DISTRIBUTED RENEWABLE ELECTRICITY

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

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

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

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

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

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

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

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

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

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

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

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

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

COMMUNITY RENEWABLE ENERGY ARRANGEMENTS

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

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

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

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

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

SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

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

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

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

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

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

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

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

iv Prosumers both produce and consume electricity.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 3. Renewable Energy Targets and Policies, 2019

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

Note: Please see key on last page of table.

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

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

Note: Please see key on last page of table.

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

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

Note: Please see key on last page of table.

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

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

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

Policies
- ★ New (one or more policies of this type)
- ★* New subnational
- ☆ Revised (from previously existing)
- ☆* Revised sub-national
- ● Removed
- ● Existing national policy or tender framework (could include sub-national)
- ◖ Existing sub-national policy or tender framework (but no national)
- ○ National tender held in 2019
- ◟ Sub-national tender held in 2019

[1] Certain Caribbean countries have adopted hybrid net metering and feed-in policies whereby residential consumers can offset power while commercial consumers are obligated to feed 100% of the power generated into the grid. These policies are defined as net metering for the purposes of the GSR.
[2] FIT support removed for large-scale power plants.
[3] Spain removed FIT support for new projects in 2012. Support remains for certain installations linked to this previous scheme.
[4] State-level targets in the United States include RPS policies.
[5] The area of the State of Palestine is included in the World Bank country classification as "West Bank and Gaza".
[6] Includes renewable heating and/or cooling technologies.
[7] Includes aviation, maritime or rail transport.
[8] Heat FIT
[9] Fossil fuel heating ban

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

Source: See endnote 2 for this chapter.

03

HARVESTING GEOTHERMAL ENERGY IN RURAL COMMUNITIES, EL SALVADOR

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

03 MARKET AND INDUSTRY TRENDS

KEY FACTS

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

BIOENERGY

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

BIOENERGY MARKETS

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

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

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

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

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

Bio-heat Markets

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

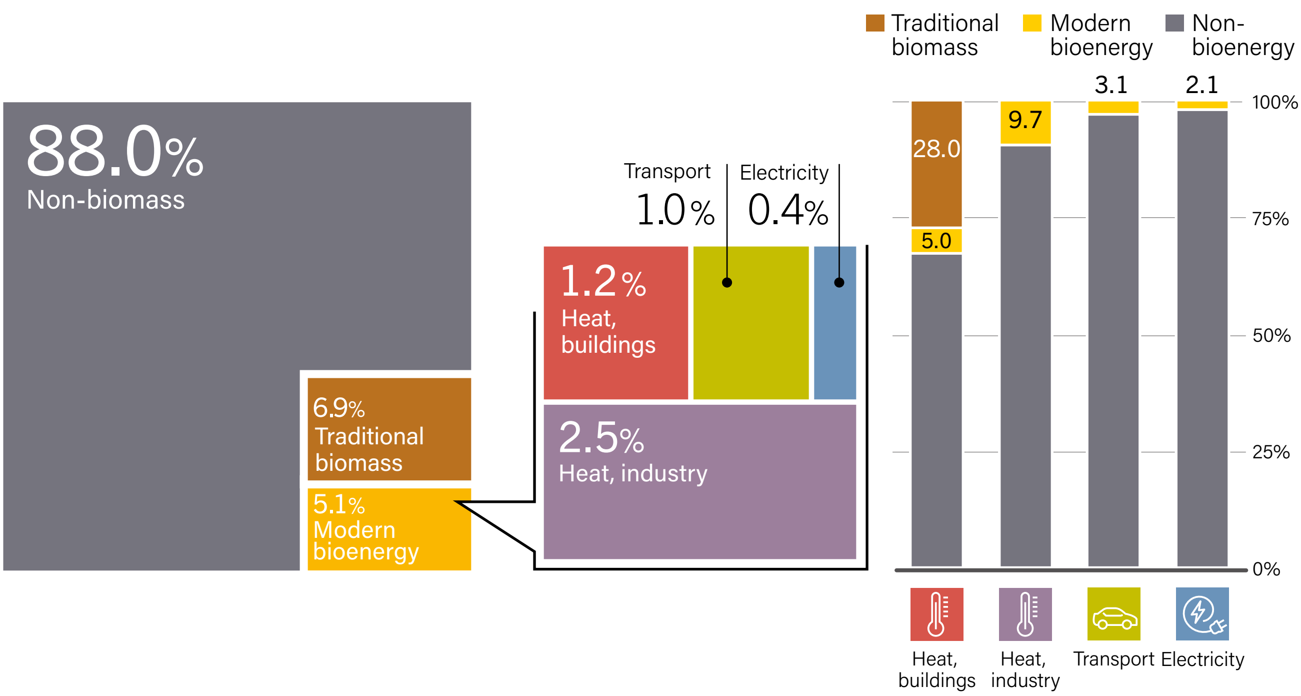
The **traditional use of biomass** in developing and emerging economies supplies energy for cooking and heating in simple and usually inefficient fires or stoves.[9] (→ *See Distributed Renewables chapter.*) The amount of biomass used in traditional applications has decreased slightly in recent years,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

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

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

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

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



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

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

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

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

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

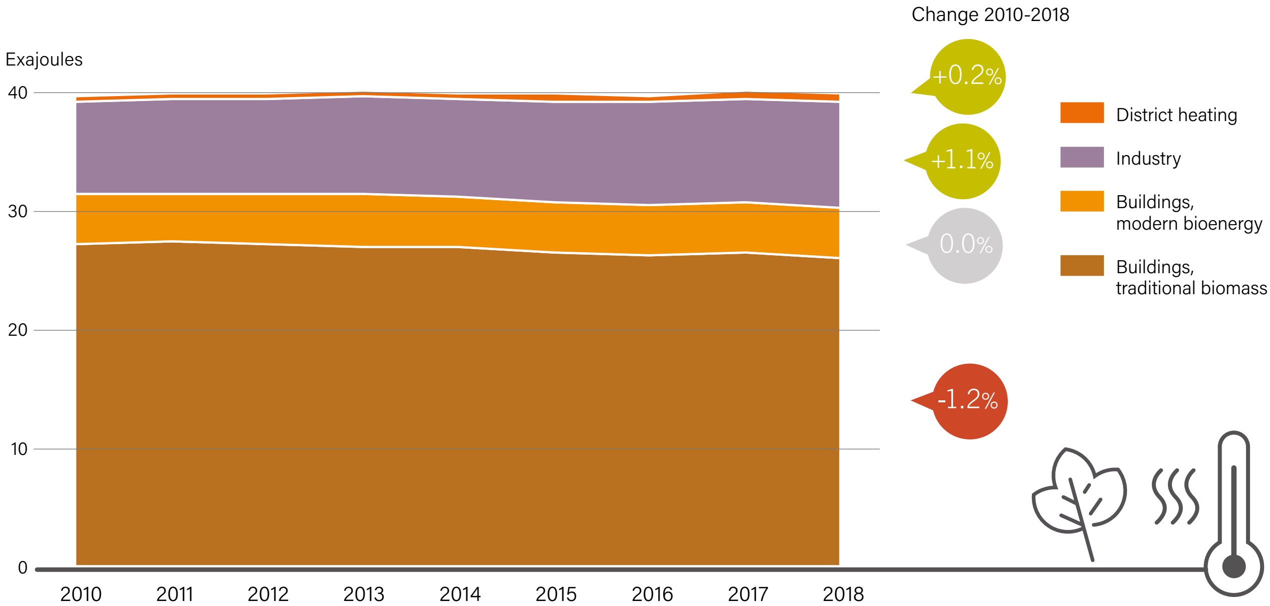
Biomass can produce heat for residential building use through the burning of wood logs, chips or pellets produced from wood or agricultural residues. The informal use of wood and other biomass to heat individual residences is prevalent in developing and emerging economies as well as in more developed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

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

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

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

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



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

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

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

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

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

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

Transport Biofuel Markets

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

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

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

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

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

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

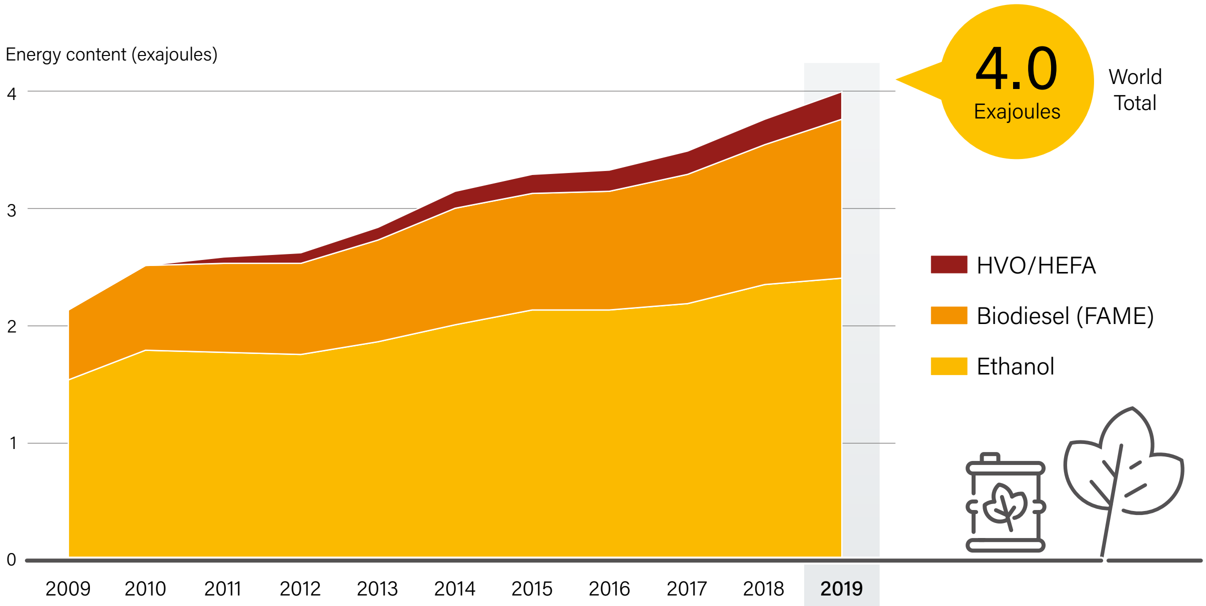
China's ethanol production increased to 4 billion litres in 2019, up from 3.3 billion litres in 2018, to meet growing domestic demand.[63]

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

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

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

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



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

Source: See endnote 50 for this section.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Bio-power Markets

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

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

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

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

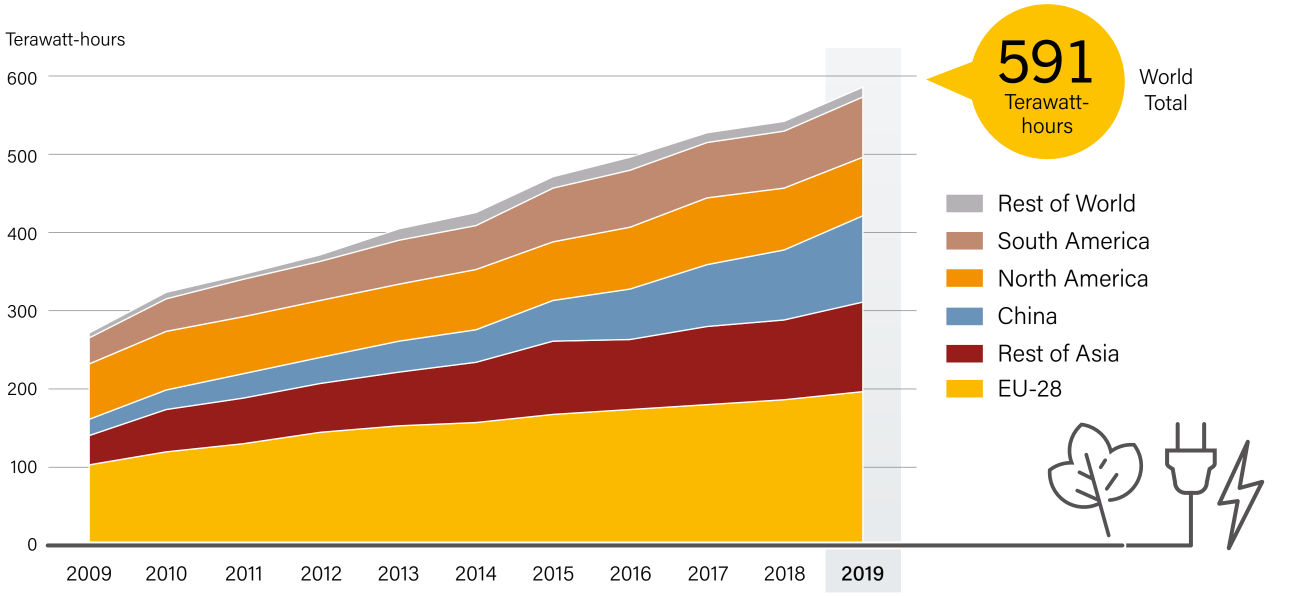
Japan's growth in bio-power capacity and generation remained strong during the year, stimulated by the Feed-in Tariff scheme.[109] The capacity of dedicated bio-power plants increased 8% to 4.3 GW, and generation grew 18% to 24 TWh.[110] In the Republic of Korea, bio-power generation rose 50% to 10.9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

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

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

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

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



Source: See endnote 105 for this section.

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

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

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

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

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

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

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

BIOENERGY INDUSTRY

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

Solid Biomass Industry

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

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

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

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

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

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

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

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

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

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

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

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

In 2019, HVO/HEFA plants in the pipeline were enough to **triple** global production capacity.

Liquid Biofuels Industry

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

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

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

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

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

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

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

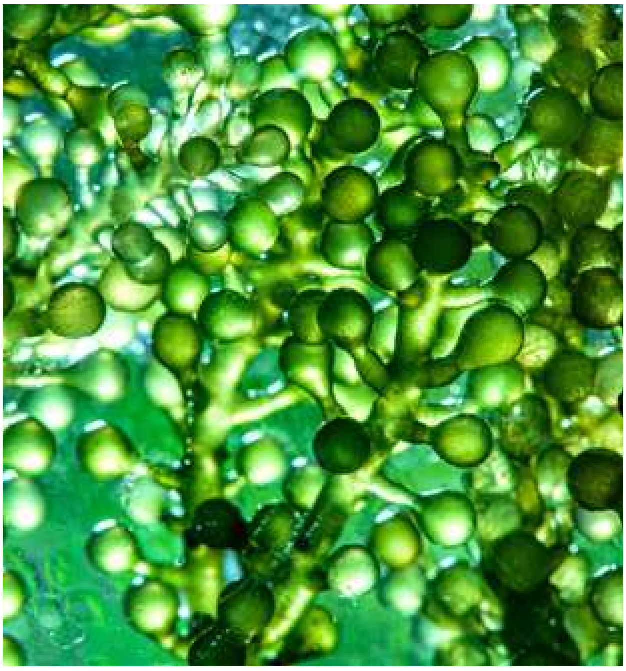
Many pathways are under development to produce advanced biofuels, including bio-based fuels (from an array of feedstocks) in the form of ethanol, butanol, diesel jet fuel, gasoline, biomethanol and mixed higher alcohols.[174] The most advanced pathways include the production of ethanol from cellulosic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

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

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

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

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



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

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

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

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

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

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

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

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

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

Gaseous Biomass Industry

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

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

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

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

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

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

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

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

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

Bioenergy with Carbon Capture and Storage or Use

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

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

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

MARKET AND INDUSTRY TRENDS

KEY FACTS

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

GEOTHERMAL POWER AND HEAT

GEOTHERMAL MARKETS

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

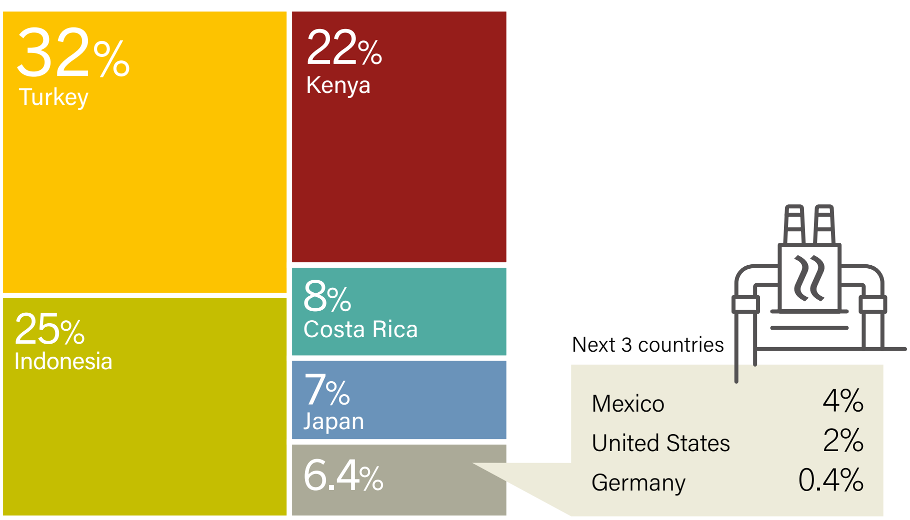
An estimated 0.7 GW[iii] of new **geothermal power** generating capacity came online in 2019, bringing the global total to around 13.9 GW.[2] As in 2018, Turkey and Indonesia remained in the lead for new installations, followed closely by Kenya. Together, these three countries represented three-quarters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

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

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

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

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



Source: See endnote 4 for this section.

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

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

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

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

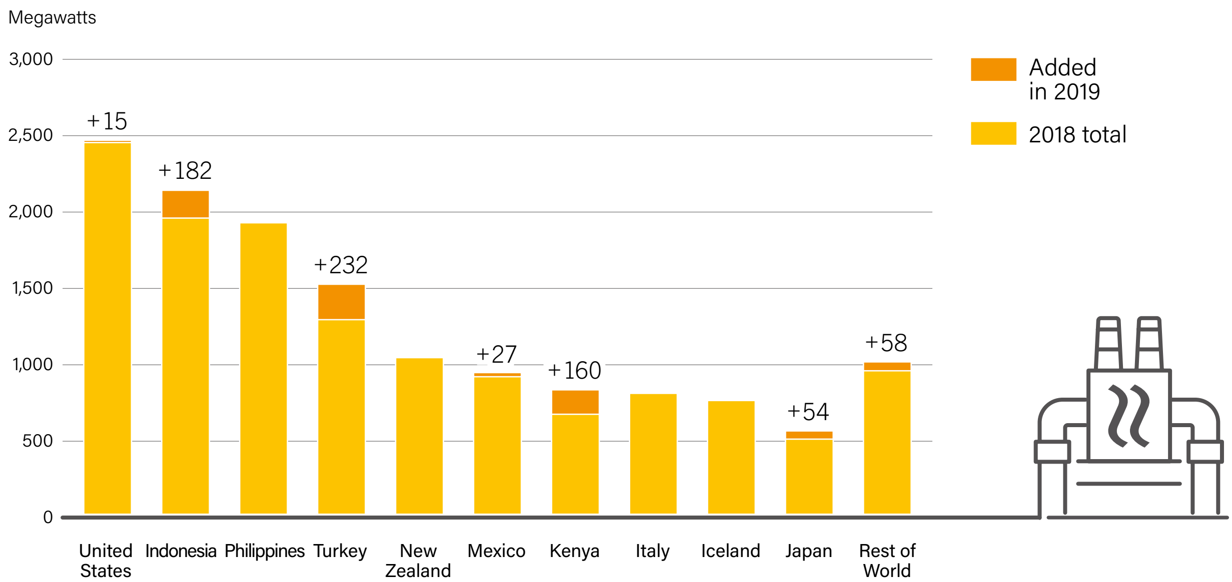
Turkey's geothermal sector also faced mounting community concern about the potential adverse impacts of air emissions (mainly hydrogen sulphide) and groundwater contamination (heavy metals) from existing geothermal power plants on public health, wildlife and agricultural output (primarily olives and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

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

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

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

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



Source: See endnote 5 for this section.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

GEOTHERMAL INDUSTRY

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

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

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

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

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

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

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

KEY FACTS

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

HYDROPOWER

HYDROPOWER MARKETS

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

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

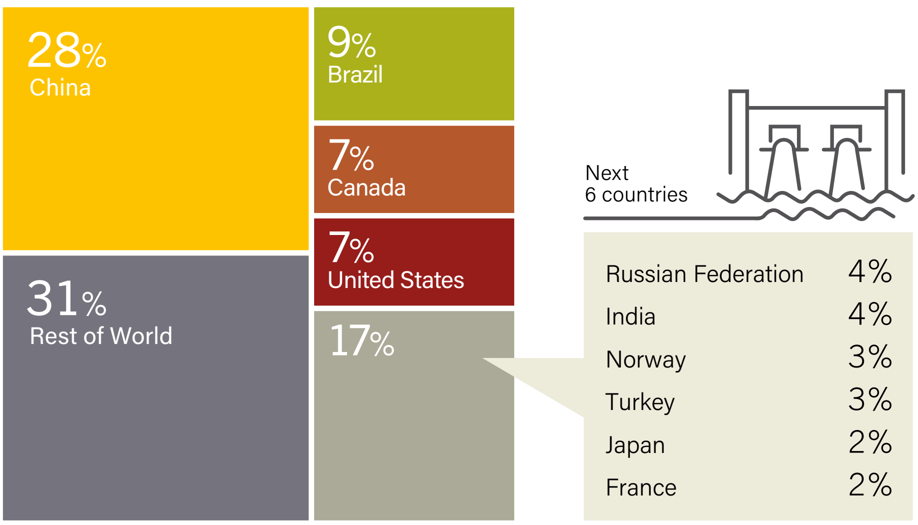
Brazil took the lead in commissioning new hydropower capacity in 2019, followed by four countries in Asia: China, Lao PDR, Bhutan and Tajikistan.[4] (→ *See Figure 27.*) This marked the first year since at least 2004[iii] in which China did not maintain a wide-margin lead over all other countries for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

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

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

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

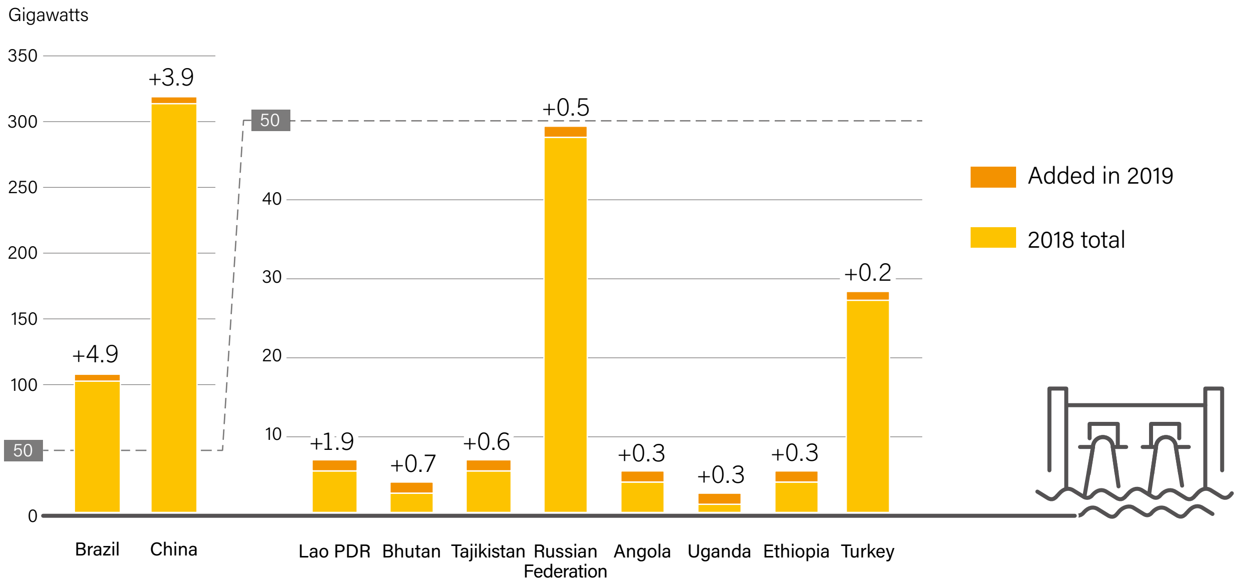
FIGURE 26. Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2019



Note: Totals may not add up due to rounding.

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

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



Source: See endnote 4 for this section.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

i This excludes 22.9 GW of US pumped storage capacity.

ii A reservoir created by a dam.

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

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

HYDROPOWER INDUSTRY

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

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

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

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

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

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

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

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

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

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

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

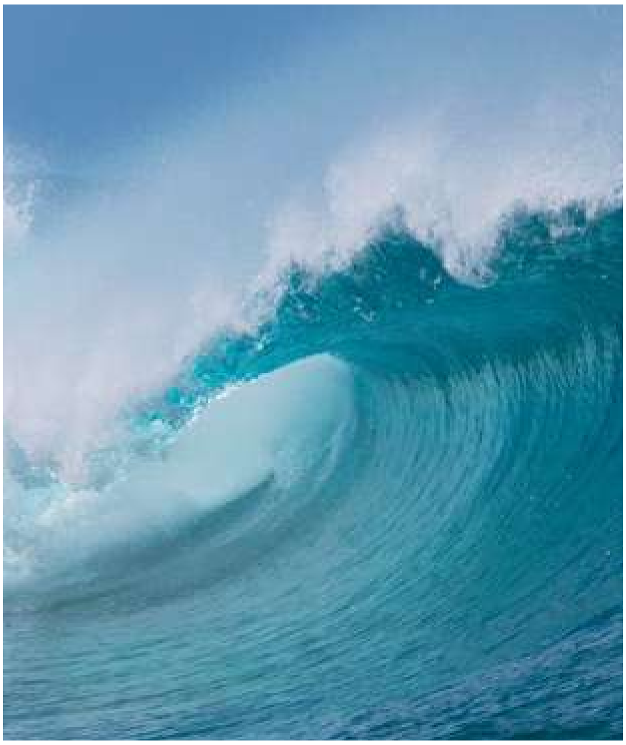
In 2019, the European Commission and 19 partners in industry, academia and research launched an EUR 18 million (USD 20.2 million) initiative to demonstrate how modern hydropower systems can provide the flexibility and power grid services required to integrate larger shares of variable solar and wind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

i A roughly 80% cycle efficiency means that energy sold needs to carry a 25% premium over energy consumed (1/0.8 = 1.25).

ii Provider-specific information noted based on availability of reports on operations.

KEY FACTS

- Ocean power generation rose substantially in 2019, surpassing 45 GWh.
- The industry began moving from small-scale demonstration and pilot projects towards semi-permanent installations and arrays of devices.
- Maintaining revenue support to ocean power technologies is considered paramount for allowing the industry to achieve greater maturity.



OCEAN POWER

OCEAN POWER MARKETS

Ocean power[i] represents the smallest share of the renewable energy market. Although the resource potential of ocean energy is enormous, the technologies are still in the early stages of development.[1] (→ *See Sidebar 4.*) Net additions[ii] in 2019 were around 3 MW, bringing the total operating installed capacity to an estimated 535 MW at year's end.[2]

Two tidal barrages using mature turbine technologies[iii] – the 240 MW La Rance station in France (installed in 1966) and the 254 MW Sihwa plant in the Republic of Korea (2011) – represent more than 90% of total installed capacity.[3]

Tidal stream and wave power are the main focus of development efforts. Advancements in these technologies have been concentrated largely in Europe, especially the United Kingdom. However, generous revenue support and ambitious R&D programmes in Canada, the United States and China have spurred increased development and deployment.[4]

Tidal stream devices are approaching maturity, with design converging on horizontal-axis turbines mounted on the sea floor or attached to a floating platform.[5] These devices have demonstrated considerable reliability in performance, and electricity generation rose substantially in 2019, owing to an increase in operating hours.[6] Total generation surpassed 45 GWh, with tidal stream devices in European waters alone generating 15 GWh in 2019 (up 50% from 2018).[7]

Wave power devices have not yet seen convergence on design, owing to the complexity of extracting wave energy from a variety of wave conditions and the wide range of possible operating principles.[8] Developers generally have chosen one of two distinct pathways for wave energy development: devices above 100 kW target utility-scale electricity markets, whereas smaller devices, usually below 50 kW, are intended primarily for specialist applications (oil and gas, aquaculture, maritime monitoring and defence).[9]

> Although the potential of ocean power is enormous, the technologies are still in the early stages of development.

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

ii A proportion of current installed capacity is removed or redeployed each year as demonstration projects reach their term or advance to a subsequent phase of testing. In Europe, for example, 10.3 MW of wave energy capacity had been decommissioned as of end-2019, following the successful completion of testing programmes.

iii The same in-stream technologies used in some types of hydropower plants.

SIDEBAR 4. The History of Ocean Power

Modern ocean power devices are the product of highly advanced industrial and technological systems, yet their earliest antecedents date back over 200 years. The first patent for an ocean energy device was filed in Paris by French mathematician Pierre-Simon Girard in 1799; the first operational plant was built in 1910 and was used to light and power a home. From 1855 to 1973, the United Kingdom alone granted over 300 patents for wave energy devices. Attempts to develop ocean thermal energy conversion (OTEC) started in the 1880s, and the first plant was built in Cuba in 1930, generating 22 kW of electricity before being destroyed in a storm.

The first large-scale ocean power facility, the La Rance tidal barrage in France, was built in the 1960s using proven hydropower turbine technologies. However, other methods for generating electricity from the ocean did not attract significant interest until the oil crisis of the 1970s. The US government invested USD 260 million in research and committed to producing 10 GW of electricity from OTEC systems by 1999, but ultimately no plants were commissioned[i]. The UK Department of Energy commissioned studies and ran a wave energy programme aimed at upscaling prospective devices, and the University of Edinburgh developed a device prototype and installed the first wave tank. As the oil crisis eased, interest waned and ocean power was largely abandoned, receiving very little funding in the 1980s and 1990s.

From the early 2000s onwards, ocean power experienced a resurgence, spurred by concerns about climate change and by the adoption of ambitious renewable energy objectives and policies. International co-operation was strengthened in 2001 with the establishment of the Ocean Energy Systems technology collaboration programme under the auspices of the International Energy Agency. The European Marine Energy Centre (EMEC) was established in 2003, providing an essential proving ground for devices by allowing for grid-connected testing in harsh weather conditions. More than 20 developers have since tested devices at EMEC.

In 2016, MeyGen deployed the first turbine of a planned 86 MW tidal stream array in the Pentland Firth, Scotland, marking a key milestone on the path to commercialisation. Progress has also been made in developing novel applications for ocean power technologies. In 2017, for example, EMEC began harnessing the excess electricity generated at one of its tidal testing sites to produce hydrogen, which is then used in a variety of fuel, power and heat applications. In 2018, Naval Group deployed a 450 kW Microsoft data centre at an EMEC wave test site, using wave energy to power the device and seawater for cooling.

The trajectory of ocean power has been volatile. On the one hand, a number of countries have invested considerable public funds into R&D, and large companies and private investors have become increasingly involved in device and project development. The EU turned its attention to ocean power for its potential to increase energy security and lower greenhouse gas emissions, while also creating jobs amid an economic downturn. On the other hand, government funding has been inconsistent, while the industry, in a bid to entice investors, overpromised what it could deliver in the near term and underestimated the technical challenges and costs. A number of bankruptcies ensued, large investors and energy companies withdrew, and the momentum generated by past public support slowed as private sector investors lost confidence.

Overall, the outlook for ocean power is positive. Costs are declining, and capital expenditure is lower than expected at this stage of development. Ongoing technological progress and development activity are encouraging, with the industry moving beyond pilot projects towards semi-permanent installations and arrays of devices exporting electricity to the grid, and significant investments and deployments were planned for 2020 and beyond.

i A 50 kW plant was tested for three months in 1979. The Department of Energy was poised to award a contract for a 40 MW pilot plant in 1982, but this did not come to fruition because of a change in the administration.

Source: See endnote 1 for this section.

OCEAN POWER INDUSTRY

Following a turbulent 2018, during which one industry leader ceased operations amid discouraging forecasts and limited development opportunities, the ocean power industry regrouped in 2019 and continued its gradual advance towards commercialisation.[10]

Tidal stream benefited from significant new investments of public funds and policy measures to support development. Three full-scale devices based on novel design principles were deployed for testing, although overall capacity additions were limited as developers prepared for large deployments totalling 9 MW in 2020.[11]

In Canada, the government of Nova Scotia offered a feed-in tariff of between CAD 385 and CAD 530 (USD 295 and USD 405) per MWh for demonstration projects, and as of the end of 2019 five developers were approved for a total of up to 22 MW.[12] During the year, two permits were awarded under Nova Scotia's demonstration permits programme: 2 MW to Jupiter Hydro and 1.5 MW to Nova Innovation.[13] A total of 7 MW (of the 10 MW maximum) was permitted under the programme.[14]

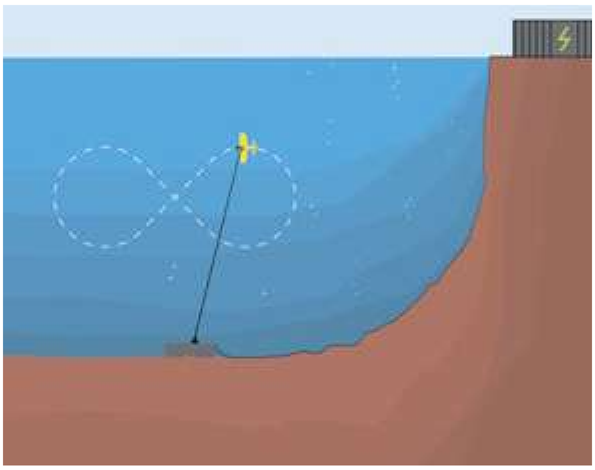
DP Energy and Sustainable Marine Energy continued to advance the Uisce Tapa project under development at the Fundy Ocean Research Centre for Energy (FORCE) in Nova Scotia. The CAD 117 million (USD 85.8 million) project aims to install a 9 MW array of six Andritz Hammerfest turbines and is supported by a Canadian government grant of CAD 29.8 million (USD 21.9 million).[15] Other provinces also are making progress on ocean power, particularly as a means to provide electricity to remote communities in Canada.

In the United Kingdom, a number of innovative cross-border collaborations and test deployments occurred in 2019, and some tidal devices demonstrated their reliability by generating electricity continuously throughout the year. In a large boost for the sector, Interreg France (Channel) England[i] announced that it would contribute EUR 28 million (USD 31 million) to the Tidal Stream Industry Energiser (TIGER) project – 70% of the project's EUR 47 million (USD 52 million) budget.[16] Led by the UK's Offshore Renewable Energy Catapult, TIGER brings together 19 partners from the United Kingdom and France to install 8 MW of capacity in and around the English Channel region.[17] The long-term objective is to cut generating costs from the current EUR 300 (USD 336) per MWh to around EUR 150 (USD 168) per MWh by 2025.[18]

Having entered its 25-year operational phase in 2018, Scotland's MeyGen tidal stream array (the world's largest at 6 MW) generated continuously in 2019, the longest period of uninterrupted generation to date from a commercial-scale tidal array.[19] The developer, SIMEC Atlantis Energy Ltd (United Kingdom), holds a seabed lease that would allow it to build the project out to 398 MW.[20] In 2019, SIMEC announced development of the next phase of the project, which will add a further 80 MW of capacity.[21] The company also was awarded a GBP 1.5 million (USD 1.8 million) government grant to develop a subsea connection hub for the next phase of the project.[22]

Also in Scotland, Nova Innovation's three-turbine 0.3 MW array in the Bluemull Sound of the Shetland Islands continued to generate consistently, with the turbines accumulating more than 20,000 operational hours as of December 2019.[23] Orbital Marine Power (formerly Scotrenewables Tidal Power) began building an optimised model of its SR2000 twin-turbine floating tidal power device, the Orbital O2, which it planned to deploy at EMEC in 2020.[24] Orbital also raised GBP 7 million (USD 9 million) through a crowdfunding campaign.[25]

Minesto (Sweden), which in 2018 successfully demonstrated the ability of its "energy kite"[ii] to harness relatively low-energy tidal streams and ocean currents, signed a power purchase agreement with the Faroe Islands utility for up to 2.2 MW of installed tidal capacity and obtained the required consents.[26] In May 2019, the Welsh government announced its continued support for Minesto's commercial development in Wales, awarding EUR 14.9 million (USD 16.7 million) of EU funding through the Welsh European Funding Office.[27] Minesto's long-term plan is to



i Interreg is a series of programmes to stimulate co-operation between regions in and out of the European Union, funded by the European Regional Development Fund. Interreg France (Channel) England was set up to foster economic development in the south of the United Kingdom and north of France by funding innovative projects that have a sustainable cross-border benefit. See Interreg, "About the programme", https://www.channelmanche.com/en/programme/about-the-programme.

ii Minesto's Deep Green device comprises a turbine integrated with a wing, which is tethered to the seabed and operates in a manner similar to an airborne kite.

deploy a commercial tidal energy array of up to 80 MW capacity at its Holyhead Deep site, eight kilometres off the coast of north-west Wales.[28] Minesto also was awarded a EUR 2.4 million (USD 2.7 million) grant as part of the TIGER project to install and operate a device at a grid-connected test site off the French coast.[29]

France remains an attractive location for tidal stream development, owing to its competitive grid-connected test centres, active support from regional and local governments, and the potential for scaling up projects in the future.[30] Two turbines were deployed in 2019: a 1 MW vertical-axis turbine at Paimpol-Bréhat (HydroQuest Ocean), which has already surpassed six months of continuous operation, and a short-term test deployment of a 20 kW horizontal-axis turbine at Ria d'Etel (Guinard Energies).[31]

Wave power advanced steadily in 2019, with a range of test deployments hitting the water in Europe and China, the announcement of significant new public funding and a number of developers pursuing novel device designs. More than 4 MW of deployments were planned in 2020, mostly of full-scale, high-capacity devices in Europe.[32]

In Europe, 0.6 MW was added through six individual units in 2019. Ocean Power Technologies (OPT) deployed a 3 kW device in the North Sea, where it supports an autonomous communications and remote monitoring platform used by Premier Oil.[33] The deployment began a nine-month lease that includes a purchase option. Another OPT device in the Adriatic Sea marked a full year of maintenance-free continuous operation in 2019.[34] In Portugal, AW-Energy deployed its 350 kW WaveRoller device, and commissioning work is under way to connect the device to the local electricity network.[35] Deployments also took place in Belgium, France and Italy.[36] In the United Kingdom, Wave Energy Scotland (WES) awarded GBP 9 million (USD 12 million) to 11 wave projects.[37]

In the United States, a 1.25 MW wave energy device was transported to the state of Hawaii for testing.[38] The country continued to provide funding for ocean power, with a focus on wave power devices and associated technology. In 2019, the US Department of Energy's Water Power Technologies Office awarded USD 25 million in research projects with the aim of reducing capital costs and shortening project development times.[39] The three topic areas for funding were early-stage device design, advancement of new power take-off (PTO) devices and control systems, and the consolidation of scientific knowledge and understanding of potential environmental impacts.

In China, the government supported its first megawatt-level test site (the Wanshan Wave Energy Demonstration Project) with an overall budget of RMB 151 million (USD 22 million), and a consortium began building two 500 kW test units.[40] The Guangzhou Institute of Energy Conversion completed the first open-sea test of a floating wave energy platform, which was successfully connected to the power grid of a remote island.

Carnegie Clean Energy (Australia) resumed construction of its CETO 6 device, having entered into voluntary administration in 2018 after a net loss of some AUD 45 million (USD 31 million) in 2018-19.[41] Carnegie continued to operate its Garden Island Microgrid in Western Australia, delivering more than 1,000 MWh to the country's largest naval base.[42] Wave Swell Energy also began construction of its 250 kW wave energy device.[43]

Bombora (United Kingdom) was on schedule to deploy its mWave device in mid-2020 and was progressing through the consenting phase of a proposed 2 MW project in Lanzarote, Spain, which it aimed to commission in 2022.[44] The novel device sits below the water surface and harnesses the pressure of overhead waves, an approach that the company hopes will allow it to overcome the survivability challenges facing wave energy devices.

Other ocean power technologies, such as **ocean thermal energy conversion** (OTEC) and **salinity gradient**, remain well short of commercial deployment, and only a handful of pilot projects have been launched. Nonetheless, novel applications continue to be developed. In 2019, for example, the Indian government approved the construction of a new OTEC-powered desalination plant.[45]

Technology improvements and steep cost reductions are still needed for ocean power to become competitive, and the industry is yet to receive the clear market signals it needs to take the final steps to commercialisation.[46] The lack of consistent support schemes for demonstration projects has proven especially challenging for developers, who have struggled to build a compelling business case, and the sector remains highly dependent on public funding to leverage private investment.[47]

Uncertainty regarding environmental interactions has often led regulators to require significant data collection and strict impact assessments, which can be costly and threaten the financial viability of projects and developers.[48] Current scientific knowledge suggests that the deployment of single devices poses little risk to the marine environment, but the impacts of multi-device arrays are not well understood.[49]

Continuing revenue support is considered paramount for increasing investment certainty by providing predictable returns until the industry achieves greater maturity.[50] As of 2018, more than EUR 6 billion (USD 6.9 billion) had been invested in ocean power projects worldwide, of which 75% was from private finance.[51] A 2018 European Commission implementation plan estimates that EUR 1.2 billion (USD 1.4 billion) in funding is needed by 2030 to commercialise ocean power technologies in Europe, requiring equal input from private sources, national and regional programmes, and EU funds.[52]

KEY FACTS

- Solar PV markets saw more capacity installed than ever before, with the strong demand in Europe, the United States and emerging markets making up for a substantial decline in China.
- Corporate purchasing expanded considerably, and self-consumption (increasingly with battery storage) was an important driver for new distributed systems in some countries.
- The industry continued to face strong competition which, coupled with policy uncertainties, resulted in extremely low bids at some auctions and thin margins for developers and manufacturers; at the same time, competition and price pressures encouraged more efficient manufacturing and ongoing innovation.
- Solar PV accounted for high shares of electricity generation in countries including Honduras (10.7%), Italy (8.6%), Greece (8.3%), Germany (8.2%) and Chile (8.1%).

SOLAR PHOTOVOLTAICS (PV)

SOLAR PV MARKETS

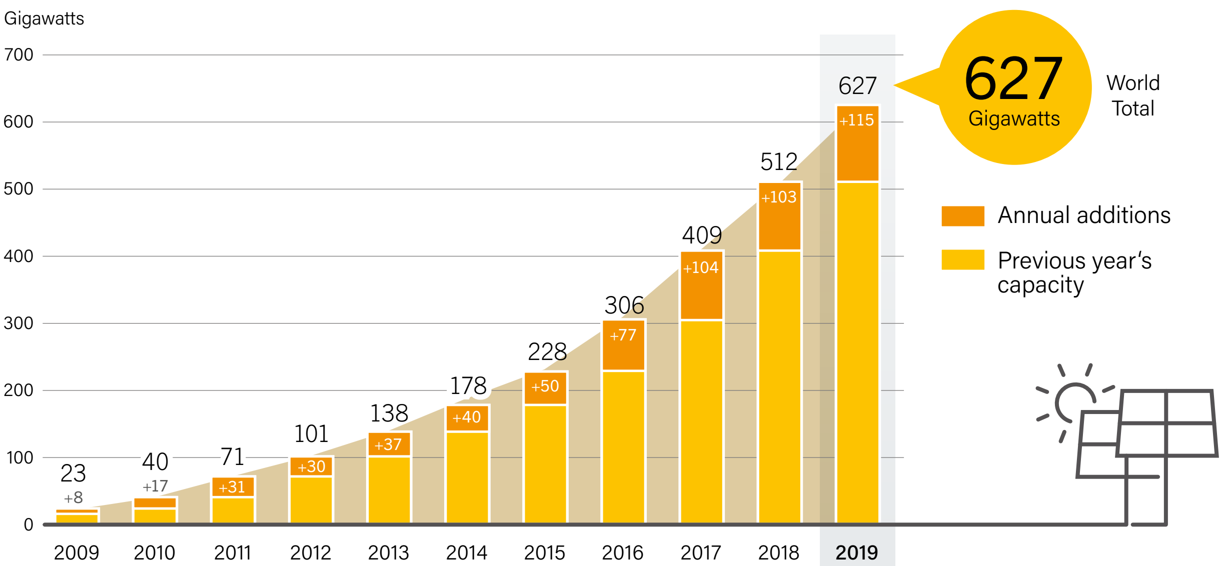
Following a year in which global solar photovoltaics (PV) additions were stable or even contracted slightly, in 2019 the solar PV market increased an estimated 12% to around 115 GW[i],[1] The decade ended with strong demand in Europe, the United States and emerging markets around the world, more than making up for a substantial decline in China, the single largest market.[2] Not including China, the global market for solar PV grew about 44% in 2019.[3] The global total of 627 GW, which includes on- and off-grid capacity, compares to a total of less than 23 GW only 10 years earlier.[4] (→ *See Figure 28.*)

Demand for solar PV is spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of locations – for residential and commercial applications and increasingly for utility-scale projects – even without accounting for the external costs of fossil fuels.[5] In some markets, this is becoming the case for solar-plus-storage as well.[6] In 2019, an estimated 18 countries added at least 1 GW of new capacity, up from 11 countries in 2018, and all continents contributed significantly to global growth.[7] By the end of 2019, at least 39 countries had a cumulative capacity of 1 GW or more, up from 31 countries one year earlier.[8]

In several countries, solar PV already plays a significant role in electricity generation.[9] By the end of 2019, 22 countries had enough capacity in operation to meet at least 3% of their electricity demand with solar PV, and 12 countries had enough

i For the sake of consistency, the GSR endeavours to report all solar PV capacity data in direct current (DC); where data are known to be in AC, that is specified in the text and endnotes. See endnotes and Methodological Notes for further details.

FIGURE 28. Solar PV Global Capacity and Annual Additions, 2009-2019



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

Source: Becquerel Institute and IEA PVPS. See endnote 4 for this section.

for at least 5%.[10] For the full year, solar PV accounted for around 10.7% of total generation in Honduras and substantial shares also in Italy (8.6%), Greece (8.3%), Germany (8.2%), Chile (8.1%), Australia (7.8%) and Japan (7.4%), among others.[11] Enough capacity was in operation worldwide by year's end to produce around 2.8% of global electricity generation.[12]

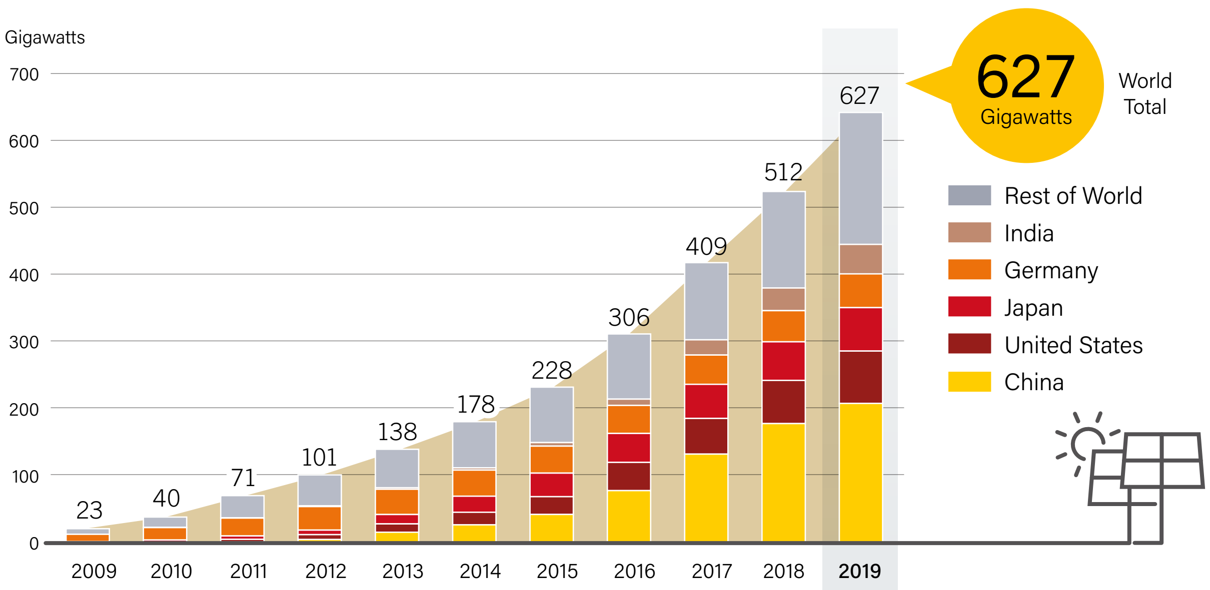
There are still challenges to address in order for solar PV to become a major electricity source worldwide, including policy and regulatory instability in many countries, and financial and bankability challenges.[13] As the level of penetration rises, solar PV is having an increasing effect on electricity systems, raising the importance of effectively integrating solar energy under varying technical and market conditions in a fair and sustainable manner.[14] Opposition from incumbents is generally lower than a decade ago, and many utilities are actively engaging in solar PV deployment and operations, including distributed generation; however, challenges remain in several countries and among some actors, particularly some in the fossil and nuclear industries.[15]

In most countries, the need still exists for support schemes for solar PV, as well as for adequate regulatory frameworks and policies governing grid connections.[16] Government policies – particularly traditional feed-in tariffs (FITs), feed-in premiums and tenders – continued to drive most of the global market in 2019.[17] Corporate purchasing of solar PV expanded considerably, and self-consumption was an important driver of the market for new distributed systems in several countries.[18] Although still a small share of the annual market, a number of purely competitive (without direct government support) large-scale systems were being constructed in 2019; interest in this segment is significant and growing quickly.[19]

For the seventh consecutive year, Asia eclipsed all other regions for new installations, accounting for half of global additions, despite declines in the region's top three markets (China, India and Japan).[20] Asia was followed by Europe (17%) and the Americas (15%).[21] China continued to dominate the global market (and solar PV manufacturing), accounting for around 26% of the year's capacity additions, but this compares with 44% in 2018.[22] The top five national markets – China, the United States, India, Japan and Vietnam – were responsible for around 56% of newly installed capacity, down from around three-quarters in 2018 as the global market becomes less concentrated; the next five markets were Spain, Germany, Australia, Ukraine and the Republic of Korea.[23] The annual market size required to rank among the top 10 countries more than doubled in 2019, reaching 3.1 GW[i].[24] At year's end, the leading countries for cumulative solar PV capacity remained China, the United States, Japan, Germany and India, and the leaders for capacity per inhabitant were Germany, Australia and Japan.[25] (→ *See Figure 29.*)

i This is the capacity additions of the country that ranked tenth for annual installations, the Republic of Korea.

FIGURE 29. Solar PV Global Capacity, by Country and Region, 2009-2019



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

Source: See endnote 25 for this section.