IRENA
International Renewable Energy Agency

RENEWABLE ENERGY POLICIES FOR CITIES

BUILDINGS

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IRENA
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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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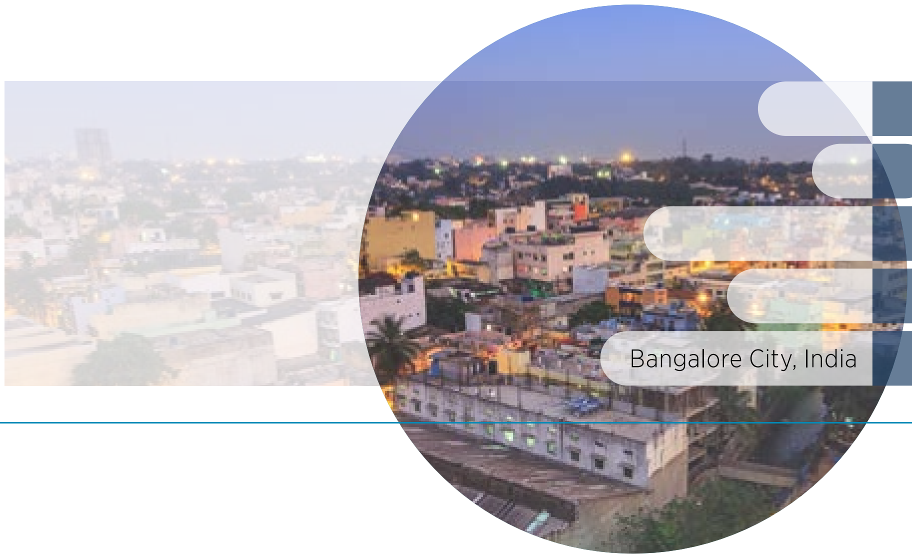


Bangalore City, India

ABOUT THE RENEWABLE ENERGY POLICIES FOR CITIES SERIES

Renewable Energy Policies for Cities: Buildings is one of several briefs intended to help policy makers accelerate efforts to create sustainable cities powered by renewable energy. The series includes briefs focused on the power and transport sectors, and this one on buildings. In addition, IRENA has produced a larger analytical report with case studies from three countries and an executive summary. The case studies are also available as stand-alone reports.

The series recognises that cities are critical actors in energy and climate policy making, complementing actions taken at the national and state/provincial levels of government. Cities are home to an ever increasing share of the world's population and are economic engines that use a large share of the energy consumed in the world. Thus, municipalities will play a major role in advancing and shaping the global energy transition. The briefs in this series focus on city action that may be undertaken independently by cities or in combination with initiatives at higher governmental levels.

The briefs carry a common understanding that the energy transition in cities is really a story of urban transformation. Renewables have impacts that extend well beyond the energy sector; they shape transport, buildings, land use and a host of other sectors critical to cities' functioning. Even within the energy sector, adoption of renewable energy involves more than a shift in energy sources; it includes an emphasis on greater energy efficiency and changed consumption patterns as well, both of which can change the face of a city. In sum, the energy transition is an opportunity to remake cities in a variety of ways that are better for people and the planet alike.

In addition, the *Renewable Energy Policies for Cities* series supports the International Renewable Energy Agency's (IRENA's) urban policy guidelines toolkit, an online resource that may be of particular interest to staff of municipal-level entities but is open to any interested individuals who want to strengthen their knowledge of options to facilitate the deployment of renewable energy in the urban environment. Part of IRENA's Policy Framework for the Energy Transition (PFET) (see Box), this innovative toolkit centres on the same areas of city-level action as IRENA's series of sectoral briefs: that is, renewable energy in (1) the power sector, (2) transport and (3) buildings. Based on a series of yes/no questions about basic circumstances in a city of interest (such as basic policy making objectives, settlement density or the availability of public transit), the toolkit points out basic policy recommendations, as well as case studies and examples of how policies have been implemented in cities across the world. These recommendations are intended to offer a broad orientation; specifically tailored advice requires detailed assessments of a given city. These recommendations are intended to offer a broad orientation; specifically tailored advice requires detailed assessments of a given city.

BOX IRENA'S POLICY FRAMEWORK FOR THE ENERGY TRANSITION (PFET)

The PFET aims to translate the knowledge products developed by IRENA's Knowledge, Policy and Finance Centre on policy, socio-economic benefits and finance into actionable advice, and to bring the messages and recommendations to policy makers on the ground to create impact. The PFET includes a set of **packages** that synthesise the knowledge products of IRENA and proposes different **tools** to deliver the capacity building to policymakers. These tools may include but are not limited to: presentations that can serve to deliver capacity building exercises; interactive exercises to conduct during the trainings; and short videos to convey key messages. PFET materials have been prepared or are under development for IRENA's work on cities, auctions, targets, and heating and cooling policies.

PFET
Policy Framework for the Energy Transition

IRENA
International Renewable Energy Agency

THE RENEWABLE ENERGY POLICIES FOR CITIES SERIES INCLUDE THE FOLLOWING REPORTS AND AN ONLINE TOOL

- Renewable Energy Policies for Cities: **TRANSPORT**
- Renewable Energy Policies for Cities: **BUILDINGS**
- Renewable Energy Policies for Cities: **POWER SECTOR**

INTRODUCTION

Picture a city, and a skyline of structures likely comes to mind. Buildings are the most prominent feature of most cities, occupying a large share of a city's area as they provide shelter for residents and operating space for stores, hospitals, offices and cultural institutions. Not surprisingly, buildings are among the biggest users of energy and contribute substantially to greenhouse gas emissions.

According to the 2020 Global Status Report for Buildings and Construction, the operation of buildings accounted for 30% of world energy demand in 2019, rising to 35% when construction is included, or 151 exajoules. Emissions from building operations ran to 10 gigatonnes of carbon dioxide ($GtCO_2$), the highest ever, and were equal to 28% of total global energy-related CO_2 emissions. Construction-related emissions (including manufacturing of materials like cement and steel) brought the total to 13.5 $GtCO_2$ and buildings' share to 38% (UNEP, 2020).

The growth of building floor area in the last decade far outpaced population growth. The encouraging news is that energy demand from this new construction grew far less, expanding at roughly half the rate of floor space additions (with floor space increasing by 21% versus 9% for energy use), indicating higher levels of energy efficiency (UNEP, 2020). Although the COVID-19 pandemic triggered a substantial drop in new construction during 2020, building floor area worldwide is expected to double to more than 415 billion square metres (m^2) by 2050, with energy demand potentially increasing by 50% (Steer, 2018).

In this context, ensuring that the global average temperature increase stays well below 2 degrees Celsius and as close as possible to 1.5 degrees Celsius requires cutting building-related CO_2 emissions by up to 85% within the next three decades. From 2030 onwards all new buildings need to be zero-energy buildings; meanwhile, the renovation of existing buildings needs to increase from just around 1% of building stock per year, to 3% per year (IRENA, 2020).

Reducing overall building energy demand through better design and greater efficiency (foremost in new structures, and also through retrofitting existing buildings) makes the task of meeting remaining energy needs with a large share of renewable energy and achieving net zero emissions more feasible. It is therefore critical to think holistically and regard renewable energy as part of an integrated package of measures. In addition, because buildings have a useful life of several decades and even up to a century, the design of such structures has long-term consequences for energy consumption. Retrofits of existing buildings may promise substantial benefits but are more expensive than designing a building to be energy efficient and renewables-ready from the very beginning.

50%

Expected growth of global energy demand in buildings by 2050

Some of the greatest opportunities for reducing buildings' carbon footprint are found in avoiding conventional energy requirements through smart building design. By designing to reduce floor area – for example, by opting for co-working or co-housing – or by siting and positioning buildings to maximise the benefits of solar rays, a building's energy and carbon footprint is reduced compared to traditional design. Improved building insulation and connection to efficient district heating and cooling networks can also help achieve decarbonisation goals.

Of course, energy consumption can be best minimised in new construction rather than retrofits since avoidance strategies (*i.e.*, smart design) can be integrated into every facet of new buildings. However, most efforts to reduce buildings' energy use will centre on existing structures. For this reason, this brief will examine broadly applicable strategies for reducing energy use in existing buildings, such as improving efficiency and promoting renewable energy.

Municipal governments can influence the decisions of builders, owners and users of buildings through a variety of regulations and incentives (IRENA, 2016, 2021; see also Box 1). These include land-use policies such as urban planning and zoning, building codes and permitting processes, energy performance regulations, solar ordinances, technical standards and public housing programmes (IRENA, 2016). In addition to regulations, mandates, financial and fiscal incentives, raising public awareness through information campaigns, stakeholder forums and public consultation is crucial (Renner, 2016). Energy performance monitoring and reporting are essential for establishing benchmarks and setting goals. Energy audits can pinpoint problems and opportunities for improvement. The US city of Seattle, for example, has made reporting on building energy performance mandatory for owners (Renewable Cities, 2015).

Pointing to the need to integrate renewable energy and energy-efficiency solutions, this brief discusses four critical types of actions: (1) setting standards and ordinances (e.g., green rating systems and municipal building codes); (2) advancing the use of renewable energy technologies and enabling infrastructure in buildings (such as rooftop solar photovoltaic [PV][1] or the electrification of heating and cooling energy uses); (3) leveraging renewables for social equity ends, such as through social housing programmes, and (4) partnering for effectiveness – by, for example, supporting grassroots and municipal-level initiatives.

1 The use of solar PV panels on rooftops is discussed in a parallel brief in this series, *Renewable Energy Policies for Cities: Power Sector.*

BOX 1 THE SIGNIFICANCE OF CITIES IN DEPLOYING RENEWABLE ENERGY

The boundaries of urban policy making are defined by the legal and regulatory authority vested in governments not only at the municipal level but also at the state, provincial and national levels. These boundaries are drawn in different ways across countries; some are governed in a highly centralised way while in others there is a considerable degree of devolution of authority.

IRENA's continuing work on renewable energy in cities (IRENA, 2016; 2021) has identified several dimensions of cities' roles in shaping climate adaptation and mitigation efforts, and as such in accelerating the deployment of renewable energy solutions as a key pillar of national sustainable energy targets (see Figure 1). Cities can be target setters, planners and regulators. They are often owners and thus operators of municipal infrastructure. Cities are always direct consumers of energy and therefore aggregators of demand, and can be conveners and facilitators and financiers of renewable energy projects. Finally, local authorities can play an important role in raising awareness by informing citizens of target setting and planning, and also by giving citizens an opportunity to provide comments and other inputs.

Figure 1 Roles of municipal governments in the energy transition

Source: IRENA urban policy analysis (based on IRENA 2016).

1. SETTING STANDARDS AND PASSING ORDINANCES

Cities can require new and existing buildings to adhere to minimum requirements for energy performance, such as those expressed in a variety of rating systems (subsection 1.1). Rating systems may also be reflected in municipal building codes (1.2) or ordinances that require the integration of renewable energy into buildings (typically focused on solar thermal applications) (1.3).

1.1 RATING SYSTEMS

A number of building design rating systems and performance certifications have been developed in countries around the world. Among the most prominent systems are the Building Research Establishment's Environmental Assessment Method (BREEAM), originally developed in the United Kingdom, and the Leadership in Energy and Environmental Design (LEED), developed by the US Green Building Council in 2000. While most of these certification systems are voluntary in character (and used by a growing number of developers and others for guidance), they are increasingly reflected in building codes and performance standards adopted by cities and other levels of government. Some countries have adapted them to reflect specific national or regional needs and circumstances (Vierra, 2016).

Cities' adoption of building rating systems can enable their deployment of renewables. Some, like **Copenhagen** and Singapore, for example, have been trailblazers for years. New buildings in Copenhagen are required to meet Denmark's Low Energy Class ratings, part of the city's 2012 plan to become the world's first carbon-neutral city by 2025 and to increase reliance on renewable energy and combined heat and power (Gerdes, 2013). In **Singapore**, the 2008 Building Control Act (amended in 2012) requires that building owners meet Green Mark–certified standards, conduct energy audits of cooling systems (for buildings with a gross floor area of at least 15 000 m^2) every three years and submit energy consumption data yearly (Tokyo Metropolitan Government and C40 Cities Climate Leadership Group, 2014).

Figure 2 Green building labels around the world

Note: Selected logos and labels from various green building standards, certifications, and rating systems aimed at mitigating the impact of buildings on the natural environment through sustainable design.

1.2 BUILDING CODES

A building code is a set of regulations, enacted by either national or subnational (including municipal) governments, for the construction, renovation and repair of buildings and other structures that people may occupy. Local building codes and related mandates can be major drivers for reducing energy consumption as well as raising the share of renewable energy, especially if they exceed national standards. The manner in which they are applied varies. They may:

- be either mandatory or voluntary, and their degree of stringency varies considerably across cities and countries.
- apply only to municipally owned structures or also to privately owned buildings.
- apply only to new buildings or also to existing structures.

Building codes may entail energy use/efficiency targets for new buildings, specify insulation standards and decree building design choices (such as zero-carbon, zero-energy or passive-house standards, or "green roof" requirements) to increase building energy efficiency and therefore lower the amount of heating and cooling energy required. They may prescribe measures that ensure that new buildings are "solar ready".[2] City ordinances also increasingly mandate the use of solar water heaters or solar PV panels for new construction.

Building codes are already widely used to improve the energy performance of new and refurbished buildings by setting standards of energy efficiency or greenhouse gas emissions (IRENA, IEA and REN21, 2020). At the end of 2019, around 41 countries had implemented national building codes to promote energy efficiency and renewables in buildings (REN21, 2020). Some cities have played a pioneering role for years, adopting ambitious targets, policies, and fiscal and financial incentives with the aim to improve energy efficiency, reduce the greenhouse gas footprint of buildings and enhance the role of renewables.

2 "Solar ready" buildings, as defined by the National Renewable Energy Laboratory (NREL, 2012), are designed and engineered for the installation of solar PV and solar thermal collectors.

1.3 SOLAR THERMAL ORDINANCES

More than three-quarters of energy use in buildings relate to heating and cooling needs. Direct use of solar thermal for water and space heating can be accomplished either through decentralised applications (*e.g.*, solar water heaters) or centralised district energy networks (discussed later in this brief). Globally, more than half of installed solar collectors (684 million m^2) are domestic solar water heaters for single-family houses (IRENA, IEA and REN21, 2020).

Solar thermal ordinances are municipal regulations which stipulate that solar energy provide a specified minimum share of heating demand. They may apply to new buildings or structures undergoing major refurbishment. Over the past decade or so, solar ordinances have become an increasingly common tool to promote increased deployment of solar thermal technology (ESTIF, 2018). Along with national governments, municipalities in China, Brazil, Israel and Spain have been among the leaders in support of solar water heating (SWH) in residential and commercial buildings. Israel has the oldest SWH ordinance: as far back as in 1976, the country mandated solar water heaters for all new residential buildings that are up to eight stories tall. This mandate was extended to all residential buildings in December 2019. Some 85% of Israeli households use solar thermal energy for water heating (Berenbaum and Datta, 2020).

China is home to about 75% of the global installed SWH capacity, with more than 80 cities having adopted favourable policies for installing such systems, often including mandatory installation in new buildings. The city of **Rizhao**, in Shandong province, has promoted SWH in residential buildings for the past 20 years through regulations, subsidies and information campaigns. Today, nearly all households in the city centre use it. The Shandong provincial government helped finance solar research and development, resulting in competitive pricing of SWH systems compared to electric heaters (IRENA, 2016; REN21, ISEP and ICLEI, 2011).

In a number of cases, steps taken by a pioneering city led others in the same country to follow suit. This was the case in Spain, Brazil and Argentina. For example, the city of **Barcelona**, Spain, became the first city in Europe to pass a solar thermal ordinance, in 2000. It requires that 60% of running hot water be covered through solar thermal energy in all new or renovated buildings and in buildings whose primary purpose has been altered. The city has made notable efforts to familiarise residents with this technology and to address initial performance problems. The "Solar Reflection Days" initiative showcased state-of-the-art solar thermal systems. "Taula Solar", a stakeholder forum, was formed to discuss the objectives and scope of the ordinance with architects, engineers, residential building administrators, a consumer association, solar industry representatives and others. More than 70 other cities in Spain subsequently replicated Barcelona's ordinance, and in 2006, a requirement to install solar thermal systems became part of Spain's national Technical Building Code (ICLEI, 2014).

Spain

Other cities elsewhere in Europe have followed suit, including far smaller ones than Barcelona. The European Solar Thermal Industry Federation (ESTIF, 2018) lists examples such as the towns of **Vellmar** (Germany) and **Carugate** (Italy), and a number of Irish local authorities. Since 2013, **Loures** (Portugal) has mandated solar thermal systems for all schools and sports facilities that have adequate sun exposure (REN21, 2018). Examples are also available from other parts of the world, in cities such as **Santa Monica** (United States) (IRENA, 2016) and **Bangalore** (India) (REN21, 2019); or **Chandigarh** (India), where SWH was made mandatory as of 2013 for industrial facilities, hotels, hospitals, prisons, canteens, housing complexes, and government and residential buildings (REN21, 2015).

Inspired by the Spanish experience, Brazil's solar thermal industry association DASOL-ABRAVA and Vitae Civilis, a prominent non-governmental organisation, decided to jointly promote the use of solar water heaters. **São Paulo's** 2007 Solar Ordinance mandates that solar technology cover at least 40% of the energy used for water heating in all new buildings (the target can be made more stringent in the future, since solar heaters are believed to be capable of meeting up to 70% of energy use). Public consultations were a key element in drafting the ordinance. Product certification efforts (through a national labelling programme, "Programa Brasileiro de Etiquetagem") were critical to avoid the use of low-quality equipment that could have damaged the public's acceptance of the technology (ICLEI and IRENA, 2013; ABRAVA, 2015). As was the case in Spain, this pioneering ordinance inspired similar measures in cities across Brazil. As of 2018, the country had installed a cumulative 16 million m^2 of solar collectors, mostly in residential buildings and social housing; this is the fifth-largest amount deployed in the world (Weiss and Spörk-Dür, 2020).

Rosario, Argentina's third-largest city with a population of approximately 960 000, became the first municipality in the country to pass a solar ordinance, which entered into force in 2012. It requires that all new or upgraded public buildings – including schools, hospitals, public swimming pools, sports facilities and community centres, and social housing owned by the municipality and by other government authorities – cover at least 50% of their hot water consumption through solar water heaters. The policy reflects a successful collaboration among multiple levels of government, academia, civil society, the private sector and the community at large. A local non-profit environmental protection organisation, Taller Ecologista, provided critical technical advice and, together with the Universidad Tecnologica Nacional Facultad Regional Rosario (UTN), published an installation and maintenance manual for SWH (ICLEI and IRENA, 2018).

Barcelona's solar ordinance was imitated by many other Spanish cities, just like São Paulo's ordinance inspired many other Brazilian cities to follow suit and Rosario galvanised action in other Argentinian cities.

2. DEPLOYING RENEWABLE ENERGY IN MUNICIPAL AND PRIVATELY OWNED BUILDINGS

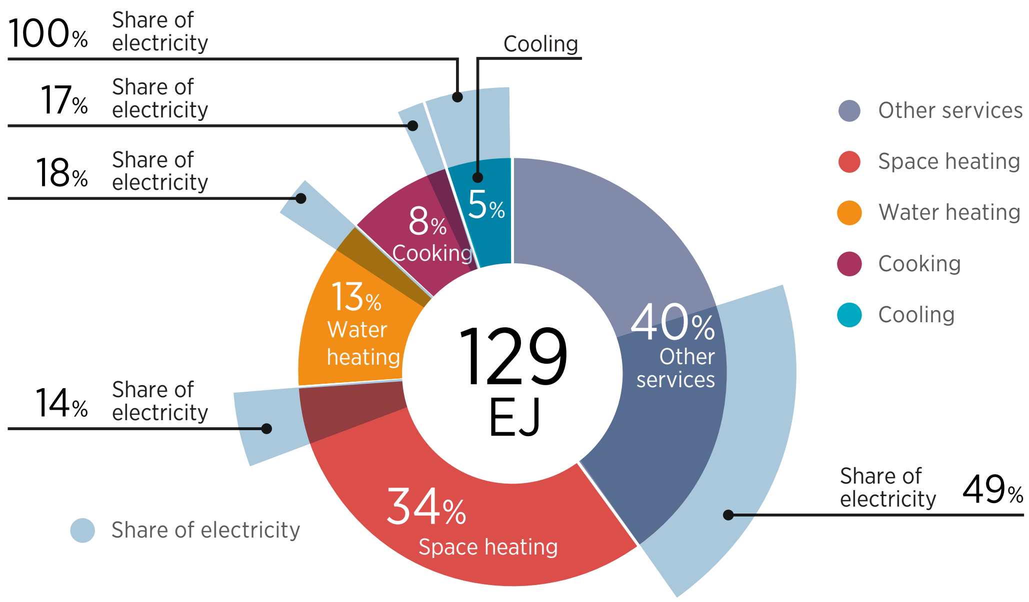
It is clear that ramping up the share of renewables is central to making urban energy use more sustainable – a strategy that needs to be paired with efforts to increase the efficiency with which energy is used in buildings. Electrifying heating and cooling energy uses and promoting district heating and cooling networks based on renewable energy are key to decarbonising urban energy uses. They require proactive support that municipalities are often very well positioned to provide due to their role of planning and regulating urban building development. While renewable energy technologies are becoming much cheaper, high up-front costs are often still a considerable barrier to widespread adoption, especially for poor or disadvantaged urban residents. Efforts to increase the share of renewables must thus be undertaken in close alignment with support for low-income households to be part of this transition.

2.1 ELECTRIFYING HEATING AND COOLING ENERGY USES

At present, energy used for heating and cooling purposes accounts for half of global final energy consumption, generates 40% of energy-related CO_2 emissions and is responsible for a majority of air pollution due to a high degree of dependency on fossil fuels. In principle, electrification offers a huge potential to address these problems, but only if power generation is switched to renewables.

Currently, electricity accounts for 14% of total energy used for space heating worldwide, for 18% for water heating, 17% for cooking and for close to 100% for space cooling (IRENA, IEA and REN21, 2020). Figure 3 displays these shares and indicates the energy used for these and other services. While still small in comparison to other uses in buildings, energy for cooling purposes in buildings doubled between 2000 and 2018 to 7 exajoules (EJ), reflecting higher temperatures, expanding populations and economic growth. In the absence of greater efficiency, cooling energy could again more than double by 2040 as the use of air conditioning becomes more widespread, especially in developing and emerging economies. A number of measures can help avoid a rise in emissions associated with rising demand for cooling; these include improved insulation and building thermal envelopes, more efficient systems (*e.g.*, heat pumps) and the decarbonisation of the electricity used to power cooling systems (IRENA, 2020).

Figure 3 Global share of electricity used in buildings, by service, 2019



Source: IRENA, IEA and REN21, 2020.

Note: EJ = exajoule.

In this context, renewables-based electrification is a key pathway to the decarbonisation of heating and cooling. Meanwhile, the flexibility of the urban power system to integrate more variable renewables can be enhanced with demand-side appliances such as heat pumps (IRENA, IEA and REN21, 2020). Heat pumps could play a major role in electrifying the heating and cooling of urban buildings. Heat pumps can provide heating and cooling services for individual houses or an entire urban area through their integration with district heating and cooling networks.

Scaling up the deployment of heat pumps may benefit from policies such as including minimum performance standards and redesign of tariffs.

Aarhus, Denmark, utilises excess wind energy to power a 2 megawatt (MW) heat pump and 80 MW electric boiler connected to the city's district heating networks. Some households in the Orkney islands, United Kingdom, also utilise excess wind generation to power efficient electric heating appliances (IRENA, IEA and REN21, 2020). In the cities of Hebei province, China, government authorities and the state grid company facilitate trading of excess onshore wind electricity for electric heating users, including those who depend on the district heating system (IRENA, 2021).

Global energy use for space cooling has tripled since 1990. An electrified district cooling system using chilled water integrated with cold storage can enable the use of renewable electricity. Such systems have been adopted by cities such as **Dubai** (United Arab Emirates), **Shenzhen** and **Hong Kong** (China), **Boston** (United States) and others (IRENA, 2019).

National policies can help to address cost and market barriers that impede cities from electrifying heating and cooling energy uses. New Zealand's Warmer Kiwi Homes programme provides grants to support households installing heat pumps. China's Clean Winter Heating in Northern Regions pilot programme provided grants for cities and in some cases subsidies for electric heating in the winter season. Hungary's "H Tariff" provides preferential tariffs for the electricity consumption of electric heating appliances during heating seasons (Nádor, Kujbus and Tóth, 2019).

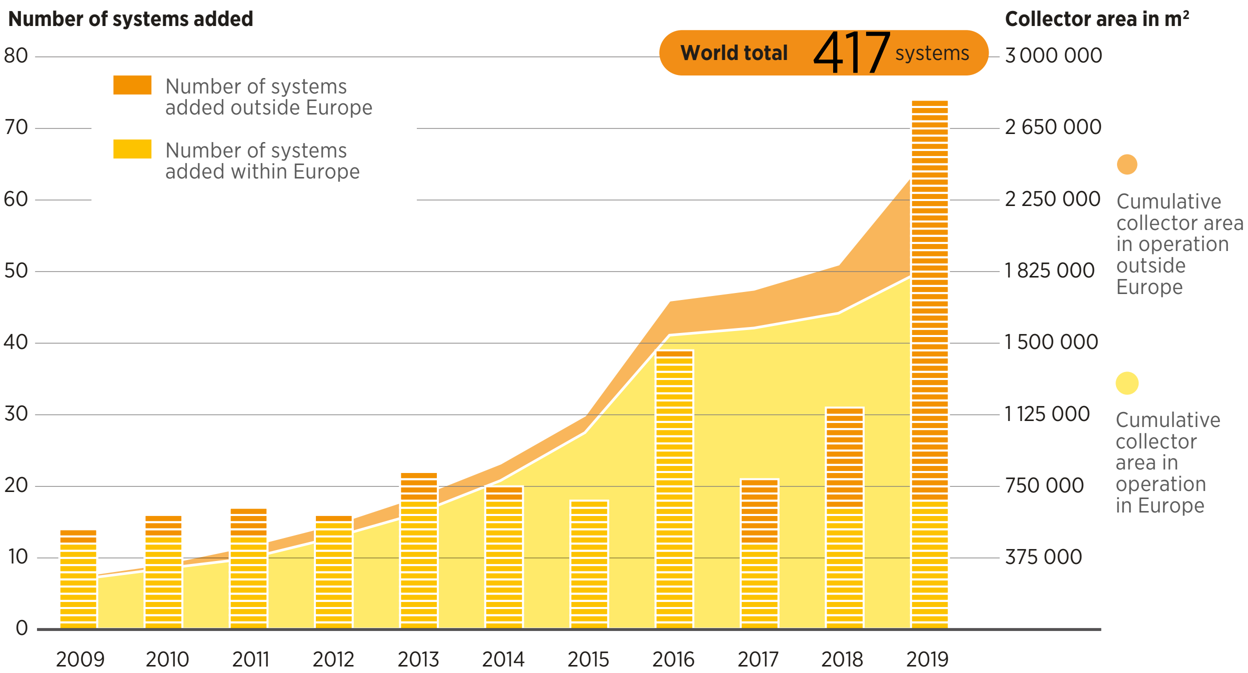
2.2 DISTRICT HEATING AND COOLING NETWORKS

Globally around 60% of building energy consumption goes to heating and cooling. Currently most of these energy needs are provided by decentralised options. However, in dense urban areas, district heating may offer the most effective way to integrate a large share of renewables; the use of individual biomass boilers, solar thermal systems or heat pumps in such settings may often be constrained by lack of available space or access, or noise restrictions (IRENA, IEA and REN21, 2020).

Many cities have considerable authority over the generation and distribution of heating and cooling energy. Notwithstanding the benefits of district energy systems, they supplied only 6% of heating and cooling demand in the buildings sector in 2018 (IEA, 2019). Business and policy models vary, depending on local conditions and priorities, ranging from full public ownership of district systems to public-private partnerships, to private ownership.

In Nordic countries and elsewhere in Europe, district heating networks using renewable energy have been in operation for a long time. In Iceland's capital, **Reykjavik**, some 95% of residences are connected to the geothermal-based district heating network. Industrial waste heat is being recycled in various European cities (IRENA, 2016). While still small, the number of solar district heating systems rose to about 420 as of 2019 (see Figure 4). Solar district heating systems are still concentrated in Europe, although the vast majority of new systems added in 2019 were in other regions. European cities, especially in Austria, Denmark, Germany and Sweden, are in the lead, but such systems are beginning to spread to other regions, such as **Bishkek** in the Kyrgyz Republic, which inaugurated a solar system in 2017 (REN21, 2018).

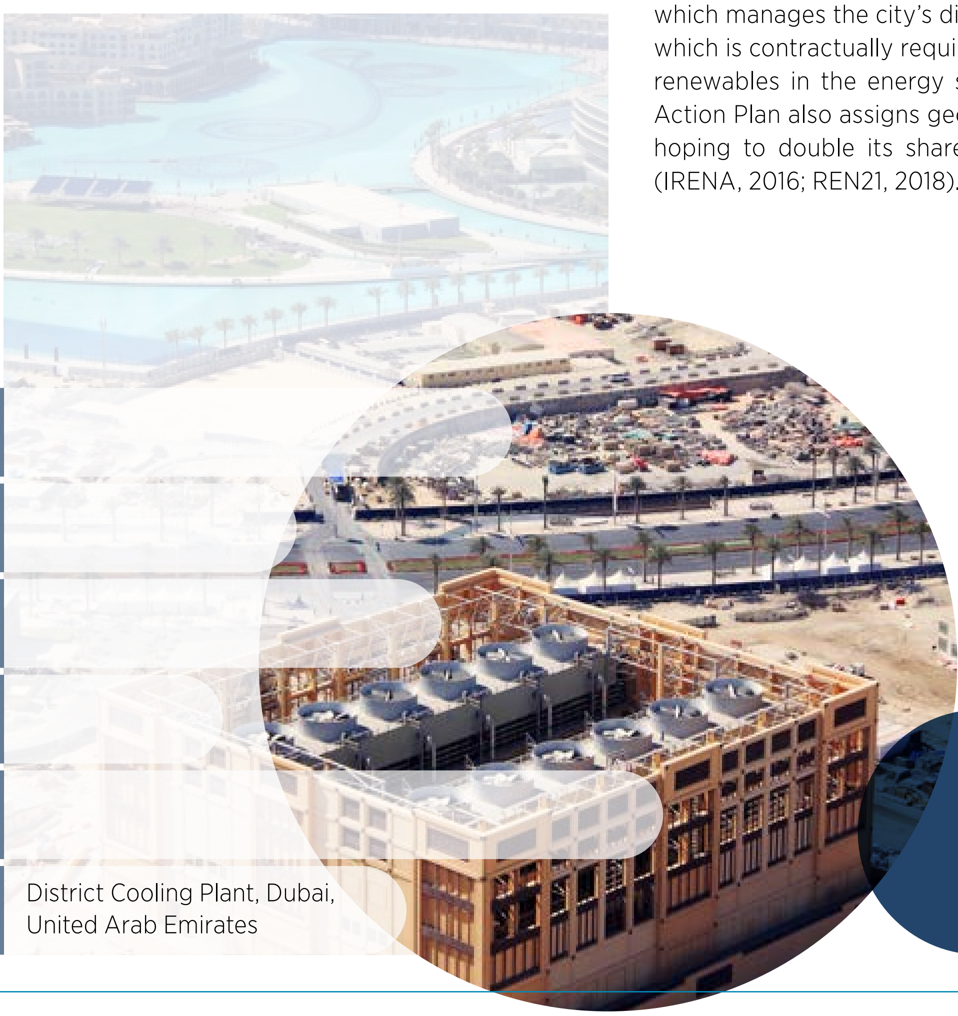
Figure 4 Solar district heating systems worldwide, 2009–2019



Source: REN21, 2020.

The high up-front cost of the networks is a major barrier to promoting district heating and cooling in cities. Municipal policies can help. Examples include mandating connections for new buildings to ensure an "anchor load" of new developments, as well as direct municipal investment, grants or subsidies and other financial support. Also, zoning and heat mapping are very important to guide private sector investments (IRENA, IEA and REN21, 2020).

Municipal regulations in **Växjö**, Sweden, require homeowners to connect to the municipal district heating network, and the city is known as a pioneer in using biomass-based co-generation for this purpose (Agar and Renner, 2016). Austria's capital, **Vienna**, for example, owns the utility companies responsible for the city's district heating, gas and electricity (IRENA, 2016). Connecting to a heating or cooling network can be made mandatory for businesses and residents by urban planning authorities, a move that helps stabilise demand and allows large investments to be made with a steady hand.



District Cooling Plant, Dubai, United Arab Emirates

Central government policies can also help expand district systems powered by renewables. In Germany, many municipal utilities submitted applications under "District Heating Network 4.0", a new subsidy scheme that provides generous grants for feasibility studies and investments in fourth-generation networks, defined as renewables (geothermal, solar thermal or biomass) or waste heat covering at least half of heating demand (REN21, 2018).

Some examples stand out for their scale. **Copenhagen** has built one of the world's largest district heating networks, serving 98% of the city's buildings. By 2025, the aim is to make the system carbon neutral by replacing fossil fuels at combined heat and power plants with wood pellets from sustainably grown forests, in addition to large-scale heat pumps powered by wind and geothermal energy (C40 Cities, 2015). **Dubai** has developed the world's largest district cooling network. **Paris** developed Europe's first and largest district cooling network (UNEP, 2015). Paris also owns a third of the Paris Urban Heating Company (Compagnie Parisienne de Chauffage Urbain, CPCU), which manages the city's district heating network, and which is contractually required to increase the share of renewables in the energy source mix. Paris's Climate Action Plan also assigns geothermal energy a key role, hoping to double its share between 2012 and 2022 (IRENA, 2016; REN21, 2018).

3. RENEWABLES IN SOCIAL HOUSING

Low-income inhabitants of cities may not be able to afford renewable energy solutions. Even though costs continue to come down, up-front expenses can be high. Low-income residents are also far more likely to be renters than homeowners. This means that they depend on landlords to invest in renewable technologies. However, in a situation recognised as a "split incentive", landlords may decide against making the necessary investment if they feel they are not able to reap an adequate share of the financial benefits within a relatively short period of time.

The calculus can be a different one in social housing, where public authorities may be able to take a longer view. There are now many national and local government initiatives to promote sustainable practices in the context of social housing programmes in emerging economies like Brazil, Chile, China, Mexico and South Africa, as well as in developed countries like Australia or Belgium.

In China, for example, the Ministry of Finance and the Housing Department announced that, from 2014 onwards, all newly constructed government low-income housing must be Chinese Green Building Label certified (USGBC, WGBC and C40 Cities, 2015). Where such efforts surpass the financial capacity or regulatory authority of municipalities, other levels of government will have a critical role to play.

Brazil's programme Minha Casa, Minha Vida ("My House, My Life"), first launched in 2009, has led to the construction of about 4 million housing units for low-income families. The programme was the main driver of growth in Brazil's solar heat sector in 2009 2014. Partly due to a recession and partly because of a new federal government, interest waned in 2015 and funding became tight (Folha de S. Paulo, 2018; Sother, 2019). In 2019, overall solar thermal installations in Brazil picked up again (Weiss and Spörk-Dür, 2020). Minha Casa, Minha Vida stipulates that housing units must meet a number of specific requirements, including installation of solar water heaters (ILO, 2013). Since June 2015, the government-owned Caixa bank has offered preferential loan terms for energy-efficient housing built under the programme. Developers need to be certified under LEED, BREEAM or one of three Brazilian standards (Kriele, 2015).

In the Brazilian state of Goiás, the housing agency Agência Goiana de Habitação (AGEHAB) incorporates solar power into social housing programmes, in partnership with municipalities. As of 2019, there were four solar-supplied residential complexes, with plans for more. Its Cheque Mais Moradia programme supports construction and renovation of social housing stock. AGEHAB also offers subsidies of BRL 3 000 (USD 780) per eligible family for the installation of two PV panels. The programme has also provided support for solar water heaters (Osava, 2019).

Elsewhere in Latin America, the Sustainable Housing Programme under **Mexico City's** Climate Action Plan promotes the inclusion of green building features such as solar PV panels, energy efficiency, water efficiency and wastewater treatment facilities in new and existing multi-family buildings (USGBC, WGBC and C40 Cities, 2015).

In the Australian province of Queensland, the regional government's Affordable Energy Plan includes a scheme targeted at public housing that offers no-interest loans to residents wishing to invest in rooftop solar and battery storage solutions. The government hopes this programme will lead to the installation of more than 700 solar systems with a total capacity of 3 MW in the cities of **Cairns** and **Rockhampton** (Vorrath, 2018). The Queensland government also has developed a programme to cut household electricity bills by allowing low-income families living in public housing to buy solar power at a discounted per kilowatt hour rate from approved energy providers. The programme will include installations in selected state-owned homes in Waterford, Coomera, Woodridge, Logan, Algester and Springwood. In an effort to support local economies, successful tenderers will be required to generate employment for local skilled workers such as electricians (9 News, 2018).

Housing agencies in many cities lack expertise in integrating renewable energy into building renovation projects. To remedy this problem, the housing agency of the **Brussels** capital region of Belgium, SLRB launched VAMOS Vert. Une Aide à la Maîtrise d'Ouvrage Sociale in 2013 to develop relevant local expertise. VAMOS Vert had an overall budget of EUR 124 million in the three-year period to 2016, with about 10% dedicated to renewables. SLRB was planning to develop new financing instruments to cover additional costs of installing energy-producing equipment in buildings, including a revolving fund of EUR 3 million, an effort to secure a grant from the European Regional Development Fund, and third-party financing. VAMOS Vert was expected to generate 1.3 gigawatt hours (GWh) of electricity from renewables by 2016 and yield energy savings of 5.4 GWh per year (Energy Cities, 2015; EIB, 2018).

In addition to social housing, other programmes can be designed to give low-income households access to renewable energy and/or enable them to afford energy efficiency measures. Box 2 offers examples from cities in the United States.

3 Société du Logement de la Région Bruxelles-Capitale.

BOX 2 STIMULATING INCENTIVES TO DEPLOY HIGH-EFFICIENCY SYSTEMS

Cities could offer "incentive" funding to enable private housing improvements and energy-efficient upgrades. These schemes are typically for low-income homeowners but can also be available for higher-income individuals.

Home repair programme loans: Lacking the up-front money to make needed repairs, low-income households are often eligible for forgivable low-interest loans or grants. Although many programmes target low- and middle-income homeowners, other schemes do not set a limitation on household income; also, programmes pay via a variety of mechanisms. Eligibility can be based on a dynamic interest rate tied to income, so the higher the income of a household, the higher the interest rate it is set to pay. The city of **Dallas** (United States), for instance, offers deferred loans to low-income homeowners for major systems repairs such as roof improvements, and the replacement or upgrade of plumbing, electrical systems, and heating, ventilation and air conditioning (Dallas Economic Development, n.d.).

Property tax abatement or exemptions: Cities can defer property taxes on the value of the improved portion of a property for a prescribed period of time, or exempt it from such taxes altogether. For example, the city of **Cambridge**, (United States), through the Cambridge Energy Alliance, provides services to help residents, businesses and institutions access energy-efficient and renewable energy services (CEA, n.d.).

State tax credits: Another option that municipalities may want to explore is offering tax credits to help homeowners undertake specific repairs or upgrades that enhance energy efficiency. In the United States, for example, several energy efficiency and renewable tax credits are available at the state or local level (DSIRE, n.d.).

4. PARTNERING FOR EFFECTIVENESS

Renewable energy deployment can benefit from collaboration among municipalities. For example, the Net Zero Carbon Buildings Commitment was launched by the World Green Building Council in September 2018, with the C40 Cities serving as the secretariat. The commitment entails enacting regulations and/or planning policy to ensure that new buildings operate at "net zero carbon" (defined as highly energy efficient, powered by a combination of renewables and offsets) by 2030 and that all buildings achieve this status by 2050. As of late 2020, the initiative had attracted commitments from 28 cities, 6 states and regions, and 79 businesses and other organisations. These covered nearly 6 000 assets and more than 32 million m^2 of total floor area (WGBC, 2020).

In addition to peer-to-peer networks, bottom-up and intergovernmental collaboration initiatives can play a critical role. Grassroots initiatives create space for local communities to identify and engage suitable ways for renewable energy to meet local community aims, while national governments – with their ability to systematically plan, fund and support local governments – are central to accelerating and scaling up innovative local programmes and initiatives. This section explores the roles of both in more detail.

4.1 GRASSROOTS INITIATIVES

Around the world, community energy approaches are an increasingly popular solution to local energy supply challenges. Many bottom-up grassroots efforts feature the active involvement of local residents and community groups, including co-operatives, non-profit associations, community trusts and others that support renewable deployment in urban spaces. Models differ, but often involve a significant ownership share for local communities. The majority of the social and economic benefits of such projects are typically distributed within local communities (IRENA Coalition for Action, 2018).

In the favela of Morro de Santa Marta, **Rio Janeiro**, solar panels were installed at day care centres, schools and along alleys and courtyards by Insolar, a local social enterprise. Favela residents typically pay a higher price for grid electricity than wealthier areas of Rio. The panels reduce energy costs of the 4 000 residents and provide relief from frequent power outages. Insolar hopes to extend installations to 30 local businesses and to initiate pilots in 14 other Rio favelas. The effort will involve local residents and offer training to workers on the basics of electricity and installation of solar panels (Osava, 2018).

Brixton, a district within the **London** borough of Lambeth, is home to three pioneering solar energy co-operatives. They allow residents of local council estates to invest in local renewable energy generation. The initiatives have created local jobs and training opportunities and are helping to alleviate fuel poverty. To date, three Brixton solar co-operatives have a combined rooftop generating capacity of about 135 kilowatts. A fourth project is in planning. Some of the energy generated is used on-site and the remainder fed into the grid. Revenues are used to fund improvements to the energy efficiency of the local housing stock, as well as for dividends paid to community members (Brixton Energy, n.d.).

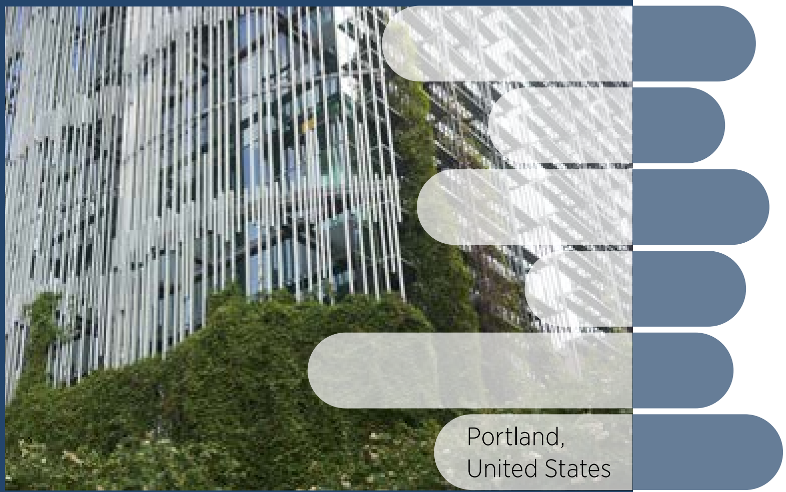
In a small municipality outside **Copenhagen**, the social housing estate of Hvidovrebo exercises a form of tenants' democracy based on self-governance provisions enshrined in Danish housing association law. When ten estate building roofs needed renovation, the tenants agreed to generate their own solar electricity and SWH. Local district heating company Hvidovre South A.m.b.A.[4] conducted feasibility studies on the integration of the needed systems. Helping to make the estate more energy self-sufficient, the installation was planned to feed 120 160 megawatt hours per year into the communal grid. The project is owned by the housing estate, with individual tenants making payments in addition to their regular rents or mortgages (Roberts, Bodman and Rybski, 2014).

Financing represents a significant barrier to bottom-up initiatives. In **Portland**, Oregon (United States), a proposed ordinance would create a municipal tax revenue stream to fund rooftop solar panels, home weatherisation, job training and other projects in support of low-income communities (see Box 3).

4 Co-operative limited companies (*Andelsselskaber med begrænset ansvar*, or A.m.b.A.) are a popular model for community ownership of district heating (Roberts, Bodman and Rybski, 2014).

BOX 3 PORTLAND CLEAN ENERGY COMMUNITY BENEFITS INITIATIVE

The initiative proposes an ordinance to be added to the **Portland** city code governing business licenses. It aims to support the city's Climate Action Plan and 100% renewable energy goal, by providing a long-term funding source for the installation of solar panels and other climate-friendly measures in low-income communities. The proposed ordinance requires large retailers to pay a surcharge of 1% on gross revenues from sales in Portland (excluding basic groceries, medicines and health care services). Revenues would flow into the Portland Clean Energy Community Benefits Fund. The fund would finance renewable energy and energy efficiency projects, clean energy skills training and workforce development programmes for low-income and disadvantaged residents (City of Portland, 2018).



Portland, United States

4.2 THE ROLE OF NATIONAL GOVERNMENTS

Although municipal authorities are often more ambitious than higher-level governments, national (or state and provincial level) policies do play a critical role in supporting local efforts through their regulatory authority and financing capacity (IRENA, 2021).

For example, Chile's Ministry for Public Works, Housing and Urban Development, and Ministry for Energy and Environment jointly formulated a National Strategy for Sustainable Construction that seeks to link to, and coordinate, the energy and environmental plans of local authorities. South Africa's Department of Energy has created a Municipal Energy Efficiency Demand Side Management programme. And the Republic of Korea has developed an eco-friendly building certification programme for new buildings known as the Green Standard for Energy and Environmental Design, or G-SEED. The national government had set a target for all new multi-family housing in the country to achieve "zero net energy" by 2025, but Seoul's Metropolitan Government aims to meet this goal two years earlier (USGBC, WGBC and C40 Cities, 2015).

In India, energy policies are overseen mostly by state and national governments, while the decision-making authority of municipalities is limited. However, the Solar Cities programme of India's Ministry of New and Renewable Energy is helping local authorities achieve a minimum 10% reduction in conventional energy use over five years through a combination of renewable energy and energy efficiency measures. Altogether, the ministry had proposed supporting 60 cities with financial, technical and planning assistance, requiring candidate cities to undertake a number of steps, such as promoting the National Rating System for construction of energy-efficient buildings; amending building by-laws to make SWH systems mandatory in certain types of buildings; providing property tax rebates to SWH users and organising publicity and training programmes for various stakeholders (Agar and Renner, 2016).

National governments also play a key role in promoting green building codes. Among a set of 15 major countries examined by the American Council for an Energy-Efficient Economy (ACEEE), 7 (Australia, France, Germany, Russia, Korea, Spain and the United Kingdom) have mandatory national building codes for both residential and commercial structures. Others have mandatory codes in one category but voluntary codes in the other (Young, 2014).

SUMMARY

As a key user of energy in cities, buildings are a high-pay-off target in the process of advancing the global energy transition. A combination of energy efficiency and renewable energy can do a great deal to shrink the carbon footprint associated with the heating, cooling and other energy uses of a city's buildings. The toolbox is large, consisting of building codes and permits, building and zoning regulations, mandates, solar thermal ordinances, tax incentives, targeted subsidies and other financial and fiscal tools.

Cities have extensive power to regulate energy use in buildings through the use of building codes and rating systems such as BREEAM in the United Kingdom and LEED in the United States. Rating systems set standards that cities and developers can incorporate into their building codes, quickly advancing energy efficiency, especially if the standards are mandatory and cover all buildings, existing and new, public and private.

Cities can also release policies for electrifying heating and cooling in urban structures. Heat pumps have a major role to play but need additional policy support to reduce the barriers such as high up-front costs and preferential tariffs. District heating and cooling based on renewable energy hold significant potential and can benefit final consumers through reduced bills. Moreover, many cities now integrate solar energy into social housing projects. By offering clean energy and cutting-edge efficiency, such initiatives provide low-income families access to energy that is at once clean and affordable.

Integrating renewable energy into the building stock need not always be initiated by government action. Grassroots initiatives of co-operatives, non-profit associations, community trusts and other organisations sometimes take the lead in efforts to escape the exorbitant energy charges found in impoverished neighbourhoods. Of course, capital is often an obstacle, but some city governments bridge the financing gap to encourage such grassroots initiatives.

Finally, national governments can be useful in stimulating the use of renewables in buildings, especially by setting nationwide standards for building codes. Boundary-setting activities create incentives for renewables and can help to create markets for cutting-edge products.

REFERENCES

9 News (2018), "Government trial will see cheaper solar energy provided to public housing families", 9 July, www.9news.com.au/national/2018/07/09/11/10/pulic-housing-logan-set-to-receive-cheap-solar-energy.

ABRAVA (Associação Brasileira de Refrigeração, Air Condicionado, Ventilação e Aquecimento) (2015), *Relatório de Pesquisa: Produção de Coletores Solares para Aquecimento de Água e Reservatórios Térmicos no Brasil: Ano de 2014*, National Department of Solar Heating, Brazil.

Agar, B. and M. Renner (2016), "Is 100 percent renewable energy in cities possible?" in *State of the World: Can a City Be Sustainable? Worldwatch Institute (ed.)*, pp. 161 170, Island Press, Washington, DC.

Berenbaum, D. and M. Datta (2020), "In the 1980s, solar water heaters took off in Israel, but stalled in the U.S. It's a simple fix", GreenBiz, 18 November, www.greenbiz.com/article/1980s-solar-water-heaters-took-israel-stalled-us-its-simple-fix.

Brixton Energy (n.d.), "Completed projects", https://brixtonenergy.co.uk/projects/.

C40 Cities (2015), "Cities100: Copenhagen – Carbon Neutral District Heating", 30 October, www.c40.org/case_studies/cities100-copenhagen-carbon-neutral-district-heating.

CEA (Cambridge Energy Alliance) (n.d.), http://cambridgeenergyalliance.org/.

City of Portland (2018), "Portland Clean Energy Community Benefits Initiative 2018", www.portlandoregon.gov/auditor/article/674246.

Dallas Economic Development (n.d.), "Property Assessed Clean Energy (PACE)", www.dallasecodev.org/260/Property-Assessed-Clean-Energy-PACE.

DSIRE (Database of State Incentives for Renewables & Efficiency) (n.d.), www.dsireusa.org/.

EIB (European Investment Bank) (2018), "Vers une Aide à la Maîtrise de l'Ouvrage Sociale", www.eib.org/attachments/documents/elena-completed-vamos-en.pdf.

Energy Cities (2015), *Unlocking Investment in Cities: ELENA-EIB Technical Assistance Facility: Project Review in Five European Local Authorities*, June, https://energy-cities.eu/publication/unlocking-investment-in-cities/.

ESTIF (European Solar Thermal Industry Federation) (2018), "Solar ordinances", www.estif.org/policies/solar_ordinances/.

Folha de S. Paulo (2018), "Minha Casa, Minha Vida tem meta de 650 mil unidades em 2018", 9 February, www1.folha.uol.com.br/mercado/2018/02/minha-casa-minha-vida-tem-meta-de-650-mil-unidades-em-2018.shtml.

Gerdes, J. (2013), "Copenhagen's ambitious push to be carbon neutral by 2025", *Yale Environment 360*, 11 April, https://e360.yale.edu/features/copenhagens_ambitious_push_to_be_carbon_neutral_by_2025.

ICLEI – Local Governments for Sustainability (2014), "Barcelona, Spain: Using solar energy – Supporting community energy self sufficiency", ICLEI Case Study No. 173, ICLEI, Barcelona, Spain, December, http://old.iclei.org/fileadmin/PUBLICATIONS/Case_Studies/ICLEI_cs_173_Barcelona_UrbanLEDS_2014.pdf.

ICLEI and IRENA (2018), "Promoting solar water heaters for urban homes and businesses: Rosario, Argentina", International Renewable Energy Agency, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Dec/IRENA_Cities_2018c_Rosario.pdf.

ICLEI and IRENA (2013), "São Paulo, Brazil: Local government regulation: Ordinances and laws to promote renewable energy", International Renewable Energy Agency, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/Jan/IRENA-cities-case-1-Dezhou.pdf.

IEA (International Energy Agency) (2019), "How can district heating help decarbonise the heat sector by 2024?", IEA, Paris, www.iea.org/articles/how-can-district-heating-help-decarbonise-the-heat-sector-by-2024.

IEA (2018), *The Future of Cooling: Opportunities for Energy Efficient Air Conditioning*, IEA, Paris, www.iea.org/reports/the-future-of-cooling.

ILO (International Labour Organization) (2013), *Sustainable Development, Decent Work and Green Jobs*, ILO, Geneva, www.ilo.org/ilc/ILCSessions/previous-sessions/102/reports/reports-submitted/WCMS_207370/lang--en/index.htm.

IRENA (2021), *Renewable Energy Policies for Cities: Experiences in China, Uganda, and Costa Rica*, International Renewable Energy Agency , Abu Dhabi.

IRENA (2020), *Global Renewables Outlook, Edition 2020*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Apr/IRENA_Global_Renewables_Outlook_2020.pdf.

IRENA (2019), *Solar Simulators: Application to Developing Cities*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2019/Jan/Solar-simulators-Application-to-developing-cities#:~:text=Developing%20cities%20seeking%20to%20assess,sophistication%20of%20rooftop%20PV%20simulators.

IRENA (2016), *Renewable Energy in Cities*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2016/Oct/Renewable-Energy-in-Cities.

IRENA, IEA and Ren21 (Renewable Energy Policy Network for the 21st Century) (2020), *Renewable Energy Policies in a Time of Transition: Heating and Cooling*, www.irena.org/publications/2020/Nov/Renewable-energy-policies-in-a-time-of-transition-Heating-and-cooling.

IRENA Coalition for Action (2018), "Community energy: Broadening the ownership of renewables", International Renewable Energy Agency, Abu Dhabi, https://coalition.irena.org/-/media/Files/IRENA/Coalition-for-Action/Publication/Coalition-for-Action_Community-Energy_2018.pdf.

Kriele, V. (2015), "Brazil offers new green building credit terms", Solar Thermal World, 29 September, www.solarthermalworld.org/content/brazil-offers-new-green-building-credit-terms.

Nádor, A., A. Kujbus and A. Tóth (2019), "Geothermal energy use, country update for Hungary", presentation at European Geothermal Congress 2019, Den Haag, 11 14 June 2019.

NREL (National Renewable Energy Laboratory) (2012), *Solar Ready: An Overview of Implementation Practices*, NREL, Golden, CO, www.nrel.gov/docs/fy12osti/51296.pdf

Osava, M. (2019), "Solar energy crowns social housing programme in Brazil", IPS News, 4 January, www.ipsnews.net/2019/01/solar-energy-crowns-social-housing-programme-brazil/.

Osava, M. (2018), "Solar energy drives social development in Brazil's favelas", IPS News, 21 November, www.ipsnews.net/2018/11/solar-energy-drives-social-development-brazils-favelas/.

REN21 (Renewable Energy Policy Network for the 21st Century) (2020), *Renewables 2020: Global Status Report*, REN21 Secretariat, Paris, www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf.

REN21 (2019), *Renewables 2019: Global Status Report*, REN21 Secretariat, Paris, www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf.

REN21 (2018), *Renewables 2018: Global Status Report*, REN21 Secretariat, Paris, www.ren21.net/wp-content/uploads/2019/08/Full-Report-2018.pdf.

REN21 (2015), *Renewables 2015: Global Status Report*, REN21 Secretariat, Paris, www.ren21.net/wp-content/uploads/2019/05/GSR2015_Full-Report_English.pdf.

REN21, ISEP (Institute for Sustainable Energy Policies) and ICLEI (2011), *Global Status Report on Local Renewable Energy Policies*, www.ren21.net/wp-content/uploads/2019/06/REN21_Local_Renewables_Policies_2011.pdf.

Renewable Cities (2015), *Final Report: Global Learning Forum*, May 13 15, Vancouver, BC, www.renewablecities.ca/rc-wp/wp-content/uploads/Renewable-Cities-Global-Learning-Forum-Final-Report-1.pdf.

Renner, M. (2016), "Reducing the environmental footprint of buildings", in *State of the World: Can a City Be Sustainable? Worldwatch Institute (ed.)*, pp. 115 133, Island Press, Washington, DC.

Roberts, J., F. Bodman and R. Rybski (2014), *Community Power: Model Legal Frameworks for Citizen-Owned Renewable Energy*, ClientEarth, London, www.academia.edu/37019807/Community_Power_Model_Legal_Frameworks_for_Citizen_Owned_Renewable_Energy.

Sother (2019), "New Brazilian government has no appetite for solar", Solar Thermal World, 19 March, www.solarthermalworld.org/content/new-brazilian-government-has-no-appetite-solar.

Steer, A. (2018), "Q&A: What is the future of green building?" World Resources Institute blog, 4 June, www.wri.org/blog/2018/06/qa-what-future-green-building.

Tokyo Metropolitan Government and C40 Cities Climate Leadership Group (2014), "Chapter 4: Experiences from frontrunner cities", in *Urban Efficiency: A Global Survey of Building Energy Efficiency Policies in Cities*, Tokyo Metropolitan Government and C40 Cities Climate Leadership Group, Tokyo and New York.

UNEP (United Nations Environment Programme) (2020), *2020 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*, UNEP, Nairobi, https://globalabc.org/sites/default/files/2020-12/2020%20Buildings%20GSR_FULL%20REPORT_v2.pdf.

UNEP (2015), *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*, UNEP, Paris, http://wedocs.unep.org/bitstream/handle/20.500.11822/9317/-District_energy_in_cities_unlocking_the_potential_of_energy_efficiency_and_renewable_ene.pdf

USGBC (US Green Building Council), WGBC (World Green Building Council) and C40 Cities (2015), Green Building City Market Briefs, USGBC, Washington, DC.

Vierra, S. (2016), "Green building standards and certification systems", Whole Building Design Guide (WBDG), 9 December, www.wbdg.org/resources/green-building-standards-and-certification-systems.

Vorrath, S. (2018), "Solar installed on 500 public housing homes in Queensland, focus turns to rental market", One Step Off the Grid, 22 March, https://onestepoffthegrid.com.au/solar-rolled-500-public-housing-homes-queensland-focus-turns-rental-market/.

Weiss, W. and M. Spörk-Dür (2020), *Solar Heat Worldwide: Edition 2020*, IEA Solar Heating and Cooling Programme, Gleisdorf, Austria, https://iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2020.pdf.

WGBC (World Green Building Council) (2020), "The net zero carbon buildings commitment", www.worldgbc.org/thecommitment, accessed 29 November.

Young, R. (2014), "Global approaches: A comparison of building energy codes in 15 countries", in *American Council for an Energy-Efficient Economy (ACEEE) Proceedings: 2014 ACEEE Summer Study on Energy Efficiency in Buildings*, www.aceee.org/files/proceedings/2014/data/papers/3-606.pdf.

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