Despite China's year-end rally with more than 12 GW brought online in December alone, the country's annual solar PV market declined almost 32% (following a 15% drop in 2018), to 30.1 GW newly installed (including 17.9 GW of utility-scale and 12.2 GW of distributed[i] solar PV).[26] Although installations fell for the second consecutive year and were down in almost every region of China, 12 provinces added more than 1 GW each and the country's total additions were more than double those of the next largest national market, the United States.[27] (→ *See Figure 30* and ***Reference Table R16.***) The leading provincial installer in 2019 was Guizhou (3.4 GW), one of China's poorest provinces, followed by Shandong (2.6 GW) and Hebei (2.4 GW).[28] By year's end, China's cumulative grid-connected capacity of around 204.7 GW was almost twice the national solar PV target (105 GW by 2020) that was established in 2016.[29]

China's market decline in 2019 was due largely to policy uncertainty. The country is in the process of restructuring its renewable energy market – shifting from high-speed capacity growth and dependence on direct financial support through uncapped FITs, to deployment of high-quality technologies and systems through auctions and subsidy-free deployment to reduce costs and improve overall performance.[30] The national government ceased approvals for new subsidised projects at the end of May 2018, and took more than a year to provide clarity on a revised FIT policy.[31] Multiple delays in publication of policy implementation rules pushed back completion dates for several large solar PV projects.[32] The market also was tempered by ongoing delays in FIT payments for existing facilities; challenges related to grid connections, land availability and access to finance; an increase in module exports, which curbed expected domestic price reductions and left developers waiting for prices to come more in line with their bids; and more positive and clear guidance for wind power projects, which led some developers to prioritise wind deployment.[33]

Countries that ranked among the top 10 for new solar PV installations added

3.1 GW

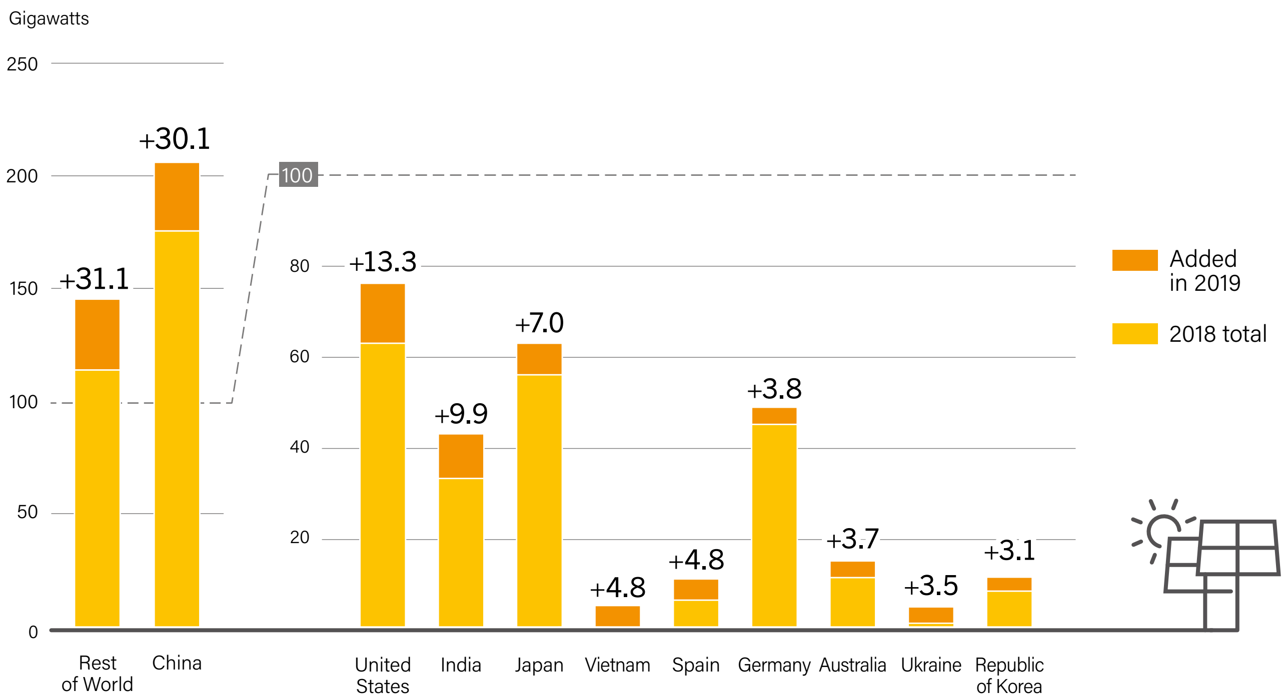
or more.

As part of China's transition to a market without direct policy support by 2021, a bidding scheme was launched to select solar PV projects for FIT support as well as those for "grid-parity"[ii], and by July the government approved 22.8 GW and 14.8 GW of capacity respectively.[34] For a variety of reasons, however, less than

i "Distributed" solar PV in China includes ground-mounted systems of up to 20 MW that comply with various conditions, in addition to commercial, industrial and residential rooftop systems. Distributed generation consists largely of commercial and industrial systems and, increasingly, residential and floating projects. See endnote 26 for this section.

ii Grid parity in China refers to market-driven with no FIT support, but with priority off-taking. See endnote 34 for this section.

FIGURE 30. Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2019



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

Source: See endnote 27 for this section.

10 GW of FIT-supported projects were executed and only about 2 GW of grid-parity projects became operational during the year.[35]

China's market for large ground-mounted systems declined around 23% in 2019, and distributed installations (which include residential) were down 41%, but annual installations of residential systems (at 4.2 GW) increased 74% relative to 2018 and exceeded the official full-year target of 3.5 GW.[36] Centralised utility power plants (>20 MW) accounted for more than 59% of annual grid-connected installations (and 69% of the year-end total), with distributed systems making up the remainder.[37]

Curtailment of solar energy in China continued to fall, down 1 percentage point from 2018 to average 2% (or a total of 4.6 TWh) for the year.[38] Most curtailment (87%) occurred in the north-west region, and the curtailment rate was highest in Tibet (24.1%, down 19.5 percentage points), but it declined in every province except Qinghai, which saw a large increase in renewable power capacity and a decline in load.[39] Reduced curtailment and rising capacity helped increase China's solar PV output from grid-connected systems more than 26% relative to 2018, to 224 TWh.[40] As a result, solar PV's share of total electricity generation (from grid-connected sources) in the country rose to 3% in 2019 (2.6% in 2018).[41]

The second largest market in Asia and the third largest globally was India, which added an estimated 9.9 GW in 2019 for a total of 42.8 GW.[42] India targets 100 GW of installed solar PV, including 40 GW of rooftop solar capacity, by the end of 2022.[43]

India's annual installations were down in 2019, following significant growth in 2018.[44] Reasons for the decline were many: India's economic slowdown, tariff caps and higher costs associated with tender participation, payment delays, renegotiation of power purchase agreements (PPAs) in Andhra Pradesh, challenges related to land acquisition, lack of transmission infrastructure and of access to grid connections, liquidity issues and lack of financing (due in many cases to delays in tariff adoption).[45] Curtailment also acted as a deterrent to new installations, and the severity was worsened by a decline in power demand due to the slowing economy.[46] In August, the national government called for "must run" status for solar and wind power projects, but lacked the ability to strictly enforce the rules.[47] Even so, generation from solar power for the year was up 27% relative to 2018.[48]

Large-scale projects accounted for more than 85% of India's newly installed capacity and represented the vast majority of total solar PV operating capacity.[49] Around 35 GW of tenders was announced in India during 2019, down 8% relative to 2018, with more than 15.8 GW of projects auctioned (up 2%).[50] But several tenders were undersubscribed and, as in 2018, many auctions were cancelled retroactively.[51] Nonetheless, by the end of 2019 nearly 24 GW of large-scale capacity was reportedly in the pipeline.[52]

India's rooftop market declined in 2019 for the first time in five years.[53] The contraction was due largely to the economic slowdown combined with liquidity issues, as well as challenges to net metering and lengthy approval processes in some states.[54] An estimated 1.1 GW of distributed and off-grid capacity was installed during the year.[55] The rooftop market continued to consist mainly of large commercial and industrial companies (which together account for more than 70% of total capacity), as well as government entities (including Indian Railways) and educational institutions, all seeking to reduce their electricity bills; comparatively few residential customers can afford the upfront costs.[56]

In 2019, 26 countries in the EU-28 **added more capacity** than they installed in 2018.

The market in Japan also contracted, for the fourth consecutive year, and was down significantly from the peak year (2015).[57] Japan's market continued to suffer from grid constraints, lack of available land and of low-cost financial resources, high prices of solar generation (Japan's prices are some of the world's highest) and high labour costs.[58] Even so, Japan progressed towards the national target of 82 GW by 2030: around 7 GW was added during 2019, for a total of 63 GW.[59] For the year, solar PV accounted for an estimated 7.4% of Japan's total electricity generation, up from 6.5% in 2018.[60]

By late 2019, 530,000 residential solar PV systems in Japan, totalling some 2 GW of capacity, reached the end of their 10-year contract period and exited the country's FIT scheme; as a result, and to increase resilience of supply, many system owners increased their focus on self-consumption and on achieving net-zero energy use by combining solar PV with energy storage.[61] Power companies, home builders and others introduced new programmes for post-FIT residential systems, offering to purchase surplus solar electricity and renewable energy credits for their own use or resale to achieve corporate renewable energy targets.[62]

In contrast to other large markets in Asia, Vietnam saw a surge in installations as developers rushed to win attractive FIT rates before they expired mid-year, rocketing the country to fifth place globally for additions.[63] More than 8.9 GW of large projects had been approved by year's end, including around 4.5 GW of capacity that came online at the end of June.[64] During all of 2019, an estimated 4.8 GW was added (up from 106 MW in 2018 and 8 MW in 2017) for a total of 4.9 GW.[65] Vietnam's interest in solar PV is largely to meet rising electricity demand, which has grown an average of 10% annually in recent years due to population growth and economic expansion.[66] Post-June, increasing concerns about grid congestion in the sunniest regions led the government to incentivise new projects in provinces with lower solar resources; in December, the national government urged a suspension of authorisations for all new solar facilities until further notice.[67]

Other Asian countries that added substantial capacity in 2019 included the Republic of Korea, which installed an estimated 3.1 GW for a total of 11.2 GW, followed by Chinese Taipei, Pakistan, Turkey, Malaysia (approaching 0.6 GW) and Kazakhstan (0.5 GW).[68] Chinese Taipei (added 1.4 GW) aims for 20 GW by 2025, but faces several challenges including policy uncertainty, a struggling manufacturing sector and difficulties securing needed land.[69] Pakistan had another strong year, adding 1.3 GW for a total of 3.4 GW.[70]

Turkey's annual installations declined significantly for the second consecutive year, due to an economic downturn, lack of available financing and other challenges; the country installed 0.9 GW for a

total of 8 GW.[71] In its first attempt to support small-scale systems, Turkey introduced net metering in 2019.[72] Numerous additional countries in Asia brought projects online or held tenders during the year, including Cambodia, which held its first solar PV tender.[73]

Europe moved ahead of the Americas to rank second for additions (nearly 20.4 GW), and maintained its second-place regional ranking for total operating capacity.[74] Demand rose significantly in the EU and beyond: Ukraine, for example, installed a record 3.5 GW (surpassing 1 GW for the first time), thanks to a generous FIT and a scheduled reduction, to place third in all of Europe and ninth globally, while the Russian Federation brought online its largest solar PV plant (75 MW) to date, part of a pipeline of projects allocated in a 2016 auction.[75]

The EU-28[i] added around 16 GW of grid-connected solar PV, nearly double the 8.2 GW installed in 2018, bringing total capacity close to 131.7 GW.[76] Most markets in the region have moved beyond FITs and were driven in 2019 by the competitiveness of solar generation – which is increasing interest in self-consumption (particularly combined with digital technologies and storage) and in corporate renewable power sourcing (including via direct bilateral PPAs) – as well as by governments looking to meet national renewable energy targets through tenders.[77] At the same time, new challenges are emerging, including access to grid connections, land availability and planning permission (particularly in some areas that already have a large installed base), and a shortening of PPA time periods with the shift towards merchant deals[ii].[78]

In 2019, 26 of 28 countries in the EU added more capacity than they installed in 2018; even so, around three-fourths of new capacity came online in only five countries.[79] Spain (4.8 GW) was the top installer for the first time in 11 years, followed by Germany (3.8 GW), the Netherlands (2.4 GW), France (0.9 GW) and Poland (0.8 MW).[80] The Netherlands' installations were up an estimated 66%, led by the country's rooftop market, and Poland saw its installations quadruple in response to rising incentives for rooftop systems and the extension of net metering.[81] For cumulative capacity, Bulgaria, Denmark and Hungary each exceeded 1 GW for the first time in 2019.[82] The leaders Germany and Italy together were home to more than half of the EU's cumulative capacity at year's end, but their shares are declining as markets expand elsewhere.[83]

Spain added nearly 4.8 GW in 2019, up from less than 0.3 GW in 2018, for a total exceeding 9.9 GW.[84] The high level of installations was due mostly to the commissioning of projects tendered in 2017 to meet the country's EU obligations, as well as to Spain's first PPA- and wholesale-based plants, and rooftop installations for self-consumption.[85] Installation of rooftop systems picked up considerably following the elimination of Spain's "Sun Tax" in November 2018 and the streamlining of the permitting process.[86] By year's end, grid constraints were the primary barriers to large-scale project implementation.[87] In response to an influx of applications for grid connection that far exceed Spain's expected demand growth, the government tightened grid connection rules as of 2020.[88]

Annual demand in Germany was up almost 33% relative to 2018, with more than 3.8 GW added in 2019 for a total exceeding 49 GW.[89] The market was driven primarily by self-consumption and FIT premiums; limited volume tenders for large (>750 kW) ground-mounted systems accounted for less than 20% of added capacity.[90] The number of prosumers[iii] in Germany increased by almost 100,000 between February 2019 and January 2020.[91] An estimated one of every two rooftop installations was sold with a battery storage system.[92] In late 2019, the German government announced a new goal of 98 GW of solar PV by 2030, and removal of the 52 GW feed-in tariff cap was under discussion.[93] Solar PV generated an estimated 8.2% of Germany's electricity during the year.[94]

i EU throughout this text refers to the EU-28, including the United Kingdom. Not including the UK, EU additions in 2019 were over 15.7 GW for a year-end total of more than 118 GW. See endnote 76 for this section.

ii Merchant deals (or projects) are those with no regulated or contracted income. The electricity generated is sold into competitive wholesale markets.

iii Individuals, families, commercial enterprises and energy co-operatives that produce electricity with solar PV and consume at least some of it locally.

The United Kingdom's FIT, a key policy for supporting rooftop solar, closed to new applicants at the end of March 2019.[95] In response, new residential installations fell 94% in May.[96] Paralysis caused by uncertainty over Brexit as well as policy changes also resulted in reduced investment in community solar projects.[97] The country had its slowest year since at least 2010, with an estimated 0.3 GW added, well below the 2015 peak (4.2 GW), bringing total capacity to 13.4 GW.[98] By year's end, however, the pipeline of large-scale projects was reportedly more than 6 GW.[99]

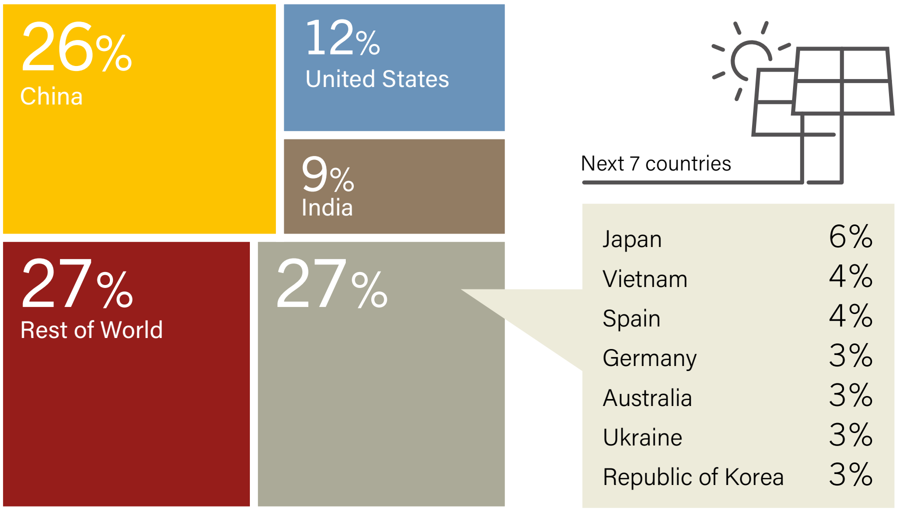
Across Europe, the number of direct bilateral PPAs continued to climb, and solar PPAs are becoming increasingly competitive with wholesale power markets in some countries.[100] Europe's largest PPA was signed in 2019 for a 708 MW solar PV project portfolio in Spain and Portugal.[101] The year also saw the region's first large-scale PPA for a crowdfunded project; this financing approach represents one of the many innovations taking place in Europe, the United States and elsewhere to aggregate risk and enable the spread of PPAs beyond utilities and large energy-consuming corporations to smaller offtakers and to new countries.[102] By early 2020, around 8.4 GW of solar PV capacity was operating or planned under PPAs in Europe, with the largest portion in Spain (4.4 GW), followed by Italy (1.9 GW) and Germany (over 1 GW).[103]

The Americas represented around 15% of the global market in 2019, due largely to the United States, which ranked second globally for both new installations and cumulative capacity.[104] (→ *See Figure 31.*) The country added 13.3 GW for a total exceeding 76 GW.[105] Solar PV accounted for nearly 40% of all new US power capacity additions in 2019, the largest share to date.[106] California again led all states in added capacity (3.1 GW), followed by Texas (1.4 GW) and Florida (1.4 GW).[107] Hawaii led in the adoption of rooftop solar per capita, followed by California and Arizona.[108] Utility-scale solar PV generated 69 TWh, or 1.7% of US utility-scale generation in 2019; small-scale systems generated an additional estimated 35 TWh.[109]

The US market as a whole grew 23% in 2019.[110] It was led by the utility-scale sector, which expanded 37%, to 8.4 GW, and accounted for 63% of US additions.[111] Non-residential[i] installations declined for the second consecutive year (down 7%), due to policy changes and interconnection delays in some key states.[112] But the residential sector had a record year, up 15% to 2.8 GW, driven by ever more attractive economics in many emerging states, as well as by power shutoffs (associated with wild fires) and new-build homes in California.[113] California achieved a target of 1 million solar roofs in late 2019, and the state's mandate to install solar on most new homes entered into force at the start

i Includes commercial, government, non-profit and community solar PV systems.

FIGURE 31. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2019



Source: See endnote 104 for this section.

of 2020.[114] Also towards the end of 2019, the National Community Solar Partnership was relaunched with the aim of expanding affordable access to solar energy for all US households by 2025.[115]

The US rush to complete projects, large and small, and to contract for new ones during 2019 was driven in part by impending cuts in the federal investment tax credit (ITC)[i].[116] Project developers and small commercial installers stockpiled modules and other equipment to take advantage of the 30% ITC, and installers were at capacity during the second half of the year.[117] Falling technology costs and rising renewable energy commitments also drove demand, including in the US Midwest, which historically has favoured wind energy.[118] A record high of new solar PPAs (30.6 GW) was signed or announced, bringing the cumulative contracted project pipeline to 48.1 GW.[119] Voluntary purchasing accounted for 57% of new procurement in 2019, with an estimated 14% driven by state renewable portfolio standards.[120] Innovations such as aggregation[ii] continued to open the market for smaller businesses as well as large corporations.[121]

Rapidly falling costs of solar PV and battery installations have led to a surge in solar PV-plus-storage projects across the United States by enabling them to begin competing with natural gas-fired generation.[122] In 2019, the number of US solar-plus-storage projects announced or already online increased from 16 to 38, and in California most new utility-scale solar was being proposed with some storage capacity.[123] Interest in solar-plus-storage is rising in the residential market as well, particularly in Hawaii and in California, where consumers seek energy resiliency and reliability.[124] (→ *See Systems Integration chapter.*)

To the south, several countries in Latin America and the Caribbean continued their rapid expansion, despite challenging economic conditions in some countries, thanks largely to an abundance of solar resources, falling prices and favourable political climates until 2019.[125] The region's top installers were Brazil (adding 2 GW), Mexico (nearly 2 GW) and Argentina (0.5 GW).[126] Several other countries brought online significant capacity, including Colombia, which commissioned a 86 MW plant, and Jamaica, which completed the Caribbean's largest solar PV facility (51 MW) – the plant is expected to provide the island's lowest-cost electricity.[127] Numerous countries called for public bids for future solar PV projects.[128]

Brazil added more than 2 GW in 2019 and ended the year with nearly 4.5 GW.[129] An estimated 650 MW of large-scale capacity was brought online, including the first solar PV plant in Latin America to be built with a digital sub-station.[130] By year's end, around 5.7 GW of additional permitted solar PV projects was in advanced stages of development, and there was a growing interest in new opportunities for bilateral PPAs.[131] Several large-scale projects reached record-setting low bid prices in government auctions, with plans to sell at least 30% of their electricity into the wholesale market.[132] Brazil's distributed solar PV segment (defined as <5 MW) saw the most growth during 2019 in terms of capacity added (1.4 GW), investments and jobs, driven by net metering and rising energy prices.[133] The segment was led by residential systems but saw growing shares of commercial and rural systems.[134] An end-of-year push to install distributed systems resulted from proposed policy changes, including a debate under way regarding revisions to the national net metering mechanism.[135]

Innovations such as crowdfunding and aggregation are opening PPA markets to more participants.

i The ITC provided a 30% investment tax credit for projects that began construction by the end of 2019. The credit steps down to 26% in 2020, 22% in 2021 and 10% from 2022 onwards for commercial and utility projects, and for residential systems owned by companies; it falls to zero in 2022 for residential installations owned by homeowners. See endnote 116 for this section.

ii For example, a large corporation acts as "anchor tenant", providing a strong credit rating to support project financing, and enabling the developer to build a larger project than the corporation requires. The developer then negotiates separate PPAs for the additional capacity with smaller purchasers, who have differing credit ratings, and who benefit from lower transaction costs and reduced complexity. Alternatively, a number of companies jointly negotiate an agreement, aggregating their individual capacity requirements in order to organise a larger deal and, thereby, to more cost-effectively acquire a PPA. See endnote 121 for this section.

Mexico continued to lead the region for its cumulative capacity, which rose an estimated 62% compared with 2018 to more than 5 GW.[136] Several large plants came online, including a 220 MW facility that will sell electricity into the wholesale market.[137] The country also completed what was reportedly the first large-scale project in Latin America to combine solar PV and battery storage.[138] However, the Mexican government cancelled all plans for renewable energy auctions, raising concerns about the impact on solar PV deployment after 2020.[139] Mexico also had substantial rooftop capacity, totalling 818 MW at the end of 2019.[140]

Across the Pacific, Australia saw record additions in the small, medium and large-scale segments, and ranked eighth globally for installations.[141] Around 3.7 GW was added during 2019, increasing the country's total capacity to 14.7 GW.[142] Although output from solar PV was affected by haze and fallout from the bushfires across much of the country, generation rose 55% in 2019, to 18.1 TWh, or 7.8% of Australia's total.[143] Deployment has been driven by several factors, including falling system prices, increasing awareness of the benefits of solar PV to businesses and households, and the corporate market for PPAs.[144]

Corporate solar PPAs continued to be announced in Australia, although at a slower pace than in 2018, with solar PV accounting for 82% of the 400 MW that was newly contracted in 2019.[145] An important innovation in Australia during the year was the development of retail PPAs, in which buyers (particularly a growing number of mid-scale buyers) contract for power via a retailer.[146] Among the new smaller agreements was a seven-year PPA signed by the Sydney Opera House for solar and wind power projects and a residential solar PPA for home buyers in a Western Australia housing development.[147] The number of merchant projects (selling on the spot market) rose as well.[148]

Australia's capacity in large-scale (>5 MW) solar PV projects saw record increases.[149] Yet small-scale (<100 kW) household and commercial rooftop solar PV continued to be the largest sector in Australia by far, as both the number and average size of new systems continued to rise.[150] Annual installations increased 35% over 2018, to nearly 2.2 GW added (287,504 new systems), for a year-end total approaching 10.4 GW (2.3 million systems).[151] During the year, small-scale systems powered the equivalent of more than 2.6 million households, accounting for 5.3% of the country's total electricity generation.[152] In addition, 22,000 small-scale batteries were installed in 2019, bringing Australia's household storage capacity to more than 1 GWh.[153]

Rapid growth in solar (and wind) generation is transforming Australia's electricity landscape, reducing electricity prices and air emissions while pushing out coal-fired power plants (which are increasingly unreliable and expensive to operate).[154] The vast scale of installations in 2018 and 2019 – well beyond expectations – resulted in an overcrowded grid and connection delays as transmission investment failed to keep up with the growth in renewable energy.[155] By mid-year, grid connections for large projects were increasingly time-consuming and costly (reducing revenue for projects once they were online); this challenge – combined with a lack of clarity about state and federal policies and targets, and the increase in regulatory risks as well as curtailment – led to delayed and cancelled projects, and raised barriers to investment.[156] The rooftop sector also has experienced problems related to the ability of distribution networks to integrate high penetration rates of solar energy with battery technology.[157]

The Australian Energy Market Operator (AEMO) responded by starting to upgrade grids in key regions and by creating renewable energy zones.[158] AEMO also is working on an integrated roadmap for efficient development of the country's national electricity market over the coming decades.[159] By early 2020, frustration over grid congestion led Victoria to break away from national electricity rules to fast-track transmission upgrades and ensure grid-connection for large projects.[160]

The Middle East and Africa also saw substantial solar PV installations in 2019. An estimated 6.7 GW was added for a year-end total of 15.1 GW, an 80% increase in cumulative capacity across these two regions.[161] As in 2018, the largest installer in the Middle East was the United Arab Emirates, which aims to achieve 50% renewable energy by 2050.[162] Commercial operations began at the 1,177 MW Sweihan facility in Abu Dhabi, the world's largest single-site solar project at the time of completion, expected to cover the electricity requirements of 90,000 people.[163] In addition, Dubai allocated the fifth phase (0.9 GW) of its 5 GW Mohammed bin Rashid Al Maktoum Solar Park.[164] At year's end, the United Arab Emirates had more than 1.7 GW of solar PV in operation, including at least 125 MW of rooftop capacity under Dubai's Shams initiative.[165]

Other noteworthy installers in the Middle East included Saudi Arabia, where production began at the country's first grid-connected solar PV plant (0.3 GW Sakaka) in late 2019; Jordan (added 0.6 GW), where at least two large plants were completed and efforts continued towards the goal to install solar PV on all of the nation's 7,000 mosques; and Israel, which completed its largest solar PV park (120 MW) and added a total of 0.8 GW.[166] Kuwait and Oman added large projects to their pipelines, and Iraq launched a tender for 755 MW of capacity.[167] Policy makers in several countries – including Jordan, Oman, Saudi Arabia and the United Arab Emirates – have reduced electricity tariffs and are

starting to prioritise distributed solar PV, particularly in Dubai, but many countries are still struggling to find the right mix of policy, financing and procurement options.[168]

Across Africa, as costs fall, solar PV is viewed increasingly as a means to diversify the energy mix, to meet rising demand while limiting the growth of CO_2 emissions and to provide energy access.[169] But considerable challenges remain, including a lack of suitable financing tools, ongoing subsidies to fossil fuels in many countries as well as social and political unrest in some, a reliance on tenders for new capacity and a race to the bottom in bid prices.[170] Even so, several countries brought projects online during 2019, including the first large plants in Kenya (50 MW), Mozambique (40 MW), Namibia (45 MW) and Zambia (54 MW), among many others.[171] The largest solar PV plant in all of Africa, Egypt's Benban solar complex, became fully operational in late 2019; the facility, covering more than 37 square kilometres of desert and with a capacity of nearly 1.5 GW, is expected to provide electricity to 1 million people.[172] At the other end of the spectrum of scale, several countries saw numerous rooftop and other small-scale systems come into operation during the year. South Africa, for example, had more than 100 MW of rooftop systems by the end of 2019.[173] (→ *See Distributed Renewables chapter for more on access and small-scale solar PV.*)

Many other countries on the African continent held solar PV tenders or had large plants being planned, under construction or commissioned, including Morocco, which had several solar PV-concentrating solar thermal power (CSP) complexes under way.[174] Also in 2019, a plan was unveiled to dramatically expand solar PV (and CSP) capacity in Botswana and Namibia to reduce reliance on energy imports and enable the export of surplus electricity to surrounding countries.[175] Regional efforts also were under way to expand the use of solar PV across the continent.[176] At year's end, Africa's top countries for cumulative solar PV capacity were South Africa with 3.4 GW (added 1 GW), Egypt with nearly 2.3 GW (added 1.65 GW), Algeria with 0.5 GW (no additions) and Kenya (added 0.2 GW for a total of 0.3 GW).[177]

Around the world, even as favourable economics are raising interest in distributed[i] systems, especially for commercial and industrial uses (as well as off-grid), large utility-scale projects continued to dominate the global market for newly installed capacity.[178] (Even the size of distributed systems is trending larger in many countries.[179]) The move towards ground-mounted large-scale systems is due at least in part to the growing use of tenders and auctions, and increasingly also to PPAs, whether in Europe, Australia or new markets such as Vietnam.[180]

Solar PV plants are approaching the scale of fossil-fired power plants as developers aim to drive down the price of solar electricity.[181] The size and number of large projects continued to grow during 2019, with more than 50 solar PV plants of 50 MW and larger completed, and such plants were operating in at least 44 countries[ii] by year's end.[182] Developers commissioned at least 35 projects that were 200 MW or larger.[183] In addition to those mentioned previously, new facilities included a 420 MW solar complex in Vietnam; Spain's 494 MW Mula plant (reportedly Europe's largest solar PV project at year's end); China's largest (500 MW) project without direct financial support (which will compete against coal- and natural gas-fired plants); and India's 2 GW Pavagada Solar Park, which began development in 2016 and was completed in 2019.[184]

Operating capacities of many new **solar PV** plants are approaching the level of fossil-fired power plants as developers aim to drive down the price of solar electricity.

Large-scale ground-mounted plants can cover vast areas, raising concerns about potential environmental impacts, grid-connection challenges and the use of agricultural lands.[185] The potential for rooftop solar systems remains enormous, and many countries, such as India, have established large rooftop programmes and targets.[186] The relatively small market for floating solar also continues its rapid expansion, driven by the limited availability and high costs of land in many places.[187] Floating projects bring new risks and generally higher costs than ground-mounted facilities, but economies of scale in project sizes are helping to reduce associated costs.[188] (→ *See Sidebar 3 in GSR 2019.*)

Most floating solar PV projects are sited in Asia, but they can be found from Africa to Europe to the Americas.[189] During 2019, China completed several large plants, including a 70 MW project at a former coal mining area in Anhui Province; India held a tender for a floating solar PV project (70 MW); Portugal held a tender to seek engineering, procurement and construction contractors for 10 floating solar PV plants (50 MW total) and, in early 2020, Vietnam announced pilot auctions for an eventual 400 MW.[190] Floating projects also are being constructed

i Distributed refers to systems that provide power to grid-connected consumers, or to the grid, but on distribution networks rather than bulk transmission, or off-grid systems. See endnote 178 for this section.

ii Countries that added their first 50-plus MW plants in 2019 include Argentina, Belgium, Colombia, Jamaica, the Russian Federation, Saudi Arabia and Vietnam. See endnote 182 for this section.

offshore, with a pilot project completed off the Dutch coast in the North Sea, and plans were announced for projects off the coasts of the United Arab Emirates, the Republic of Korea and Singapore.[191] A total floating capacity of at least 2.4 GW was expected to be operating in 35 countries by year's end, with projects completed or under way in almost every region.[192]

Other niche markets that minimise land requirements include building-integrated PV, which is progressing only slowly (a highlight in 2019 being a new high-rise building in China with a 460 kW façade), and the emergence of plans among mainstream auto manufacturers, particularly in Asia, to incorporate solar cells into electric vehicles.[193] Agricultural PV[i] also is an emerging sector that can address concerns associated with land use, especially with the growing availability of bifacial systems (see later discussion).[194] Several studies have highlighted the advantages, including improved crop yields, reduced evaporation, rainwater harvesting (with modules), provision of shade for livestock and prevention of wind and soil erosion, as well as additional income for farmers from electricity production.[195] In 2019, a total of more than 2.9 GW of capacity was operating in Japan and elsewhere, and plans were announced for new projects, including a 1 GW agricultural PV livestock farming project in Malaysia.[196]

SOLAR PV INDUSTRY

The year reflected a dichotomy of perspectives on the health and prosperity of the solar PV industry. On the one hand, competition drove declining prices, which in turn opened new markets, while the pressure of lower prices and expectations of rising global demand encouraged expanded and more efficient manufacturing, the entrance of new companies into the sector and ongoing pursuit of innovation. On the other hand, the relentless competition, coupled with policy vagaries and uncertainty, prompted highly competitive bids at some auctions – resulting in razor-thin margins for some developers and manufacturers – and contributed to ongoing consolidation.

Globally, solar PV prices continued to decline in 2019.[197] The price of modules fell around 12% during the year, to a world average of USD 0.36 per watt, but with significant variations in price from country to country.[198] A ramp-up in manufacturing along the supply chain in recent years, due to overly optimistic expectations about global demand growth (particularly in China), held down prices for polysilicon, wafers, cells and modules.[199] Innovations and improvements in design and operation also helped to reduce operations and maintenance (O&M) costs.[200] By one estimate, the global benchmark levelised cost of electricity (LCOE) from solar PV declined 17% relative to 2018.[201]

Tenders and auctions saw bid prices[ii] drop to new lows in 2019, and in some countries they fell below the average price of wholesale electricity.[202] The average bid price across all markets was close to USD 30 per MWh, but bids below USD 20 per MWh became more common towards year's end.[203]

The lowest bid prices were seen in Brazil, Dubai (United Arab Emirates) and Portugal. In Brazil's A-6 auction, solar PV came in with the most competitive final average electricity price among all competing technologies (including wind power and natural gas) at BRL 67.48 (USD 16.48) per MWh.[204] Dubai allocated 0.9 GW of capacity at a price of USD 16.95 per MWh, and Portugal awarded 1.29 GW with a world-record low bid of EUR 14.76 (USD 16.53) per MWh.[205]

Time will tell if the lowest bids will be viable. Outside of locations with a low cost of finance, open desert and excellent solar resources, such as Dubai, a broad range of experts believe that very low bids, such as Portugal's winning price, are possible only because firms made overly optimistic assumptions about future cost reductions (ahead of project construction) or plan for merchant sales at the end of the contract period, betting on the merchant price (until the end of project lifetime) to supplement revenues.[206] Several record-setting low bid prices in Brazil's auctions were made by developers planning to sell at least some of their electricity into the wholesale market.[207]

Direct bilateral PPA prices also reached new lows in 2019 and in early 2020.[208] In the United States, PPA prices were in the range of USD 16 to USD 35 per MWh, and solar PV-plus-storage achieved

i Agricultural PV is defined as use of the same site for both energy and crop production. See endnote 194 for this section.

ii Bid prices do not necessarily equate with energy costs. Also, energy costs vary widely according to solar resource, project size, regulatory and fiscal framework, customer type, the cost of capital and other local influences. Distributed rooftop solar PV remains more expensive than large-scale solar PV but has followed similar price trajectories, and is competitive with (or less expensive than) retail electricity prices in many locations. See endnote 202 for this section.

a new record low in the country of USD 40 per MWh for the Eland project[i] in California's Mojave Desert, which should be operational by 2023.[209] In January 2020, a PPA was signed in Qatar for 800 MW at QAR 57.1 (USD 15.8) per MWh, one of the lowest prices ever recorded.[210] Agreement periods are shortening in Australia, Germany, the United States and elsewhere, with price trajectories flattening (at least in Australia and the United States), and several markets have begun shifting towards the merchant model.[211]

New lows in auction prices, resulting from intense competition (with some instances of bidding below marginal costs to win tenders) – in some cases driven by policy design – constrained margins and brought further consolidation in the industry.[212] Among the casualties in 2019: China-based module manufacturer Hareon Solar was forced into bankruptcy liquidation; Suntech (China), once the leading global manufacturer, again came up for sale or liquidation; another former world leader, Yingli (China), continued to lose money, following several difficult years; Panasonic (Japan) transferred a solar module manufacturing subsidiary in Malaysia to GS-Solar (China), as part of an effort to return its solar business to profitability; Moser Baer Solar (India) began liquidating its assets; and several solar-related companies in Chinese Taipei consolidated to survive through economies of scale.[213]

By contrast, many Chinese cell and module manufacturers benefited from record-low prices for polysilicon, solar wafers and cells, as well as from strong demand from most regions around the world.[214] LONGi, for example, saw both its revenues and net profit rise in 2019, with further improvements in the first quarter of 2020.[215] LONGi and other top-tier vertically integrated companies were able to cope with price declines by expanding production to take advantage of lower costs of new equipment and economies of scale, in some cases through joint partnerships.[216] For example, LONGi and Tongwei signed a strategic co-operation agreement to support each other's supply chains, following on earlier joint ventures and agreements; and GCL-Poly and Zhonghuan Semiconductor announced a plan to further their co-operation by increasing joint manufacturing capacity.[217]

Many companies achieved or announced significant increases in production capacity in 2019, reflecting optimism about future market growth, efforts to maintain market share, as well as policies to promote local manufacturing.[218] By the end of 2019, global crystalline and thin-film cell production and module assembly capacities[ii] were estimated to be 153.1 GW (cell) and 185 GW (module), respectively, up 35% and 29% over 2018.[219]

Much of the expansion occurred in China.[220] China has dominated production and global shipments of solar PV cells and modules since 2011, which means the country also has dominated the prices of cells and modules, influencing the margins that other manufacturers receive.[221] This continued to be the case in 2019. During the year, 123.5 GW of cells and modules were shipped worldwide (up 39% over 2018), mostly from manufacturers in Asia, and particularly China.[222] Of the estimated 78 GW of cell/module volume shipped by the top 10 suppliers, over 80% was shipped by Chinese firms, with the others representing equal shares of the remaining volume and hailing from the Republic of Korea (Hanwha Q-Cells), Chinese Taipei (UREC) and the United States (First Solar).[223]

The solar PV industry **remained vulnerable** to turbulence in some countries, and particularly in China.

The solar PV industry remained vulnerable to turbulence in some countries (the list of countries changing annually), and particularly in China.[224] In China and elsewhere, policy uncertainty as well as policies that are stop-go or poorly designed – including cancelled or postponed auctions – hampered the industry.[225] The industry also was challenged by unreliable or insufficient grid infrastructure (often the reason for revisions to policies and targets), particularly in emerging markets.[226]

Trade policies also continued to affect the solar PV industry in 2019.[227] (→ *See Sidebar 3 in Policy Landscape chapter.*) India imposed new duties on product imports from several other Asian countries and from Saudi Arabia as part of the push towards domestic manufacturing.[228] US tariffs imposed in 2018 on nearly all major sources of solar PV imports, as well as on steel and aluminium[iii], were in place throughout 2019.[229] The United States added tariffs on Chinese solar inverters, and removed India from duty-free status for many products, including solar cells and modules.[230] In addition to tariffs on imports, several countries had measures in place to encourage local production or to penalise the use of foreign-made products.[231]

During the year, the US International Trade Commission found that US tariffs had boosted module manufacturing in the country – including new module plants set up by Hanwha Q-Cells and LG (both Republic of Korea), and by China's Jinko Solar – but had failed to halt the decline of domestic cell makers.[232] The Commission also found that tariffs had softened solar price declines in the United States compared to those experienced globally.[233] Bifacial panels were granted exemption from US import tariffs in June (with a temporary reversal in October[iv]), and US demand for bifacial panels soared in an effort to evade tariffs and improve project efficiency, as well as to stockpile modules to qualify for the 30% federal investment tax credit[v],[234]

i The project includes 400 MW of solar PV capacity and 300 MW/12,000 MWh of energy storage capacity. See endnote 209 for this section.

ii Cell capacity is MW or GW of semiconductor (cell) capacity available to a manufacturer; module assembly capacity is that available to assemble cells into modules.

iii Tariffs on imports of these metals are significant because they are used to manufacture balance-of-systems equipment.

iv In April 2020, a decision was made to remove the exemption again, effective as of 18 May 2020; the tariffs are due to end in 2022.

v The US solar "safe harbor agreement" governs when a solar PV project qualifies for the ITC. Projects that began construction before the end of 2019 qualify for the full 30% credit, which started to step down in 2020. To qualify, one option was to incur 5% of the total cost of a project before the end of 2019, and the easiest way for developers to do that was to buy up panels and inverters.

In spite of the challenges faced by some actors in the solar PV industry, new companies continued to enter in.[235] For example, most of the largest wind power developers in the United States have expanded into solar PV and energy storage, and similar trends are seen in China, India and elsewhere.[236] Oil and gas giants, particularly Europe-based companies, are moving into solar project development and operation, and using solar PV to power their operations around the world.[237]

Competition and price pressures have encouraged investment in solar PV technologies, particularly in cells and modules.

In addition to driving the construction of new, more-efficient manufacturing facilities, competition and price pressures have encouraged investment in solar PV technologies across the entire value chain, and particularly in solar cells and modules, to further improve efficiencies and reduce the LCOE.[238] New record cell and module efficiencies were achieved during 2019.[239] Monocrystalline[i] cell technology, which lost its lead to multicrystalline in 2002, raced ahead for the majority share of global shipments.[240]

Demand for higher-efficiency modules has steered a shift towards Passivated Emitter Rear Cell (PERC)[ii] technology and the next generation of technologies.[241] PERC has become the new standard for the monocrystalline silicon solar cell variety because it increases efficiencies, making it an economically attractive option for many projects.[242] Manufacturers of PERC (particularly China's LONGi) have invested heavily in its commercialisation.[243]

While monocrystalline PERC is the focus of most capacity expansions, and substantial commercial capacity came online in 2019, the industry is already looking beyond PERC.[244] In 2019, several manufacturers were converting or building new factories to produce heterojunction cell technology[iii] (HJT), which offers higher efficiencies and occurs at low temperatures and with fewer production steps than other high-efficiency cell technologies.[245] A number of China-based companies were actively looking into HJT, and some had small production lines in operation.[246] European manufacturers were considering HJT (and other technologies) as an option to regain market share.[247] In late 2019, REC (Norway) started production at a HJT cell and module facility in Singapore.[248]

Researchers also were working to overcome the theoretical efficiency limits of silicon-based solar cells by stacking cells of different types and developing new, more efficient cell technologies.[249] Perovskites[iv], in tandem with crystalline silicon or a thin-film base, are attracting substantial research dollars and seeing increasing efficiencies.[250] Researchers continued to focus on the long-term stability of perovskites, lead content and other challenges during the year.[251] By one estimate, more than a dozen companies worldwide were working on perovskites in 2019 with aims to sell panels soon (although some also pulled out of the market).[252]

Improvements in cell technology and module design have enabled the development of modules with higher power ratings.[253] In 2019, for example, SunPower (United States) launched the industry's most powerful residential panel, at 400-plus watts, and Canadian Solar unveiled what it claimed was the first poly bifacial module of 400-plus watts for large projects.[254] Raising the power rating increases electricity output per module, thereby reducing the number needed for a project, meaning that less space is required and associated land, installation and other costs are reduced.[255]

Bifacial modules, which can capture light on both sides, also offer potential gains in output (and thus a lower LCOE) – with even greater performance gains if used in installations with trackers[v] – although there are ongoing uncertainties about real-world performance.[256] The scale of bifacial exports from China (the largest manufacturer of and market for bifacial panels) and the geographical distribution of demand increased considerably

i Crystalline technologies account for nearly all cell production. Historically, monocrystalline cells have been more expensive but also more efficient (more power per unit of space) than multi- or poly-crystalline cells, which are made of multi-faceted or multiple crystals. See endnote 240 for this section.

ii PERC is a technique that reflects solar rays to the rear of the solar cell (rather than being absorbed into the module), thereby ensuring increased efficiency as well as improved performance in low-light environments.

iii HJT combines advantages of conventional crystalline silicon solar cells with good absorption and other benefits of amorphous silicon thin film technology.

iv Perovskite solar cells include perovskite (crystal) structured compounds that are simple to manufacture and are expected to be relatively inexpensive to produce. They have achieved considerable efficiency improvements in laboratories, with reports of about 3% in 2006 to more than 24% in 2019, and 28% was achieved in a silicon-based tandem cell in 2018. See endnote 250 for this section.

v Trackers enable panels to track the movement of the sun. More and more large ground-mounted projects are using trackers because they flatten the production curve and increase yield. See endnote 256 for this section.

in 2019 thanks to improvements in cell technology.[257] Several manufacturers announced plans to ramp up bifacial production or launched new products in 2019.[258]

Operators are playing a growing role in project development, working to maximise generation and to reduce the LCOE as direct government support declines and solar assets become exposed to market prices.[259] Plant operations are increasingly digital and automated as rising competition pushes companies to further reduce costs, improve system performance and integrate energy storage.[260] Digitalisation, thanks in large part to advances in inverter[i] technology, is helping to improve performance (for example, through predictive maintenance, remote sensing and control, satellite and ground-based as well as numerical solar forecasting schemes) and to provide grid services such as ramping capability and frequency regulation in order to support grid reliability.[261] (→ *See Systems Integration chapter.*)

Remote maintenance and control technologies are improving efficiency and reducing O&M costs as well as outage times.[262] Drone technologies are allowing operators to access and analyse performance data via remote thermographic imaging of facilities.[263] Interest in robotic cleaning is increasing in India, Israel and elsewhere to reduce labour and other costs, save water and improve efficiency.[264] In addition, research is under way to develop surface coverings that can reduce dust deposition on solar panels, an advance that improves system performance and lowers cleaning costs in dusty environments.[265]

Even as solar PV technologies and operations continue to advance, there is concern that low tender bidding and resulting low margins have negatively affected quality along the entire value chain.[266] Poor quality – from product manufacturing and shipping, to project design and construction, to the commissioning and O&M stages – is a concern in a number of countries, as manufacturers feel pressure to cut corners in production or quality control and as developers seek the lowest-cost products.[267] There are many areas where problems can enter in – particularly in emerging markets with rapid deployment as well as political and policy uncertainty.[268] Although the volume of related literature is increasing, there is still limited understanding of the issues involved, and several countries continue to lack quality standards and regulations.[269]

To address some of these quality-related concerns, in 2019 India's Ministry for New and Renewable Energy approved a series of guidelines for solar inverters under a quality control order that was first introduced in 2017.[270] In Bangladesh, concerns about imports of sub-standard products that are threatening sustainability of the domestic market led the national government to introduce minimum quality standards on solar modules, inverters, charge controllers and batteries.[271] Australia made significant progress on a new consumer code to establish minimum standards for consumer protection and good practice for solar PV, batteries and other emerging products and services.[272] Also in 2019, global standards-making organisations continued working to establish rigorous standards for improving the quality of module production and system installation.[273]

Industry efforts to further advance environmental sustainability also continued in 2019. While the technical lifetimes of solar panels can be up to 25-40 years, the volume of decommissioned panels in the coming decade is expected to be large, and research into second-life (reuse) and end-of-life (recycling) options was ongoing in many countries during the year.[274] PV Cycle (France) collected more than 280,000 solar PV panels for recycling.[275] Also in 2019, Jinko Solar, the world's top module manufacturer, became the first solar PV manufacturer to join RE100, pledging to source all of its energy from renewable sources, aiming for 70% by 2023 and 100% by 2025.[276] It was followed, in early 2020, by LONGi, which committed to 100% renewable electricity across its operations by 2028.[277]

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

KEY FACTS

- Global CSP capacity in operation again grew exclusively in emerging markets and spread to new countries including Israel, Kuwait and France.
- An estimated 21 GWh of thermal energy storage was operating in conjunction with CSP plants across five continents.
- Levelised costs of energy from CSP continued to decline, with CSP being built increasingly alongside both solar PV and wind power to lower costs and raise capacity value.

CONCENTRATING SOLAR THERMAL POWER (CSP)

CSP MARKETS

Global CSP[i] capacity grew 11% in 2019 to 6.2 GW[ii], with 600 MW of capacity coming online.[1] This was down from the 700 MW commissioned in 2018 and well below the average annual increase (24%) of the past decade.[2] (→ *See Figure 32 and* ***Reference Table R17.***) However, CSP continued to spread to new markets, and more than 1.1 GW of additional capacity was under construction at year's end.[3]

Five countries brought new CSP plants into operation during the year: Israel led the market in new additions, followed by China, South Africa, Kuwait and France.[4] Israel, Kuwait and France saw the implementation of their first commercial CSP capacity.[5] For the fourth consecutive year, all new CSP capacity came online outside of Spain and the United States, the two leading countries for cumulative capacity since the technology was first commercialised in the 1980s.[6]

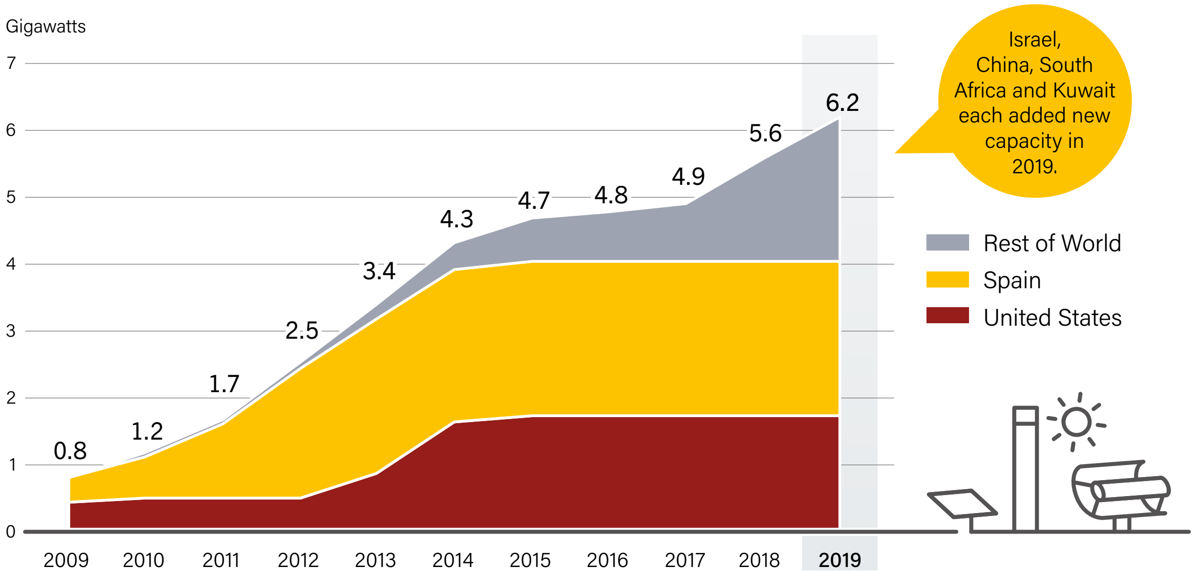
For the first time, as much tower capacity as parabolic trough capacity was completed in 2019.[7] Each of these technologies represented around 45% of total additions, and linear Fresnel plants accounted for the remaining 10%.[8] However, parabolic trough plants continue to represent the majority of total global installed capacity. At year's end, the plants under construction worldwide included just under 0.9 GW of trough systems, just under 0.3 GW of tower systems and a 14 MW Fresnel system.[9] With the exception of two hybrid CSP-natural gas plants[iii], all of these plants will include thermal energy storage (TES).[10]

i CSP is also known as solar thermal electricity (STE).

ii GSR 2019 reported that the 150 MW Noor III CSP plant in Morocco entered operations in early 2019. Subsequent reports have indicated that the plant is considered to have begun commercial operations in late 2018. This edition of the GSR has revised CSP market data accordingly. See endnote 1 for this section.

iii The two plants without TES are integrated solar combined-cycle (ISCC) facilities, hybrid plants that use both solar energy and natural gas to produce electricity.

FIGURE 32. Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2009-2019



Source: See endnote 2 for this section.

Israel added more CSP capacity than any other country in 2019, bringing online 242 MW, including the 121 MW Megalim tower plant (no TES) and the 121 MW Negev parabolic trough plant with molten salt storage (4.5 hours; 495 MWh).[11] The projects are Israel's first two commercial CSP facilities and the country's largest renewable energy plants of any type.[12] The Megalim project also includes the world's tallest solar tower, at 240 metres high.[13]

China followed with a total of 200 MW of capacity completed in four CSP plants of 50 MW each, all with molten salt TES.[14] The projects include the Dacheng Dunhuang Fresnel plant (13 hours; 650 MWh), the Power Qinghai Gonghe tower plant (6 hours; 300 MWh), the CPECC Hami tower plant (8 hours; 400 MWh) and the Luneng Haixi tower plant (12 hours; 600 MWh).[15] The first three of the new plants are among 20 CSP "demonstration"[i] plants that were announced by China's National Energy Administration in 2017; 5 of the plants were operational at the end of 2019.[16] The plants completed during the year brought the country's total CSP capacity to 420 MW.[17] At year's end, China had an additional 250 MW of both parabolic trough and tower capacity under construction, in parallel with 2.4 GWh of TES.[18]

In South Africa, the 100 MW Kathu parabolic trough plant (4.5 hours; 450 MWh) entered commercial operations, bringing the country's total installed CSP capacity to 500 MW.[19] An additional 100 MW of tower capacity was approaching construction during 2019.[20] However, further development of the South African CSP sector was in doubt following the release in late 2019 of the country's Integrated Resource Plan (IRP), which makes no capacity allocations for CSP before 2030.[21]

Kuwait brought its first CSP capacity online with the opening of the 50 MW Shagaya parabolic trough plant (9 hours; 450 MWh).[22] This is the first phase of a planned 3 GW renewable energy park that will incorporate multiple renewable energy technologies, including wind power and solar PV.[23]

The Shagaya plant is part of a growing market in the Middle East and North Africa (MENA) region, where 15 plants totalling almost 1.8 GW accounted for nearly 30% of global capacity in operation at the end of 2019.[24] Capacity in the region is expected to increase significantly with completion of the Noor 1 Energy project under construction in the United Arab Emirates.[25] The Noor 1 project will include 700 MW of CSP capacity, consisting of three 200 MW parabolic trough plants and a 100 MW tower plant, coupled with 15 hours of storage capacity.[26]

The smallest CSP plant to reach commercial operations in 2019 was the 9 MW eLLO Fresnel plant (4 hours; 36 MWh), the first commercial CSP facility in France.[27] Although no other commercial CSP projects were being built in Europe during the year, a Chinese consortium was selected for the engineering, procurement and construction of a 52 MW (5 hours; 260 MWh) tower project on the Greek island of Crete; the project is planned for operation in 2020.[28]

In addition, construction continued on the 110 MW Cerro Dominador project in Chile (17.5 hours TES).[29] Construction began in 2014 and has been hampered by delays, but the plant was expected to be operational in 2020.[30] Despite significant past CSP development activity, Cerro Dominador remains the only CSP plant in Chile to have passed the development phase and entered construction.[31]

i While the GSR generally excludes pilot and demonstration facilities from the CSP market data, the Chinese demonstration plants are included due to their scale and the fact that they are being grid connected.

For cumulative capacity in operation, Spain remained the global leader with 2.3 GW at the end of 2019, followed by the United States with just over 1.7 GW.[32] With no new capacity additions in six years, Spain's share of global CSP capacity in operation declined from a high of nearly 80% in 2012 to just under 40% by the end of 2019.[33] The United States, which has added no new CSP capacity since 2015, was home to just under 30% of global CSP capacity by the end of 2019.[34] Neither country had new facilities under construction at year's end, although the Spanish government announced plans to increase installed capacity 5 GW by 2030.[35]

All of the commercial CSP capacity under construction by the end of 2019 was in Asia (China and India), the Middle East (United Arab Emirates and Saudi Arabia) and Latin America (Chile).[36] The pipeline of CSP projects under construction reached around 1.1 GW, with the United Arab Emirates accounting for more than 60% of this capacity.[37]

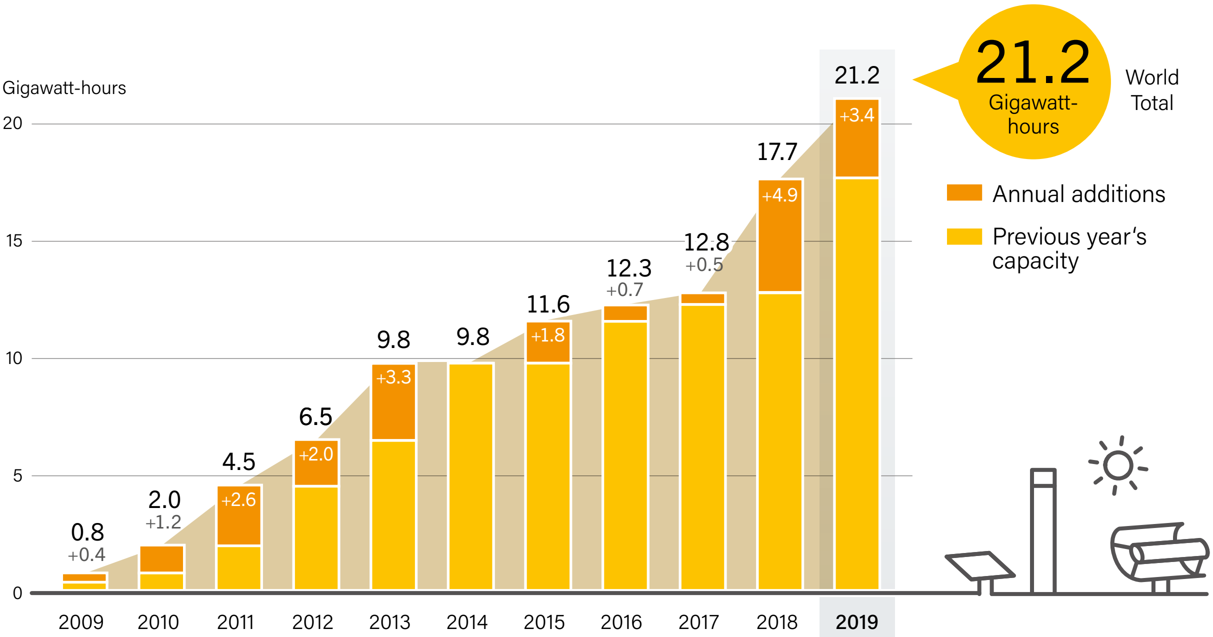
Nearly all of these projects will include thermal energy storage, which improves plant economics and increases system benefits – such as providing relatively dispatchable electricity and grid flexibility – which can support the integration of higher shares of variable renewable electricity in power systems.[38] (→ *See Systems Integration chapter.*)

At the end of 2019, an estimated 21 GWh[i] of TES, based almost entirely on molten salts[ii], was operating in conjunction with CSP plants across five continents.[39] (→ *See Figure 33.*) Of the 23 CSP plants completed globally since the end of 2014, only two do not incorporate TES: an ISCC facility in Saudi Arabia and the Megalim plant in Israel.[40]

i The total TES capacity in MWh is derived from the sum of the individual storage capacities of each CSP facility with TES operational at the end of 2019. Individual TES capacities are calculated by multiplying the reported hours of storage for each facility by their corresponding rated (or net) power capacity in MW.

ii More than 95% of global TES capacity in operation on CSP plants is based on molten salt technology. The remainder use steam-based storage.

FIGURE 33. CSP Thermal Energy Storage Global Capacity and Annual Additions, 2009-2019



Note: Totals may not add up due to rounding.

Source: See endnote 39 for this section.

CSP INDUSTRY

The CSP industry has become increasingly diverse geographically, in terms of the location of commercial plants as well as the origins of developers, investors and contractors involved in project implementation. CSP projects that either entered operations or were under construction during 2019 involved lead developers and investors from at least eight countries including China, France, Israel, Kuwait, Saudi Arabia, Spain, the United Arab Emirates and the United States.[41] Contractors were based in China, Denmark, Israel, Spain and the United States, with Chinese companies involved in almost half of the completed or active projects.[42] By contrast, before 2015 most CSP companies hailed from the United States and Spain.[43]

The Saudi company ACWA Power remained the leading CSP project developer in 2019, with around 700 MW of projects under construction.[44] Other notable developers, investors or owners of CSP plants that either entered operations or were under construction during the year included EIG Global Partners (United States), ENGIE (France), Royal Tech (China), Noy Fund and Shikun & Binui (both Israel), as well as at least 13 other developers from around the world.[45]

The leading companies involved in the engineering, procurement and construction of CSP facilities (ranked in terms of megawatts completed and/or under construction) included Abengoa (Spain), Shanghai Electric (China), Acciona (Spain), General Electric (United States), Sener (Spain), Brightsource (Israel) and China Shipbuilding New Power Company (China).[46]

With the spread of markets around the world, the broadening of supply chains and increasing experiences in the industry, costs have continued to fall.[47] Lower total installed costs combined with longer or more flexible power purchase agreements and higher capacity factors (thanks largely to including TES and the shift towards locations with better resource conditions for CSP) have reduced the cost of electricity from CSP.[48]

A 2019 study estimated that the global weighted average levelised cost of electricity (LCOE) of CSP in 2018 (USD 18.5 per MWh) was 26% lower than it was in 2017, and 46% lower than in 2010.[49] Another study from 2019 estimated that the average LCOE of new CSP capacity with storage was lower than the average LCOE of new natural gas peaking plants under certain circumstances.[50] Despite these advances, developers of CSP with TES faced strong competition from projects coupling solar PV and wind power with battery storage, which were increasingly prevalent in 2019.[51] (→ *See Systems Integration chapter.*)

In many cases CSP and TES capacity are being combined with solar PV and/or wind power capacity in hybrid facilities to lower costs and increase capacity value. For example, Israel's Megalim and Negev CSP plants each are located alongside solar PV plants, and China's new 50 MW Luneng Haixi plant forms part of a 650 MW renewable energy complex that also includes 200 MW of solar PV and 400 MW of wind power capacity, plus 50 MW of storage capacity.[52] The 110 MW Cerro Dominador plant in Chile will incorporate 17.5 hours of TES alongside an existing 100 MW solar PV plant.[53]

In 2019, a hybridised project in Morocco that will combine CSP, solar PV and energy storage was awarded by the Moroccan Agency for Sustainable Energy at a tariff of MAD 680 (USD 68) per MWh.[54] Contractual agreements for the United Arab Emirates' Noor Energy 1 project, which will combine 700 MW of CSP capacity with 8.1 GWh of TES and 250 MW of solar PV capacity, were finalised in early 2019 based on a CSP tariff of USD 73 per MWh in parallel with a solar PV tariff of USD 24 per MWh.[55]

CSP capacity has been combined with solar PV and/or wind power capacity in hybrid facilities to lower electricity generation costs.

Also in 2019, a range of R&D activities were under way that aimed to further reduce the costs of CSP. Some of this work focused on increasing system operating temperatures in order to unlock greater thermal energy efficiencies[i]. For example, a partnership between the French utility EDF and Chinese CSP technology company Shouhang aimed to convert an existing CSP demonstration project from using a steam cycle for thermal power generation to using a closed-loop supercritical CO_2 cycle, which is capable of higher operating temperatures.[56]

In the United States, a government-backed programme at Sandia National Laboratories was focused on developing a CSP central receiver that is capable of operating at temperatures above 1,000 °C, allowing for greater heat concentration.[57] Also in 2019, the US Department of Energy announced USD 30 million in support for 13 research projects, with the goal of improving CSP economics by reducing manufacturing costs, developing new storage technologies and allowing for more autonomous system operations.[58]

R&D attention during the year also was focused on addressing the environmental impacts of CSP. In Europe, for example, researchers were evaluating novel ways to reduce water consumption for heliostat cleaning through the development of ultrasonic cleaning systems and hydrophobic[ii] coatings.[59]

i Higher operating temperatures can enable greater thermodynamic efficiency in the heat transfer processes that are involved in steam-based power generation.

ii Hydrophobic coatings repel water that otherwise might collect on the surface of the heliostat and absorb dust particles from the surrounding air.

KEY FACTS

- China remained the world's largest national market for solar thermal systems, followed distantly by the United States, Turkey, Germany and Brazil.
- Outside China, new additions in the largest solar heating and cooling markets were stable, with growth in some markets balancing declines in others.
- The year saw record-high additions of solar industrial heat capacity, led by Oman, China and Mexico.
- The largest collector manufacturers stabilised their production volumes on average, but small and medium-sized collectors faced increased pressure.

SOLAR THERMAL HEATING AND COOLING

SOLAR THERMAL HEATING AND COOLING MARKETS

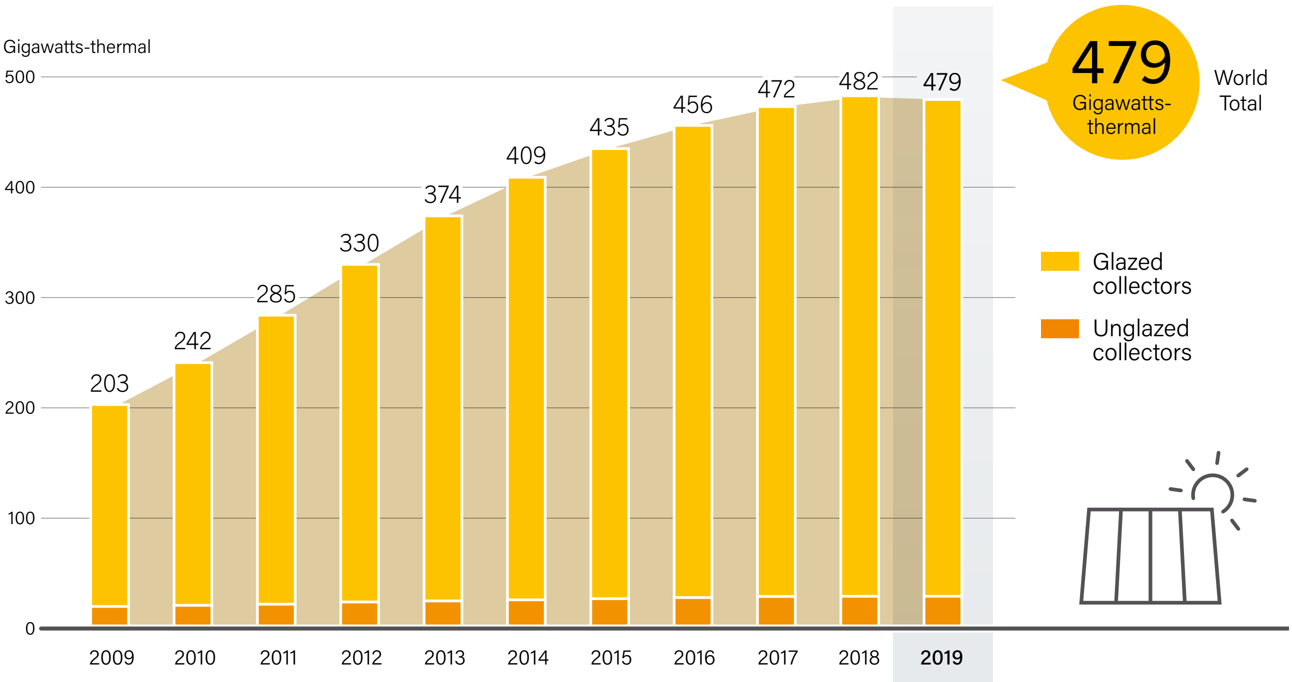
Solar thermal heating and cooling systems served millions of residential, commercial, industrial and public clients in 2019. By year's end, the systems had been sold in at least 134 countries for use in a wide range of applications including hot water, space heating and cooling, product drying and water desalination.[1]

An estimated 31.3 gigawatts-thermal (GW_{th}) of glazed (including flat plate and vacuum tube technology) and unglazed solar collectors was added globally in 2019, and by year's end a total of an estimated 479 GW_{th} was in operation.[2] These three types of solar thermal collectors provided around 389 terawatt-hours (TWh) (1,402 petajoules, PJ) of heat annually by the end of 2019 – equivalent to the energy content of 229 million barrels of oil.[3]

For the first time ever, the estimated cumulative global operating solar thermal capacity declined in 2019, down 1% from the previous year's total of 482 GW_{th}.[4] (→ *See Figure 34 and* ***Reference Table R18.***) The drop is attributed to insufficient new additions in China to meet or exceed the capacity of systems that were retired during the year[i,5] China remained the world's largest national market for solar thermal systems, accounting for 69% of cumulative world capacity, followed distantly by the United States, Turkey, Germany and Brazil.[6] Not including China, global capacity increased 3% to an estimated 148 GW_{th} in 2019, up from 144 GW_{th} in 2018.[7]

i The service life of systems operating in China is assumed to be 10 years. In 2019, the new capacity installed in the country (22.8 GW_{th}) was less than the capacity added 10 years earlier, in 2009, when 29.4 GW_{th} was put in operation.

FIGURE 34. Solar Water Heating Collectors Global Capacity, 2009-2019



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

Source: IEA SHC. See endnote 4 for this section.

In addition to the three main collector types, other technologies such as hybrid, concentrating and air collectors are available to meet specific heat needs. Because annual additions of these technologies are small, they are not yet included in global and national capacity statistics. As of the end of 2019, hybrid or solar PV-thermal technologies provided 608 MW_{th} of thermal capacity (as well as 208 MW of electric power capacity) for space and water heating.[8] In addition, around 554 MW_{th} of concentrating solar thermal capacity provided hot water or steam for commercial and industrial customers.[9] An estimated 1.1 GW_{th} of air collectors for drying and space heating was in operation at the end of 2018 (latest data available).[10]

China again led the world for new installations of glazed and unglazed collectors – accounting for 73% of the total – followed by Turkey, India, Brazil and the United States.[11] The top 20 countries accounted for 94% of global additions in 2019.[12] Global newly commissioned capacity in 2019 (31.3 GW_{th}) was down 7% from 2018, due mainly to an 8% contraction in China.[13] Outside China, new additions in the largest solar heating and cooling markets remained stable in 2019, with growth in Brazil, Cyprus, Denmark, Greece, South Africa and Tunisia balancing declines in Australia, Austria, Germany, Israel, Italy, Poland and Switzerland.[14] (→ *See Figure 35.*)

Among glazed collectors, the transition from vacuum tube to flat plate accelerated in 2019, driven by high demand for flat plate units in China's building industry. Flat plate collectors dominated in the largest European markets and reached a 28% market share in the world's 20 largest solar thermal markets (up from 24% in 2018).[15] The share of vacuum tube collectors among new additions in the 20 largest markets fell to 67% in 2019, from 72% in 2018, although vacuum tube units still represented more than 75% of new installations in China and India and about 50% in Turkey.[16]

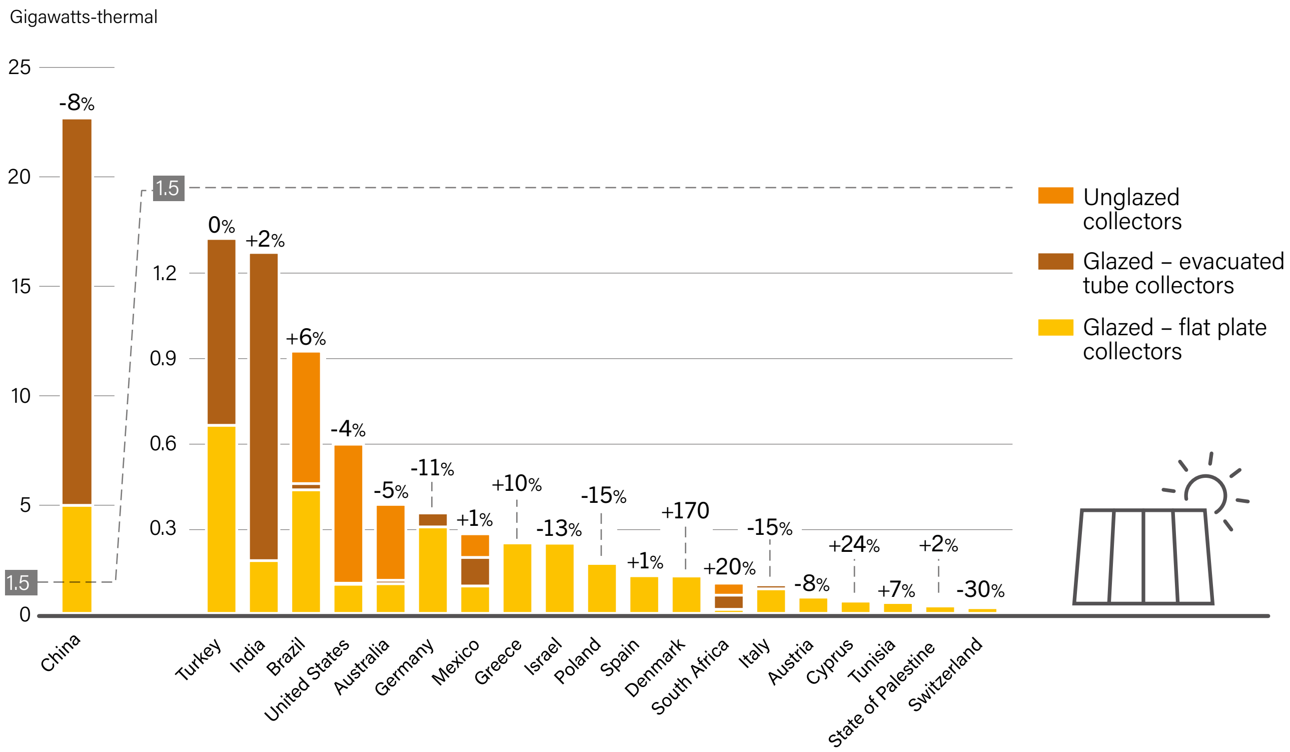
The market share of unglazed collectors, commonly used to heat swimming pools, increased slightly in 2019, to 5%.[17] Unglazed collectors accounted for more than half of all new installations in Australia, Brazil and the United States.[18]

Despite remaining the world's largest installer of solar thermal technologies, China's market has declined 8% annually on average since its record year of 2013.[19] New installations in China in 2019 totalled 22.8 GW_{th}[i], 17 times more than those in Turkey, the second largest market.[20] Shandong was the top Chinese province for both production and installation of solar collectors for the eighth year in a row, followed by Zhejiang and Yunnan.[21] Although sales of vacuum tube collectors fell 13% in China in 2019, demand for flat plate collectors rose 15%, for use on high-rise balconies and for large central hot water systems.[22]

The transition continued in China from small residential solar thermal units to large projects for multi-family residences, tourism and the public sector, with large projects accounting for 74% of Chinese capacity additions in 2019, up from 61% in 2015.[23]

i New additions in China were based on produced collector area, and included export volumes in the national statistics for 2019 and earlier years. The export volumes for previous years were not known at the time of publication, and to the extent possible GSR 2021 will reflect corrected statistics.

FIGURE 35. Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2019



Note: Additions represent gross capacity added.

Source: See endnote 14 for this section.

MARKET AND INDUSTRY TRENDS

In many provinces and cities, authorities called on businesses and industry to abide by existing solar building codes by installing solar hot water systems in new and refurbished buildings.[24] Tenders for solar thermal in the construction business represented three-quarters of China's total market volume in 2019.[25]

China saw only limited progress in the use of solar thermal systems for space heating and for industrial and agricultural processes, with 282 MW_{th} installed in the first half of 2019.[26] A key reason for the slow growth was the preference in "green" heating policies for stand-alone heat pumps rather than solar thermal systems to replace coal boilers in the northern provinces. Concerns have arisen around overheating associated with large solar space heating fields during the summer months, as well as the need for an auxiliary heating device and the limited experience of users in operating solar space heating systems.[27]

Turkey's market remained stable in 2019, and the country's 1.32 GW_{th} of new installations was divided roughly equally among flat plate and vacuum tube collectors.[28] Flat plate sales were buoyed by public orders for central hot water systems in hospitals, prisons and refugee camps. Vacuum tube collectors were sold in the residential market and mainly in the colder regions of Turkey (such as middle and eastern Anatolia), as well as for replacement of existing solar water heaters.[29]

Following two years of double-digit expansion (18% in 2018 and 26% in 2017), India's market grew 2% in 2019, with 1.27 GW_{th} of new installations.[30] Vacuum tube collectors again dominated sales – representing 85% of additions – but their share of the market declined relative to 2018 as sales remained stable.[31] Meanwhile, sales of flat plate collectors increased as several tenders prioritised certified collectors, which according to Indian standards apply only to flat plate units.[32]

Three Indian states – Karnataka, Gujarat and Maharashtra – accounted for nearly 90% of the country's additions in 2019.[33] Karnataka remained the leading state, with almost half of newly installed solar thermal systems, and Gujarat overtook Maharashtra to account for around 20% of total sales in 2019.[34] Gujarat's strong growth is attributed to high awareness of solar energy across the state in cities as well as increasingly in semi-urban areas and villages.[35]

Brazil added 0.93 GW_{th} of solar thermal capacity in 2019, up 6% from the previous year.[36] The growing construction industry and increasing demand from new commercial customer groups with high hot water demand – such as restaurants, spas and laundries – contributed to this surge, which followed four years of continuously declining sales in the country.[37]

The United States was the fifth largest market for the three main types of solar thermal collectors in 2019 (600 MW_{th}) and was the largest market for unglazed collectors (487 MW_{th}).[38] The unglazed segment, used mainly to heat swimming pools, accounted for 81% of US additions.[39] The smaller glazed segment remained stable in 2019, following an 8% decline in 2018, despite continuing low oil and natural gas prices and an increasing domestic focus on solar PV.[40] Hawaii's solar obligation and the California Solar Initiative's solar thermal rebate programme, which is set to expire in July 2020, helped to stabilise sales.[41]

The European Union (EU-28) remained the second largest regional market after Asia, with estimated gross additions of 1.5 GW_{th} in 2019, down 1.8% from 2018.[42] More than 10 million solar thermal systems were in operation by year's end.[43] The decline in sales is attributed to the low rate of refurbishment of old heating systems, the low interest in solar thermal systems among installers and the still relatively high cost of residential solar thermal systems in most European countries.[44] In addition, continued discussion about the electrification of residential heat demand generated interest in heat pump solutions among private homeowners and public and commercial clients, which reduced the demand for solar thermal systems.[45]

Annual additions in the two leading EU countries for solar thermal installations – Germany (358 MW_{th}) and Greece (253 MW_{th}) – converged in 2019 due to opposing national trends.[46] The German market continued its decade-long decline (down 11% in 2019), whereas additions in Greece grew 10% for the fifth year in a row due to cost-competitive products, a regulation stipulating a minimum 60% solar hot water share in new buildings and the Energy Savings in Households grant programme.[47] Germany's situation changed in early 2020, however, following a ruling in December 2019 that enabled the provision of grants that cover 40% of the costs of replacing an outdated oil boiler with a natural gas condensing boiler supported by a solar space heating unit.[48]

The globalisation of solar thermal technologies continued in 2019, with sales picking up for example in the Middle East's Gulf region as users in some countries found it financially attractive to use solar thermal rather than electricity to provide domestic hot water.[49] In Saudi Arabia, a gradual reduction in subsidies for electricity (commonly used to heat water) led to greater demand for solar hot water solutions among hotels and the construction industry.[50] Imports of solar thermal systems to the United Arab Emirates reached a record high in 2019 in response to a building regulation in Dubai that requires solar thermal systems on new construction.[51]

In Kuwait, where imported natural gas generates half of all electricity, the government began using solar water heating in public buildings to reduce electricity use and natural gas imports.[52] The country's Sabah Al Ahmed University installed a 0.5 MW_{th} rooftop system on its buildings, and the Kuwaiti Public Authority for Housing Welfare announced plans to install solar water heaters on all new villas that it builds in the coming years.[53]

The year 2019 was a bright period for **solar district heating** in Denmark, China and Germany. Denmark had a record year for new installations, bringing online 10 new solar district heating plants and expanding 5 existing plants, for a total of 134 MW_{th} added (compared to only 6 new plants and 4 expanded plants totalling 47 MW_{th} added in 2018).[54] Denmark consolidated its lead in the global solar district heating market as capacity topped 1 GW_{th} in August 2019, when as many as 113 Danish villages, towns and cities were using solar energy for space heating.[55]

Denmark's strong market was supported by good framework conditions, including high taxes on fossil fuels, sufficient land for cost-effective ground-mounted collector fields and low-cost financing for the non-profit, user-owned utilities that operate the district heating networks.[56] Flat plate collectors were the dominant technology for new solar district heating systems in both Denmark and Germany.

In China, under the state-financed solar district heating programme for Tibet, three solar district heating systems were commissioned in the last quarter of 2019.[57] In October, 1,800 households in the Tibetan town of Shenzha were connected to a district heating system that was designed to cover 75% of its demand with heat from a 14 MW_{th} parabolic trough collector field.[58] An even higher annual solar share of around 90% may be achieved at a new solar district heating plant in the town of Zhongba, where since 2019 a 24.5 MW_{th} flat plate collector field with 15,000 m^3 of seasonal storage has provided households with a total heated floor area of 118,000 m^2.[59] A second 13.4 MW_{th} flat plate collector field began operation in the town of Saga to supply public buildings with 80,000 m^2 of heated floor space.[60]

Outside Tibet, no new large solar space heating systems were reported in China in 2019, as coal boilers were replaced mostly with heat pumps under the green heating policies in the northern provinces.[61]

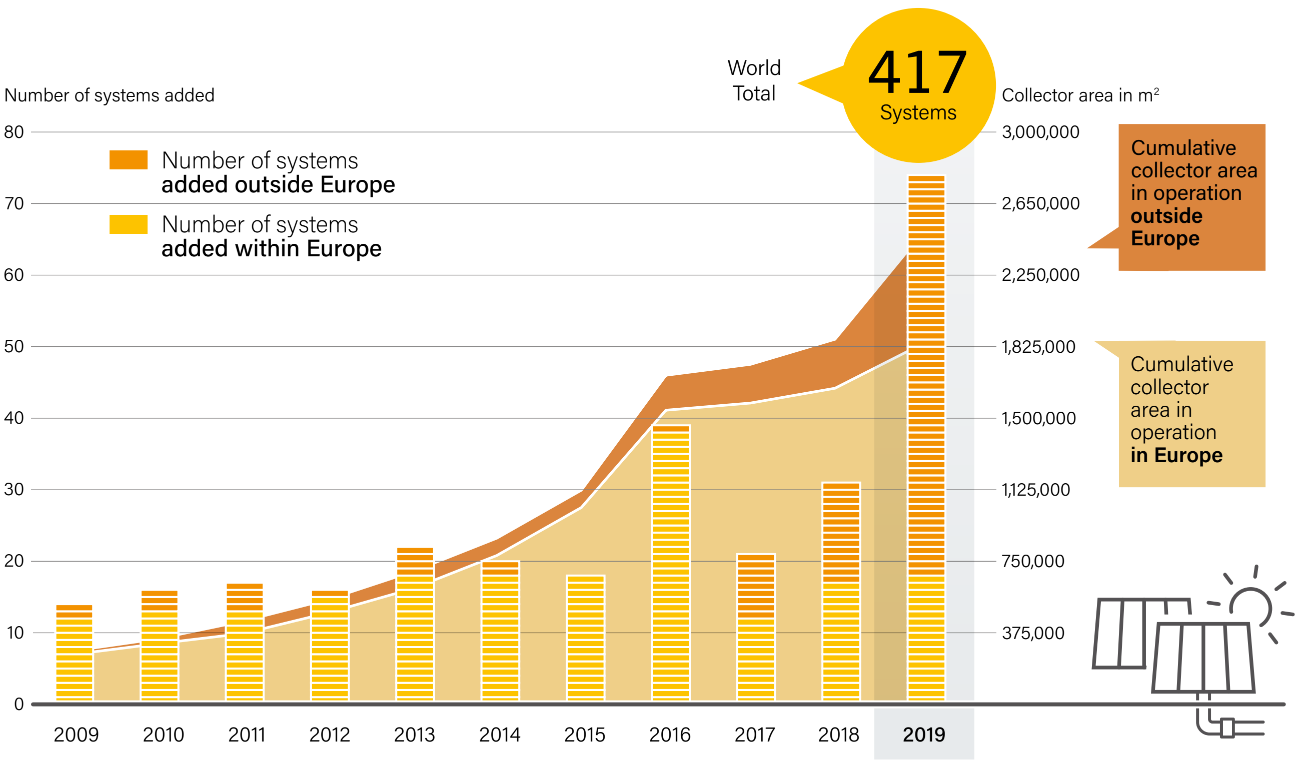
Germany again saw an increase in its solar district heating installed capacity, as a growing number of municipal utilities discovered large solar thermal systems to be an economically feasible solution. Six new systems totalling 9.9 MW_{th} were added in 2019, compared to a total of 5.8 MW_{th} for five smaller solar fields completed in 2018.[62] Three additional systems were under construction as of the end of 2019, including a 10.4 MW_{th} field in Ludwigsburg, which will be Germany's largest solar district heating plant when it comes online in 2020.[63]

The successful development of solar district heating in Denmark, China and Germany has generated interest beyond these countries. In September 2019, the district heating operator in Salaspils, Latvia inaugurated a 15 MW_{th} solar field paired with a wood chip boiler to meet 90% of demand from the local heat network.[64] Solar district heating also attracted interest in Serbia and Kosovo after the European Bank for Reconstruction and Development provided funding for (pre-)feasibility studies. As of early 2020, a feasibility study was completed for the Serbian town of Pancevo, with promising results, and pre-feasibility analyses had been conducted for Belgrade, Bor and Novi Sad in Serbia and Pristina in Kosovo.[65]

Two very large solar district heating projects were delayed in 2019. In China, a 51 MW_{th} solar field intended to meet heating and cooling needs in Turpan (Xinjiang province), one of the country's energy demonstration cities, was put on hold because of funding challenges.[66] The Big Solar Graz project, a planned 154 MW_{th} solar field with 0.9 million m^3 of seasonal storage for district heating in Graz, Austria did not develop further due to conflicts with the project's Danish major financing institution.[67]

In addition to solar district heating, **central solar hot water systems** for large residential buildings, hospitals and prisons sold well in China and Turkey in 2019. In China, 44 such projects were commissioned during the year, each with collector fields of at least 350 kilowatts-thermal (kW_{th}) (500 m^2), for a combined total of 175 MW_{th}.[68] In Turkey, the government ordered central hot water systems for three prisons and three hospitals, for a total of 4.8 MW_{th}.[69] By the end of 2019, at least 417 district heating and central hot water systems were in operation around the world (up from 345 systems in 2018), with a cumulative capacity of 1.73 GW_{th} (including glazed and concentrating solar thermal collectors).[70] (→ *See Figure 36.*)

FIGURE 36. Solar District Heating Systems, Global Annual Additions and Total Area in Operation, 2009-2019



Note: Includes large-scale solar thermal installations for residential, commercial and public buildings. Data are for solar water collectors and concentrating collectors.

Source: IEA SHC. See endnote 70 for this section.

In addition to the growing interest in new water heating installations for public and residential buildings, solar thermal technologies are used increasingly to provide heat for industry around the world. Industry accounts for a large share of global heat demand, and solar energy is suitable for meeting needs in the low-to-medium temperature range (below 400 °C), which account for around 50% of industrial heat demand.[71]

In 2019, global additions of **solar industrial heat capacity** reached a record high of 251 MW_{th}, up from 39 MW_{th} in 2018 and 153 MW_{th} in 2017.[72] The top country for newly installed capacity was Oman – where the Miraah solar steam project developed by Glasspoint (United States) added 180 MW_{th} – followed by China (53 MW_{th}), Mexico (3 MW_{th}), India (2 MW_{th}) and Germany (1 MW_{th}).[73] China and Mexico led in the number of new solar heat for industrial processes (SHIP) systems, with 26 systems each, followed by Germany with 11 new installations.[74] By year's end, at least 817 SHIP systems totalling more than 700 MW_{th} were supplying process heat to factories worldwide.[75]

Solar industrial heat plants in Mexico, Oman and Spain were cost-competitive with fossil fuels, suggesting the potential for further market growth.[76] In many other countries, however, achieving competitiveness against oil and natural gas remained challenging.[77] Consequently, a growing number of governments supplied funding for solar industrial heat installations in 2019, including Austria, China, France, Germany and the Netherlands. Supported by grants, several new large installations were built, including a 3.4 MW_{th} flat plate collector system supplying heat to a French paper mill and a 6.5 MW_{th} field providing heat for floral greenhouses in the Netherlands.[78] As of early 2020, a 10 MW_{th} plant was under construction in France to deliver process heat to a malting plant.[79]

Potential new markets were discovered in 2019 with the installation of the first industrial solar heat plants in Malaysia, Portugal, Saudi Arabia and Senegal.[80] Financed by the World Bank, feasibility studies for selected industry sectors also were conducted in the Middle East and North Africa region, and construction of the first plant within the Word Bank's support programme in Morocco was expected to begin in 2020.[81]

SOLAR THERMAL HEATING AND COOLING INDUSTRY

Manufacturers are producing and delivering a wide range of solar heating and cooling solutions to meet customer needs in the residential, public, commercial and industrial sectors. In 2019, significant consolidation occurred – with large players expanding their market shares mostly through contracts for large capacities or high numbers of systems, and smaller manufacturers (particularly in Europe) struggling because of declining demand.

Although the worldwide solar thermal market declined in 2019, Chinese manufacturers of flat plate collectors expanded their production volume by 21% in response to increased demand from the national construction industry for both façade integration and central collector fields.[82] However, some large manufacturers competed against one another with low-price bids and sacrificed margins to utilise their greatly expanded production capacities.[83] Industry consolidation occurred in Europe in 2019, with the largest flat plate collector manufacturers stabilising their production volumes on average, but small and medium-sized collectors facing increased pressure as demand contracted in several major markets.[84] Consequently, a number of companies in the region's small and medium-sized manufacturer group became insolvent or ceased production during the year.[85]

Two long-time European solar brands, KBB Kollektorbau (Germany) and Kingspan Renewables (Ireland), closed their collector factories, with Kingspan halting completely its manufacturing of solar thermal products.[86] KBB, citing the lack of effective support measures in the renewable heating market as well as falling prices and dwindling margins, announced that it would sell its machinery to an independent business outside Europe and maintain only a sales and engineering team in Berlin.[87]

The insolvencies of manufacturers Aventa Solar (Norway) and Fresnex (Austria) were caused by their inability to secure the necessary funding to increase business volumes and maintain financial health.[88] Investors took over the technologies of both companies: 3 Norske AS purchased the assets of Aventa Solar's polymeric collector technology in 2019, and in early 2020 it announced plans to build up collector production in Jevnaker, Norway under the new name Inaventa Solar.[89] Ecotherm, the former business partner of Fresnex, took over that company's collector technology.[90]

The top markets for solar district heating in 2019 were **China, Denmark and Germany.**

After filing for bankruptcy in May 2019, Austria's turnkey solar heating and cooling system developer S.O.L.I.D. successfully restructured its business with a new investor under the name Solid Solar Energy Systems.[91] S.O.L.I.D. had suffered after its former project partner VKR Holding (Denmark) failed to deliver milestones related to the delayed Big Solar Graz project, a large solar district heating plant that was expected to cover a double-digit share of heat demand in the district heating network of Graz, Austria.[92]

Fluctuations in the volume of contracted projects affected some of the world's larger collector manufacturers in 2019, with some seeing growth and others seeing contractions.[93] Linuo Paradigma, one of the largest collector manufacturers in China, recorded strong sales of large solar hot water systems in the national market.[94] Working with local partners, the company's domestic engineering team designed and installed 6 central solar hot water projects with a capacity of more than 7 MW_{th} each and listed 21 projects with collector areas between 3.5 MW_{th} and 7 MW_{th}, for a total of 154 MW_{th} – the second largest project volume of any company in 2019 after Glasspoint.[95]

On the negative side, a major Turkish flat plate collector manufacturer, Solimpeks, recorded a severe drop in production volumes due to the postponement of a large project that was to have been finalised in 2019.[96] In early 2020, Arcon-Sunmark, the Danish market leader in solar district heating, announced that it would sell its collector factories due to a large financial deficit in recent years.[97] The heavy losses were because of high fluctuations in turnover and low margins in contracted projects. For example, the company had commissioned 10 solar district heating fields in Denmark during the first half of 2019, but business dried up for the rest of the year after an energy savings scheme[i] for utilities expired.[98] Greenonetec (Austria) acquired Arcon-Sunmark's key assets in Denmark, and Solareast Group (China) bought the shares in the company's Asian business.[99]

Technology suppliers of **solar heat for industrial processes** also had a difficult year. Only 30% of the around 80 companies listed in the world database of turnkey SHIP suppliers commissioned a project in 2019, mainly because of low fossil fuel prices, lack of awareness of SHIP technology and a consumer focus on the high upfront costs.[100] A growing number of technology suppliers responded to the challenges of signing contracts with industrial clients by using new manufacturing strategies to reduce costs.

For example, rather than offering solar heat solutions for individual projects, the parabolic trough collector manufacturer Absolicon Solar Collector (Sweden) took the approach of selling complete production lines, with a typical annual capacity of 100,000 m^2.[101] After commissioning its first production line in China in 2018, the company signed agreements in 2019 with Greenline Africa (South Africa) and Ariya Finergy (Kenya) to sell lines for construction in those countries.[102] With this strategy, Absolicon aims to reduce technology costs by producing solar collector fields close to large numbers of potential heat customers, such as the tea industry in Kenya. The company expects to achieve benchmark costs of EUR 250 (USD 280) per kW_{th} to be cost competitive in the target countries.[103] Also in 2019, Trivelli Energia (Italy) signed an agreement with Yaoguo (China) to build a parabolic trough collector production line in China.[104]

Other solar technology suppliers created new, mutually beneficial partnerships with conventional energy technology providers to overcome some of the challenges of developing SHIP projects. These partnerships enable the collaborating companies to offer solutions that meet the heat, steam and/or cooling demands of their customers while minimising the use of fossil fuels.[105] For example, the linear Fresnel collector manufacturer Industrial Solar (Germany) and the boiler producer Gasco (Australia) agreed to collaborate on hybrid solar-fossil systems to expand solar process heat markets in Australia and neighbouring countries.[106]

Several solar collector manufacturers tapped into the wastewater treatment market to widen their sales activities, and joined forces with water separation and purification experts.[107] In early 2019, Rioglass Solar (Belgium), a manufacturer of linear Fresnel collectors, partnered with Condorchem Envitech (Spain), a specialist in multi-effect evaporators, to form Solarvap, a solar-powered wastewater evaporation system.[108] Financed by the issuance of new shares, in early 2020 Industrial Solar (Germany) announced the acquisition of Solarspring (Germany), a manufacturer of membrane-based water treatment systems, to offer clean energy and clean water for industrial customers.[109]

Concentrating collector technologies have been used increasingly for heat and steam production. As with glazed collectors, consolidation occurred in 2019 for manufacturers of concentrating collectors that provide systems for heat and steam at temperatures above 100 °C for boiling, sterilising and cleaning. Glasspoint, which focuses on large deals with oil producers to provide solar steam for enhanced oil recovery, added 180 MW_{th} of parabolic trough collector capacity at the Miraah project in Oman – the largest single project capacity commissioned as of the end of 2019.[110] By contrast, small and medium-sized manufacturers of concentrating solar solutions in Europe, India and Mexico recorded lower sales figures in 2019 than in 2018.[111]

Third-party financers discovered new opportunities in the commercial solar heat market in 2019. Third-party financing avoids the high upfront costs for the clients and in most cases is combined with an operation and maintenance contract with solar thermal specialists over the contractual or repayment period, which reduces the client risk associated with a new technology.[112] For example, the crowdfunding platform ecoligo.investments (Germany), which until 2019 focused on solar electricity projects, funded three solar hot water systems for hotels in Costa Rica and Kenya during the year.[113]

i The energy savings scheme allowed district heating utilities to fulfil their energy-saving mandates by extending existing solar district heating plants or by initiating the construction of new facilities by mid-2019. See endnote 98 for this section.

Another model of third-party financing is a heat supply contract, or energy service company (ESCO). Kyotherm (France), which specialises in financing renewable heat projects, played a pioneering role in setting up ESCOs in 2019 by developing and financing what is anticipated to be Europe's largest solar industrial heat plant, a 10 MW_{th} system for a malting plant in France.[114] The malt producer profits from a price below the average price it would pay for heat produced from natural gas combustion. Kyotherm, together with its network of solar thermal project developers, also started contractual negotiations with 11 commercial heat consumers outside France, with plans to sign some project contracts in the first half of 2020.[115]

A few solar heat project developers signed their first heat supply contracts in 2019. NewHeat (France) financed a 3.4 MW_{th} single-axis tracked flat plate collector system to sell heat to the Condat paper mill in southwest France.[116] Azteq (Belgium) signed a solar steam delivery contract with a chemical producer in Antwerp and contracted with Solarlite (Germany) for a parabolic collector field at the client's factory.[117]

Other project developers faced difficulties in developing their ESCOs because some clients have slow decision-making processes or have been reluctant to commit to medium- or long-term contracts. For example, after Millennium Energy Industries (Jordan) signed its first solar heat delivery contract in mid-2019, the client asked for a delay in the installation, and the project had not been realised as of early 2020.[118] SWA Solar Wärme (Austria), established in 2018, completed only one project in 2019 after clients delayed decisions because of a temporary halt in national funding for large-scale projects.[119]

SHIP project developers in Asia shifted their ESCO businesses away from solar thermal technology, finding it more economical to design heat delivery contracts based on heat pumps. Linuo Paradigma's newly founded subsidiary for developing heat supply contracts realised its first two projects in 2019, both with air-source heat pumps.[120] Aspiration Energy (India), which announced big plans for solar industrial heat supply contracts in 2017, did not close a single deal with solar heat in 2019 and focused only on heat pump solutions.[121]

Third-party financiers discovered new opportunities in the commercial solar heat market in 2019.

Solar thermal air conditioning and cooling remained a niche market in 2019. A handful of sorption chiller manufacturers promoted solar thermal cooling systems in southern Europe and the Middle East.[122] After realising publicly effective reference projects in 2018, Fahrenheit (Germany) contracted seven new solar thermal cooling projects in 2019: two smaller projects in Europe – in an office building in the Netherlands and a family residence in Germany – which were commissioned by the end of the year, and five projects across Australia, Dubai (United Arab Emirates), India, Morocco and Pakistan, which were still under construction at year's end.[123]

In Italy, despite high investment subsidies under the national Conto Termico 2.0, the solar thermal cooling market did not pick up in 2019. Maya (Italy), a joint venture with Yazaki (Japan) installed only one solar air conditioning system in the country (at a hospital), with a second system under construction at year's end.[124] Customer demand failed to materialise because in many cases solar heat-driven cooling systems were not cost-effective compared to gas-driven heat pumps or electricity-driven compression chillers, both of which are established air conditioning technologies.[125]

The German-Indian joint venture VSM Solar increased sales efforts for its solar cooling technology, mainly among hospitals and corporate buildings.[126] The company refurbished a solar air conditioning system with 225 tonnes of refrigeration at an IBM building in Bangalore, India and signed a strategic alliance with Blue Star, a large HVAC manufacturer in India, promoting the large power-saving potential compared to electricity-driven cooling units.[127] Newly founded Solid Solar Energy Systems (Austria) finished the design phase for an industrial cooling system for the engine manufacturer AVL in Graz, Austria.[128]

Although Thermax (India) was no longer actively promoting solar thermal cooling solutions in 2019, its competitors – other sorption chiller manufacturers such as Energy Concepts (United States) and Shuangliang (China) – redirected their thermal cooling solutions to utilise waste heat (rather than a solar collector field) to drive the cooling machines, as a way to lower investment costs.[129]

In an important step towards the standardisation of solar cooling systems, the world's first standard for space cooling and ventilation systems was published in Australia following seven years of preparation.[130] The standard includes methods for calculating energy consumption and determining the thermal comfort of space heating and cooling devices and ventilation systems for five different solar air conditioning technologies.[131]

KEY FACTS

- The global wind power market saw its second largest annual increase, with offshore wind accounting for a record 10% of new installations.
- Market growth reflected surges in China and the United States in advance of policy changes, and a significant increase in Europe despite continued market contraction in Germany.
- At least 102 countries had some level of commercial wind power capacity, enough to provide an estimated 5.9% of global power generation; the highest shares of generation were in Denmark (57%), Ireland (32%), Uruguay (29.5%) and Portugal (26.4%).
- Falling prices are opening new markets, but the global transition to auctions and tenders has resulted in intense price competition, reducing the number and diversity of participants and leading to further attrition among turbine manufacturers.

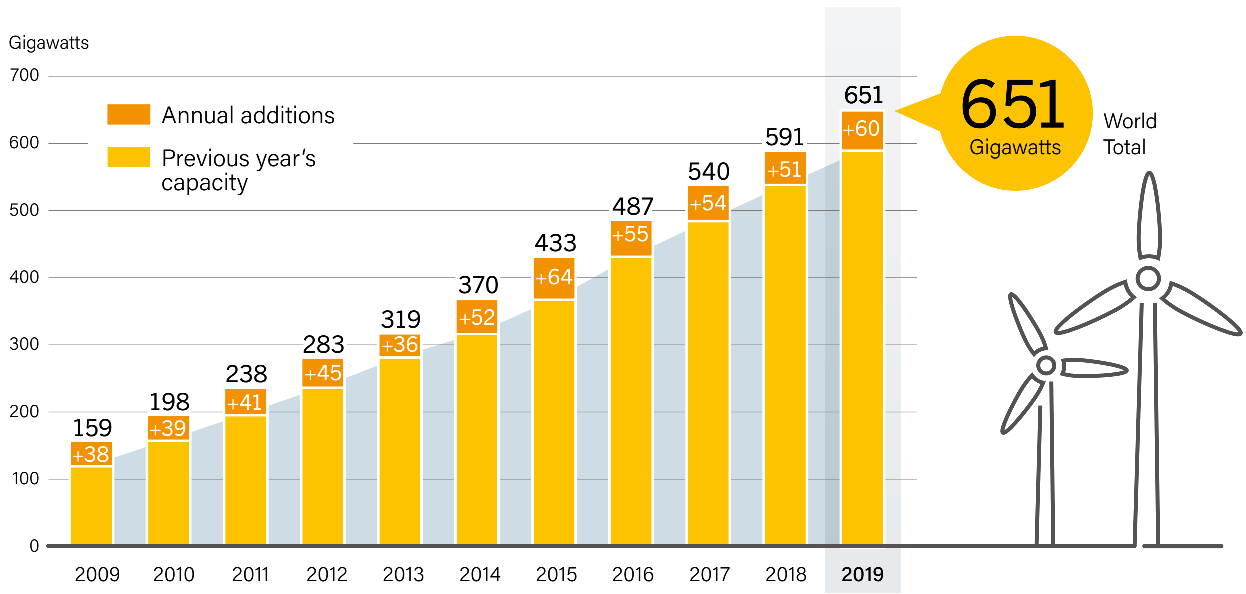
WIND POWER

WIND POWER MARKETS

The global wind power market expanded 19% in 2019, with around 60 GW of new capacity added to the world's electric grids (including more than 54 GW onshore and over 6 GW offshore).[1] This was the second largest annual increase in capacity ever, and followed three consecutive years of decline after the peak in 2015 (63.8 GW).[2] Offshore wind power plays an increasingly important role in the global market, accounting for a record one-tenth of additions in 2019.[3] The year's newly installed wind power capacity increased the global total by 10% to around 651 GW overall (621 GW onshore and the rest offshore).[4] (→ *See Figure 37.*)

The rapid growth in 2019 was due largely to surges in China and the United States in advance of policy changes and to a significant increase in Europe, despite continued market contraction in Germany.[5] Some emerging markets experienced slowdowns due to delays in public tenders and stop-and-go policies, which have deterred investment, although several markets in Africa, Latin America, the Middle East and Southeast Asia saw notable growth relative to 2018.[6] New wind farms reached full commercial operation in at least 55 countries during 2019, up from 47 in 2018, and at least one country, Senegal, brought online its first commercial project.[7] By year's end, the number of countries with some level of commercial wind power capacity exceeded 102, and 35 countries – representing every region – had more than 1 GW in operation.[8]

FIGURE 37. Wind Power Global Capacity and Annual Additions, 2009-2019



Note: Totals may not add up due to rounding.

Source: GWEC. See endnote 4 for this section.

> **Wind power**
> provides a substantial share of electricity in a growing number of countries.

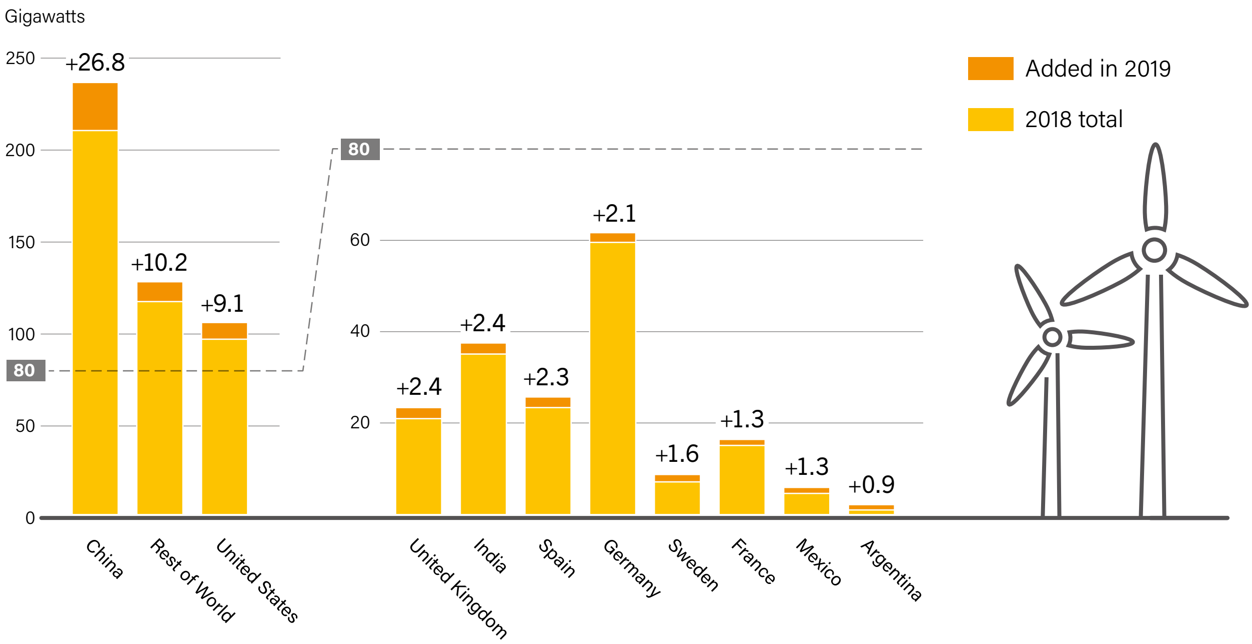
Rapidly falling costs per kilowatt-hour (both onshore and offshore) have made wind energy ever more competitive and allowed onshore wind power to compete head-to-head with fossil fuel generation in a large and growing number of markets around the world, often without financial support.[9] The economics of wind energy have become the primary driver for new installations.[10] Outside of China (which has a feed-in tariff, or FIT, for wind power) and the United States (which offers tax credits and state renewable portfolio standards, or RPS), global demand for wind power in 2019 was driven largely by other policy mechanisms including auctions (or tendering), which have exerted a downward pressure on prices.[11] In some mature markets – such as in North America (around 80% of the global market) and northern Europe – corporate power purchase agreements (PPAs) are playing an ever more important role; worldwide, newly signed PPAs during 2019 were up an estimated 30% compared with 2018.[12]

Wind power provides a substantial share of electricity in a growing number of countries. In 2019, wind energy generated enough to provide an estimated 15% of the EU's annual electricity consumption, and equal or higher shares in at least seven individual Member States.[13] Wind energy met an estimated 47% of Denmark's electricity demand in 2019 and accounted for nearly 57%[i] of the country's total generation.[14] Other countries in Europe with wind generation shares above 20% for all of 2019 included Ireland (32%), Portugal (26.4%), Germany (21.8%) and Spain (20.9%).[15] Uruguay (29.5%), Nicaragua (17.4%) and Costa Rica (15.8%) also achieved high shares of generation from wind energy in 2019, and shares were high at the sub-national level in several countries.[16] By year's end, wind power capacity in operation worldwide was enough to provide an estimated 5.9% of total global electricity generation.[17]

For the 11th consecutive year, Asia was the largest regional market, representing more than 50% (down from 52% in 2018) of added capacity, with a total exceeding 292 GW by the end of 2019.[18] Europe (24%), North America (16%) and Latin America and the Caribbean (6%) accounted for most of the rest of the year's installations.[19] China retained its lead for new capacity (both onshore and offshore) and was followed distantly by the United States, the United Kingdom and India (both adding almost equal amounts) and Spain; together, these five countries accounted for 70% of annual installations.[20] Other countries in the top 10 for total capacity additions were Germany, Sweden, France, Mexico and Argentina.[21] For cumulative capacity, the top 10 countries were unchanged from 2018.[22] (→ *See Figure 38* and ***Reference Table R19***.)

i The difference between generation (electricity produced within a country's borders) and consumption is due to imports and exports of electricity and to transmission losses.

FIGURE 38. Wind Power Capacity and Additions, Top 10 Countries, 2019



Note: Additions are net of decommissioning.

Source: See endnote 22 for this section.

China again saw an increase in new installations (up 22%) during 2019, adding around 26.8 GW (24.3 GW onshore and 2.5 GW offshore) for a total of 236.3 GW installed.[23] More than 25.7 GW (23.8 GW onshore and nearly 2 GW offshore) of wind power capacity was integrated into the national grid in 2019, with just over 210 GW[i] considered officially grid-connected by year's end.[24]

China's support through the FIT (and its looming expiration), as well as the country's first wind power auction, drove the domestic market in 2019.[25] In May, the national government announced that, starting in 2021, FITs for onshore wind generation will no longer exceed those provided for coal-fired generation.[26] The government also published an initial list of approved projects (totalling 5.7 GW) to be built without direct financial support.[27] The policy changes result from a belief that the wind energy sector is mature enough to proceed without direct government support, as well as the need to clear a backlog of outstanding FIT payments for existing projects.[28]

Although the northern and western provinces were still home to the majority of China's cumulative capacity by year's end, the top provinces for official grid-connected additions in 2019 were Henan (nearly 3.3 GW), Hebei (2.5 GW), and Shanxi and Shandong (2.1 GW each), with Jiangsu in the lead for offshore installations – all of which are relatively close to demand centres and where curtailment rates were relatively low.[29] Overall, an estimated 16.9 TWh of potential wind energy was curtailed in China – a national average of 4% for the year, down from 7% (27.7 TWh) in 2018, and below the national government's targeted cap (10%) for 2019.[30] Curtailment remained concentrated mainly in Xinjiang, Gansu and Inner Mongolia, but all three provinces saw substantial reductions relative to 2018.[31] China's generation from wind energy was up nearly 11% (to 405.7 TWh), and wind energy's share of total generation continued its steady rise, reaching 5.5% in 2019 (up from 5.2% in 2018).[32]

India was the only other Asian country to rank among the top 10 for installations of wind power capacity in 2019, placing fourth globally for additions and for total capacity.[33] The country's additions increased 8.5% over 2018, when installations fell nearly 50% from their record high in 2017, as India shifted from FITs to reverse auctions.[34] India added 2.4 GW in 2019, bringing the year-end total to 37.5 GW.[35] Another 8.6 GW was in the active pipeline at year's end, but many wind (and other) power projects have been delayed by problems obtaining land and accessing transmission lines.[36]

Although the issuance of tenders remained strong in India during 2019, many were cancelled or undersubscribed, and projects that were already tendered faced delays (due to efforts to renegotiate for lower tariffs or to outright withdrawal of existing PPAs), which have held up turbine deliveries and put significant pressure on the domestic manufacturing industry.[37] Among the many challenges deterring investment have been policy uncertainties, India's slowing economy, aggressive bidding, low ceiling tariffs for auctions, curtailment and infrastructure constraints, delayed payments for generation, lack of low-cost financial resources, lack of available land in good wind areas (where developers want to be, due to low wind energy tariffs) and duties and tariffs on imports.[38] The number and diversity of local investors has declined since the shift to auctions, while installations have become more concentrated geographically.[39]

Elsewhere in Asia, Turkey's annual installations increased relative to 2018, with nearly 0.7 GW added for a total exceeding 8.1 GW.[40] Wind energy accounted for 7.4% of Turkey's electricity generation in 2019.[41] Thailand placed fourth in the region (added 0.3 GW for a total of 1.5 GW), although its market contracted after a significant drop in FIT rates dampened investor confidence.[42] Other Asian countries that added capacity included Japan (adding nearly 0.3 GW for a total of 3.9 GW), the Republic of Korea, Pakistan and Vietnam.[43] Vietnam's capacity increased 70% (to 388 MW) in a rush to complete projects before generous FIT rates were reduced, and wind power projects competed with solar PV and conventional power projects for space on the country's grid networks.[44] In much of Southeast Asia, policy uncertainty and subsidies to fossil fuels continued to curb deployment.[45]

After Asia, Europe installed the most capacity of any region during 2019. All of Europe added nearly 14.7 GW of new wind power capacity, bringing the total to 196.8 GW.[46] Most of this was in the EU-28[ii], which installed roughly 13.2 GW (9.6 GW onshore and 3.6 GW offshore), or net additions of 13 GW (accounting for decommissioning), for a year-end total of 192.2 GW (170.2 GW onshore and 22.1 GW offshore[iii]).[47]

Net EU additions, although below the all-time high in 2017, were up 34% over 2018.[48] The sharp increase was due mainly to strong growth in Greece (added a record 0.7 GW), Spain and Sweden – which more than doubled its additions relative to 2018, installing 1.6 GW for a total of 9 GW.[49] In total, 19 EU countries added capacity during 2019, up from 16 countries in 2018.[50]

i Statistics differ among Chinese organisations and agencies as a result of what they count and when. For more details, see endnote 24 for this section.

ii Here, the EU refers to the EU-28, including the United Kingdom. The EU-27 added nearly 10.8 GW during the year and had 169 GW of capacity at end-2019. See endnote 47 for this section.

iii Numbers do not add up to total of 192.2 GW due to rounding.

Net installations of wind power capacity in the EU-28 were up

34%

over 2018.

However, the market was again fairly concentrated, with the top five countries – the United Kingdom, Spain, Germany, Sweden and France – accounting for almost 75% of net additions, even though markets in France and Germany contracted for the second consecutive year.[51] The leading EU countries for cumulative capacity were Germany, Spain, the United Kingdom, France and Italy.[52]

The United Kingdom was the region's top installer in 2019, adding 2.4 GW, three-quarters of which is operating offshore, for a total of 23.5 GW.[53] Most new onshore capacity (0.6 GW) was added in Scotland and Wales, and was awarded under Contracts for Difference[i] (CfD) in 2015.[54] Elsewhere in the United Kingdom, wind energy projects rely on merchant options such as PPAs.[55] The country saw historic lows for generation from coal (less than 1% for the second quarter of 2019), due largely to the rise of wind power, which accounted for nearly 20% of domestic electricity generation during the year.[56]

Spain, which ranked second in the region and fifth globally for installations, had its best year in a decade. The country added 2.3 GW (all onshore) – more than five times its 2018 installations – to end 2019 with 25.8 GW.[57] While most of this capacity was awarded in auctions held in 2016 and 2017, Spain also led the region for investments in new onshore capacity.[58] In late 2019, to mitigate regulatory uncertainty regarding future revenue from renewable power plants, the national government introduced a series of measures in an effort to guarantee a stable economic and regulatory framework to encourage further investment in renewable energy projects.[59]

Although still among the EU's top installers, Germany saw a sharp decline in annual additions (as well as in investment in new projects), ceding its first-place ranking in Europe, held since 2011.[60] Germany added 2.2 GW (nearly 2.1 GW net, including almost 1 GW onshore and 1.1 GW offshore) in 2019 for a cumulative 61.4 GW (53.9 GW onshore and more than 7.4 GW offshore).[61] Onshore installations have declined markedly since the 2014-2017 period (to 16% of the volume in 2017, when the auction model was introduced), due mainly to long, complex permitting processes and policy uncertainty.[62]

As of late 2019, more than 10 GW of wind power projects was stuck in Germany's permitting process, which has lengthened from around 10 months just a few years ago to more than two years.[63] The largest permitting barriers relate to aviation and the military; in addition, rising public opposition and a proposed setback distance of 1,000 metres for wind turbines have ruled out several prime locations.[64] (→ *See Feature chapter.*)

Growing economic risk, the increased complexity associated with tenders, permitting challenges and the threat of legal action have deterred potential investors, including community wind energy actors, and the removal of some privileges for community projects has reduced the number and diversity of participants in auctions.[65] Of the total 3.7 GW of onshore capacity auctioned in 2019, only 1.8 GW was awarded – far below the volume envisioned in Germany's expansion plan.[66] The number of companies active in the domestic wind power industry has declined with new installations, affecting the entire local value chain.[67]

Germany's gross generation from wind energy was up 12% onshore and 27% offshore, reaching a total of 126 TWh, or 21.8% of electricity generation in 2019.[68] Much of this electricity is produced in northern Germany, and a lack of grid capability hinders the transmission of excess electricity to load centres in the country's south, resulting in curtailment of wind energy and challenges for neighbouring countries due to electricity exports.[69] Curtailment in Germany has declined since 2017, however, as have exports, and the country has completed the first 1,300 kilometres of 7,700 kilometres of new transmission lines planned by 2030.[70] In Germany and elsewhere, interest in the use of excess renewable generation for electric heating, cooling and transport as well as for hydrogen production is quickly gaining ground.[71] (→ *See Systems Integration chapter.*)

For the EU as a whole, onshore wind energy met around 12.2% of total electricity demand, and offshore wind energy met 2.3%, with an estimated total of 417 TWh of wind generated electricity.[72] The one percentage point share increase relative to 2018 resulted from additional capacity and from windy conditions during the year throughout the region.[73]

Outside the EU-28, Norway was again the largest installer in Europe (adding 0.8 GW) in 2019.[74] However, Norway's plans for future installations were put on hold due to local opposition across the country sparked by environment and tourism concerns.[75] Ukraine saw a nearly 10-fold increase in installations relative to 2018 (adding 0.6 GW), more than doubling its capacity to 1.2 GW in advance of a transition from attractive FITs to auctions in 2020.[76] Throughout all of Europe, 2.1 GW of wind power PPAs were signed, and 10 countries held auctions in which wind energy secured contracts, including 8.6 GW onshore and 6.8 GW offshore.[77]

Across the Atlantic, the Americas added 13.4 GW (up 13% over 2018) and accounted for more than one-fifth of the world's newly installed capacity in 2019.[78] The United States installed 68% of the region's total and had its third biggest year[ii].[79] US additions were up 20% over 2018, to 9.1 GW, for a total of 105.6 GW across

i The CfD is the UK government's primary mechanism for supporting renewable electricity generation. Developers that win contracts at auction are paid the difference between the strike price (which reflects the cost of investing in the particular technology) and the reference price (a measure of the average market price for electricity).

ii The year 2019 saw the third highest installations of new capacity after 2009 and 2012, when the US production tax credit was due to expire and then was extended retroactively.

41 states and 2 territories.[80] At year's end, another 22.1 GW was under construction.[81] The rush of new installations was driven mainly by the phase-out of the federal production tax credit (PTC), which was granted a one-year extension[i] in late 2019.[82] Demand from utilities to meet customer preferences, sustainability goals and mandates under state RPS laws as well as demand from corporations also played a role.[83] Wind power PPAs achieved a new record (8.7 GW) in 2019, with utilities contracting 5.1 GW; at year's end, almost half of the project pipeline had a PPA in place, with 27% of these owned by utilities.[84]

The state of Texas (nearly 4 GW) again led for annual installations and, along with Iowa (1.7 GW), set new records for capacity additions.[85] Six US states ended the year with more than 5 GW in operation – including Texas, with more than 28.8 GW.[86] In Texas and much of the rest of the country, wind power set short-term generation records, exceeding 66% in the US central region, and grid operators were reliably managing such high penetration levels.[87] Tests by the California Independent System Operator during 2019 found that wind turbines equipped with inverter-based smart controllers can provide grid services similar to those provided by natural gas power plants.[88] (→ *See Systems Integration chapter.*)

For the full year, utility-scale wind power facilities accounted for more than 30% of electricity generation in 3 US states – with Iowa (in the lead at 42%) passing Kansas (41.4%) – and accounted for more than 16% of annual generation in 13 states.[89] In total, wind power accounted for 7.3% of US utility-scale electricity generation (up from 6.5% in 2018).[90] As an indication of how big wind power has become in the United States, it exceeded hydropower for generation in 2019, having already surpassed it for capacity three years earlier.[91]

Latin America and the Caribbean added 3.7 GW of capacity in 2019, with two countries – Mexico and Argentina – ranking among the top 10 globally.[92] The slight decline relative to 2018 was due mainly to a significant drop in Brazil that was nearly offset by increases elsewhere.[93] The region ended the year with around 29.2 GW of wind power capacity operating in at least 26 countries.[94] The top installers were Mexico (nearly 1.3 GW) and Argentina (0.9 GW), which both surpassed Brazil (0.7 GW) in annual additions for the first time, followed by Chile (0.5 GW).[95] Colombia held its first successful renewable energy auction, in which wind power was awarded nearly 1.2 GW.[96] More than 80% of the non-hydro renewable power capacity operating across the region (mostly wind power) at year's end was driven by public tenders and auctions, and PPAs also were becoming increasingly important.[97]

Mexico was again among the world's top 10 installers, ranking ninth for additions ahead of Argentina, and ending the year with 6.2 GW.[98] The country cancelled planned auctions and revised its renewable energy support scheme, and annual installations (up 38% over 2018) were due mainly to bilateral PPAs.[99] Argentina's market also has been affected by on-and-off policies but, thanks to awarded capacity from auctions launched between 2016 and 2018, the country more than doubled its capacity to end the year with 1.6 GW.[100] Argentina's largest wind farm (220 MW) was completed in 2019; the project has an average capacity factor of 51%, and is expected to supply enough electricity for more than 330,000 homes.[101]

Brazil added its lowest amount of wind power capacity since 2011, due to a break in the country's auction schedule during the recent national economic crisis; even so, by one account, more wind power than thermal power capacity was installed in 2019.[102] Brazil's free market[ii] has expanded in recent years, and in 2019 more than 2 GW of new wind power capacity was sold into the free market compared to 1.1 GW via public auctions.[103] At year's end, with almost 15.5 GW of capacity in operation, Brazil remained home to more than half of the total capacity operating in Latin America and the Caribbean.[104] Wind power accounted for 9.4% of Brazil's electricity generation (up from 8.3% in 2018).[105]

Canada again added a modest 0.6 GW, bringing total capacity to 13.4 GW.[106] Wind power has been the country's largest source of new electricity generation over the past decade, driven by environmental concerns and by the relatively low price of wind-generated electricity.[107] The leading provinces for cumulative capacity were Ontario (5.4 GW), Quebec (3.9 GW) and Alberta (1.7 GW).[108] Wind power accounted for 6.5% of Canada's electricity generation in 2019, up from 5.8% in 2018.[109]

i The PTC gives wind energy generators a tax credit of roughly USD 0.02 per kWh for electricity fed into the grid. Starting in 2021, the credit will decline steadily until it ends in 2025.

ii Brazil's power sector is undergoing a transition that encourages the development of a free market, in which power buyers, sellers and traders can negotiate PPAs directly. See endnote 103 for this section.

Wind energy is also playing a growing role in Australia, which again saw records for both installations and output in 2019.[110] The country brought online more than 0.8 GW of capacity for a total approaching 6.3 GW.[111] Wind power surpassed hydropower in 2019 to become Australia's largest renewable source of electricity, producing 19.5 TWh, or 8.5% of the country's total generation.[112] Far higher shares were achieved in several states, including in South Australia (29%), Victoria (28%) and New South Wales (22.6%).[113] The rapid increase in the number and capacity of large wind (and solar) power projects in Australia continued to challenge the grid, resulting in project delays.[114] (→ *See Solar PV section in this chapter.*) By year's end, more than 5.5 GW of additional capacity was under construction or financially committed.[115] Other parts of Oceania were quiet, with little wind power activity observed in 2019.[116]

Africa and the Middle East together added about 2.6% less capacity than they did in 2018, with around 0.9 GW brought online in 2019.[117] At year's end, 13 countries in Africa and 6 in the Middle East had a cumulative 6.7 GW of wind power capacity (all onshore), with most of it in South Africa (2.1 GW), Egypt (1.5 GW) and Morocco (1.2 GW).[118] Challenges in both regions included uncertain or unsupportive policy and power market frameworks, bottlenecks in transmission infrastructure and off-taker risk.[119]

In Africa, the leaders[i] for new installations were Egypt (262 MW), Morocco (216 MW) and Ethiopia (120 MW).[120] Egypt's additions were in a single project, the country's largest and first privately owned wind farm.[121] Despite being among the top three on the continent for additions and total capacity, Egypt remained far short of its target of 7 GW by 2022, but the country had a project pipeline of 4 GW as of early 2020.[122] Senegal also added capacity: its first utility-scale wind farm (159 MW) began delivering electricity to the grid in December, with full commissioning planned for 2020.[123]

Jordan (0.2 GW) and Iran (50 MW) led the Middle East for new installations during 2019.[124] Saudi Arabia's government contracted for the country's first large-scale wind power plant, a 0.4 GW facility with an expected operation date of early 2022.[125] The Saudi government aims to free up for export much of the oil used to generate electricity.[126]

In the **offshore wind power segment**, five countries in Europe and three in Asia connected a record 6.1 GW in 2019 (up 35.5% over 2018), increasing cumulative global capacity to more than 29 GW.[127] Wind turbines operating offshore represented less than 5% of total global wind power capacity at year's end, but offshore additions accounted for 10% of all newly installed capacity (up from 5% in 2015), and 2019 was a record year for investment in future offshore capacity.[128] Europe accounted for 59% of new installations and Asia for 41%.[129]

China again led the sector, completing nearly 2.4 GW of capacity for a total of 6.8 GW, and easily surpassing a national target of 5 GW by 2020.[130] Record installations were driven by policy changes: for the first time, China announced reductions to the FIT for offshore wind power for 2019, and further cuts in 2020, and several new projects were initiated to take advantage of the policy before it expires.[131] Although the country has no long-term targets for offshore capacity, coastal provinces have targets and development plans, including Guangdong (30 GW by 2030), Jiangsu (15 GW) and Zhejiang (6.5 GW).[132] At year's end, more than 10 GW was under construction and an additional 30 GW had received approval.[133]

Elsewhere in Asia, Chinese Taipei commissioned its first offshore utility-scale (120 MW) project and announced that, in addition to its target of 5.7 GW by 2025, the country aims for a further 10 GW between 2026 and 2036.[134] Japan launched 3 MW of floating capacity to end the year with nearly 66 MW of offshore capacity and 14 GW in the pipeline; Vietnam had 0.1 GW of intertidal capacity with several projects under construction; and India launched a tender process for offshore wind power.[135]

Offshore wind power additions accounted for

10%

of all newly installed capacity, up from 5% in 2015.

i Kenya's 310 MW Lake Turkana wind power project remained the largest in Africa at the end of 2019. Several sources note that it started operations in 2019; however, the project began supplying electricity to the national grid in 2018, and Vestas announced the project's completion that year, so it was included with 2018 data in GSR 2019. See endnote 120 for this section.

Europe continued to be home to most of the world's offshore capacity. In 2019, the region added more than 3.6 GW (up 36% from 2018), a new high, bringing the regional total close to 22.1 GW.[136] Installations came online in the United Kingdom (1.8 GW), Germany (1.1 GW), Denmark (374 MW), Belgium (370 MW) and Portugal (8 MW); all but Germany set new records.[137] The United Kingdom accounted for about half of Europe's offshore installations and reached a year-end total of 9.9 GW offshore.[138] All turbines were grid-connected for the UK's 1.2 GW Hornsea One, making it the world's largest offshore wind farm as well as the farthest from shore.[139] Germany added more capacity offshore than on land, for the first time, and exceeded the national offshore target for 2020.[140]

Several European governments also increased targets for offshore wind power, driven at least in part by falling prices, raising the region's total targeted capacity by 2030 from 76 GW to 100 GW.[141] France, the Netherlands and the United Kingdom all held auctions for offshore capacity during 2019, including the world's largest-ever offshore auction – 5.5 GW was awarded by the UK government.[142] An additional five offshore corporate PPAs were signed, following the first in 2018, totalling more than 360 MW of future capacity.[143] In Sweden, however, a proposed 300 MW offshore wind farm that was permitted in 2012 was cancelled after the national military rejected revised plans.[144]

The US offshore capacity remained at 30 MW, but targets for state procurement increased from 9.1 GW in 2018 to 25.4 GW in 2019.[145] Vineyard Wind, a 0.8 GW project off the Massachusetts coast, was scheduled to begin construction in 2019, but was delayed repeatedly for further government study of the broader impacts of offshore wind farms[i] on commercial fisheries.[146] The project is the first in a long pipeline of large wind farms along the country's east coast, and the delay has caused wider uncertainty in the US offshore market.[147] However, construction did begin on a 12 MW project off Virginia's shores, and by year's end an estimated 7.5 GW was in advanced development[ii] along the US east coast.[148] During the year, six east coast states procured capacity, approved projects or passed legislation[iii], and a new coalition was launched to push for at least 10 GW off the California coast by 2040.[149] At year's end, a Maine utility announced that it was the anchor buyer in a PPA for the first US floating wind power project, a 12 MW facility off the state's coast.[150]

By the end of 2019, 18 countries (12 in Europe[iv], 5 in Asia and 1 in North America) had offshore wind capacity in operation.[151] The United Kingdom maintained its lead for total capacity (9.9 GW), followed by Germany (7.5 GW), China (6.8 GW), Denmark (1.7 GW) and Belgium (1.6 GW).[152] Europe was home to about 75% of global offshore capacity (down from 79% in 2018), with Asia accounting for nearly all the rest.[153] (→ *See Figure 39.*)

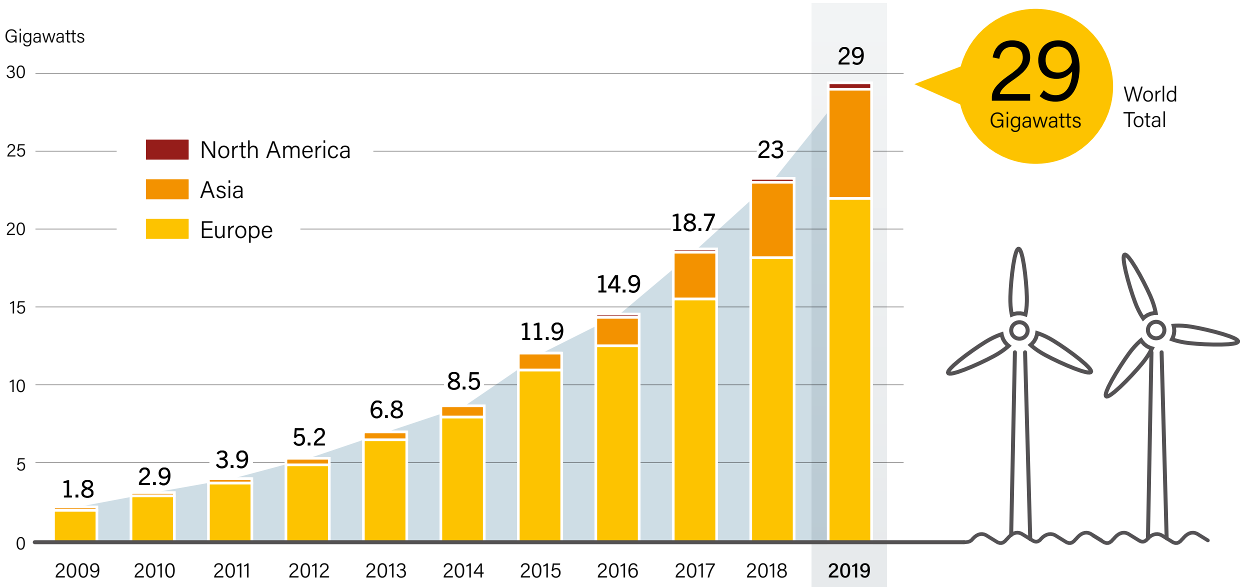
i Opposition that resulted in the failure of the proposed Cape Wind project in 2017 led developers and regulators to locate leases farther out from shore, pushing them into vessel routes and commercial fishing areas. See endnote 146 for this section.

ii Advanced development means that projects have a signed PPA, a firm turbine order or are proceeding under utility ownership. See endnote 148 for this section.

iii Connecticut committed to solicit 2 GW by 2030, enough to meet 30% of the state's electricity demand; Maryland raised its Renewable Portfolio Standard (RPS) to 50% by 2030, with incentives for deployment of 1.2 GW offshore capacity; and New Jersey more than doubled its offshore wind capacity target from 3.5 GW by 2030 to 7.5 GW by 2035. See endnote 149 for this section.

iv By year's end, all of the offshore capacity in France, Norway and Spain was in demonstration projects; all other European countries with offshore wind power capacity also had demonstration projects in place. See endnote 151 for this section.

FIGURE 39. Wind Power Offshore Global Capacity by Region, 2009-2019



Source: See endnote 153 for this section.

Additional countries were studying the feasibility of offshore wind or starting project development in 2019, and the World Bank Group announced a new programme to speed the deployment of offshore wind power in emerging markets, many of which have strong offshore wind resources.[154]

Cost reductions in new wind power projects have resulted from a combination of lower capital costs and **improved performance**.

Offshore and (mostly) onshore, wind turbines of various sizes, totalling an estimated 0.4 GW of capacity in nine countries, were decommissioned in 2019.[155] The United States took the lead, decommissioning about 195 MW of capacity.[156] In Europe, around 170 MW of capacity was decommissioned (down from 451 MW in 2018), led by Germany (97 MW), with turbines also decommissioned in Austria, Denmark, France and the United Kingdom.[157] Some of the decommissioned projects were repowered. (→ *See Industry section.*)

WIND POWER INDUSTRY

Wind energy has emerged as one of the most economical ways to add new generating capacity.[158] Yet, while falling prices are helping to move wind power into new markets and are pushing up sales, the global transition from FITs to auctions and tenders has resulted in intense price competition in some countries, challenging wind developers and causing attrition among turbine manufacturers.[159] Even as progress is made, new challenges have emerged in some markets, such as poorly designed tenders, permitting delays and lack of available land and grid access, as well as the inherent limitations of power systems and markets that were designed and optimised for centralised, large-scale fossil power.[160] (→ *See Systems Integration chapter.*) Meanwhile, the industry is working to meet each new challenge with improved technologies (including larger and more efficient turbines) and other advances (such as supply chain efficiencies) that are helping to further reduce the cost of energy and to better integrate wind energy with existing electricity grids.[161]

By one estimate, from 2018 to 2019 the global benchmark levelised cost of energy (LCOE) from new wind power projects declined 10% onshore (to an average USD 48.5 per MWh) and 28% offshore (USD 83.50 per MWh).[162] Cost reductions have resulted from a combination of lower capital costs and improved performance.[163]

Auctioned capacity in 2019 was more than double the 2018 total, with 25 GW auctioned onshore and 15.8 GW offshore in at least 18 countries (including wind-specific and technology-neutral/renewable energy auctions[i]).[164] Auction results vary widely depending on local conditions and costs[ii], project scale, expected commissioning date and other factors.[165] While declining costs and fierce competition have driven average bid prices down in many markets, bids have been rising in others, such as Germany.[166]

Some of the lowest winning bids (excluding China) in 2019 were seen in Brazil (USD 20.8 per MWh) and Denmark (USD 22.8 per MWh).[167] Saudi Arabia's first commercial wind farm, the 400 MW Dumat Al Jandal project, reached financial close in July at USD 19.9 per MWh.[168] In Latin America and the Caribbean, the surge in public auctions helped to drive down the region's average price for wind energy by 46% from 2016 to 2019.[169] Colombia's first successful renewable energy auction brought low average winning prices (for both wind and solar energy) of USD 28 per MWh in 2019.[170]

Across Europe, more than 14 GW of new wind power capacity was awarded (about 7.6 GW onshore and 6.8 GW offshore) through auctions in 2019.[171] The region's largest onshore auction was held in Poland, where 2.2 GW of capacity was awarded at an average price of EUR 49 (USD 55) per MWh.[172] Europe's winning onshore bids were in the range of EUR 21 to EUR 67.2 (USD 23.5 to USD 75.3) per MWh.[173] However, while average awarded bid prices continued to fall in Denmark and

i Unless noted otherwise, mentions of auctions and tenders as support mechanisms presume wind technology-specific tenders or those specific to renewables in general. Technology-neutral tenders (open to non-renewables) do not constitute a support mechanism, although such tenders can and do draw successful bids from renewable energy developers.

ii Note that bid levels do not necessarily equate with costs. Also, energy costs vary widely according to wind resource, project and turbine size, regulatory and fiscal framework, the cost of capital and other local influences. Bid levels differ from market to market due to varying auction designs, policies and risks, among other factors. See endnote 165 for this section.

Greece, for example, they increased further in Germany (above the statutory tariffs under the old FIT), where five of the six onshore wind power auctions in 2019 were undersubscribed.[174]

Offshore in Europe, prices in auctions (in France, the Netherlands and the United Kingdom) continued to fall due in part to technology innovations and economies of scale.[175] The United Kingdom awarded 5.5 GW of capacity offshore in a single auction, for projects to be commissioned between 2023 and 2026, with strike prices 30% below those of the 2017 auction.[176] The Netherlands held its second offshore wind tender for which the winning project (due online by 2023) will receive only the wholesale price of electricity and will pay an annual rent for seabed rights.[177]

In the United States, while average contract lengths shortened, wind PPA prices[i] remained level or even rose throughout 2019, following historic lows in 2018, in anticipation of the PTC phase-out and further exacerbated by tariffs.[178] Vestas blamed its rising execution costs and falling margins in the United States (the company's most important market) on trade conflicts and tariffs, which had cascading effects on the global supply chain.[179] US tariffs on steel and aluminium, which make up 70-90% of wind turbines, as well as tariffs on permanent magnets, have put pressure on the US network of suppliers.[180] By one estimate, US tariffs on Chinese imports increased the costs of US wind projects by as much as 20%.[181] Several other countries also have introduced new trade barriers on wind-related commodities and components, which affects the flexibility of supply chains, even as local content rules push for localisation of manufacture.[182] (→ *See Sidebar 3.*)

While the shift from FITs to other instruments such as tenders and auctions has helped push down the cost of energy, it also has helped create a race to the bottom on price.[183] This intense competition (combined with trade tariffs in some cases) has challenged the sustainability of the entire supply chain, squeezing the margins of turbine manufacturers, developers and operations and maintenance (O&M) suppliers.[184] For a variety of reasons, including tender design and unrelenting competitive pressures, the diversity (in size and geography) and the number of auction participants has dropped sharply in some countries, including Germany and India, with only a handful of large international corporations submitting bids.[185]

The wind industry has seen more than 100 turbine suppliers over the years, with a peak of 63 suppliers reporting installations during 2013, but the number has declined rapidly since 2015; in 2019, four companies (three in China and one in India) had no new installations.[186] While 33 manufacturers delivered wind turbines to the global market during the year, the top 10 companies captured 85.5% of the capacity installed (up from 85% in 2018, 80% in 2017 and 75% in 2016).[187] The leading four companies – Vestas (Denmark), Siemens Gamesa (Spain), Goldwind (China) and GE Renewable Energy (United States) – were responsible for about 55% of capacity installed during 2019.[188] Vestas stayed on top but lost the most market share; Siemens Gamesa jumped from fourth to second (and led the offshore market); GE benefited from the healthy US market; and Goldwind continued to dominate in China while also increasing its presence in the Asia-Pacific region and beyond.[189] China-based Envision also remained in the top five globally.[190] Germany's Nordex-Acciona and Enercon (despite a significant decline in market share) took the seventh and eighth spots, and the remaining companies among the top 10 (all Chinese – Ming Yang, Windey and Dongfang) moved up in ranking thanks to a strong domestic market.[191]

By contrast, Senvion (Germany) and India's Suzlon – both of which were among the top 10 in 2017 – suffered severely as a result of declining home markets, as did Enercon, despite

i Prices in the United States reflect the US production tax credit, which applies to commercial wind power systems.

remaining among the top 10 (80% of the company's installations were outside of Germany).[192] After two years of dramatic decline in the German onshore market, Enercon cut thousands of jobs at home and abroad, ended co-operation with domestic production partners and reported significant losses.[193] Senvion, once a leading innovator in the global industry, filed for insolvency in 2019; Siemens Gamesa took over some of Senvion's key European assets and businesses.[194] In early 2020, Suzlon disclosed outstanding debt of about USD 1.8 billion and started debt restructuring.[195]

Even the top manufacturers suffered losses, closed factories and laid off workers in 2019, despite record turbine orders (globally and for individual companies) and increased revenues, due to rising costs that included trade-related tariffs.[196] But some companies opened new facilities as well, driven by the need to reduce transport costs and to access new revenue sources, as well as by local content requirements.[197] For example, Vestas opened a new turbine factory in Brazil, and MHI Vestas Offshore Wind (Denmark) signed a contract for blade materials in Chinese Taipei; Nordex opened a rotor blade factory in Mexico; Siemens Gamesa completed Turkey's first nacelle factory, a condition of Turkey's first wind tender in 2017, and confirmed plans for a nacelle assembly plant in Chinese Taipei; and GE started constructing a factory in China for its 12 MW Haliade-X.[198]

Many wind turbine manufacturers and project developers were pulling together teams to expand into solar PV, and many were developing hybrid projects during 2019.[199] In Australia, China, India, the United States and several European countries, wind power projects have been co-located with solar and/or storage projects to reduce energy prices while mitigating the impacts of variability and expanding revenue opportunities.[200] Some companies have taken this a step further. In 2019, Acciona (Spain) was studying the use on its turbine towers of flexible solar PV thin films made of carbon to power auxiliary systems.[201] Also during the year, a 2 MW hybrid project in Minnesota was the first in the United States to combine solar and wind power at the same interconnection, using a GE turbine that routes solar and wind energy through a shared inverter.[202] Pairing technologies not only side-by-side but at the same interconnection reduces costs of equipment, siting, grid connection, financing, and operations and maintenance compared to separate projects, while also increasing capacity factors.[203] The Minnesota project, for example, expects a capacity factor of 65-70%.[204]

Both the number and size of large projects continued to increase in 2019, especially onshore in China and the United States and offshore in the United Kingdom.[205] By year's end, the largest projects in operation were the East Anglia (0.7 GW) and Hornsea One (1.2 GW) off the UK coast.[206] Particularly offshore, the rapid increase in project and turbine size has helped to reduce costs through scale and standardisation – as project size increases, the costs of capital and the per MW costs of planning and balance-of-plant all typically decline.[207]

The trend also continued towards larger machines (including longer blades, larger rotor size and higher hub heights, and therefore higher power rating) for both onshore and offshore use, as turbine manufacturers aimed to boost output and to gain or maintain market share.[208] The average size of turbines delivered to market was 12% larger than in 2018 (2.45 MW), at 2.76 MW (2.6 MW onshore and nearing 5.7 MW offshore) in 2019.[209] Onshore, the largest country averages were seen in Morocco (4.2 MW), Finland (almost 4.2 MW) and Norway (3.8 MW), with averages exceeding 2 MW in all other established markets – including Brazil (2.6 MW), the United States (2.5 MW) and China (nearly 2.4 MW).[210] Offshore, the highest average power ratings were in Belgium and Portugal (both 8.4 MW), and in Denmark (8.3 MW).[211] Across Europe, the average per unit capacity of newly installed turbines offshore in 2019 was 7.2 MW, up from 6.8 MW in 2018.[212]

The world's **largest turbine,** at 12 GW, started generating electricity in November, and serial production was scheduled to begin in 2021.

Turbines are set to get only bigger. Siemens Gamesa launched a 10 MW offshore turbine in January 2019 and presented an upgraded 11 MW model late in the year; the company plans to have the machine on the market in 2022.[213] MHI Vestas also had a 10 MW turbine under way in 2019.[214] Chinese manufacturers are in competition to develop machines that match these capacities, and both Dongfang (prototype) and CSIC Haizhuang (plan only) unveiled 10 MW machines in 2019.[215] GE installed its first Haliade-X (12 MW) prototype at the Port of Rotterdam; the world's largest turbine to date started generating electricity in November, and serial production was scheduled to begin in 2021.[216] The machines blades are the longest ever made, at 107 metres, about the length of a football pitch (soccer field), and a single turbine is expected to generate enough electricity for 16,000 European homes.[217] Other turbine and generator companies are working on the next generation, envisioning unit capacities of 20 GW.[218]

Offshore developers are taking advantage of larger turbines as soon as they become available, with several orders placed for these mega-turbines during 2019.[219] Larger turbines mean that fewer foundations, converters, cables, less labour and other resources are required for the same output, translating into faster project development, reduced risk, lower grid-connection and O&M costs, and overall greater yield.[220]

At the same time, increasing machine size (whether for onshore or offshore use), large projects and developments farther out to sea have required that suppliers adapt designs to minimise the logistical challenges of manufacture, transport, installation as well as O&M.[221] GE, for example, developed a two-part blade that can be assembled on-site for its largest onshore turbine (5.3 MW).[222] Drones already have been used to inspect blades, reducing outage time from hours to minutes and reducing the required numbers of vessel trips.[223] In 2019, Vestas unveiled a research partnership to develop drone technology to support blade installation, and Siemens Gamesa, Ørsted (Denmark) and Esvagt (Danish vessels supplier) were exploring how to use drones to transport spare parts to offshore wind projects.[224] Some operators have begun to pool resources at centralised facilities or to expand operations hubs at sea that can house technicians for weeks at a time.[225]

The offshore industry also made advances in the segment of floating turbines, which offer the potential to expand the areas where offshore wind energy is viable and economically attractive because they can be placed where winds are strongest and most consistent, rather than where the sea-floor topography is suitable.[226] Several configurations for floating substructures continue to be developed and demonstrated in Europe and elsewhere, and the technology is becoming increasingly cost-competitive.[227]

During 2019, Portugal installed the first platform of WindFloat Atlantic, and the first of three 8.4 MW turbines began feeding the grid, while Spain tested the first multi-turbine floating platform.[228] Innogy SE (Germany), Shell (Netherlands) and Steisdal Offshore Technologies (SOT, Denmark) announced the final investment decision to build a demonstration project off Norway using SOT's modular floating foundation concept, which can be fully industrialised and deployed without installation vessels.[229] By year's end, Europe's floating fleet reached 45 MW, and an estimated 80.5 MW was operating offshore around the world.[230]

The low centre of mass of vertical-axis wind turbines and their potential for use with a floating platform has revitalised interest in the concept.[231] Several attempts, often unsuccessful, have been made in the past to develop these turbines for offshore use.[232] In 2019 and early 2020, Swedish company SeaTwirl, which is developing a floating vertical-axis turbine, announced that it had secured patents in China, Europe and the United States.[233] In September the firm launched a two-year project with the ultimate aim to commercialise its 1 MW turbine.[234] Vertical-axis designs have the potential to greatly reduce costs by eliminating the need for a number of components, enabling the use of cheaper platforms, improving stability and requiring easier and less costly maintenance compared to horizontal-axis turbines.[235]

In Europe, major offshore wind power developers advanced efforts to produce hydrogen from excess wind energy for greater grid flexibility or for use in transport and industry.[236] In 2019, Ørsted (Denmark), the world's largest offshore wind developer, announced plans to use electricity from wind farms being built off the Dutch coast to produce hydrogen for sale to industrial customers.[237] Siemens joined a partnership to develop a hybrid solar PV-wind power project in Australia for hydrogen production, and partnered with Shell (Netherlands) and grid operator TenneT (Netherlands/ Germany) to propose a joint offshore wind power and hydrogen tender in Germany.[238] (→ *See Systems Integration chapter.*)

As offshore wind power has advanced, particularly floating technologies, Shell and other major oil companies have become interested in the sector.[239] Developments in 2019 included: Italy's oil and gas contractor Saipem unveiled a new substructure that can be a foundation for a range of turbine sizes; US-based ExxonMobil was researching the use of floating turbines to enhance oil production; and Equinor (Norway), which built the world's first floating offshore wind project (Hywind Scotland), entered the Chinese offshore market and committed to constructing a project to supply oil and gas facilities by 2022, aiming to reduce costs 40% compared to Hywind Scotland.[240]

New offshore markets still face challenges that Europe and China have addressed, including developing supply chains, a trained workforce and associated infrastructure such as ports, rail links and installation vessels, as well as grid infrastructure and technology for electrical connections.[241] Much of the Asian market also lacks viable finance solutions and co-operation among the relevant countries.[242] However, several countries – including India, Turkey and Vietnam – were collaborating with Denmark in 2019 to develop roadmaps and build technical capacity.[243]

In the United States, states are collaborating to establish an efficient supply chain and are investing in grid infrastructure.[244]

US utilities and project developers are partnering with Europe's largest offshore wind developers to set up manufacturing hubs and build projects, while also working with US government agencies, environmental organisations and the fishing industry to study and address the potential impacts of offshore wind power on fisheries and wildlife.[245]

Around the world, and particularly onshore, major manufacturers are focused increasingly on the repowering segment.[246] Historically, repowering has involved the replacement of old turbines with fewer, larger, taller, and more-efficient and reliable machines at the same site, but increasingly operators are switching even relatively new machines for larger and upgraded turbines (including software improvements) or are replacing specific components, such as blades (partial repowering).[247] Such partial repowering can extend turbine lifetime while greatly increasing a wind farm's performance.[248] Nearly every major turbine manufacturer offers various upgrading services.[249]

In the United States, project owners partially repowered a total of 2.8 GW at existing projects, up from 1.2 GW in 2018.[250] Despite the rising number of ageing turbines in some European countries, repowering was down relative to 2018 due to permitting challenges, lack of regulatory support and high wholesale electricity prices[i].[251] An estimated 185 MW of European capacity was repowered, mostly in Germany but also in Austria, Greece and the United Kingdom.[252] Repowering in China has been limited to date.[253]

As the earliest fleets of wind turbines reach retirement age, concerns are increasing about what to do with turbines at the end of their life. Although most of a turbine can be used on another wind farm or recycled, blades are made of materials that are difficult and expensive to recycle.[254] Developments in 2019 that were aimed at addressing this challenge included a partnership in Europe among wind power and chemical industries to advance recycling efforts for composite wind turbine blades; plans by the Danish company Miljoskarm to grind blades into small pieces and use them in recycled plastic casing as noise barriers; and the construction by US-based Global Fiberglass Solutions of a recycling plant that will break down blades and turn them into water-resistant pellets or panels for use as flooring and walls.[255] In addition, US researchers were working to develop blades from a thermoplastic resin system, which has the potential to reduce the energy, time and cost involved in manufacturing while also allowing for blades to be recycled at the end of their life.[256]

Also in 2019, GE Renewable Energy announced that it would make its operations 100% carbon neutral by the end of 2020.[257] Siemens Gamesa committed to becoming a carbon-neutral company by, for example, switching all operations to renewable energy-based electricity sources, and in early 2020 it turned its attention to its international supply chain.[258] Also in early 2020, Vestas (which achieved 100% renewable electricity in 2013) joined RE100 and set a target to become carbon-neutral by 2030 through its own corporate actions. Vestas also announced plans to eliminate non-recyclable waste from manufacturing, operating and decommissioning of its wind turbines by 2040.[259]

→ *See Box 1 for developments in the small-scale wind power sector. Also see Sidebar 5 and Figure 40 on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.*[260]

i Old wind turbines that are no longer receiving FIT payments can operate in the open market or contract under PPAs (with similar prices). As long as wholesale prices are high enough to more than cover rising O&M costs, operators have a business case for continuing to operate the old turbines. See endnote 251 for this section.

Around the world, major manufacturers are focused increasingly on the **repowering segment.**

BOX 1. Small-scale Wind Power

Small-scale[i] (up to 100 kW) wind turbines are used for a variety of on- and off-grid applications, including defence, rural electrification, water pumping and desalination, battery charging, telecommunications and to displace diesel in remote locations. The annual global market continued to shrink in 2018 (latest data available) in response to unfavourable policy changes and ongoing competition from relatively low-cost solar PV.

By one estimate, 47 MW of new small-scale wind power capacity was installed in seven countries during 2018, down from an estimated 114 MW[ii] in 2017. China continued to be the largest market, with an estimated nearly 31 MW installed in 2018, a slight increase from 2017 but a substantial decline relative to previous years. The United States deployed an estimated 1.5 MW (2,661 units) in 2018, a 12% annual reduction that continued the country's downwards trend in small-scale turbines. The UK market also fell further from its 2014 peak, in step with FIT changes.

Japan and Denmark, by contrast, both saw significant increases during 2018. Japan added an estimated 12.9 MW (up from 2.85 MW in 2017) and had another 153 MW in the FIT-approved queue by year's end. Worldwide, more than 1 million small-scale turbines (totalling at least 1.7 GW) were estimated to be operating at the end of 2018.

In response to shrinking markets in recent years, the number of producers of small-scale wind turbines in China and the United States has declined sharply, with manufacturers relying heavily on export markets, which also are in decline. US-manufactured exports, for example, fell from 5.5 MW (USD 42 million) in 2017 to less than 1 MW (USD 4.6 million) in 2018. The number of small-scale wind turbine manufacturers that reported sales in the United States fell from 31 in 2012 to 8 in 2018, and several manufacturers reported that costs were affected during 2018 by tariffs on materials imported from China.

At least in the United States, however, things were looking up in 2019 with evidence that a 2018 extension of the US investment tax credit for small-scale wind power, combined with public research and development funding, could enable small and distributed wind power technology to turn the corner in the country. In addition, US R&D efforts were under way to make wind power a plug-and-play component in hybrid systems and microgrids, among other options.

Also in 2019, a small-scale turbine made by Hi-VAWT (Chinese Taipei) became the first vertical-axis turbine to achieve certification under the Small Wind Certification Council's Small Wind Turbine Program.

i Small-scale wind systems generally are considered to include turbines that produce enough power for a single home, farm or small business (keeping in mind that consumption levels vary considerably across countries). The International Electrotechnical Commission sets a limit at approximately 50 kW, and the World Wind Energy Association and the American Wind Energy Association as well as the US government define "small-scale" as up to 100 kW, which is the range also used in the GSR; however, size varies according to the needs and/or laws of a country or state/province, and there is no globally recognised definition or size limit. See endnote 260 for this section.

ii The significant reduction in reported deployment between 2017 and 2018 could be due in part to differences in data availability, from US Department of Energy, Office of Energy Efficiency and Renewable Energy, *2017 Distributed Wind Market Report* (Washington, DC: 2018), p. 12, https://www.energy.gov/sites/prod/files/2018/09/f55/2017-DWMR-091918-final.pdf.

Source: See endnote 260 for this section.

SIDEBAR 5. Renewable Electricity Generation Costs in 2019

Renewable power generation is increasingly becoming the default source of least-cost new power generation. The global weighted average levelised cost of electricity (LCOE)[i] from solar and wind power technologies again declined in 2019, with utility-scale solar PV down 13%, onshore and offshore wind both down 9%, and concentrating solar thermal power (CSP) down 1% compared with 2018[ii].

The 13% decline in the global weighted average LCOE of solar PV in 2019 – which was slightly below the 15% reduction in 2018 – was driven by declines in module prices and balance-of-system costs. The 9% decline in onshore wind costs was only slightly below the 10% reduction in 2018; however, the LCOE of offshore wind fell by three times the 3% decline of 2018. These cost decreases are due in part to technology improvements and to reductions in total installed costs, but also to increasing market competition. For example, major suppliers of turbines and associated technology for solar PV noted strong and increasing competition in the global marketplace, contracting sales, and declining or even negative margins. (→ *See Market and Industry chapter.*)

Because the LCOE of different technologies can vary greatly by country and region, the global weighted average LCOE is an imperfect measure; however, trends in this metric give a sense of overall movement and comparison with costs of generation from conventional fuels. In 2019, mature renewable electricity generation technologies – hydropower, bio-power and geothermal power – remained cost competitive with fossil-fuelled power technologies. The global weighted average LCOEs of solar and wind power technologies show that they continue to become more cost competitive with fossil fuels.

In particular, costs for solar PV and CSP as well as onshore and offshore wind have fallen sharply over the past decade. (→ *See Figure 40.*) Global average hydropower costs have risen since 2010 as more challenging sites are exploited, but nine-tenths of the new hydropower capacity added in 2019 still had lower costs than the cheapest fossil fuel-fired source of new electricity.

i All references to LCOE in this sidebar exclude the impact of any financial support policies, so the cost to final consumers will be lower than quoted here in markets where this support is material. The other key assumption is that the weighted average cost of capital is 7.5% in member countries of the Organisation for Economic Co-operation and Development (OECD) and in China, compared with 10% (adjusting for inflation) elsewhere. LCOE numbers presented here are therefore conservative given the low interest rate environment in 2019. Note also that costs are very location- and project-specific, and cost ranges can be substantial; the LCOEs presented here should be considered in the context of the country- and region-specific project cost ranges provided in International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2019* (Abu Dhabi: 2020), which also provides further details on the LCOE methodology.

ii All data in this sidebar are from the IRENA Renewable Cost Database 2020, which contains cost data on more than 17,000 renewable power generation projects, accounting for around half of all deployment to 2019. All cost data are expressed in USD_{2019}.

Source: IRENA. See endnote 260 of Wind Power section in this chapter.