 21,106 MW offshore) added in 2021 for a year-end total of 837,451 MW (780,275 MW onshore and 57,176 MW offshore), from Global Wind Energy Council (GWEC), *Global Wind Report 2022*, April 4, 2022, pp. 8, 102, 107, 112, https://gwec.net/global-wind-report-2022, and from GWEC, "Global Wind Report 2022," April 2022, unpublished document. Adjustments for China (excluding Hong Kong, Macao and Chinese Taipei) based on data from Chinese Wind Energy Association (CWEA), *Chinese Wind Power Installation Statistics Report 2021*, April 22, 2022, provided by F. Zhao, GWEC, Copenhagen, personal communication with REN21, May 4, 2022, and from CWEA, "2021 China Wind Power Hosting Capacity Statistical Brief Released," April 22, 2022, https://mp.weixin.qq.com/s/eW3OuSxYRQeGqmXdpxVaoQ (using Google Translate). Includes upwards adjustment for annual additions in the United States (all onshore) of 653 MW, based on data from J. Hensley, American Clean Power Association (ACP), Washington, DC, personal communication with REN21, April 13, 2022. Note that 97,272 MW (preliminary) was added in 2021 (up from 92,674 MW in 2020), from World Wind Energy Association (WWEA), "World Market for Wind Power Saw Another Record Year in 2021: 97,3 Gigawatt of New Capacity Added," March 18, 2022, https://wwindea.org/world-market-for-wind-power-saw-another-record-year-in-2021-973-gigawatt-of-new-capacity-added. An estimated 99.2 GW of new capacity was commissioned globally in 2021 (16.8 GW offshore and the rest onshore, including capacity commissioned in 2021 outside of China and some turbines that were partially commissioned but not necessarily connected to the grid in China), up from 98.5 GW in 2020, from N. Weekes, "BloombergNEF Figures Show Which Wind Turbine Makers Led Global Market in 2021," Windpower Monthly, March 23, 2022, https://www.windpowermonthly.com/article/1750491/bloombergnef-figures-show-wind-turbine-makers-led-global-market-2021. Note that 1,132 MW was decommissioned in 2021, up from 509 MW in 2020 (the previous high was 817 MW, in 2015), from GWEC, "Global Wind Report 2022," April 2022, op. cit. this note. Annual installations reported in this section are gross additions unless otherwise noted, but most countries did not decommission capacity during the year, and year-end totals account for decommissioned capacity. Note that GWEC reports installations with turbines larger than 200 kW; projects with smaller turbines are not included. Some capacity included in additions and year-end total might not have been grid-connected at the end of 2021. See China discussion and endnotes for more information.

2 Figure of 7% based on data and sources in endnote 1, and on total global additions of 95,289 MW in 2020, from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1; highest and offshore based on data from sources in endnote 1, including 2020 offshore additions of 6,582 MW, from GWEC, idem.

3 Capacity at the end of 2021 based on data from sources in endnote 1; increase over 2020 based on 744,978 MW in place at the end of 2020, from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. **Figure 43** based on historical data from GWEC, op. cit. note 1, both sources; data for 2021 based on sources provided in endnote 1.

4 Note that wind capacity in operation at the end of 2021 was enough to meet more than 7% of global electricity demand, from WWEA, op. cit. note 1. Wind power accounts for 8% of global electricity generation, from Rethink Energy, cited in Saur Energy International, "Wind Power Now Accounts for 8% of Global Generation," April 19, 2022, https://www.saurenergy.com/solar-energy-news/wind-power-now-accounts-for-8-of-global-generation; and for an estimated 7.6% of global electricity generation, based on data from GWEC, Global Wind Energy Statistics 2021 database, April 2022, provided by Zhao, op. cit. note 1, April 26, 2022.

5 GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1. See also information and sources throughout this section.

6 Based on data from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, pp. 8, 102, 107, and from other sources in endnote 1. Asia, Africa and the Middle East, Latin America and the Caribbean, and the Pacific regions all saw records; Europe (not including Turkey) was very close to its record year; North America was well below its 2020 record due to the US decline.

7 Based on sources in endnote 1 and on data for global installations and China additions in 2020 and 2021, from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1.

8 At least 55 countries in 2021 based on data from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1; at least 49 countries in 2020 based on data from GWEC, "Global Wind Statistics 2020: Status as End of 2020," March 2020, and from Zhao, op. cit. note 1, 26 April 2021; at least 55 countries in 2019 based on data from GWEC, "Global Wind Statistics 2019: Status as End of 2019," March 2020, and from Zhao, op. cit. note 1, April 13, 2020; at least 47 countries in 2018 based on data from GWEC, Global Wind Report 2019, April 2019, https://gwec.net/global-wind-report-2019; J. Engel, "Saudi Arabia's First Wind Farm Is Now Connected to the Grid," Renewable Energy World, September 8, 2021, https://www.renewableenergyworld.com/wind-power/saudi-arabias-first-wind-farm-is-now-connected-to-the-grid; the Saudi project is the largest in the Middle East, from N. Weekes, "EDF and Masdar Deliver First Power from Saudi Arabia's First Wind Farm," Windpower Monthly, August 9, 2021, https://www.windpowermonthly.com/article/1724278/edf-masdar-deliver-first-power-saudi-arabias-first-wind-farm.

9 Economics from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1. Energy security from, for example, A. Morales, "U.K. to Ramp Up Offshore Wind Targets in Energy Security Push," Bloomberg, March 17, 2022, https://www.bloomberg.com/news/articles/2022-03-17/u-k-to-ramp-up-offshore-wind-targets-in-energy-security-push; Evwind, "UK Energy Strategy Further Increases Offshore Wind Power Targets," April 13, 2022, https://www.evwind.es/2022/04/13/uk-energy-strategy-further-increases-offshore-wind-power-targets/85638; Renewable Energy Magazine, "Germany Raises the Bar on Renewable Energy with New Set of Laws for 100 Percent Renewable Power," 14 April 2022, https://www.renewableenergymagazine.com/panorama/germany-raises-the-bar-on-renewable-energy-20220414; K. Das, "Renewables in Vietnam: Current Opportunities and Future Outlook," Vietnam Briefing, November 12, 2020, https://www.vietnam-briefing.com/news/vietnams-push-for-renewable-energy.html; J. Guild, "What's Driving Vietnam's Renewable Energy Boom?" The Diplomat, January 12, 2021, https://thediplomat.com/2021/01/whats-driving-vietnams-renewable-energy-boom. Climate mitigation from, for example, the following: L. Stark and C. Kelly, "Biden Administration Approves First Major Offshore Wind Project in US Waters," CNN, May 11, 2021, https://www.cnn.com/2021/05/11/politics/first-major-offshore-wind-project-us-waters/index.html; S. Kaplan et al., "Europe Wants to Cut Russian Energy. Climate Policies Can Help," *Washington Post*, March 24, 2022, https://www.washingtonpost.com/climate-solutions/interactive/2022/europe-ban-russian-oil-gas-climate; C. Busch, "China's Emissions Trading System Will Be The World's Biggest Climate Policy. Here's What Comes Next," *Forbes*, April 18, 2022, https://www.forbes.com/sites/energyinnovation/2022/04/18/chinas-emissions-trading-system-will-be-the-worlds-biggest-climate-policy-heres-what-comes-next.

10 Market support mechanisms for new onshore wind power capacity in 2021 included China's grid parity scheme, which accounted for the largest share (42% of onshore market), auctions and tenders (31%), the US federal production tax credit (PTC) (17.6%), feed-in tariffs (FITs) (about 5%) and green certificates (4.3%), from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 103. The two primary support schemes for onshore additions in 2020 were FITs and the US PTC, from idem. In 2020, about 56% of the market was driven by FITs (China), 19% was driven by the US Production Tax Credit, followed by auctions and tenders (19.7%), and green certificates and other mechanisms (totalling a combined 4.6%), from GWEC, *Global Wind Report 2021*, 2021, p. 53, https://gwec.net/global-wind-report-2021. For future installations, the amount of capacity auctioned in 2021 totalled 88 GW, up 153% over 2020, and included 69 GW onshore (up 78%) and 19 GW offshore. Auctioned onshore capacity was led by China (52 GW, with 49.2 GW "grid parity" projects onshore), followed by Spain, India, South Africa and Germany, but Latin America saw less than 1 GW; offshore, 19.4 GW was awarded through auctions, including 8.4 GW in the United States, 7.8 GW in Europe and 3.1 GW in Asia (Japan and China), all from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, pp. 9, 104.

11 GWEC, Global Wind Report 2022, April 4, 2022, op. cit. note 1, p. 106.

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15 Investment and slowing transition in Europe, from Chestney, Koutantou and Jewkes, op. cit. note 14; impacts on global investment and list of permitting challenges, both onshore and offshore, from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, pp. 2, 4, 48, 52. See also the following: B. Radowitz, "Turbine Manufacturers Battered by 'Perfect Storm' of Post-Covid Crosswinds," Recharge News, November 22, 2021, https://www.rechargenews.com/wind/turbine-manufacturers-battered-by-perfect-storm-of-post-covid-crosswinds/2-1-1102325; A. Lee, "'Bad Permitting Prime Example' Italy in Wind Industry Firing Line After Green Power Auction Flops," Recharge News, February 1, 2022, https://www.rechargenews.com/wind/bad-permitting-prime-example-italy-in-wind-industry-firing-line-after-green-power-auction-flops/2-1-1161131.

16 Throughout value chain (rising turbine capacities and economies of scale have driven down capital expenditure costs, operational learning and data analytics have reduced operation and maintenance costs, etc.), from Ford, op. cit. note 12. See also GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1; N. Ford, "Giant Turbines Position Onshore Wind at UK Grid Parity," Reuters, April 21, 2021, https://www.reutersevents.com/renewables/wind/giant-turbines-position-onshore-wind-uk-grid-parity. Years of falling prices are due to larger turbines (scale), innovation and learning, digitalisation (improves performance), which has increased wind farm revenues, and improving technician safety, from Evwind, "Wind Energy Digitalisation Drives Costs Down and Yields Up," Reve, November 23, 2021, https://www.evwind.es/2021/11/23/wind-energy-digitalisation-drives-costs-down-and-yields-up/83400. See also N. Nhede, "Digital Solutions to Optimise China's Wind Energy Potential," Power Engineering International, November 23, 2021, https://www.powerengineeringint.com/renewables/wind/digital-solutions-to-optimise-chinas-wind-energy-potential; Evwind, op. cit. this note; advances have occurred both onshore and off, from WindEurope, "Onshore Wind Energy Scores Lowest Ever Price Under New Spanish Auction Design," January 27, 2021, https://windeurope.org/newsroom/news/onshore-wind-energy-scores-lowest-ever-price-under-new-spanish-auction-design; focus on lowest bids from, for example, Reuters, "Wind Power Risks Becoming Too Cheap, Says Top Turbine Maker," November 24, 2021, https://www.reuters.com/markets/commodities/wind-power-risks-becoming-too-cheap-says-top-turbine-maker-2021-11-24; low interest rates are a major reason for falling cost of capital, from S. Gsänger, WWEA, Bonn, Germany, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), April 8, 2022; cost of capital down due to increased investor confidence, from Ford, op. cit. note 12; see also Ford, op. cit. this note.

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27 See, for example, the following: GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1; Wade, Baker and Saul, op. cit. note 17; Energy Monitor, op. cit. note 12.

28 Figure of 61.4% in 2021 (including Turkey) based on data from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1, and on revised data for China from CWEA, op. cit. note 1, both sources, and for the United States from Hensley, op. cit. note 1, April 13, 2022. Share of market in 2020 based on GWEC, "Global Wind Statistics 2020," op. cit. note 8, and revised data for Spain (1,720 MW added) from I. Komusanac, WindEurope, personal communication with REN21, April 12, 2021. Share of market in 2019 (including Turkey) was 50%, based on data from GWEC, "Global Wind Statistics 2020," op. cit. note 8.

29 Regional shares based on data from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1, and on revised data for China from CWEA, op. cit. note 1, both sources, and for the United States, from Hensley, op. cit. note 1, April 13, 2022. Numbers in text are based on regional groupings that include Turkey as part of Asia, rather than Europe; other regional shares include Oceania (Australia and New Zealand added capacity) with more than 1.8% of the total added in 2021, and Africa and the Middle East with nearly 1.8%, based on data from idem, all sources.

30 The top five markets accounted for 77.3% of global installations in 2021, based on data from sources in endnote 1; this was down from 80.6% in 2020, from GWEC, Global Wind Report 2022, April 4, 2022, op. cit. note 1, p. 102.

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32 Based on data from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 112, and from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1.

33 Since 2014 based on data from previous editions of REN21, *Renewables Global Status Report*, https://www.ren21.net/reports/global-status-report; top 10 for cumulative capacity in 2021 based on data from WWEA, op. cit. note 1, and from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. **Figure 44** based on country-specific data and sources provided throughout this section, and drawn largely from the following: GWEC, Global Wind Report 2022, April 4, 2022, op. cit. note 1; GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1; WWEA, op. cit. note 1; WindEurope, op. cit. note 31.

34 Based on an estimated 55,920 MW added in 2021, including 41,440 MW onshore and 14,480 MW offshore, from CWEA, op. cit. note 1, both sources, and on 54,420 MW added in 2020 (including 50,575.5 MW onshore and 3,844.5 MW offshore), from CWEA, October 2021, provided in GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. Data for 2020 from GWEC and CWEA exclude 26.3 GW that was already installed prior to 2020 but was reported as grid-connected capacity for 2020 by China's National Energy Administration (NEA), based on information from Zhao, op. cit. note 1, April 26, 2022 and May 7, 2022. China added a record 55,800 MW in 2021 (compared with net additions of 52,000 MW in 2020) for a year-end total of 343,829 MW, based on preliminary data from WWEA, op. cit. note 1. Note that annual installations declined by 34% based on grid-connected installations of 47.57 GW in 2021 and 71.67 GW in 2020, from NEA, "National Energy Administration Releases 2021 National Power Industry Statistics," January 26, 2022, http://www.nea.gov.cn/2022-01/26/c_1310441589.htm (using Google Translate).

35 New installations on land were down 18.1% based on 50,575.5 MW added onshore in 2020, from CWEA, provided in GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1, and on 41,440 MW added onshore in 2021, from CWEA, op. cit. note 1, both sources. Decline in 2021 due to end of FIT programme, from pv magazine Australia, "Trend-Breaking Year for Renewables as Residential Solar Up and Onshore Wind Down in 2021," December 24, 2021, https://www.pv-magazine-australia.com/press-releases/trend-breaking-year-for-renewables-as-residential-solar-up-and-onshore-wind-down-in-2021, and from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 8; rush to install in 2020 from GWEC, Global Wind Report 2021, op. cit. note 10, pp. 45, 49, 71; regulated price for coal from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 103; and from C. Richard, "Onshore Wind Operators Face Hit from Grid Parity in China," Windpower Monthly, January 6, 2021, https://www.windpowermonthly.com/article/1703798/onshore-wind-operators-face-hit-grid-parity-china.

36 GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 8.

37 Based on 55,920 MW added in 2021, including 41,440 MW onshore and 14,480 MW offshore, for a total of 346,670 MW, including 320,000 MW onshore and 25,350 MW offshore, all excluding Hong Kong, Macao and Chinese Taipei and from CWEA, op. cit. note 1, both sources. China added 55.8 GW in 2021, up from 52 GW in 2020, for a total of 343,829 MW, from WWEA, op. cit. note 1. China commissioned 55.8 GW of new capacity in 2021, including 14.2 GW of offshore capacity, from BloombergNEF, cited in Weekes, op. cit. note 1. GWEC published additions of 47,570 MW (37,670 MW onshore and 16,900 MW offshore) for a total of 338,309.7 MW, from

GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 112, and from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. Note that historically GWEC has used the new installation data from CWEA but, due to a delay in data availability in early 2022, temporarily used NEA grid-connected data for 2021, from Zhao, op. cit. note 1, April 2022.

38 Based on the latest available data from China NEA and provided in GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 112, and in GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. Note that historically the GSR has used CWEA data (as have GWEC and other wind energy associations) for China rather than official data, which vary depending on government agency; CWEA (and GWEC) use these numbers because of the delay of grid connection in China, from GWEC, Global Wind Report 2021, op. cit. note 10, p. 74. China added 47.57 GW of grid-connected capacity, including 30.67 GW onshore and 16.9 GW offshore, for a year-end total of 328 GW, of which 302 GW was onshore and 26.39 GW was offshore, are also official data and sourced from NEA, "Transcript of the Online Press Conference of the National Energy Administration in the First Quarter of 2022," January 28, 2022, http://www.nea.gov.cn/2022-01/28/c_1310445390.htm (using Google Translate). Figure of 61% in central, eastern and southern regions, from NEA, idem. Net additions of 47,570 MW in 2021 (compared with 72,110 MW added in 2020) for a year-end total of 328,480 MW (up from 281,650 MW at end of 2020), are official data from China Electricity Council (CEC), cited in China Energy Portal, "2021 Electricity & Other Energy Statistics (Preliminary)," January 27, 2022, https://chinaenergyportal.org/en/2021-electricity-other-energy-statistics-preliminary. Note that the CEC data are based on grid-connected capacity; in addition, "Due to differences in statistical standards, confirmation of moment of grid connection, and other reasons, there are certain discrepancies in data on total and newly installed generation capacity", from CEC cited in China Energy Portal, op. cit. this note. The difference in statistics among Chinese organisations and agencies results from the fact that they count different things. No Chinese statistics provide actual grid-connected capacity, and discrepancies among available statistics can be large. In general, installed capacity refers to capacity that is constructed and usually has wires carrying electricity from the turbines to a sub-station (i.e., CWEA annual statistics); capacity qualifies as officially grid-connected (i.e., included in CEC statistics) once certification is granted and operators begin receiving the FIT premium payment, which at times has required weeks or even months. In recent years, due to transmission constraints in China, there often were lags of several months from when turbines were wire-connected to the sub-station until the process of certification and payment of the FIT premium was complete. Even with the end of the FIT (1 January 2021 for new onshore wind capacity and 1 January 2022 for new offshore wind), official grid-connection certification is required before projects are paid for generation under the grid-parity scheme. Data cited by CWEA are based on information collected from the industry, and are believed to most closely reflect the status of the market in China. All based on information provided in past years by GWEC and CWEA, as well as updates for 2022 and confirmation of accuracy provided by H. Yu, CWEA, Beijing, personal communication with REN21, May 8, 2022.

39 The national average utilisation rate in 2021 was 96.9%, an increase of 0.4 percentage points over 2020, from NEA, op. cit. note 38.

40 Wind energy generated 652.6 billion kWh for a year-on-year increase of 40.5%, and accounted for 7.9% of total electricity consumption in 2021, from NEA, op. cit. note 38; up by 40.5% based on wind generation of 655,600 GWh in 2021 and 466,500 GWh in 2020, from CEC, cited in China Energy Portal, op. cit. note 38; share of total generation in 2021 was 7.8% based on total electricity production of 8,376,800 GWh in 2021, from idem; 6.1% in 2020 based on total power production in 2020 of 7,623,600 GWh and total wind energy production of 466,500 GWh (based on grid-connected capacity), for a share of 6.1%, from CEC, cited in China Energy Portal, op. cit. note 38. This was up from a share of 5.5% in 2019, based on total annual generation of 7,326,900 GWh and wind energy generation of 405,300 GWh, from idem. Wind energy produced 5.2% of total in 2018 based on generation of 365.8 TWh that year, from China Energy Portal, "2018 Wind Power Installations and Production by Province," January 28, 2019, https://chinaenergyportal.org/en/2018-wind-power-installations-and-production-by-province, and based on data from China Electricity Council Express, cited in NEA, "National Energy Administration Releases 2018 National Electric Power Industry Statistics," January 28, 2019, http://www.nea.gov.cn/2019-01/18/c_137754977.htm (using Google Translate). In 2017, wind energy generation was 305.7 TWh and its share of total generation was 4.8%, from China National Energy Board, cited in NEA, "Wind Power Grid-connected Operation in 2017," February 1, 2018, http://www.nea.gov.cn/2018-02/01/c_136942234.htm.

41 Half of manufacturing, installed domestically and cooling demand, from Wood Mackenzie, op. cit. note 23; competitive pricing from BloombergNEF, Wind Turbine Price Index, cited in BloombergNEF, op. cit. note 20. The average price of an onshore wind turbine in China is about half that outside of China, while Chinese-made offshore turbines available in the market also cost less than those made elsewhere, from BloombergNEF, idem. Note that China accounts for 60-65% of global production of nacelles and key components (e.g., gearboxes, generators and blades), from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 120.

42 BloombergNEF, op. cit. note 20; MingYang also installed its first offshore turbine in Europe (in Italy) in early 2022, from WindDaily, "Mingyang Intelligent Offshore Wind Turbine, the First Show in Europe!" February 12, 2022, https://mp.weixin.qq.com/s/vexl2K581-rcM--r9eVOrQ (using Google Translate); Goldwind from Gsänger, op. cit. note 16, 8 April 2022, and from Goldwind, "Gold for Goldwind… China takes away the main prize in the 3MW-plus class," January 3, 2018, https://www.goldwindamericas.com/news/windpower-monthly-gold-goldwind%E2%80%A6-china-takes-away-main-prize-3mw-plus-class; VENSYS, "More Wind Power Worldwide with VENSYS Technology," https://www.vensys.de/en/latest/detail/news/weltweit-mehr-windpower-mit-vensys-technologie, accessed May 2, 2022. Also, note that Chinese manufacturers exported nearly 3.3 GW of turbine capacity (including the first offshore turbines) to 13 countries in 2021, up from 1.2 GW in 2020, from Yu, op. cit. note 23, slide 3.

43 Top 10 are preliminary global supply data from GWEC, provided by Zhao, op. cit. note 1, April 26, 2022. For all wind capacity installed, the ranking is: Vestas, Goldwind, Siemens Gamesa, Envision, GE, Windey, MingYang, Nordex, Shanghai Electric, Dongfang Electric; for offshore only, Chinese firms took the top four spots because China's market so large: Shanghai Electric, MingYang, Goldwind and CSSC Haizhuang, followed by Vestas and Siemens Gamesa, all rankings based on 99.2 GW (16.8 GW offshore and the rest onshore) commissioned in 2021 outside of China and some turbines that were partially commissioned but not necessarily connected to the grid in China, from BloombergNEF, cited in Weekes, op. cit. note 1. The top five manufacturers in 2021 were Vestas, GE Renewable Energy, Siemens Gamesa Renewable Energy, Xinjiang Goldwind and Nordex, which together accounted for nearly 65% of total capacity added in 2021, from GlobalData, cited in D. Proctor, "Vestas Cutting Jobs Despite Leading Wind Installations," Power Magazine, March 22, 2022, https://www.powermag.com/vestas-cutting-jobs-despite-leading-wind-installations. For specifics about top manufacturers in China, see J. Wood, "Windey Becomes One of China's Top Three Turbine Makers in 2021," BloombergNEF, March 11, 2022, https://www.windpowermonthly.com/article/1749415/windey-becomes-one-chinas-top-three-turbine-makers-2021-%E2%80%93-bloombergnef.

44 The top five include Vestas (Denmark), Siemens Gamesa (Spain), GE (United States), Nordex (Germany) and Enercon (Germany); share range based on wind power capacity that came online outside of China in 2021, all based on preliminary global supply data from GWEC, provided by Zhao, op. cit. note 1, April 26, 2022. The range was 92-94%, from BloombergNEF, op. cit. note 20. The wind industry has seen more than 100 turbine suppliers over the years, with a peak of 63 suppliers reporting installations during 2013; the number has declined rapidly since 2015, with 33 in 2019. More than 100 suppliers from GWEC, *Global Wind Report 2019*, 2019, https://gwec.net/global-wind-report-2019, p. 18; down from 63 original equipment manufacturers that reported installations in 2013, and 51 in 2015, and 33 suppliers reported installations in 2019 (20 of these were from Asia Pacific), also from F. Zhao, J. Lee and A. Lathigara, *Global Wind Market Development – Supply Side Data 2019*, GWEC, May 2020, p. 20. China's top five, based on cumulative capacity installed and market share (Goldwind, Envision, MingYang, Windey and Shanghai Electric) had a market share of 69.3% in 2021, as the Chinese industry also becomes more consolidated, from Yu, op. cit. note 23, slide 9.

45 The United States added 12,747 MW for a total of 134,996 MW, from ACP, "Clean Power Quarterly Report Q4 2021," February 15, 2022, pp. 4, 6, https://cleanpower.org/resources/clean-power-quarterly-report-q4-2021; the figure for additions was later revised to 13,400 MW installed in 2021 for a total of 134,996 MW (with an estimated

482 MW of decommissioned capacity and 1,986 MW partially repowered – replacements of nacelles and blades), from Hensley, op. cit. note 1, April 13, 2022. Note that decommissioning was 668 MW (all onshore), from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. The United States added 12,518 MW for a total of 124,846 MW, from WWEA, op. cit. note 1. Added 13 GW in 2021, from BloombergNEF, cited in Weekes, op. cit. note 1. Utility-scale capacity added in 2021 was 14,021.9 MW, for a year-end total of 132,400.6 MW, from US Energy Information Administration (EIA), "Electricity," Table 6.1, February 2022, https://www.eia.gov/electricity.

46 Second highest based on data for 2021, from Hensley, op. cit. note 1, April 13, 2022, and on estimated data for previous years, from "U.S. Annual and Cumulative Clean Energy Capacity Growth", figure in ACP, op. cit. note 45, p. 6; decline relative to 2020 based also on data for 2020 from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. The year 2021 saw the third highest capacity installed, after 2020 and 2012; 5,409 MW came online in the final quarter of 2021, down almost 50% compared to same period in 2020, all from ACP, op. cit. note 45, pp. 6, 8.

47 ACP, op. cit. note 45, p. 4; GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 103; P. Stevens, "U.S. Added Less New Wind Power in 2021 than the Previous Year — Why?" CNBC, March 7, 2022, https://www.cnbc.com/2022/03/07/us-added-less-new-wind-power-in-2021-than-the-previous-year-why.html. Interconnection queues also from E. Pontecorvo, "Renewables Are Growing — But a Backlog of Projects Is Holding Up a Greener Grid," Grist, April 20, 2022, https://grist.org/energy/renewables-are-growing-but-a-backlog-of-projects-is-holding-up-a-greener-grid, and from J. St. John, "The US Has More Clean Energy Projects Planned Than The Grid Can Handle," April 20, 2022, https://www.canarymedia.com/articles/transmission/the-us-has-more-clean-energy-projects-planned-than-the-grid-can-handle.

48 ACP, "U.S. Surpasses 200 Gigawatts of Total Clean Power Capacity, but the Pace of Deployment Has Slowed According to ACP 4Q Report," February 15, 2022, https://cleanpower.org/news/u-s-surpasses-200-gigawatts-of-total-clean-power-capacity-but-the-pace-of-deployment-has-slowed-according-to-acp-4q-report; extended through 2021 from US EIA, "U.S. Wind Energy Production Tax Credit Extended through 2021," January 28, 2021, https://www.eia.gov/todayinenergy/detail.php?id=46576; see also GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 103; J. Calma, "Renewable Energy Growth in the US Lags Far Behind Biden's Climate Ambitions," The Verge, February 16, 2022, https://www.theverge.com/2022/2/16/22937248/biden-climate-goals-renewable-energy-growth-us-lags-solar-wind-batteries; P. Tisheva, "GE Renewable Energy's Loss Deepens to USD 795m in 2021," Renewables Now, January 26, 2022, https://renewablesnow.com/news/ge-renewable-energys-loss-deepens-to-usd-795m-in-2021-770701.

49 J. Wood, "American Clean Power Association: US Wind PPA Prices Rise Faster than Solar," Windpower Monthly, February 16, 2022, https://www.windpowermonthly.com/article/1740775/american-clean-power-association-us-wind-ppa-prices-rise-faster-solar.

50 The US pipeline of new projects included 23,868 MW for onshore wind and 17,458 MW offshore, from ACP, op. cit. note 45, p. 13. As of early 2022, nine states (Connecticut, Louisiana (announced in early 2022), Maryland, Massachusetts, New Jersey, New York, North Carolina, Rhode Island and Virginia) had set offshore procurement targets totaling 44,593 MW; Louisiana announced an offshore goal of 5 GW by 2035 in early 2022, from idem, p. 28.

51 Figure of 9.1% from Hensley, op. cit. note 1, April 8, 2022. The estimate for 2021 was 9.2% based on preliminary data of 379,767 GWh of utility-scale wind generation and 4,115,540 GWh generation from all utility-scale sources during 2021, from US EIA, *Electric Power Monthly with Data for December 2021*, February 2022, Table ES1.B, https://www.eia.gov/electricity/monthly/current_month/february2022.pdf. Figure of 8.4% in 2020, from US EIA, Electric Power Monthly, cited in US EIA, "The United States Installed More Wind Turbine Capacity in 2020 Than in Any Other Year," Today in Energy, March 3, 2021, https://www.eia.gov/todayinenergy/detail.php?id=46976. Wind's share was 7.3% in 2019 and 6.5% of US total generation in 2018 based on data for utility-scale facilities net generation during 2018, from US EIA, *Electric Power Monthly with Data for December 2020*, February 2021, Table ES1.B. Wind energy production was up 11% in 2021 relative to 2020 based on data from Lawrence Livermore National Laboratory, cited in A. Fine, "Wind Energy Production Increased by 11 Percent in 2021," North American Windpower, April 12, 2022, https://nawindpower.com/wind-energy-production-increased-by-11-percent-in-2021-research-institute-discovers.

52 Third from WWEA, op. cit. note 1, and from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 112; share of installations in Latin America and the Caribbean, based on data from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1.

53 Pandemic-related challenges and data for 2021 (added 3,830 MW for a total of 21,580 MW), from GWEC, Global Wind Report 2022, April 4, 2022, op. cit. note 1, pp. 112, 127. Brazil added 3,694 MW, for total of 20,870 MW, based on 21,580.4 MW as of 24 March 2022, and subtracting 710 MW installed during 2022 as of same date, all from National Agency for Electrical Energy (ANEEL), "Geração," March 2022, https://www.gov.br/aneel/pt-br/centrais-de-conteudos/relatorios-e-indicadores/geracao. Brazil added 3,355 MW for total of 21,365 MW (preliminary data, as of November 2021), from WWEA, op. cit. note 1. Increase over additions in 2020 based on data for 2021 and on Brazil added 2,297 MW in 2020, from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1.

54 GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 127.

55 Ibid., p. 9.

56 Brazil's generation from wind energy was 72,196 GWh in 2021 (up from 56,993 GWh in 2020), from Electrical System Operator of Brazil, "Geração de Energia," http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, accessed April 13, 2022. Share of electricity mix from ABEEólica, cited in L. Morais, "Brazil Tops 21 GW of Installed Wind Capacity," Renewables Now, January 24, 2022, https://renewablesnow.com/news/brazil-tops-21-gw-of-installed-wind-capacity-770287.

57 Length of coastline from Charts Bin, "Length of Coastline by Country," http://chartsbin.com/view/ofv, accessed April 13, 2022; decree and offshore plans from Reve, "Offshore Wind Energy Has Great Potential in Brazil," February 20, 2022, https://www.evwind.es/2022/02/20/offshore-wind-energy-has-great-potential-in-brazil/84740.

58 FIT expiration from GWEC, Global Wind Report 2022, April 4, 2022, op. cit. note 1, pp. 8, 107, 112, 114-115; Vietnam added 125 MW in 2020 and, in 2021, the country added 3,496.6 MW (including 2,717.3 MW onshore and 779.3 MW offshore) for total year-end 2021 capacity of 4,108.9 MW, from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1; Vietnam added 3.6 GW of onshore and near-shore wind power capacity in 2021, from BloombergNEF, cited in Weekes, op. cit. note 1.

59 Das, op. cit. note 9; Guild, op. cit. note 9. As of 2020, electricity demand was projected to increase 8% annually until 2025, from Das, op. cit. note 9. Electricity consumption is rising at more than 11% per year, faster than rate of GDP growth, and domestic projection of fossil fuels not able to keep up, forcing Vietnam to import fuels, which has driven the rising interest in renewable energy, from Guild, op. cit. note 9. See also GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 114.

60 National FIT extension and capacity targets from M. Breu and J. Castellano, "Vietnam Offshore Wind Opportunities Increasing," McKinsey, November 1, 2021, https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/capturing-the-wind-renewable-energy-opportunities-in-vietnam; grid infrastructure from US EIA, "Vietnam's Latest Power Development Plan Focuses on Expanding Renewable Sources," Today in Energy, July 1, 2021, https://www.eia.gov/todayinenergy/detail.php?id=48176; see also GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, pp. 114-115.

61 Supply chain disruptions from GWEC, *Global Wind Report 2022*, April 4, 2022, op. cit. note 1, p. 114; lack of capital and weak grid from Das, op. cit. note 9; full load or overloaded from US EIA, op. cit. note 60.

62 TaiyangNews, "Vietnam to Go Slow with RE In 2022," January 21, 2022, https://taiyangnews.info/markets/vietnam-to-go-slow-with-re-in-2022.

63 Rankings worldwide based on data from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1.

64 The United Kingdom added 2,645 MW (328 MW onshore and 2,317 MW offshore) for a total of 26,812 MW (14,073 onshore and 12,739 MW offshore), from WindEurope, op. cit. note 31, p. 11; added 2,645 MW for a total of 26,812 MW, from WWEA, op. cit. note 1; added 328 MW onshore and 2,316.5 MW offshore for a year-end total of 26,586 MW, from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1.

65 Four-fold based on data from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1, and 4.5 GW in 2017 from I. Komusanac, WindEurope, Brussels, personal communication with REN21, April 28, 2022.

66 WindEurope, op. cit. note 31, p. 13.

67 Komusanac, op. cit. note 65.

68 Pinset Masons, "UK government launches fourth CfD allocation round worth £285m," December 15, 2021, https://www.pinsentmasons.com/out-law/news/uk-government-launches-fourth-cfd. After five years with no public support for onshore wind (or solar) power, the UK government announced in 2020 that the technology will again be allowed to participate in the Contracts for Difference scheme, from J. Parnell, "UK Lifts Block on New Onshore Wind and Solar," Greentech Media, March 2, 2020, https://www.greentechmedia.com/articles/read/uk-lifts-block-on-new-onshore-wind-and-solar.

69 Annual additions and total capacity based on data (not including Turkey) from WindEurope, op. cit. note 31, p. 11, and from Komusanac, op. cit. note 65. Europe (not including Turkey) added 15,958 MW (nearly 12,641 MW onshore and 3,318 MW offshore) for a total of 224,953 MW (196,621 MW onshore and 28,333 MW offshore, based on data from idem, both sources. Increase relative to 2020 additions based on data for 2021 and on 13,526 MW added in 2020 based on data provided by Komusanac, op. cit. note 65.

70 Ibid. p. 12; see also, for example, Lee, op. cit. note 15.

71 Share of 57.7% based on total combined gross additions in top five countries of 9,210 MW and total regional capacity additions of 15,958 MW in 2021: the United Kingdom added 2,645 MW (328 MW onshore and 2,317 MW offshore), followed by Sweden (2,104 MW, all onshore), Germany (1,925 MW, all onshore), the Netherlands (952 MW onshore and 392 MW offshore, for a total of 1,344 MW added), and France (1,192 MW, all onshore), based on data from WindEurope, op. cit. note 31, p. 11, and from Komusanac, op. cit. note 65. Down from 60.6% based on data for top five countries in 2020 (Netherlands, Spain, Germany, Norway and France), which together added 8,199 MW (gross) and total additions in Europe of 13,526 MW (gross), from Komusanac, op. cit. note 65.

72 WindEurope, op. cit. note 31, p. 12; Finland's strong year was driven by PPAs and merchant projects, from idem, p. 14.

73 The EU added 11,035 MW (10,038 MW onshore and 997 MW offshore) for a total of 188,883 MW (173,295 MW onshore and 15,588 MW offshore), based on data from Ibid. p. 11, and from Komusanac, op. cit. note 65.

74 Based on data for 2021, from WindEurope, op. cit. note 31, pp. 11, 14, and on data for 2020 from Komusanac, op. cit. note 65. Note that the Europe figure does not include Turkey.

75 Additions in 2020 included more than 8 GW onshore and 2.4 GW offshore, based on data from Komusanac, op. cit. note 65.

76 WindEurope, op. cit. note 31, p. 12.

77 Ibid., pp. 12, 13; fifth place in 2020 from WindEurope, *Wind Energy in Europe: 2020 Statistics and the Outlook for 2021-2025*, 2020, https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2020-statistics-and-the-outlook-for-2021-2025, p. 11.

78 Sweden added 2.1 GW in 2021, from Swedish Energy Agency, cited in N. Buli, Reuters, "Swedish Wind Power Generation to Rise 70% by 2024 – Agency," March 14, 2022, https://www.reuters.com/business/energy/swedish-wind-power-generation-rise-70-by-2024-agency-2022-03-14; added 2,104 MW (all onshore) for a total of 12,097 MW, from WindEurope, op. cit. note 31, p. 11 ; added 2,175 MW for a total of 12,097 MW, from WWEA, op. cit. note 1.

79 Electricity generation from Swedish Energy Agency, op. cit. note 78. About 16.5% based on wind generation in 2021 (27.4 TWh) and total net electricity generation (165.7 TWh), from idem. Note that a significant amount of electricity generated in Sweden (25.6 TWh in 2021) is exported; if all electricity generated by wind energy remained in Sweden, it would account for nearly 20% of consumption, all based on data from idem.

80 Svensk Vindenergi, cited in reNEWS, "Wind Pushes down Power Prices in Sweden," February 10, 2022, https://renews.biz/75630/wind-pushes-down-power-prices-in-sweden.

81 S. Vindenergi, "Revised Road Map 2040: 'Wind Power – Combating Climate Change and Improving Competitiveness,'" Vindkraft, January 20, 2020, https://swedishwindenergy.com/press-releases/revised-road-map-2040-wind-power-combating-climate-change-and-improving-competitiveness.

82 Placement in 2020 based on data from WindEurope, op. cit. note 77, p. 11; Komusanac, op. cit. note 65; data for 2021 based on data from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1, and from WindEurope, op. cit. note 31, p. 11.

83 Germany added 1,925 MW in 2021 (and decommissioned 233 MW onshore, for net additions of 1,692 MW), all onshore, for a total of 63,843 MW (56,130 MW onshore and 7,713 MW offshore), from Komusanac, op. cit. note 65, and from WindEurope, op. cit. note 31, p. 11. Increase of over 15% based on gross annual installations from ibid., both sources, and from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. Note that net additions were up almost 16% based on net additions of 1,446 MW in 2020 and net additions of 1,677 MW (all onshore) in 2021, for total capacity of 56,091 MW onshore and 7,774 MW offshore, from Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) and Umwelt Bundesamt, "Erneuerbare Energien in Deutschland Daten Zur Entwicklung Im Jahr 2021," March 2022, pp. 8-9, 20, https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/hg_erneuerbareenergien_dt.pdf. Germany added 1,925 MW (all onshore) and decommissioned 233 MW in 2021 for a year-end total of 64,541.9 MW (56,813.9 MW onshore and 7,728 MW offshore), from GWEC, "Global Wind Report 2022," April 2022, op. cit. note 1. Note that Germany added 1,925 MW onshore in 2021, repowered 244 MW and decommissioned 233 MW for net installations of 1,692 MW and a year-end total of 56,130 MW onshore, all from Deutsche Wind Guard, "Status of Onshore Wind Energy Development in Germany," 2021, p. 3, https://www.windguard.com/year-2021.html?file=files/cto_layout/img/unternehmen/windenergiestatistik/2021/Status%20of%20Onshore%20Wind%20Energy%20Development%20in%20Germany_Year%202021.pdf. Added 1,716 MW for a total of 63,924 MW, from WWEA, op. cit. note 1.

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95 Based on estimates from Ibid., pp. 9, 19, 20. Estimated shares for other countries above 20% were Portugal (26%), Spain (24%), Germany (23%) and the United Kingdom (22%), from idem. Electricity prices from idem, p. 22.

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125 Yu, op. cit. note 23, slide 14.

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127 WindEurope, op. cit. note 31, p. 11. Also, there were demonstration projects installed in the Borssele zone of the Netherlands and a new floating concept (TetraSpar) in Norway, from idem, p. 15.

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