In the **Middle East**, as part of the Shams Dubai Initiative, the Dubai Electricity and Water Authority (United Arab Emirates) connected more than 1,300 solar PV installations (totalling 125 MW) on residential, commercial and industrial buildings across the city by the end of 2019.[42] As of 2020, Israel's Tel Aviv Solar Roof Project aimed to install solar PV systems on the roofs of residential and commercial buildings in the city to reduce living costs for residents and to protect the environment.[43]

Renewable power systems also have been installed at places of worship in the Middle East and North Africa (as well as elsewhere).[44] As of 2019, around 500 mosques in Jordan were relying on on-site solar power, thanks to a national initiative that aims to extend solar PV to most of the country's 6,500 mosques (as well as its smaller number of churches) to reduce energy costs and increase awareness of renewables.[45] In Casablanca (Morocco), the Hassan-II Mosque, Africa's largest, was undergoing extensive renovations in 2020 to install solar PV panels and reduce the building's energy use by more than half.[46]

In **Oceania**, the University of Monash (Melbourne), Australia's largest university, installed its first on-campus solar panels in 2010, and in 2019 it launched a Net Zero Initiative to achieve 100% renewable energy by 2030.[47] The university aims to transform its four domestic campuses to operate fully on renewable electricity (including converting all buildings, appliances and vehicles to electricity), relying as much as possible on on-site solar systems.[48] One of Australia's largest behind-the-meter solar installations, a 12 MW solar farm at Melbourne airport, was nearing completion in 2020.[49] Several other towns and cities nationwide, including Mosman, Greater Shepparton and Shoalhaven, have installed rooftop solar PV on local sports facilities.[50] As of early 2020, New Zealand's then-largest solar array (1.17 MW) was being built atop Foodstuffs North Island's distribution centre in Auckland.[51]

GREEN TARIFFS

In cities where this option is available, numerous urban electricity consumers are participating in green tariff programmes, purchasing electricity from traditional utilities along with associated renewable energy certificates or RECs (in the United States) and guarantees of origin or GOs (in Europe)[i] (→ *see Box 2*).[52] Commercial and industrial customers have driven most of these green tariff deals, but local governments are playing a role as well, often with a preference for deploying projects nearby that can provide local economic and environmental benefits.[53]

As of 2019, consumers in more than 80 cities and communities across 16 US states and Washington, D.C. were purchasing renewable electricity via green tariff programmes, for a combined total of nearly 8.6 billion kWh annually.[54] In early 2020, Charlotte (North Carolina) became the most populous US city to procure renewable electricity through a green tariff programme; the city is partnering with developers on a 35 MW solar PV project, and the utility Duke Energy will purchase the generated electricity and deliver it to Charlotte.[55]

In Europe, the market for GOs reached record levels in 2018 (latest data available).[56] Although corporations account for nearly all green electricity purchases, commercial businesses and residential consumers as well as local councils and government departments have turned to green tariffs to claim larger shares of renewable electricity (→ *see Citizen Participation chapter*).[57] Bedford Borough Council (UK) plans to rely on GOs from the local energy supplier to operate all council-owned and operated buildings as well as street lighting on 100% renewable electricity starting in April 2021.[58]

Melbourne, Australia

There are
thousands
of on-site renewable energy projects in cities, ranging in capacity from a few kilowatts to hundreds of megawatts.

i RECs and GOs are electronic certificates that verify that a specific amount of electricity corresponds to electricity from a specified renewable source. See Glossary for definitions.

BOX 2. RECs/GOs and Questions of Additionality

The concept of "additionality" originated in greenhouse gas project accounting and has been adopted by the renewable energy community to describe purchases of renewables that drive incremental (additional) investment and capacity and, perhaps, investment that otherwise might not have occurred. For accounting purposes, the concern is to avoid double-counting of credits for renewable energy and, at a minimum, to avoid the circumstance where purchases of RECs and GOs actually displace or undermine new and local capacity expansion.

The purchase of unbundled RECs/GOs (RECs or GOs purchased separately from the associated energy production) can undermine claims of additionality. The ample supply and resulting low prices for RECs/GOs further limits their support for the construction of new capacity. Therefore, while RECs and GOs provide a convenient way to lay claim to a share of the renewable energy supply, there is a risk of consumers claiming credit for renewable energy that is already being supplied or planned for service to other consumers.

In 2020, the Belgian renewable energy supplier Bolt returned 1,000 GOs to the Icelandic government in protest over the GOs' potential adverse impacts on Belgium's renewable energy market. Because all electricity in Iceland is renewable, no local GO market exists, and the country also is electrically isolated from the European power market. Yet, in accordance with EU market rules, GOs for electricity consumed in Iceland have been sold to suppliers of non-renewable electricity in Europe, enabling these suppliers to claim their product as "green energy" without any additional renewable energy being generated. Bolt claimed that this "greenwashing" both misleads consumers and undermines the actual renewable energy market in Belgium.

In other instances, the marketing of unbundled credits can lead to credits issued without the associated energy ever being produced. For example, in 2015 Luxembourg and the Netherlands had the highest share of consumers opting for green tariffs, yet both countries lagged in meeting their renewable energy targets. Although energy suppliers in these countries were selling a high number of GOs to customers, this did not translate into added domestic renewable electricity generation.

Many large corporations have achieved their renewable energy targets through purchases of RECs/GOs. However, as other cost-competitive options for purchasing renewables have become available, corporate actors are shifting towards sourcing options that allow them to play a more active role in adding new renewable capacity to the grid. Corporate power purchase agreements gained considerable momentum in the late 2010s, particularly in the United States and Europe. Still, the additionality of some PPAs, especially off-site, has been brought into question.

For example, Dutch Railways (Nederlandse Spoorwegen, NS) states that its customers' travel is "climate neutral" thanks to a recent offshore wind PPA. However, just over half of the company's renewable energy demand is supplied by projects in the Netherlands, while the remainder comes from wind parks in Belgium, Finland and Sweden. These wind parks were tendered and subsidised by their respective national governments, which are bound by their own renewable energy and emission reduction targets. It is thus debatable to what extent the PPA that NS signed has led to additional renewable energy capacity, especially on the Dutch grid.

The additionality discussion has extended beyond electricity, particularly since late 2018 when the demand for "green gas" certificates and GOs started growing. In the United Kingdom, a consumer buying a green gas certificate cannot claim to have directly produced "additional green gas". Because additionality is a difficult thing to prove under any circumstance, both credibility and transparency are key when making an additionality claim about renewable energy.

Source: See endnote 52 for this chapter.

Corporate actors

are shifting towards sourcing options that allow them to play a more active role in adding new renewable capacity to the grid.

Flevoland, Urk, Netherlands

POWER PURCHASE AGREEMENTS (PPAS)

City actors have **signed PPAs** for increasingly large amounts of renewable energy for both municipal operations and city-wide use.

Cities were responsible for thousands of megawatts of new renewable energy capacity procured through PPAs during 2019 and 2020, either already in operation or under development.[59] In the United States and Europe, city actors have signed PPAs for increasingly large amounts of renewables for both municipal and community-wide use.[60] Most existing PPAs are for off-site capacity, although the use of PPAs for on-site urban projects also has increased, and municipal governments often stipulate that projects be constructed close enough to provide local jobs and other benefits.[61] Towns and cities also have pooled their resources to negotiate more favourable terms.[62]

For local governments in the United States, off-site PPAs between cities and developers of large-scale projects accounted for the vast majority (90%) of new renewable power capacity from 2015 to early 2020.[63] During 2019 and 2020, local governments in at least 11 states signed 57 PPAs for off-site projects, totalling more than 3,730 MW of capacity; of this, nearly 80% was solar PV and the rest was wind and geothermal power capacity.[64]

Los Angeles (California) entered into a PPA in 2019 for what was then the largest solar and battery storage system in the country (400 MW / 1,200 MWh), at the then-lowest price for solar-plus-storage of less than 2 US cents per kWh.[65] Other US cities that have contracted for large solar capacity include Chambersburg (Pennsylvania), Cincinnati (Ohio) and Montgomery (Alabama).[66] In Florida, the first two (totalling 149 MW) of five planned solar PV plants began operating in 2020 under a PPA between the project developer and Florida Municipal Power Agency in partnership with 16 municipal utilities.[67] By aggregating the demand from multiple Florida cities, the project was able to deploy larger, more efficient facilities to minimise costs to consumers.[68]

In Europe, the number of annual PPAs for solar PV at the municipal level increased six-fold between 2016 and 2018 – rising from 66 to 399 – but then declined to around 300 in 2019 and to just over 200 in 2020.[69] Examples include a PPA between London (UK) and Voltalia in 2020 for an off-site 49 MW solar farm in Dorset; a contract for a wind farm in Motilla del Palancar (Spain) designed to create local jobs and provide electricity to the city; and a PPA for one-third of the output of Åndberg wind farm in Sweden to provide 250 GWh annually to the municipal utility in Skellefteå.[70] City airports in Europe – such as Bristol Airport (UK) and Frankfurt International Airport (Germany) – also have signed PPAs for offshore wind power to meet their electricity needs.[71]

In Australia, PPAs negotiated in several major cities in 2019 and 2020 are aimed at helping to achieve ambitious renewable energy goals. Adelaide plans to power all of its municipal operations with solar and wind energy, and in Melbourne seven large energy consumers signed a joint 10-year wind energy contract.[72] Sydney entered into a 10-year PPA requiring, among other things: that all solar PV and wind power projects be new capacity and located in New South Wales to reduce the marginal loss factor (particularly losses in electricity transmission) and create regional jobs; that the facilities achieve a combined 80% load matching[i]; to include a demand-response option for consumers; and that at least one project be community-operated.[73]

OVERCOMING CHALLENGES: PARTNERING WITH STAKEHOLDERS AND TAKING CONTROL OF SUPPLY

Although city governments often are more active in supporting renewable energy than national ones, they also are limited by laws and regulations issued at the national and state/provincial levels. These higher-level policies and regulations, as well as decisions by utilities, can create roadblocks to cities' renewables goals and commitments.[74] Cities have sought to address these challenges in a variety of ways, including by: influencing policy or regulation at higher levels of government (often in partnership with other stakeholders); partnering with utilities; municipalising local utilities; and launching community choice aggregation programmes (→ *see Citizen Participation chapter*).

Influencing higher-level policy and regulations

Several city governments have engaged with or challenged higher levels of government to remove legislative or regulatory barriers to local renewable energy production and procurement. For example, in 2017, Cape Town challenged the government of South Africa in court to release the city from having to procure coal-fired electricity from the centrally controlled national energy utility (Eskom) and to enable it instead to procure electricity from independent power producers.[75] In late 2020, the country's Department of Mineral Resources and Energy took a landmark step by amending national electricity regulations to allow municipalities in good financial standing to deploy their own electricity generation projects (→ *see Feature chapter*).[76]

City governments across the United States have partnered with community stakeholders, other cities and towns, and/or legislative or regulatory bodies at higher levels of governance to remove laws and regulations that restrict the deployment and use of renewables, or to enact new measures that encourage or require greater procurement of renewable electricity.[77] By one estimate, between early 2019 and early 2020, 24 US cities took at least 27 actions – including submitting comments on public utility commission proceedings, launching community choice aggregation programmes and formally partnering with electric utilities – to advance energy efficiency and renewables in the power sector.[78]

i This means that the combined electricity output of the wind and solar power facilities should, on average, achieve an 80% match to the electricity load (demand) profile of the city.

The US state of Virginia until recently limited the ability of many communities to purchase renewable energy. In response, localities worked to influence state-level regulations and policies, engaging with utilities to develop green tariff options and to reduce premiums on renewable energy programmes, and pooling their buying power with other cities, corporations and universities to demonstrate strong local demand for renewables.[79] Partly as a result of such efforts, in early 2020 Virginia committed to 100% zero-carbon electricity by 2050 and removed key restrictions on solar PV installations for local governments, businesses and others.[80]

Several cities have **challenged** higher levels of government to remove legislative or regulatory barriers to local renewable energy production and procurement.

Partnering with utilities

Increasingly, city governments have leveraged their status as large electricity consumers (sometimes in partnership with other cities) and worked directly with investor-owned utilities to encourage them to increase renewable energy generation.[81] A number of cities with renewable energy targets have formed productive partnerships with their local utilities, often collaborating to achieve shared goals for the deployment of renewables and energy efficiency technologies.[82]

Minneapolis (Minnesota) was among the first large US cities to partner with local utilities on increasing renewable power capacity to achieve a 100% renewable energy goal.[83] Several cities have since followed suit. In 2019, Denver (Colorado) entered a formal partnership with the utility Xcel Energy to achieve shared energy and climate goals through energy retrofits and renewable electricity procurement.[84] In Utah, after a three-year collaboration, Salt Lake City, Park City and Summit County, along with investor-owned utility Rocky Mountain Power, announced the passage in 2019 of the state's Community Renewable Energy Act, which allows the utility to work with communities to tailor electricity portfolios to meet their renewable energy targets.[85]

In several European cities – including Heidelberg and Munich (both Germany) – inhabitants are working with their municipally owned utilities to achieve renewable energy goals.[86] For example, Munich's municipal energy provider SWM is a co-owner of the DanTysk offshore wind farm, which is helping the city achieve its goal of being fully powered by renewable electricity by 2025.[87]

Municipalising local utilities

City governments that own their own utilities – such as Austin (Texas, US), Basel (Switzerland), Copenhagen (Denmark), Munich (Germany) and many others – have greater control over their energy sources and can provide renewables to their customers directly.[88] Although municipal utilities may have less financial clout than their larger national or private counterparts, due in part to their smaller scale, they also have the potential to quickly implement goals that are aligned with customer demands.[89]

Several cities have (re)municipalised their electricity systems (or debated doing so) in order to pursue renewable energy options.[90] In 2017, Barcelona (Spain) approved the creation of Barcelona Energia, the country's largest public electricity distributor.[91] Barcelona Energia, whose mission includes promoting locally produced renewables, began supplying renewable electricity to city council buildings and facilities as well as other entities in 2018, and to the general public in 2019.[92] Barcelona has inspired city councils in other Spanish cities, including Cádiz and Pamplona, to opt for similar models.[93] Additional cities that have pursued or considered (re)municipalisation include Berlin and Hamburg (both Germany), Hebron (Israel), Madrid (Spain), and the US cities of Chicago (Illinois) and San Francisco (California) (→ *see Citizen Participation chapter*).[94]

CONSUMPTION OF ELECTRICITY

Based on their estimated share of global energy demand (around 75%), cities may account for the same share of global electricity consumption (around 20,000 terawatt-hours, TWh).[95] Assuming that renewable electricity use in cities mirrors the global average share of supply[i] (an estimated 27.3%), then overall city consumption of renewable electricity could total around 5,500 TWh annually.[96] However, this figure may well be higher, to the extent that cities have successfully increased their renewable electricity supply relative to rural areas (through either committed external supply or local generation).

Differentiating city demand for renewable electricity from regional or national consumption patterns remains challenging, in part because most cities draw the majority of their electricity from regional or national grids. Even as more cities strive to increase their production and procurement of renewable electricity, city-wide accounting of renewable electricity consumption is lacking. In instances where cities do report this consumption, many (if not most)[ii] simply use local grid averages as a proxy for the city-wide electricity mix. Moreover, data on city-specific renewable energy achievements often refer only to the municipal load (city government and services) rather than to city-wide demand.[97]

i This first-order estimate makes no adjustment for any structural differences in average electricity consumption patterns between urban and ex-urban/rural areas, between relatively city-oriented demand (e.g., wastewater treatment and water supply, street lighting and traffic signals, data centres and general cooling load) and perhaps more predominantly ex-urban activity, such as energy-intensive industry (e.g., metals manufacturing).

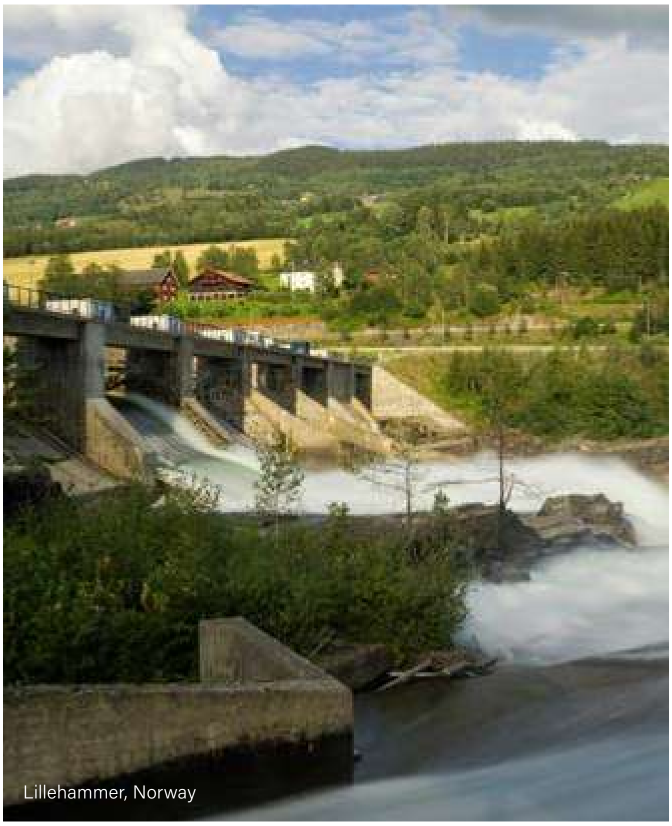
ii For example, data from CDP reflect that most cities that qualify/comment on their reported values note them as being regional or national values, based on local/regional grid data.

Further complicating the picture, city governments define their renewable energy commitments in different ways, with some specifying renewable shares of the electricity mix within a given time frame, some specifying commitments in terms of carbon reductions or carbon neutrality, and others specifying certain technologies. In some cases, cities have deployed solar and/or wind power capacity in connection with their wider city plans and have set targets to deploy even more (→ *see* ***Reference Table R6***).

Cities that already have high or rapidly rising shares of renewable electricity use can be divided into two distinct groupings. In one group are cities that benefit from large existing or rapidly rising renewable electricity supplies on regional and national grids, regardless of their own efforts to affect change to the electricity mix. Where renewable supply is already high, this is often due to plentiful and economical hydropower. In such cases, further rapid expansion of renewable electricity use may be somewhat limited, although many cities – including Montreal (Canada), Oslo (Norway), Reykjavik (Iceland), São Paulo (Brazil), Seattle (Washington, US) and Zurich (Switzerland) – are filling in the balance of existing and incremental demand with new and diverse renewable electricity supplies.[98]

In the other group are cities (and their surrounding areas) that are not endowed with grid-supplied hydropower but have greatly advanced their use of local renewable energy (particularly solar PV and wind power) to achieve technical proficiency and economic competitiveness, sometimes despite substantial resource and cost constraints. Examples include many interior US cities, such as Austin and Dallas (both Texas), Denver (Colorado), Iowa City (Iowa) and Kansas City (Missouri), as well as Adelaide and Canberra (both Australia) and Copenhagen (Denmark).[99]

In all cities, the renewable energy supply grows at least in proportion to the expansion of renewables on the regional grid, but additional local commitment further increases the renewable share for the city, and for the regional supply mix as well. Examples of this interaction between internal and external effects are found in the US state of Texas, where the regional renewable electricity supply expanded from 19% of net generation in 2019 to 22% in 2020.[100] This advancement is driven in part by local efforts and initiatives that directly affect both local and regional supply. Houston, located in Texas' oil and gas heartland, has increased its renewable energy use beyond grid-supply averages: in 2020, the city government began purchasing enough renewable electricity to meet its entire municipal requirements (around 3% of total city demand), in line with its Climate Action Plan.[101] Meanwhile, Austin (Texas), which retains its own municipal utility and thus has significant autonomy in procurement decisions, exceeded the regional average to reach 43% renewable electricity consumption in 2019.[102]


Lillehammer, Norway


Lofoten village, Norway

3

HEATING AND COOLING: PRODUCTION AND PROCUREMENT OF THERMAL ENERGY

Municipal governments and other city entities are deploying modern[i] renewable energy systems to generate thermal energy for space and water heating as well as cooling in buildings, and for process heat in industry. Modern sources of renewable heating and cooling include direct thermal energy from renewable sources (through the combustion of solid, liquid and gaseous biofuels, as well as energy from geothermal and solar thermal sources) and renewable electricity, which is used to operate heating appliances, such as heat pumps.

Although urban production and procurement of renewable thermal energy is not at the scale of renewable electricity[ii] in most cities, an increasing amount of direct thermal renewable capacity is being installed for use on-site, in stand-alone applications for individual buildings, and to feed into district energy systems that connect multiple buildings. Tracking these market trends and opportunities is difficult due to a lack of city-level data (and the fact that some heating and virtually all cooling consumption is electrically driven); however, new capacity has been added in cities around the world, driven by building mandates, fiscal incentives, and other support policies, as well as plans to phase out or ban the use of fossil fuels for heating (→ *see Urban Policy Landscape chapter*).[103]

Stand-alone renewable energy systems use a variety of technologies and typically include solar thermal systems and modern biomass stoves and boilers (fuelled by, for example, wood pellets and forestry or agricultural residues, such as bagasse and straw). In addition, renewable electricity can be used to heat or cool with electrically driven appliances such as heat pumps. In urban areas, stand-alone systems have been installed on rooftops, façades and outside of buildings.[104]

While thousands of stand-alone thermal systems have been deployed around the world, consolidated data on how many of these are in cities are not available. In China, the chemical company Solvay installed a biomass boiler at its facility in Zhangjiagang in 2019 to switch from natural gas to renewables, and six large solar thermal systems were completed in five other cities to provide hot water for schools (in Hangzhou and Zhejiang), an office building (in Shanghai) and several large blocks of flats (in Hangzhou, Linyi, Nanchang and Zaozhuang).[105] In Turkey, solar hot water systems have been installed at several prisons, including in Diyarbakır in 2019.[106] Stand-alone solar thermal systems also are popular in German cities, especially for multi-family buildings, with new projects completed in Heilbronn and Regensburg in 2020.[107]

Markets for heat pumps have expanded rapidly, meeting an estimated 5% of the global heating demand for commercial and residential buildings in 2019.[108] Heat pumps require energy input (typically grid electricity) to power the transfer of thermal energy, which makes up a portion of the total energy output. For a heat source (or a heat sink in cooling mode), heat pumps can use ambient air, surface water bodies (lakes and rivers) or the ground (whether dry or water-coupled to aquifers). Electrically driven heat pumps serve as a bridge between variable renewable electricity supply (mostly solar PV and wind power) and the demand for heat, which traditionally has been met mainly through the combustion of fuels. The benefit is two-fold: allowing variable renewable energy to supply the heat market, while allowing the heat market to act as a regulating demand-buffer, which helps integrate ever larger shares of variable renewables into the electricity mix.[109]

Most heat pumps are relatively small stand-alone units serving individual or a small group of dwellings, although a growing number of district heat systems use heat pumps to tap low-temperature sources on a large scale, such as rivers or wastewater streams. Although both air- and ground-source heat pumps (the two most common applications) are very effective, ground-source units can have an efficiency advantage for heating because of the relative constancy of ground temperatures. In 2019, ground-source heat pumps represented 167 TWh (600 gigajoules, GJ) of global heat supply.[110]

In October 2020, a ground-source heat pump was installed in the first of 60 existing homes in Blackbird Leys, Oxford (UK); the project's heat pumps are connected to a series of boreholes incorporating communal ground arrays.[111] Later phases in Oxford will see up to 240 new-build homes, and potentially various commercial properties, fitted with ground-source heat pumps.[112] Similar initiatives were implemented in Drammen (Norway) and in Glasgow (UK) in 2019.[113] In Toronto (Canada) a ground-source heat pump system to provide heating and cooling for a new 600-unit apartment complex was completed in 2019.[114] That same year, Belgrade (Serbia) presented its long-term district heating and cooling plan, which builds on large heat pumps.[115]

Tavira, Portugal

i Excluding the traditional use of biomass for heating and cooking. See Glossary for definition.

ii Note, however, that electricity accounts for the vast majority of global cooling demand, and for a growing amount of heating demand.

District energy systems, which provide thermal energy to residential, commercial, public and industrial buildings, generally are located in densely populated urban areas. Existing district heating and cooling systems can be upgraded, or new networks can be created, to enable the integration of renewable energy technologies. Renewable district heating and cooling can be provided by sustainable biomass, geothermal, solar thermal, renewable gases and heat pumps operated using renewable energy.[116]

District energy systems supplied around 6% of global heat consumption in 2018.[117] Fossil fuels were the dominant energy source for district heating and cooling networks that year, with renewables accounting for only an estimated 8%.[118] However, the renewable contribution is growing: between 2009 and 2018, renewable energy use for district energy increased more than two-thirds, due largely to the shift from fossil fuels to bioenergy in the EU.[119] In addition, cities increasingly have used urban waste in waste-to-heat plants to deliver thermal energy through district networks, and have taken advantage of waste heat from industrial processes (which is primarily an energy efficiency measure).[120]

Each district heating system differs in its use of renewable energy. Because virtually all district heat systems serve urban areas (where population density makes the systems economical), it can be assumed that virtually all energy use in such systems reported in national data represents the energy demand of cities.[121] The Russian Federation and China dominate in total production of district heating (relying heavily on natural gas and coal), followed by Germany, the United States and Ukraine.[122] In Iceland, renewable energy supplies nearly 100% of the country's district heating needs and is derived mostly from high-temperature geothermal energy (plus some renewable electricity).[123] Other countries with high renewable shares in district heating include Sweden (69%), Denmark (58%) and Estonia (56%) (→ *see Figure 13*).[124]

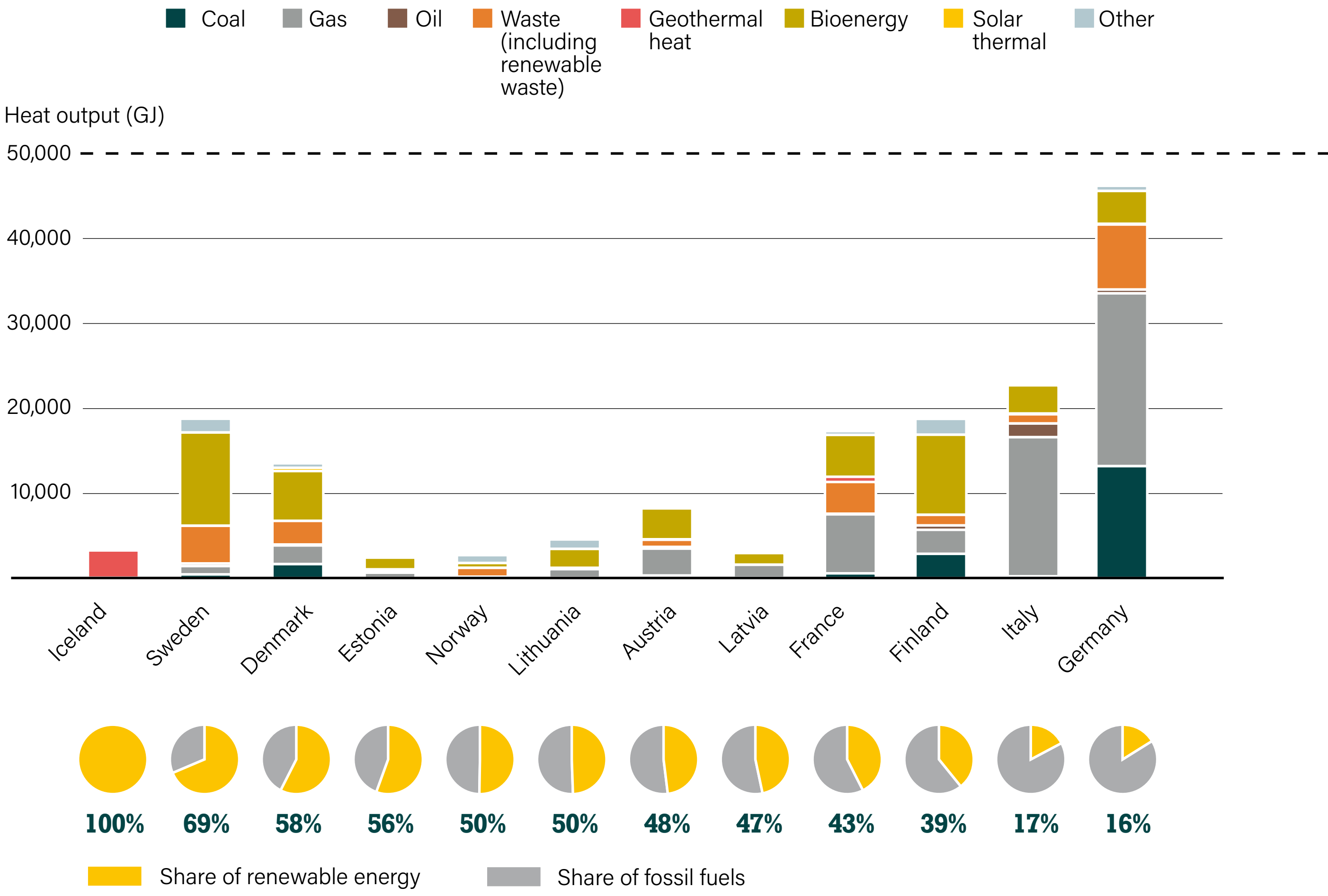
Cities are starting to use a diversity of renewable thermal sources in their

district heating networks.

Although many cities are starting to use a diversity of renewable thermal sources (as well as renewably powered heat pumps) for district heating, **bioenergy** is the most widely used renewable energy source in these networks, with an estimated 95% share.[125] Europe is home to most of this capacity (representing 87% of all biomass used for renewable district heating), where it continues to expand.[126] In 2019, the local district heating network of Lyon-Confluence (France) was connected to the central network of Lyon, and a new 51 MW biomass plant was commissioned to supply the networks.[127] Salaspils (Latvia) inaugurated a wood chip boiler as well as a 15 megawatts-thermal (MW_{th}) solar field in 2019, which together meet 90% of the district heating demand.[128] The district heating system In Oslo (Norway), which covers a quarter of the city's total heating demand, has shifted almost entirely (around 99%) to renewables, including biomass from residual waste.[129]

The number of **solar** district heating systems increased significantly in 2019, particularly in Denmark, Germany and China.

Figure 13. Renewable Share of District Heating, by Fuel Source, Top Countries, 2018



Note: "Other" includes waste heat recovery, non-renewable electricity, nuclear and any source not otherwise accounted for.

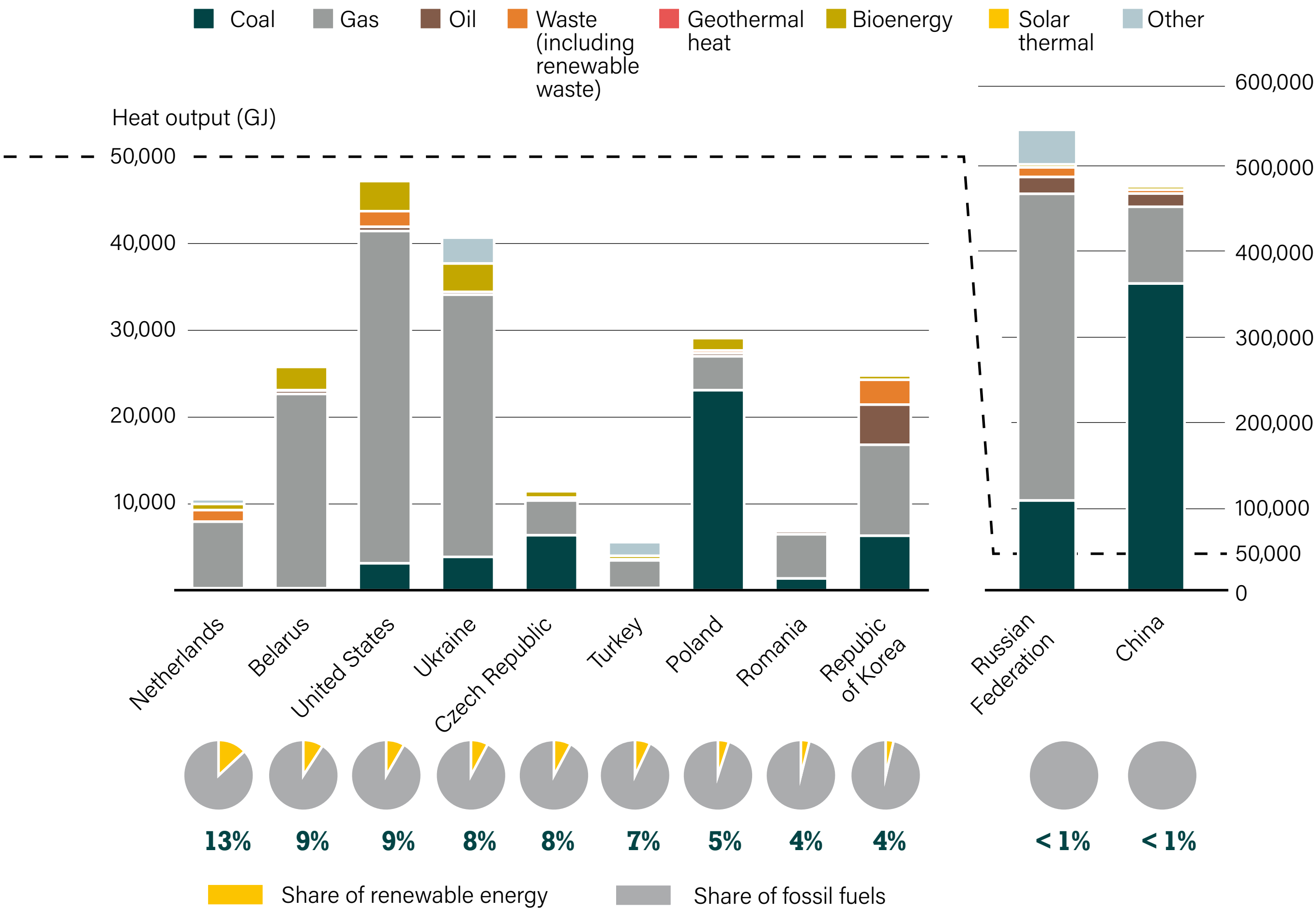
Source: IEA. See endnote 124 for this chapter.

By year's end, at least 417 solar district heating and central hot water systems were in operation worldwide (up from 345 systems in 2018), with a cumulative capacity of more than 1.7 gigawatts-thermal (GW_{th}) (including glazed and concentrating solar thermal collectors).[130]

In Denmark, the world leader in solar district heating capacity, 10 new plants were brought online in 2019 and 5 were expanded, for a total of 134 MW_{th} added; altogether, more than 113 Danish villages, towns and cities use solar heat in their district systems.[131] In Germany, six new solar district heating systems (totalling 9.9 MW_{th}) were added in 2019, and the country's largest solar district heating plant (10.4 MW_{th}) was under construction in Ludwigsburg.[132] In China, three solar district heating systems were commissioned in the Tibetan towns of Shenzha, Zhongba and Saga in late 2019.[133] Additional projects under construction worldwide included solar fields in the district heating networks of at least three Croatian cities near Zagreb in 2020.[134]

Direct use[i] of **geothermal** energy can meet various thermal energy demands in cities, including space heating and hot water supply. In 2019, geothermal direct use capacity totalled an estimated 30 GW_{th}, supplying 117 TWh (421 petajoules) of thermal energy.[135] Direct use of geothermal energy harnesses medium-to high-temperature geothermal fluid either directly or by direct transfer via heat exchangers. The majority of high-temperature geothermal energy is devoted to space heating and personal hot water applications such as bathing and swimming, and can therefore be assumed to be concentrated in urban applications, predominantly using district heat systems.[136]

i This does not include the use of shallow geothermal resources, specifically ground-source heat pumps, and the renewable portion of their final energy output. 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.



The use of direct geothermal heat for district heating systems has increased, particularly in China and in several European countries, including Germany, Hungary and Sweden (→ *see City Snapshot: Malmö*).[137] China's largest geothermal heating system came online in Fengxi New City (Shaanxi province) at the end of 2019, providing water heating and space heating and cooling for a combined buildings area of around 1.6 million m^2.[138] Additional district heating projects, using deep rock geothermal and waste water, are being planned in Chanba (Xi'an).[139]

In Munich (Germany), drilling was completed in early 2020 for a geothermal plant that exceeds 50 MW_{th}, which was expected to go online in 2021 and to supply heat for more than 80,000 residents.[140] In the Paris (France) region, district heating systems have gradually increased their geothermal heating capacity.[141]

Also in France, the community of Champs-sur-Marne launched a EUR 40 million (USD 45 million) district heating project in 2019, while Drancy and Bobigny started drilling four geothermal boreholes, with expected project completion in 2021.[142] Szeged (Hungary) continued to expand its geothermal district heating plant, and as of 2019 geothermal energy provided heat for 23 Hungarian towns, in some instances supplementing heat from natural gas on existing networks.[143]

Cities in Europe and in China have been increasing their **geothermal heating** capacity and use in district heating.

MALMÖ

SWEDEN

Land area (km²)
76.8

Population size (2018)
344,000

GHG
Greenhouse gas emissions (CO_2 equivalent)
52.7 million tonnes

The City of Malmö has a track record of urban development initiatives that have led to its recognition as a pioneering sustainable city. The most well-known examples in the city are the Western Harbour district (Västra Hamnen), which has operated on 100% renewables since at least 2012, and Augustenborgin, an industrial area that has 450 square metres of solar thermal panels connected to the central heating system.

Malmö's goal is to make all city government activities climate neutral by 2020 and to ensure that the entire city runs on 100% renewables by 2030. Malmö plans to achieve its 100% renewable energy goal from a mix of renewable sources, waste-to-energy and recycled energy. As of 2020, around 43% of Malmö's energy was from renewable sources[i], primarily wind energy.

The city has identified two challenging sectors that need to be addressed to stay on track to achieving the 2030 goal: transport and district heating. Sweden's substantial district heating network was built in the 1950s, and many cities in the country have extensive systems. Malmö's district heating system runs on a combination of biomass and fossil fuels. To help reduce fossil-based energy use, all of the municipalities in southern Sweden send their waste to Malmö, where it is processed and converted to heat that is fed into the district heating network. For example, at the Sysav waste-to-energy facility, the waste is reduced through thermal treatment processes to produce energy in the forms of electricity and heat.

Additionally, Malmö is constructing a 50 MW_{th} geothermal deep-heat plant[ii], which is expected to start operation in 2022. The city plans to build a total of five geothermal heat plants by 2028, each with an installed capacity of 50 MW_{th}, to replace the use of biofuels and biogas for heat generation. The estimated budget for this pilot project is EUR 5.4 million (USD 6 million), with the Swedish Energy Agency providing EUR 1.2 million (USD 1.34 million). The city's partners include E.ON, a privately owned energy supplier that is investigating the geological conditions, as well as the Swedish Geological Survey and the University of Uppsala.

Source: See endnote 137 for this chapter.

Malmö is replacing the use of biofuels and fossil fuels in heat generation with **geothermal heat** in order to achieve its energy and climate goals.

i This includes organic waste incineration and industrial waste heat.

ii Boreholes will be in the range of five to seven kilometres deep, and the temperature of around 160°C is expected to be sufficient to directly enter the district heating network. This project will be one of Europe's first geothermal power plants to extract heat from such a depth at the industrial level.

District cooling networks[i] are less widespread than district heating but are present in cities around the world, including Berlin and Hamburg (both Germany), Dubai (United Arab Emirates), Geneva (Switzerland) and Toronto (Canada), all of which have had operational networks for years.[144] Momentum is growing to expand existing cooling networks and to commission new ones, especially in Southeast Asia, the Middle East and Africa (→ *see Distribution Infrastructure section*).

Although relatively few district cooling networks rely on renewables, there are some exceptions, and systems that use heat pumps offer the potential to operate with renewable electricity. For example, in addition to the new geothermal heating plant, the utility in Munich plans to expand the city's district cooling network, using absorption chillers coupled to the geothermal supply.[145]

In 2019, Toronto (Canada) announced a new investment into its district cooling system (launched in 2004) utilising direct heat exchangers and the municipal water supply from Lake Ontario to cool hospitals, data centres, educational campuses, government buildings, and commercial and residential buildings.[146] In 2018, China's largest district heating and cooling network using river water and a water-source heat pump started running in public buildings in the Chongqing Jiangbeizui CBD, which covers more than 4 million m^2 of new residential areas.[147] However, such systems are mainly energy efficiency measures that displace energy demand rather than being examples of renewable energy use, with the exception of any renewables used to run heat pumps for cooling.

TRANSPORT

Globally, the share of renewable energy in transport was 3.7% in 2018, most of which was biofuels (3.7 exajoules, EJ) followed by renewable electricity (0.3 EJ).[148] The transport sector accounts for 29% of total final energy consumption and is responsible for 25% of global energy-related CO_2 emissions.[149]

More and more cities around the world are working to increase local production and consumption of renewable energy carriers such as biofuels, renewable electricity and renewable hydrogen[ii] in urban transport in order to reduce local air pollution and CO_2 emissions, and improve security of supply.[150]

In 2020, the COVID-19 health crisis deeply affected urban mobility patterns, as large numbers of people avoided public transport and altered other transport-related behaviours.[151] Lockdown measures resulted in sharp reductions in transport demand and in related air pollution in cities worldwide, prompting calls for a "green recovery".[152] In response, several cities initiated or strengthened efforts to ensure that communities have access to safe, reliable, affordable and sustainable transport[iii, 153]

Although COVID-19 restrictions and recovery packages so far have not led to structural changes in the production and use of renewable fuels in cities, the purchase and use of electric vehicles (especially electric bikes) increased throughout 2020, as did the share of renewables in electricity generation.[154]

PRODUCTION AND PROCUREMENT OF TRANSPORT FUELS AND ELECTRICITY

The majority of biofuels used in transport are **liquid biofuels**, namely ethanol (produced mostly from corn, sugar cane and other crops) and biodiesel (fatty acid methyl ester, or FAME, fuels produced from vegetable oils and fats).[155] However, the production of other diesel substitutes such as **renewable diesel**[iv], as well as **gaseous biofuels**, namely biomethane, is growing in many countries.[156] While most transport biofuel is produced outside of cities, organic waste generated in cities, including waste cooking oil, also is an important urban source of liquid biofuels and biomethane (→ *see Sidebar 5*).[157]

Although the production of transport biofuel was deeply affected by the COVID-19 crisis, some positive developments occurred at the city level during 2020.[158] Public authorities in Mexico City (Mexico), in partnership with the National Polytechnic Institute, built a biodiesel production plant that uses waste cooking oil from local households, food manufacturing facilities and restaurants to produce 500 litres of biodiesel daily, with the aim of fuelling 200 public transport vehicles.[159] In Venice (Italy), waste cooking oil began being collected and transformed into biodiesel for use by the local

i District cooling networks are centralised systems that provide chilled water to air conditioning systems.

ii Hydrogen produced with renewable energy, also referred to as "green hydrogen". See Glossary for definition.

iii These efforts have focused on promoting active modes of transport via the establishment of car-free zones and new infrastructure such as cycling lanes, bicycle parking and expanded walkways.

iv Renewable diesel is a diesel substitute fuel made by treating animal and vegetable oils and fats with hydrogen, also known as hydrotreated vegetable oil (HVO) or hydrotreated esters and fatty acids (HEFA).

BOX 3. Water Transport in Cities

Waterways are an important part of transport infrastructure for many cities around the world. They expand the capacity of urban transport systems while re-directing some road traffic. City efforts to improve urban mobility are expanding to public ferries, water taxis and other boat fleets, with some of these vehicles shifting to renewable energy, including liquid biofuels, renewable electricity and renewable hydrogen.

Although biofuels represent a promising renewable solution to decarbonise water transport, most projects to date have focused on international shipping rather than on city boat fleets. Still, a few city-level examples exist. In 2017, the New York City Council (US) passed legislation encouraging the use of biodiesel to power the city's ferries, and in 2018 the Red and White Fleet – a sightseeing and cruise ferry business in the San Francisco Bay Area (California, US) – began operating a plug-in hybrid ferry running on 100% biofuel, as part of its commitment to have a zero-emission vessel fleet by 2025. In 2020, Copenhagen (Denmark) received delivery of five electric ferries that use renewable diesel for heating.

Several other electric ferry operations have embraced renewable electricity. In 2020, a solar-powered water taxi began operation in Nusa Penida (Indonesia), and renewably powered ferries were being developed to serve commuters in Cardiff-Bristol (UK) and resort guests in Bora Bora (French Polynesia). In 2017, India's first solar-powered commuter ferry started operations in the Alappuzha district of Kerala state, and in Europe a car ferry with 15 solar panels began navigating the Moselle River between Oberbillig (Germany) and Wasserbillig (Luxembourg).

Globally, around 185 battery electric vessels were operating or scheduled for delivery as of 2018, 58 of which were passenger ferries. In 2020, two such ferries were being tested on the Chao Phraya River in Bangkok (Thailand), and once the trials are successful a new fleet of electric ferries is scheduled for roll-out in 2021 as part of a plan to cut air pollution and improve the city's image for visitors.

In Norway, several electric ferries rely on the country's high share of renewable electricity, and a new hydrogen-powered ferry is planned to start operating on the Hjelmeland-Skipavik-Nesvik route in Ryfylket in 2021. Another hydrogen ferry, being developed for the Oslo-Frederikshavn-Copenhagen route in Scandinavia, is expected to be fuelled with hydrogen produced by an electrolyser in Copenhagen (Denmark) using electricity from offshore wind turbines. In Brisbane (Australia), local companies began building fuel cell passenger ferries in 2020 that are expected to be fuelled with renewable hydrogen.

Source: See endnote 160 for this chapter.


Norway

transport company ACTV to fuel its lagoon boat fleet (→ *see Box 3* for additional examples of the use of renewables in water transport).[160]

Also in Italy, a former petrochemical plant in Gela was converted in 2019 into a renewable diesel production facility that can process up to 750,000 metric tonnes annually of used cooking oil, animal fat, other by-products and algae.[161] In the United States, Neste (Finland) has partnered with the City of Oakland (California, US) since 2019 to fuel the city's fleet with renewable diesel made from used cooking oil and other waste material sourced from businesses in the surrounding metropolitan area.[162]

Interest in **biomethane** has risen in several countries as well as in individual cities that aim to move towards a circular economy[i].[163] In 2020, the number of operating biomethane plants worldwide (both biogas upgrading and biomass gasification facilities) exceeded an estimated 1,000, with some 20% providing vehicle fuel, 60% injecting biomethane into the gas distribution network and the rest serving a variety of other local uses.[164] In 2020, a new biogas upgrading facility near Bakersfield (California, US) began using cow manure to produce biomethane to fuel heavy-duty trucks and buses.[165]

Although the use of **renewable electricity** in transport remains low, a few cities began coupling their transport electrification efforts with renewables in 2020. In The Hague (Netherlands), a new solar PV park opened to offset the electricity needs of the inter-city rail line connecting The Hague, Rotterdam and Zoetermeer.[166] Poznan (Poland) announced plans to transform local organic waste into electricity to fuel the city's electric bus fleets.[167] In the United Kingdom, Abbey Ecosse Limited secured permission to build an anaerobic digester and biomass boiler plant

i A circular economy is a closed-loop system in which the waste from one process is a resource that can be used as input for another. By having a flow of resources that is circular rather than linear, the production of waste is eliminated. See Glossary.

near Thurso (Scotland) that will use the waste from whisky distillation to produce biogas to generate electricity for EV charging in Caithness County.[168]

> Although many cities continue to support the production and use of biofuels,
> **electrification of transport**
> has been expanding rapidly.

Although more than 98% of today's **hydrogen** is produced from fossil fuels, interest in using renewable electricity for this process (currently less than 1%) is rising.[169] Several cities have turned to renewable hydrogen for transport fuel. In Fukushima (Japan), Toshiba and partners completed a 10 MW electrolyser in 2020 that uses electricity from solar PV to produce hydrogen for transport use.[170] Also that year, a consortium of businesses announced plans to build a 10 MW electrolyser to produce renewable hydrogen for fuelling buses and trucks in Copenhagen (Denmark).[171]

Hydrogen projects were under way at several urban ports during 2020. In the United States, a 2.3 MW hydrogen plant was being built to supply renewable hydrogen to Toyota's facilities at the port of Long Beach (California) and to fuel the company's fuel cell trucks and consumer vehicles.[172] The Port Authority of Santa Cruz de Tenerife (Spain) partnered with Hyundai Canarias and Enagás to build a facility to generate renewable hydrogen for transport use.[173] In the Arabian Sea port of Duqm, in Oman's Al Wusta governorate, a Belgian company was conducting a feasibility study in 2020 to build a hydrogen production facility powered by solar PV and wind energy.[174]

Hamburg, Germany

CONSUMPTION OF TRANSPORT FUELS AND ELECTRICITY

Urban transport consists of two main groupings: *passenger transport* – which includes rail (light rail and metro), road transport (buses, cars, two- and three-wheelers) and water transport (public ferries and water taxis) – and *freight transport*, including light-duty commercial vehicles and heavy-duty trucks. In 2015 (latest data available), urban transport accounted for around 40% of the energy used in the transport sector and contributed an estimated 37% of transport-related CO_2 emissions (32% from urban passenger transport and 5% from urban freight).[175]

In some cities, the transport sector consumes more energy than do the buildings or industry sectors, highlighting the importance of integrated measures to reduce transport demand, shift to more efficient modes, and transition to renewable fuels and electricity.[176] Despite recent efforts to develop local urban capacity to produce renewable energy carriers for transport, most cities continue to source their fuels and electricity from beyond city limits.[177] Of the energy carriers used in urban transport, biofuels and hydrogen are used mostly in heavy-duty transport (such as buses and trucks), whereas electricity use has now expanded beyond rail to all modes of public and private transport (→ *see Figure 14*).[178]

URBAN RAIL TRANSPORT

Rail boasts the highest renewable energy share of any transport sector, at 11%, and virtually all urban rail networks are powered by **electricity**.[179] As of 2019, nearly 200 cities worldwide had metro systems (with a combined track length exceeding 32,000 kilometres), and more than 220 cities had light rail systems (another 21,000 kilometres).[180] The length of urban rail lines expanded 3.5% annually on average between 2010 and 2019, with new metro systems opening in 46 cities (34 of them in Asia) and new light rail systems launched in 65 cities (28 in Europe and the rest split roughly evenly among Asia, North America, and the Middle East and North Africa).[181] Sub-Saharan Africa's first light rail systems entered into operation in Ethiopia in 2015 and Nigeria in 2018.[182]

As the most electrified transport sector, rail has benefited from rising renewable energy shares in the electricity mixes of many countries.[183] To specifically cover the electricity demand of their metros and trains, some city authorities also have started to install their own distributed renewable power capacity or to purchase or contract for new or existing renewable capacity, as has occurred in Delhi and Nagpur (both India), London (UK), Medellín (Colombia), Santiago (Chile), São Paulo (Brazil), Seattle (Washington, US) and Utrecht (Netherlands).[184]

To date, the testing of **hydrogen**-powered trains has focused mostly on regional/inter-urban systems, including in northern Germany and in the Dutch province of Groningen.[185] In Groningen and Friesland (Netherlands), some inter-urban trains also run on **biodiesel**.[186] In the United Kingdom, the first **biomethane**-fuelled trams started testing in Birmingham and in Warwickshire county in 2020.[187]

URBAN ROAD TRANSPORT: PASSENGER VEHICLES

Road transport contributes to urban congestion and local air pollution, leading to varying health impacts.[188] The severity of these impacts has driven municipal governments and other urban actors to pursue measures such as banning the circulation of fossil fuel vehicles, shifting to electric vehicles and encouraging the use of more-efficient transport modes such as renewables-based buses, among others (→ *see Urban Policy Landscape chapter*).

Buses

By 2020, over 3 million city buses were in circulation worldwide.[189] Diesel remained the most popular bus fuel, used in more than half of the world's buses, followed by electricity (17%), compressed natural gas (10.5%) and biodiesel (4.1%).[190]

During 2019 and 2020, some cities launched bus fleets that run on **biofuel** blends (although many more cities have opted for electric buses). In 2019, Shanghai (China) started a programme to run 2,000 city buses on B5[i], and Trondheim (Norway) began operating nearly 200 city buses able to be fuelled with biogas or biodiesel.[191] As of early 2020, all of the buses in Tartu (Estonia) were running on biomethane, making the city one of only a few[ii] in Europe with a 100% renewably fuelled public transport system.[192] Several US cities started fuelling their buses using biodiesel (produced outside of the urban area) – including Columbia (South Carolina) in 2019 and Grand Forks (North Dakota) in 2020.[193]

As of 2019, around half a million **electric** buses were in circulation globally (→ *see Figure 15*), 98% of which were in China and most of which were operating in cities.[194] Although new electric bus registrations declined some 20% overall in 2019 (relative to 2018), due mainly to China's gradual phase-out of subsidies, the number of new electric buses procured in cities outside of China[iii] continued to increase.[195] Since many cities have high and/or rising shares of renewable electricity, the electrification of buses brings opportunities for increasing the share of renewable energy in transport.

Sanya, China

During 2019 and 2020, new electric buses started circulating in many European cities, including Hamburg (Germany), London (UK), Milan (Italy) and Warsaw (Poland).[196] The transport provider Qbuzz in Utrecht (Netherlands) acquired 55 electric buses in 2019 that are charged using locally produced solar electricity.[197] The electrification of bus fleets also was under way in several US cities, with Portland (Maine) introducing new electric buses that run on 100% wind energy, and Gulfport (Mississippi), Jackson (Wyoming) and Wichita (Kansas) rolling out their first electric buses (as did the Canadian city of Brampton (Ontario)).[198]

Some of Latin America's most populous cities – including Bogotá (Colombia) and São Paulo (Brazil) – have started to electrify their bus fleets to address local air quality concerns.[199] By late 2020, an estimated 1,229 electric buses were in operation in 10[iv] countries across the region.[200] Santiago (Chile)[v], with 452 electric buses, reportedly had the largest electric urban bus fleet outside of China.[201]

Several cities in India – including Ahmedabad, Bengaluru, Delhi, Gurugam and Pune – increased the number of electric buses in circulation due to procurement programmes launched in 2019 and 2020.[202] In some cases, developing-country cities rely on their national governments to buy electric buses for use in urban fleets. As of 2019, the Philippine government had introduced 90 electric jeepneys with integrated solar PV in the city of Tacloban to replace the ageing combustion engine fleet.[203] In Cairo (Egypt), the first electric bus line was launched in 2020 as part of a nationally led initiative.[204]

A few city governments have ordered both biodiesel and electric buses. In 2019, Gothenburg (Sweden) placed the largest single order for electric buses in Europe (157 buses) as well as an order for 27 biodiesel buses, and the RATP Group in Paris (France) started converting all city bus depots to support fleets running on electricity and biogas.[205]

Several Asian (particularly Chinese) and European cities have begun adopting **hydrogen** fuel cell buses, but so far only a few operate on hydrogen produced with renewable electricity.[206] Zhangjiakou (Hebei Province, China) is a renewable hydrogen demonstration zone, with more than 70 fuel cell transit buses running on renewable hydrogen since late 2018.[207] In Aberdeen (UK), the first green hydrogen-powered double-decker buses started operating in 2020.[208]

The electrification of **bus fleets** around the world brings opportunities for increasing the share of renewable energy in transport.

i 5% biodiesel blend in petrol.

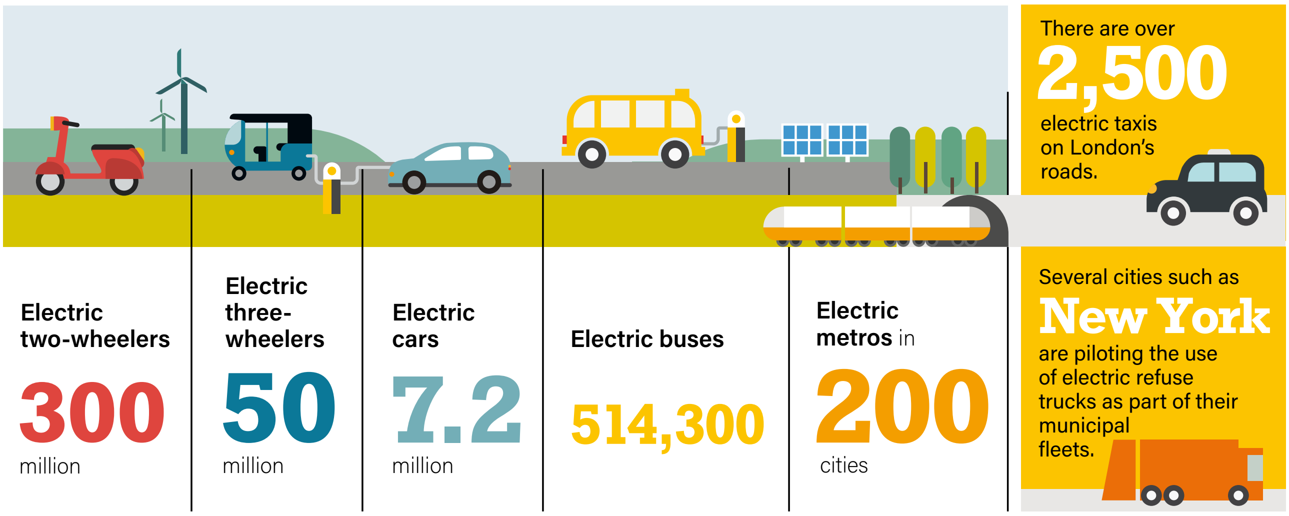
ii For example, in Stockholm (Sweden), all urban rail systems and buses have been using 100% renewable energy since 2017. Oslo (Norway) had a target to fuel all public transport will renewable energy by 2020. See Smart City Sweden, "Sustainable Public Transport in Stockholm", https://smartcitysweden.com/best-practice/368/sustainable-public-transport-in-stockholm, viewed 26 January 2021, and Oslo, "Public transport in Oslo", https://www.oslo.kommune.no/politics-and-administration/green-oslo/best-practices/public-transport-in-oslo, viewed 26 January 2021.

iii In 2019, 95% of new electric bus registrations were in China, compared to 98% in 2018. See International Energy Agency (IEA), *Global EV Outlook 2020* (Paris: 2020), https://www.iea.org/reports/global-ev-outlook-2020.

iv Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Panama, Paraguay, Peru and Uruguay.

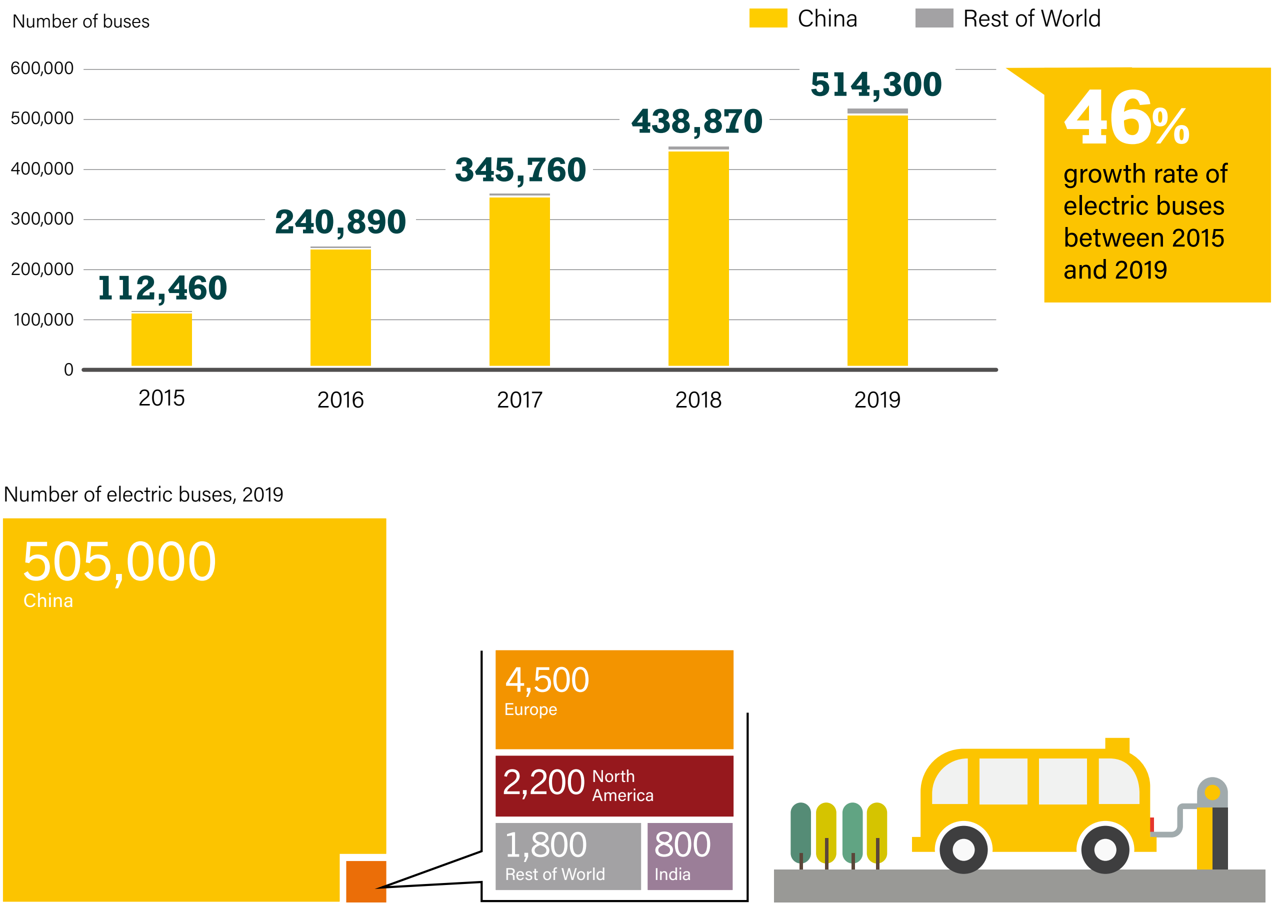
v The renewable share of electricity generation in Chile was 45% in 2019; calculated based on IEA, "Chile", https://www.iea.org/countries/chile, viewed 10 December 2020.

Figure 14. Global Electric Vehicle Markets in Cities, 2019



Source: Based on IEA data. See endnote 178 for this chapter.

Figure 15. Global Electric Bus Stock, China and Selected Regions, 2015-2019



Note: Discrepancies related to values reported in IEA's *Global EV Outlook 2020* are due to rounding.

Source: IEA. See endnote 194 for this chapter.

Passenger cars

Cities also have been exploring ways to encourage the use of renewable fuels and/or alternative propulsion technologies for passenger cars, to address the negative impacts associated with motorised individual transport, including associated air pollution and related illnesses (and fatalities).[209]

Although the number and share of **electric vehicles** on the world's roads is still small relative to vehicles with internal combustion engines, annual sales are increasing rapidly, and the EV share of the fleet is also rising. Electric cars accounted for 2.6% of worldwide car sales and for around 1% of the global car stock in 2019.[210] By year's end, an estimated 7.2 million electric cars[i] were on the road, up 40% from 2018.[211] A large portion of these vehicles were being operated in cities. The leading cities for passenger EV sales in 2019 were all in China (Shenzhen with 81,427 units sold, Beijing with 80,567 and Guangzhou with 72,270), while the leaders in the share of new passenger EVs sold were Oslo (Norway) at 64%, San Jose (California, US) at 20% and Shenzhen (China) at 19%.[212]

In some cities, municipal governments or private companies have made EVs available to residents and visitors via carsharing programmes; while some of these vehicles are offered for free public use (as in Trikala, Greece), others are for hire (as in Los Angeles (California, US) and Bristol (UK)).[213] The market for carsharing (as well as ridehailing services) has continued to grow, as has the industry's interest in electrification. A few companies – including WeShare in Berlin (Germany) and We Drive Solar in Utrecht (Netherlands) – procure renewable electricity for charging their electric fleets.[214]

Electric taxis have been in use for several years in cities worldwide, including Columbus (Ohio, US), Hong Kong, Macao and Shenzhen (all China), London (UK), Nairobi (Kenya) and New York City (US).[215] In 2019, India's Energy Efficiency Services – responsible for managing procurement programmes for government vehicles – was seeking to lease EVs to cab companies due to delays in integrating them into public fleets.[216] Also that year, four electric taxis started trials in Kigali (Rwanda) as part of the Moving Rwanda Initiative.[217] In Canada, the electric taxi service Téo Taxi put 55 EVs on the roads of Gatineau and Montreal in 2020.[218]

Passenger cars account for the majority of **hydrogen** fuel cell vehicles. In 2019, some 10,500 fuel cell vehicles were sold, for a total global stock of 22,350 vehicles[ii] (up from 5,800 vehicles sold and 12,950 total stock in 2018).[219] The hydrogen car market remains concentrated in California (US) – particularly in Greater Los Angeles and the San Francisco Bay Area – and a few pilot projects are under way in some European cities.[220] The taxi company Hype rolled out 100 hydrogen taxis in Paris (France) in 2019, with the goal of achieving a total of 600 in 2020, and a fleet of hydrogen taxis started operating in Copenhagen (Denmark) in 2019 using locally produced renewable electricity.[221]

i Including battery electric, plug-in hybrid electric and fuel cell cars.

ii Including passenger cars, buses and trucks.

iii See Glossary for definition.

iv See Glossary for definition.

v See Glossary for definition.

Two- and three-wheelers / Micromobility

The number of **electric** micromobility[iii] vehicles in use has expanded rapidly, with more than 350 million electric two- and three-wheelers in circulation in 2019, up from 300 million in 2018.[222] Although heavily concentrated in China, electric scooters, electric-assist bicycles and electric mopeds were present in over 600 cities in more than 50 countries, including in Europe, India and the United States.[223]

In a small but growing number of cities, electric two- and three-wheelers are being charged using renewable energy. Solar-powered hybrid rickshaws started operating at the Indian Institute of Technology's Delhi campus in 2019.[224] In Kampala (Uganda), motorcycle taxis ("boda bodas") began relying on a network of solar-powered charging stations in 2020, and in Windhoek (Namibia) the local company Ebikes4Africa produces SunCycles, or electric bicycles powered by solar energy.[225]

URBAN ROAD TRANSPORT: FREIGHT

Freight traffic accounts for a large share of urban traffic volume, contributing to air and noise pollution.[226] Urban freight transport[iv] involves mainly road-based vehicles, specifically light commercial vehicles[v] (such as vans) and heavy-duty trucks.

Light commercial vehicles

Around 380,000 light commercial **electric vehicles** were operating in 2019, often as part of company or municipal fleets circulating in cities.[227] China had the largest fleet of electrified light commercial vehicles worldwide in 2019, with 65% of the global stock, followed by Europe (31%).[228]

Numerous fleet owners switched to EVs for delivery services in 2020, and some coupled these vehicles with renewable energy. In 2020, the e-commerce delivery company Sendle (Australia) rolled out electric delivery vans powered by a rooftop solar PV system in western Sydney.[229] In the United Kingdom, the Royal Mail announced plans to trial a new electric van for deliveries across several cities, and the retailer John Lewis (which also operates the supermarket chain Waitrose) announced plans to transition its delivery fleets to electric in 2021, starting with 1,700 electric vans.[230] The Dutch supermarkets Albert Heijn and Picnic and the parcel delivery services DHL and PostNL were using various types of light-duty EVs in cities across the Netherlands during 2020.[231]

Cardiff, Wales, United Kingdom

Heavy-duty trucks

Trucks remain the dominant mode for transporting goods in cities, and the rise in urban energy use in recent years is attributed in part to the growing demand for delivery services in city centres. To address this challenge, municipal services, private companies and others have worked to mitigate the social and environmental impacts of truck traffic through the use of renewable fuels and electrification.[232]

Truck fleets in numerous cities have begun using **biofuels**. As of 2019, the municipally owned Orlando Utilities Commission (Florida, US) was using biodiesel (B20) to reduce greenhouse gas emissions from its 775 trucks, and in Hong Kong (China) the restaurant group Maxim's partnered with Shell (Netherlands) to launch a pilot programme to fuel more than 100 delivery trucks with biodiesel produced from used cooking oil.[233] In 2020, 22 new biogas refuse trucks entered into circulation in Esbjerg (Denmark), and in the Netherlands the fast food retailer McDonald's partnered with Neste (Finland) to recycle used cooking oil into renewable diesel to fuel delivery trucks in Dutch cities.[234]

Increasingly, city actors are exploring the **electrification** of heavy-duty freight vehicles. Although global sales of refuse collection trucks (which reached 62,155 units in 2018) continue to be dominated by internal combustion vehicles, support for electric refuse trucks is growing in cities worldwide due to favourable government policies, product innovation and the push for environmental sustainability.[235] In China, the shift from conventional heavy-duty trucks is mostly towards battery electric alternatives, used primarily for refuse collection and other municipal operations.[236] In 2018, the Chinese manufacturer BYD was contracted to deliver 500 electric refuse trucks to operate in its home town of Shenzhen.[237]

In the United States, Los Angeles and Sacramento (both California) began operating small fleets of electric refuse trucks in 2019, and the waste management company Recology acquired its first electric refuse truck in Seattle (Washington) that year.[238] In Australia, electric refuse and recycling collection trucks went into service in Adelaide, Casey and Yarra during 2020, with the electricity used for recharging Adelaide's truck being offset by a 36 kW solar PV system.[239]

Progress with electric trucks in Europe has been limited, with most deployments still in demonstration and customer trials.[240] A fully electric 16-tonne truck designed for inner-city freight deliveries began trialling in London (UK) in 2020.[241] Also in the UK, the contractor responsible for waste management in Manchester concluded an agreement to purchase 27 new electric refuse collection trucks to replace their diesel predecessors.[242] Several pilot projects involving hydrogen fuel cell waste collection trucks also were active in European cities, including in Eindhoven and Veldhoven (both Netherlands).[243]

The use of **renewable fuels and electricity in trucks** has been slowly gaining momentum.

DISTRIBUTION INFRASTRUCTURE

No city is an island in the context of energy procurement and use. All cities are physically tied to and reliant upon a larger regional network of energy systems, infrastructure and supply lines. Cities rely on the territories that surround them not only for the bulk of their energy supply, but also to manage and balance the flow of energy with the pulse of activity within city limits. Typically, the larger a city is, the larger are its interactions with wider energy systems and infrastructure.[244]

As cities pivot their energy procurement towards renewable sources (sourced from within and outside of city boundaries), their interactions with and requirements from regional energy systems and infrastructure may change – with significant implications that go well beyond city boundaries. Likewise, external changes in supply and infrastructure affect cities in ways beyond their control.

In some instances, such shifts may create relative system redundancies that represent economic sunk costs – both within and outside the city – in infrastructure networks that were built over many years to accommodate a different energy mix and supply structure.[245] In other cases, a relatively rapid, large-scale transition to renewable energy may hit system shortages and economic constraints, such as physical or technical bottlenecks that disrupt the orderly flow of energy. For example, growth in distributed electricity generation may either relieve or overload local distribution capacity during different time periods.[246]

Strømmen, Norway

Amsterdam, Netherlands

3

The distribution infrastructure relevant to cities pursuing renewable energy is varied. The physical elements include mainly wires and pipes (both within and outside of cities) as well as rail systems, road transport, ships and barges. Transmitting renewable electricity from centralised generation facilities requires high-voltage lines and then sub-stations where the electricity is stepped down to lower voltages to serve urban customers with varying voltage requirements. Alternatively, distributed (often low-voltage) renewable electricity can feed the distribution system directly, sometimes entirely off the network (behind the meter).[247]

Renewable fuels – whether gaseous, liquid or solid – are distributed by pipelines or vehicles, sometimes blended with non-renewable fuels (such as methane mixed with natural gas and ethanol blended with petrol). Secondary distribution systems carry transformed renewable energy for specific applications within cities. For example, district heating networks carry usable thermal energy that has been acquired from primary (such as renewable fuels or geothermal heat) or secondary renewable sources (such as the output of heat pumps driven by renewable electricity).

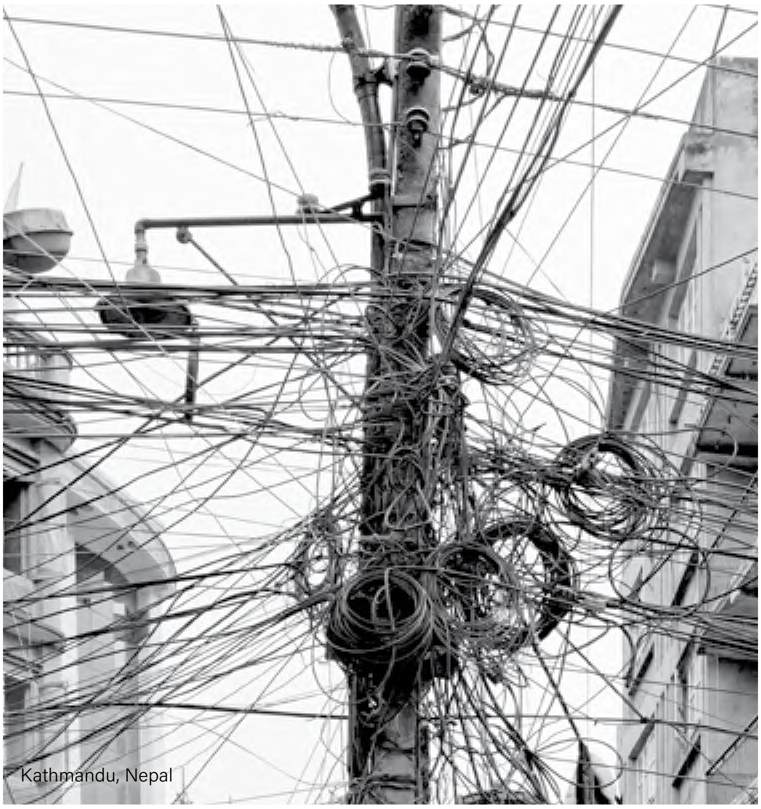
Some of the distribution infrastructure does not carry any energy but instead assists in the proper function and efficiency of the wider distribution network. Examples include storage facilities (such as tanks and batteries), metering devices that keep track of the energy flow and allow for the efficient allocation and distribution of energy (for example, "smart" meters), energy transformation devices (such as transformers, boilers, fuel cells and heat pumps) and system control infrastructure (for example, telecommunication systems and dispatch centres).

In 2019 and 2020, cities worldwide took steps to: address challenges to local and regional electricity distribution infrastructure (for example, by upgrading existing assets or deploying battery storage capacity); expand existing district heat networks or commission new systems that rely (at least in part) on renewable thermal energy or on heat pumps powered by renewable electricity; and install electric vehicle charging stations, including some that deliver 100% renewable electricity.

ELECTRICITY DISTRIBUTION

A city's electricity distribution grid is tied to, and dependent on, a larger regional or national power grid. Therefore, all city actions related to the procurement and use of electricity have implications for the broader electricity system.

In the case of distributed generation within city limits, the build-up of resources such as rooftop solar PV systems and electricity storage may relieve existing constraints on the regional transmission system and reduce excessive load on the local distribution system. However, rapidly expanding distributed (and variable) generation without also expanding system flexibility can create new challenges for the distribution network (→ *see City Snapshot: Oxford, and Citizen Participation chapter*).[248]

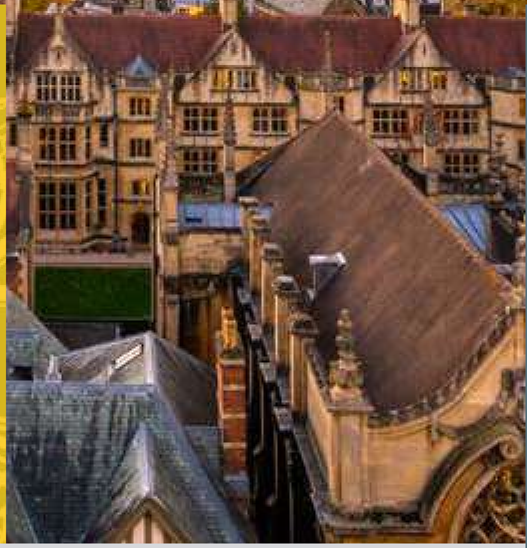

Kathmandu, Nepal

City actions
related to the procurement and use of renewable energy have implications for the broader electricity system.


Delhi, India

OXFORD

UNITED KINGDOM



Land area (km^2)	Population size (2019)	Greenhouse gas emissions (CO_2 equivalent)
45.6	152,450	718,082 tonnes

In January 2019, Oxford City Council unanimously declared a climate emergency in Oxford and agreed to create a Citizens' Assembly to help consider new carbon targets and additional measures to reduce emissions in the city. As a result, Oxford aims to become a net-zero carbon emitter by 2030, a full 20 years ahead of the UK national target. In addition, Oxford City Council pledged to achieve net-zero carbon emissions in its own operations by the end of 2020, after the Citizens' Assembly requested such a move. Oxford City Council is a member of Low Carbon Oxford, a network of 40 public and private organisations that aimed to reduce city-wide emissions 40% below 2005 levels by 2020. Oxford also is part of the UK100, a network of local government leaders who have pledged to shift to 100% clean energy by 2050.

To decarbonise energy in transport and heat systems (the major sources of carbon emissions in Oxford) and to achieve the 40% emission reduction, the City Council has facilitated an energy storage project, the Energy Superhub Oxford (ESO). It expected to be the world's largest hybrid energy storage system, with a 50 MW grid-scale battery[i] that will support a 10-kilometre network of EV charging points and ground-source heat pumps for around 300 households.

The ESO project, which started construction in 2020, will help reduce 20,000 tonnes of CO_2 annually by 2021 and 44,000 tonnes of CO_2 annually by 2032. The project will be capable of integrating multiple sources of energy to manage energy demand, including renewables. Because Oxford is part of the UK100 network, by 2050 the ESO is to run entirely on renewable energy.

The GBP 41 million (USD 53.8 million) project will help accelerate the use of electric vehicles in Oxford, by providing charging points powered by the spare capacity of the battery to City Council depots and key businesses including local bus companies, taxi providers and commercial fleet depots. The project also aims to develop the first rapid charging hub in Oxford, making available around 20 ultra-rapid EV chargers for public use. Charging speeds will range between 10 and 30 minutes.

The project scope also includes a "Trial before you buy" programme by the City Council for taxi drivers in Oxford. This will help the taxis transition from 100% diesel to 100% electric by 2025. In total, the ESO pilot project will last for 36 months; once successful, the technology is to be expanded to up to 44 other sites across the United Kingdom.

Source: See endnote 248 for this chapter.

i The battery, connected to the Cowley sub-station in Blackberry Lane, South Oxford, will store and deliver electricity (including renewable electricity) to electricity suppliers and help balance the local requirements for the grid. Electricity will be stored at times of low demand and then resupplied back to the grid when demand peaks. The technology is capable of shifting demand to periods of low prices, minimising consumers' energy bills and overcoming local network constraints.

Procuring electricity via power purchase agreements for renewable projects outside of city limits may create or exacerbate constraints in the regional transmission system, depending on the scale and location of the renewable capacity under contract. Likewise, because most such PPAs are for electricity generated by solar PV or wind power facilities, system operators need to balance the variability of the contracted resources against other system resources across the regional or national control area.[249]

When city governments set targets to achieve a 100% renewable electricity supply by a future date, this allows time for planning the required resource commitment and any needed strengthening of energy infrastructure, in co-operation with regional regulators and system planners and operators. Moreover, once the newly committed off-site renewable generating capacity is built and interconnected to meet a city's energy needs, it typically serves not only the city but also the wider regional power grid as an interconnected resource[i]. Importantly, the city (with the assistance of the local utility and system operator) needs to ensure that the electricity purchased has somewhere to flow when it is generated.

In 2019, Salt Lake City (Utah, US) and more than 20 nearby communities entered into an agreement with the local utility to enable the achievement of net-100% renewable electricity no later than 2030.[250] The goal of this plan is to catalyse the construction of enough renewable power capacity to meet all net community electricity needs on an annual basis. However, the agreement acknowledges that this cannot be achieved without reliance on regional system-wide resources to help balance the community demand against the available committed resources; this requires relying at times on non-renewable resources to make up moments of shortfall, and sometimes sharing a surplus.[251]

Some cities have sought to address specific challenges related to the local and regional distribution infrastructure. For example, they have built new (or upgraded existing) transmission and distribution assets both within and outside city boundaries to reinforce the capacity to transfer electricity. They also have expanded the ability to buffer supply by installing greater storage capacity (such as via pumped hydropower, batteries or hydrogen conversion). Adding storage increases the system's capability to match load against available supply and to capture and use available renewable generation at each moment in time (regardless of demand) while also relieving potential transmission and distribution constraints.

In 2020, Los Angeles (California, US) announced plans to pursue a combined approach (upgrading transmission and enhancing storage) to support its goal of 100% renewable electricity.[252] As part of this effort, the city plans to replace an existing coal-fired power plant in Utah with a 840 MW gas-fired unit coupled with hydrogen storage in on-site underground salt caverns.[253] The hydrogen, generated using renewable electricity (via electrolysis), will be used to store any surplus electricity generated from variable renewable energy resources (such as wind or solar power) and will subsequently be used for electricity generation at the power plant as supply and demand conditions change.[254] The city also will build additional transmission interconnection to accommodate the bi-directional flow of electricity between Los Angeles and the new generating facility for the effective integration of renewables.[255] Upon its completion in 2025, the Utah facility would run on up to 30% renewable hydrogen (the balance being natural gas), with the aim of 100% renewable hydrogen use by 2045.[256]

Upgrading transmission and distribution assets and enhancing **storage capacity** can help cities achieve 100% renewable goals.

Salt Lake City, United States

i On the power grid, electrons flow to wherever they are demanded at each instant in time – it is only on a net basis that annual city demand is actually matched with the output of the specific resources committed to the city.