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REN21

Renewable Energy Policies in a Time of Transition

Heating and Cooling

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Renewable Energy Policies in a Time of Transition

Heating and Cooling

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.

Recognising the need for broad-based, holistic solutions, IRENA examines technologies, policies and regional priorities in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

As of November 2020, IRENA has 162 Members (161 States and the European Union) and 21 additional states in the accession process and actively engaged.

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ABOUT IEA

The International Energy Agency (IEA) is at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations and real-world solutions to help countries provide secure and sustainable energy for all. Taking an all-fuels, all-technologies approach, the IEA recommends policies that enhance the reliability, affordability and sustainability of energy. The IEA is supporting clean energy transitions all over the world in order to help achieve global sustainability goals. For more information visit:

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REN21

ABOUT REN21

REN21 is the only global community of renewable energy actors from science, academia, governments, NGOs and industry. We provide up-to-date facts, figures and peer-reviewed analysis of global developments in technology, policies and markets to decision-makers. Our goal: encourage and enable them to make the transition to renewable energy happen – now.

Our more than 2000 community members guide our co-operative work. They reflect the vast array of backgrounds and perspectives in society. As REN21's eyes and ears, they collect information and share intelligence, by sending input and feedback. REN21 takes all this information to better understand the current thinking around renewables and change norms. We also use this information to connect and grow the energy debate with non-energy players.

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FOREWORD

In recent years, significant progress has been made in clean energy transitions worldwide, especially through the growth of renewable energy in the power sector. However, transforming power mixes and reducing emissions from power generation is not in itself enough to reach sustainable energy goals.

Some 50% of the energy used globally today is for heat production, and this is responsible for 40% of energy-related greenhouse gas emissions, as well as intense levels of air pollution that threaten the environment and public health. At the same time, more than one third of the world's population still relies on the traditional use of biomass, kerosene or coal – mainly for cooking – with many negative socio-economic consequences.

Progress remains inadequate in the transition to a cleaner, more efficient energy system, in which renewables meet heating and cooling needs. This is in part because the renewable heat sector has not received as much policy attention as renewable electricity – attention that is needed to overcome current barriers. A major effort is needed to develop appropriate policies and put them into action, both to reduce emissions from heat use in industry and buildings and to widen access to clean and reliable energy.

Following successful collaboration on the joint publication *Renewable Energy Policies in a Time of Transition* in 2018, the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA) and the Renewable Energy Policy Network for the 21st Century (REN21) have joined forces again, this time to focus on the status and development of renewable heating and cooling policies. This new, in-depth report highlights the main opportunities, identifies barriers to progress, and specifies the instruments needed to promote the widespread adoption of relevant policies.

The report acknowledges the diversity and complexity of heating and cooling needs, from ensuring universal access to clean and reliable energy to providing heating and cooling in buildings, as well as supplying the high-temperature heat needed for industrial processes. Practical solutions involving renewables depend on many local factors, including climatic conditions, existing infrastructure such as district heating networks or gas grids, and available local renewable resources.

Clearly, there is no single or simple solution, and policy makers must tailor solutions to their specific circumstances. While national governments must lead the way, subnational and city authorities are also increasingly active in developing and promoting renewable heating and cooling solutions.

We hope the insights provided in this report on the future role of renewables in heating and cooling, for all end uses and in all contexts, will be of practical assistance to policy makers. For those seeking solutions, the policy portfolios outlined here could result in real advances in this essential aspect of the energy economy.

On behalf of our organisations, we would like to thank all those who provided reviews and comments on this analysis. We hope our joint effort strengthens efforts around the world and serves to promote the wider deployment of renewable energy for heating and cooling.

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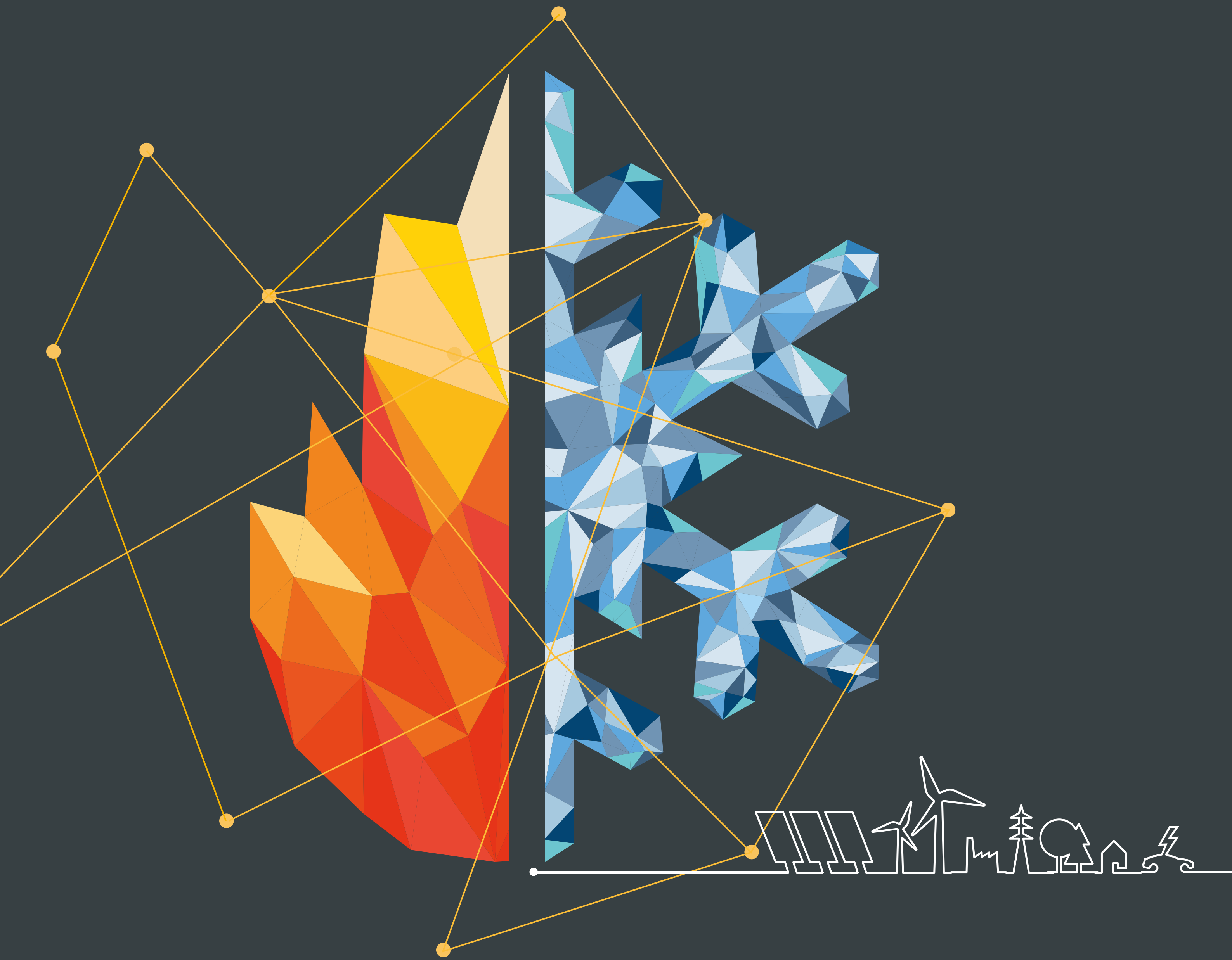


The need for efficient heating and cooling services based on renewable energy sources has emerged as an urgent priority for countries striving to fulfil their climate commitments under the 2015 Paris Agreement on Climate Change and to achieve the Sustainable Development Goals set for 2030. At the same time, the transition to cleaner, more sustainable heating and cooling solutions offers the prospect of attracting substantial amounts of investment, creating millions of new jobs and driving a durable economic recovery in the wake of the global Covid-19 crisis.

Heating and cooling demand accounts for around half of global final energy consumption. Of this, nearly 50% is consumed in industrial processes, while another 46% is used in residential and commercial buildings – for space and water heating and, to a lesser extent, for cooking. The remainder is used in agriculture, not only to heat greenhouses but also for drying, soil heating and aquaculture. Most of this energy comes either from fossil fuels or inefficient uses of biomass. Heating and cooling, consequently, is a major source of air pollution and accounts for over 40% of global energy-related CO_2 emissions.

The demand for heating and cooling is set to keep growing. Cooling demand has already tripled globally since 1990, and as climate change increases the number and severity of heat waves, the urgency increases for supplying air conditioning and refrigeration to billions of people.

A carefully managed energy transition is critical to make clean, affordable and reliable heating and cooling available to the people who currently lack access to such energy services. In Africa alone, providing households and smallholder farmers with proper cooling technologies could prevent the spoilage of USD 4 billion worth of food annually. The switch from fossil fuels and inefficient use of biomass to modern renewable sources would also bring major reductions in indoor and outdoor air pollution, reducing respiratory infections and avoidable mortality caused by air pollution.

Such a transition would create jobs, strengthen livelihoods, stimulate local production and create further socio-economic benefits, while strengthening countries' energy security and independence. Where power grids are lacking or access to energy is otherwise inadequate, renewables-based solutions can provide vital services, reduce the time spent (mainly by women and children) in collecting fuels, and enable productive economic activities. Renewables-based heating and cooling, similarly, can stimulate economic activity and strengthen people's livelihoods and welfare.

Despite these benefits, policy makers have so far given limited attention to the policies required to accelerate the transition of heating and cooling to renewables. At the end of 2019, only 49 countries – mostly within the European Union – had national targets for renewable heating and cooling, compared with 166 having goals for renewable power generation.

In addition, the number of countries that have adopted regulatory and financial policies for renewable heating and cooling has changed very little in recent years, except where local governments have adopted policies, often more ambitious than their national counterparts. As of mid-2019, thousands of city governments had adopted renewable energy targets and action plans globally, and more than 250 cities had reported at least one sectoral target for 100% renewable energy.

To decarbonise the energy used for heating and cooling, governments must implement comprehensive policy packages that prioritise efficiency and renewable energy while phasing out the use of fossil fuels. Urgent policy action is even more critical in the context of the Covid-19 pandemic, which has cut demand for heating and cooling services based on renewables and sapped the willingness of households and small businesses to invest in renewables-based solutions, while simultaneously worsening conditions for energy access in many developing countries.

This report highlights a portfolio of policies to increase the uptake of renewables in heating and cooling. It describes five transformation pathways – encompassing renewables-based electrification, renewable gases, sustainable biomass, and the direct use of solar thermal and geothermal heat – together with the enabling infrastructure required. In the course of analysing the barriers that stand in the way of each pathway, the report identifies and assesses the policy instruments that can be used to overcome those barriers and reap the enormous potential benefits of the transition.

There is no silver bullet. The combination of different policy instruments, options and technologies that works best in a given context will vary depending on local conditions, such as climatic conditions, whether necessary infrastructure (such as district heating networks or gas grids) already exists, and whether resources (such as a local supply of biomass or geothermal heat) are available. The renewable solutions chosen will also vary depending on specific applications, which range from heating and cooling buildings to providing high-temperature heat for industrial processes.

COMMON BARRIERS TO THE TRANSITION AND CROSS-CUTTING POLICIES TO ACHIEVE IT

Decarbonising heating and cooling is a complex and diverse task, given the wide range of possible approaches and the need to tailor solutions to many different locales. Yet some of the barriers to decarbonisation are widely shared – and these barriers can be overcome with policies that support all available options.

Chief among the common barriers are high upfront costs, regulatory and institutional frameworks based on fossil fuels, consumer inertia, and technical hurdles.

While renewable heating and cooling technologies often benefit from low operating costs, they are generally associated with **higher upfront costs compared with fossil fuel-based options**. For domestic heating systems, for example, the capital cost of a modern and efficient biomass boiler is USD 720–750 per kilowatt-thermal (kW_{th}), against USD 80–120/kW_{th} and USD 120–150/kW_{th} for a gas or oil boiler, respectively. While those costs are expected to decline over time owing to economies of scale and technological improvements, they still constitute a major economic hurdle to the development of renewable heating and cooling.

Government support in the form of **financial and fiscal incentives**, such as **tax credits, loans schemes, direct subsidies and accelerated depreciation** can be crucial in overcoming the barrier of high upfront cost. For example, Germany's Market Incentive Programme has dedicated EUR 300 million (about USD 360 million) per year in grants and loans for small-scale renewable heat systems like heat pumps, resulting in the installation of over 1.8 million systems between 2000 and 2020.

Mandates, such as Spain's requirement that solar water heaters be used in new government buildings, are highly effective policy tools. Governments can also help accelerate the energy transition by **setting specific targets** – for example, for the use of a precise share of renewables by a certain date,

for concrete emissions reductions for heating and cooling, and for net-zero emissions by sector or economy-wide. Near the end of 2020, more than 12 countries and the European Union had passed or proposed laws around net-zero emissions. Such targets demonstrate national commitments to the deployment and development of renewables and provide certainty for investors and consumers.

Another major barrier is **the end-user price advantage that fossil fuels still hold over renewable alternatives** because of a long history of favourable subsidies and energy regulatory frameworks. Direct and indirect subsidies were estimated to exceed 19 times the support provided for renewables, which came to approximately USD 166 billion in 2017.

The use of fossil fuels has environmental and social costs that are not included in the current price of those fuels. These so-called **negative externalities** include health costs caused by air pollution and damage from the growing impacts of climate change.

A crucial first step towards realising the energy transition is therefore **levelling the playing field** by phasing out subsidies for fossil fuels and introducing fiscal policies such as carbon taxes or emissions trading systems. However, such interventions should be preceded by a careful assessment to ensure that they will not aggravate energy poverty among low-income households or have other socially regressive effects. Dedicated support can be provided for low-income consumers or other highly affected segments of society to help them shift towards low-carbon heating and cooling solutions.

Other common barriers include **consumer inertia and lack of awareness** about the efficient, renewables-based solutions available, their effectiveness and their benefits. **Information campaigns** are a vital tool to fight inertia and raise awareness. Furthermore, the **development of reliable supply chains** for renewable fuels, such as sustainable biomass from agricultural residue, and **related infrastructure**, such as district heating and cooling networks, can in many cases be accelerated by streamlining permitting processes and making direct investments.

Technical hurdles remain in some areas, including some industrial applications in which requirements for stable flows of high-grade heat are difficult to meet with some existing renewable solutions. Support for **research and development**, and for pilot and demonstration projects, has a key role to play in enlarging the field of application of renewable technologies.

Critical conditions for the uptake of renewable heating and cooling in buildings and industrial processes are **energy efficiency policies** such as stricter building codes, support for building retrofits, and appliance standards. Most are cost-efficient in the medium term and can improve the cost-competitiveness of renewable heating and cooling applications. The Scandinavian countries have coupled the shift to renewable heat with high energy efficiency standards in new buildings using building code requirements.

Tackling all the common barriers in addition to those related to specific pathways will require a conducive institutional structure built on **strong coordination** among sectors (*e.g.* power and heat) and different level of governance (*e.g.* national and city level).

TRANSFORMATION PATHWAYS

This report identifies five transition pathways and focuses on district heating and cooling as a key enabling infrastructure towards efficient and renewable heating and cooling. It describes those pathways, their benefits and challenges, and analyses the policies needed to address those challenges. The pathways are 1) renewables-based electrification; 2) renewable gases; 3) sustainable use of biomass; 4) direct use of solar thermal heat; 5) direct use of geothermal heat. The report also analyses the policies needed to develop the enabling infrastructure which is key to achieving all pathways.

RENEWABLES-BASED ELECTRIFICATION

Switching from fossil fuels to efficient electric technologies powered by renewable electricity, such as heat pumps and electric appliances for buildings, electrified heating and cooling technologies in industry, and decentralised electrification technologies for productive uses, has substantial potential to reduce greenhouse gas emissions. Needless to say, efforts to switch to efficient electric appliances must be coordinated with the decarbonisation of the power sector.

Currently, heat pumps satisfy a minor share of residential heat demand – around 5% in 2019. Multiplying that share rapidly is one of the most effective strategies for reducing greenhouse gas emissions in buildings. Policies that can effectively accelerate their uptake include **fiscal and financial measures** such as loans, grants and subsidies. To switch from coal-fired boilers to heat pumps, China provided government subsidies equal to around 10% of the retail price of heat pumps, depending on their rated heating capacity and efficiency. As a result, over half million heat pumps were sold in 2018. Industry also presents large opportunities for electrification, with competitive applications already available in the food and beverage and textile industries. Heat pumps can also be combined with solar thermal preheating (as in some district heat networks in Denmark) or waste-heat recovery to further boost efficiency and reduce costs.

Additional reductions could come from switching to highly efficient electric cookstoves and other appliances. This can be supported by **minimum energy performance standards**.

Although widespread electrification of heating and cooling could significantly increase overall demand for electricity, it also holds out the potential to provide flexibility to the electricity system through improvements in demand response,[1] thereby facilitating the integration of higher shares of variable renewable energy – such as solar photovoltaic and wind – into the power generation mix. Thermal storage offers the possibility to shift heat-related electricity demand in time and adapt to the variability of electricity supply.

Yet exploiting this potential requires **proactive policies favouring demand response**. These may include measures to **upgrade power networks** through the deployment of remote monitoring and control technologies and to establish aggregators and dedicated flexibility products in the power market. In addition, time of use tariffs can assist users to match their demand to system needs and lower the costs.

In the off-grid and weak-grid contexts, there is a need to **coordinate plans** for decentralised heating and cooling with rural electrification plans and policies to ensure that all are implemented synergistically. Coordination measures should be part of a broader development plan to ensure that the deployment of technologies supports socio-economic development goals. Among the measures needed are **regulations, fiscal incentives, donor-sponsored research and development, roll-out programs to increase economies of scale, policies to facilitate financing, minimum energy performance standards, appliance labels, public awareness campaigns, user training and manuals, and consumer-financing models.**

Such policies hold the potential to provide considerable health benefits. These can be achieved through access to clean cooking technologies, but also through food conservation applications in agriculture. For instance, heat from electric technologies powered by off-grid renewables can be used to pasteurise milk, dry foods, sterilise crops to reduce post-harvest losses from contamination and spoilage, and help smallholder farmers transform raw produce into more valuable products.

1 Heat pumps and other electric technologies can be rapidly ramped up and down in response to changes in the electricity supply, especially in the presence of thermal storage.

RENEWABLE GASES

Since not all heating and cooling end uses can be electrified at a competitive cost, there is a role for renewable gases such as green hydrogen, biogas and biomethane to replace fossil gases. Renewable gases can often take advantage of extensive existing networks and infrastructure built for fossil gas, reducing the overall costs of the transition. Many countries are already injecting biomethane into their gas grids, and a few have begun to explore blending hydrogen into the gas grid or upgrading it to increase future compliance.

In addition to avoiding carbon emissions from fossil fuel use and methane emissions from the organic decomposition of waste, renewable gases offer several potential advantages. These include enhancing the flexibility of the energy system, since they can be produced during periods of high renewable resource supply and then stored for later use. Green hydrogen production with electrolysis, for example, could help integrate higher shares of variable renewable energy into the electricity grid.

Biogas and biomethane can also deliver environmental benefits such as lowering groundwater pollution. In Nairobi, Kenya, for example, some poultry farmers are using biogas digesters and chicken manure to produce fuel for heating and to improve their waste management. When produced locally, renewable gases can contribute to energy security for countries that do not have fossil-fuel resources.

Concerns remain about the feasibility and safety of injecting large quantities of renewable gases into existing infrastructure. However, high production costs are the primary challenge in the short term.

To increase the use of renewable gases for heating and cooling, this report recommends **establishing ambitious, clear and long-term frameworks** for the development of a renewable gas industry and related markets. Such frameworks can include **roadmaps, industrial strategies and specific targets**. France, for instance, has set a target to make 10% of the gas consumed in the country renewable by 2030; Denmark aims to make 100% of the gas injected into its grid renewable by 2035.

Other possible policies to help create markets for renewable gas products include **low-carbon fuel standards** to require greater use of renewable gas; direct investment support and production subsidies to lower costs; **thorough assessments of gas transmission pipelines** to determine whether they can be used for hydrogen; **new regulatory frameworks**; and **mechanisms for certifying the emissions reductions** from renewable gas.

SUSTAINABLE USE OF BIOMASS

Bioenergy, which presently is the largest renewable source of energy for heating, provided 21% of global heat consumption in 2018. Two-thirds of that, however, came from inefficient uses of biomass, such as wood, crop residues, and animal dung for cooking and heating in areas that lack access to energy. Such uses are typically associated with deforestation, as well as indoor air pollution and drudgery, which disproportionately affect women and children.

The transition to a more efficient use of biomass would include the adoption of improved cookstoves and modern biofuels.

Many countries are already implementing policies to increase the sustainable use of biomass. A number of Sub-Saharan countries, including Ethiopia, Ghana, Malawi, Nigeria, Rwanda, Senegal and Uganda, are launching or scaling up **national cookstove programmes**, supported by development finance. Similarly, the West African Clean Cooking Alliance aims to provide clean, efficient and affordable cooking stoves and fuels (*e.g.*, pellets or briquettes or alcohol fuels) to all citizens in the Economic Community of West African States by 2030. Cleaner cooking alternatives can also be encouraged **through loans, micro-finance and pay-as-you-go business models** for cookstove equipment and renewable fuels.

At the same time, **standards, certification and testing** play a key role in ensuring that clean cooking solutions satisfy user needs, meet air quality standards and are backed by sustainable fuel supply chains.

Certification schemes are equally important in the wider energy access context, where bioenergy can be used for heat in buildings – including through district heating systems – and for industrial processes. Such supportive policy and regulatory regimes are essential to ensure reliable and consistent supplies of biomass feedstock and avoid possible negative environmental consequences from increasing biomass exploitation. Bioenergy certification schemes are often aligned with systems already in place in other bio-based industries, such as those of the Forest Stewardship Council and the Sustainable Forest Initiative. Moreover, **financial incentives** can help overcome the higher capital costs of modern and efficient biomass boilers compared with gas or oil boilers. France's *Fonds Chaleur* (Heat Fund), for example, offers subsidies for residential, commercial and industrial renewable heat, including small-scale biomass applications.

Overall, this report emphasises the need for a consistent and long-term policy approach to bioenergy within a larger renewable energy and low-carbon strategy. These elements are needed to provide the confidence to investors and project developers.

DIRECT USE OF SOLAR THERMAL HEAT

Energy from the sun can be used directly for space and water heating, industrial processes, food drying, and wastewater treatment, among other uses. When solar collectors are paired with absorption or adsorption chillers, solar energy also can be used for cooling.

Solar water heating systems in single-family houses and multifamily buildings represent the largest use of solar thermal heat (almost 90% of the total capacity in 2018) while district heating networks (led by Denmark), industrial processes and space heating and cooling represented only 4% of the installed capacity.

Solar thermal has vast potential for air conditioning, since the greatest demand for cooling coincides with the highest solar potential. The use of solar thermal for cooling and industrial processes requires **support for research and demonstration projects** to overcome technical barriers.

Although solar thermal systems can be highly cost-competitive on a life-cycle basis, depending on the region and application, most systems come with **high upfront costs**. Effective supporting policies include fiscal and financial incentives such as loans, grants, tax credits or subsidies, combined with **targets, mandates** and **building codes** to increase the size of the market. Denmark, for example, has used tax incentives to help build large-scale solar thermal district heating plants. In Rwanda, grants and loans provided by the SolaRwanda programme led to more than 3 000 solar water heaters being installed in homes by 2018.

Public awareness efforts, like South Africa's Solar Water Heater Campaign, can increase consumers' knowledge about available solar thermal solutions and their benefits.

Solar water heaters can substantially reduce energy bills while creating local jobs and industries. In 2018, the solar water heater industry accounted for more than 810 000 jobs. Manufacturing and installing solar water heaters for 10 000 single-family households, for example, requires 41 280 and 130–560 person-days, respectively, and the skills needed are readily available in any country's workforce, being easily acquired by practitioners of other trades, such as plumbers and electricians.

DIRECT USE OF GEOTHERMAL HEAT

The thermal energy stored in rocks and and in water trapped under the surface of the earth can be tapped for a wide range of uses, from space heating and cooling to aquaculture and other commercial and industrial processes.

So far, much of the potential has yet to be realised. Geothermal energy is currently the smallest renewable heat source, with around 30 gigawatts of total capacity. Of that, 75% was in just four countries – China, Iceland, Japan and Turkey. About 44% of the total thermal use in 2019 was for bathing and swimming.

That use could increase significantly if obstacles can be overcome. Chief among those obstacles are high upfront investment costs, uncertainties about the size and best locations of geothermal resources (resulting in high exploration and well-drilling risks), and inadequate policy and regulatory frameworks.

Government initiatives and plans to **encourage the collection and sharing of detailed and comprehensive data** on geothermal resources could help attract investors, as could **loan guarantees, grants, and direct support for demonstration projects**.

Support for the use of geothermal energy in agriculture can bring important socio-economic benefits. Amongst recent examples, a geothermal grain dryer installed in Kenya in 2019 cut farmer's drying costs by more than half.

ENABLING INFRASTRUCTURE

The capacity of district heating and cooling networks to allow large-scale penetration of renewable sources makes them a key asset for most of the pathways discussed in this report. These systems combine one or more sources of heat with networks of pipes that deliver hot or cold fluids to a residential block, a neighbourhood, a district or even an entire city. District heating and cooling offers greater efficiencies and fuel savings than most decentralised systems, particularly in dense urban areas. As a result, they are expected to play a fundamental role in the wider energy transition.

So far, most district heating networks have run on fossil fuels (often linked to coal- or gas-fuelled power plants), but a growing number are integrating some renewable energy such as biomass, especially in Estonia, Finland, Latvia and Sweden. In most cases the fuel switch has been driven by policy.

Policies therefore have a key role to play both in the deployment of new district infrastructure and in the greater use of renewable energy in existing district networks. These policies, which can be designed and implemented at the national or subnational levels, include **heat mapping** and **connection mandates** to reduce investment uncertainty; **targets for renewable integration;** loan **guarantees** to minimise risks for potential investors; **concessional finance** from multilateral development banks where local financing is difficult to obtain; and **subsidies, grants or tax credits** to offset the high capital costs. One example is the German CHP Act of 2016, which offers subsidies based on the length and diameter of district heating pipes; the legislation has already led to significant investments in new and existing systems. Through **urban planning**, governments can also synchronise the deployment of piping networks with transport construction to cut costs and minimise the disruption of traffic.

District networks can often create a situation of natural monopoly. In such cases, **regulated tariffs, transparent pricing and oversight of competition** may be needed to preserve consumers' confidence.

CALL TO ACTION

Deployment policies must go hand in hand with integrating and enabling policies for renewables heating and cooling. Just as for overall energy use, a well-balanced policy package will allow countries to overcome barriers and maximise the socio-economic footprint of the transition.

- Renewable heating and cooling requires proactive policies – both to level the playing field and keep costs competitive, as well as maximise the social, economic, environmental and other benefits.
- Measures to scale up renewable heating and cooling can and should be aligned with broad socio-economic policies and objectives. These can include improving conditions for vulnerable segments of the population, developing key economic sectors, setting long-term energy plans, and pursuing international climate and sustainability goals.
- Long-standing networks for district heating and cooling can be adapted to accommodate growing shares of renewable energy.

The planet's future depends on the transformative decarbonisation of societies, which, in turn, depends on the use of clean, sustainable, renewable energy to meet the heating and cooling needs of the world's population. Solutions are ready for the taking, as are the promised rewards. What has been lacking, however, are the political will and comprehensive planning for the long haul.

The need for action is clear and urgent. Governments, civil society, consumers, research institutions and the private sector must come together to trigger the change.

01

In context: Renewable heating and cooling

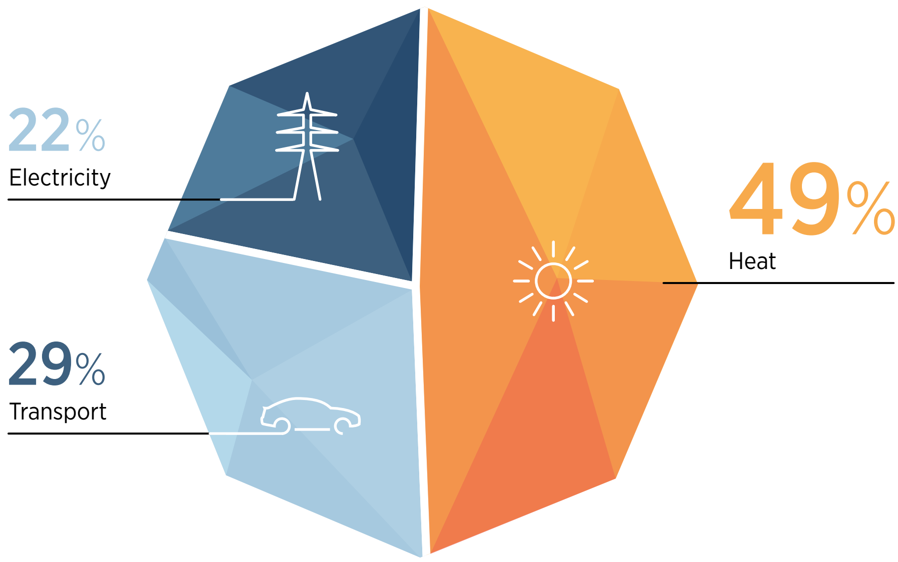
Reducing the use of fossil energy for heating and cooling remains one of the biggest challenges of the energy transition. Heating and cooling needs – including those for space heating and cooling in buildings, domestic hot water, cooking, industrial process heat, and agriculture – account for the largest share of global final energy consumption (Figure 1.1) and more than 40% of global energy-related carbon dioxide (CO_2) emissions (IEA, 2019a). Transforming the energy uses for heating and cooling is a crucial step toward meeting global goals for decarbonisation, among other key environmental and development objectives.

Improvements in energy efficiency are one important strategy for slowing demand growth and mitigating the sector's negative effects on health, the economy and the environment. Energy efficiency measures such as building codes and appliance standards often are cost-effective options for decreasing the thermal demand of buildings and industrial processes. Lowering energy demand addresses only part of the problem, however, and is not enough by itself to reduce greenhouse gas (GHG) emissions and meet the goals for sustainable development and access to energy.

Alongside efficiency, renewable energy will play a fundamental role in decarbonising the energy used for heating and cooling. Renewables have grown rapidly in recent years, having repeatedly broken annual records for newly installed power capacity and continually increasing their share in electricity generation (IRENA, n.d.). In the early stages of the Covid-19 crisis, generation of renewable electricity continued its growth, reaching record penetration in some countries despite an overall drop in electricity demand. However, modern renewable energy[1] still supplies only a small share of final demand, mainly in the power sector.

Despite its potential for advancing the energy transition, the use of energy for heating and cooling has received relatively little attention from policy makers. The objective of this report is to identify and assess policy instruments capable of addressing key barriers to the expanded use of renewable energy to meet heating and cooling needs around the world.

Figure 1.1 Total final energy consumption, by final energy use, 2018



Source: IEA, 2020a; IEA, 2020b.

Note: Consistent with statistical conventions and current data availability, the category "heat" includes electricity used for heating. The category "electricity" includes electricity used for cooling.

1 Modern sources of renewable heating and cooling include direct renewables such as sustainable bioenergy, geothermal and solar thermal heat, as well as renewable electricity (*e.g.*, via heat pumps) and renewable district heating and cooling.

1.1. THE ENERGY LANDSCAPE

Energy used for purposes of heating and cooling[2] accounts for around 50% of total final energy consumption. Of this, around half is consumed in industrial processes, while another 46% is used in residential and commercial buildings – for space and water heating and, to a lesser extent, for cooking. The remainder is used in agriculture, not only to heat greenhouses but also for drying, soil heating, and aquaculture (IEA, 2019b).

Heat demand varies by region mainly due to climatic factors but also to levels of economic development. The majority of final demand in most countries of the Organisation for Economic Co-operation and Development (OECD) stems from residential space and water heating, while in developing and emerging economies most heat is used in industrial processes. On a national level, China accounts for a quarter of global heat demand, some 70% of which is used in industrial processes (IEA, 2019c).

The energy-intensive industrial processes that account for the greatest heat demand are iron and steel manufacturing, cement production, and chemical manufacturing. These processes also have the lowest shares of heat from renewable sources and can be particularly difficult to decarbonise, because in some cases technological advancements will be required if renewable energy is to supply process heat at the required high temperatures (IEA, 2019d). Renewable heat (mainly from bioenergy) commands its highest shares in low-temperature processes such as pulp and paper, wood products, and food and tobacco (REN21, 2020).

In the buildings sector, heating and cooling dominate energy use at more than three-quarters of total demand (IEA, 2019c). Globally, energy use in buildings has continued to rise as square footage and population outstrip advances in energy efficiency (GlobalABC, IEA and UNEP, 2019).

As a result, the share of renewable heating and cooling in buildings has increased only marginally in recent years (REN21, 2020).

Cooling demand is climbing sharply each year, having tripled globally since 1990. It is increasing most rapidly in developing and emerging economies (notably in Southeast Asia), driven by expanding wealth and population, changing lifestyles, and extreme weather patterns (*e.g.* higher temperatures) caused by climate change (IEA, 2018a, 2019e). Space cooling accounted for 8.5% of total final electricity demand in 2019. As the fastest-growing energy use in buildings, it is the leading driver of electricity consumption in heating and cooling (IEA, 2020c).

As global demand for thermal energy rises, around 40% of the world's population (2.8 billion people) still lack access to modern cooking facilities, relying instead on the traditional use of biomass, kerosene or coal (IEA, IRENA, UNSD, World Bank and WHO, 2020). The traditional use of biomass,[3] which usually has negative health, socio-economic and environmental consequences, still dominates cooking practices in the rural and peri-urban, developing regions of sub-Saharan Africa and South Asia, where open-fire cookstoves are common.

In addition, 789 million people still live without electricity (IEA, IRENA, UNSD, World Bank and WHO, 2020). Even where electricity is available, some remote, rural populations still have difficulty acquiring cooling appliances, which are either unaffordable or unavailable. More than 1 billion impoverished rural and urban residents of 54 of the most vulnerable countries face risks related to lack of access to cooling solutions. The health effects of this lack include sickness from consumption of contaminated food, broken cold chains leading to loss of vaccines and medicine and suffering from extreme heat waves (Sustainable Energy for All, 2020).

2 "Heating and cooling" in this report refers to applications of thermal energy, including space and water heating, space cooling, refrigeration, drying, and heat produced in the industrial process. It includes the use of electricity for heating and cooling.

3 The term "traditional use of biomass" refers to the use of local solid biofuels (wood, charcoal, agricultural residues, and animal dung) burned with basic techniques, such as traditional open cookstoves and fireplaces.

BOX 1.1. ENSURING UNIVERSAL ACCESS TO ELECTRICITY AND CLEAN COOKING

Sustainable Development Goal (SDG) 7.1 focuses on universal access to affordable, reliable, sustainable and modern energy services. The two objectives of SDG 7.1 are access to electricity and access to clean cooking solutions. In recent years, progress has been made in providing electricity, as the global population lacking access to it dropped from 1.2 billion in 2010 to 789 million in 2018 (IEA, IRENA, UNSD, World Bank and WHO, 2020). Growth in access to electricity, however (at 0.80 percentage points per year over the period), fell short of the increase needed (0.87 percentage points) to reach universal access by 2030. Furthermore, as a result of the Covid-19 pandemic, the number of people without access to electricity in sub-Saharan Africa was expected to rise in 2020 (IEA, 2020b).

Meanwhile, progress has stalled in achieving universal access to clean cooking. The global population lacking safe and modern cooking appliances has remained largely unchanged over the past two decades, settling at nearly 3 billion people in 2018 (IEA, IRENA, UNSD, World Bank and WHO, 2020). In some countries, the rate of access to clean cooking has been outstripped by population growth, contributing to a global slowdown in the race to universal access. Over the period 2010-18, access to clean cooking grew by just 0.7-0.8 percentage points per year, far below the required 3 percentage points needed to achieve universal access by 2030.

Several organisations are supporting the development of national policy frameworks for clean cooking and heating (*e.g.* the Clean Cooking Alliance). But according to the World Bank's 2018 report on Regulatory Indicators for Sustainable Energy, most national clean cooking policies place a stronger emphasis on solutions based on solid fuels than on those powered by electricity or liquid/gaseous fuels. This is in part due to the lack of access to electricity and liquid/gaseous fuels and the comparatively lower cost of solid fuels. This highlights the need to align clean cooking policies with long-term decarbonisation objectives and to avoid perpetuating carbon dependency.

Many pathways for widening access to clean cooking, cooling and heating technologies focus on *slightly* cleaner or *slightly* more efficient options (*e.g.* more efficient cookstoves, shifting from charcoal to liquefied natural gas or promoting more efficient air conditioning).

However, if off-grid policies and subsidies are to be brought into alignment with the deep decarbonisation pathways demanded by the 2015 Paris Agreement on Climate Change, clean cooking, cooling and heating will require more than gradual improvements. By focusing their support on what seem today to be more efficient uses of charcoal, electricity, and other forms of energy, policy makers may reach short-term objectives at the cost of perpetuating dependencies that will become a barrier to the long-term transformation of the energy system. Therefore, it will be crucial to ramp up support for research and development on zero-carbon technologies and further technological innovations in the off-grid sector.

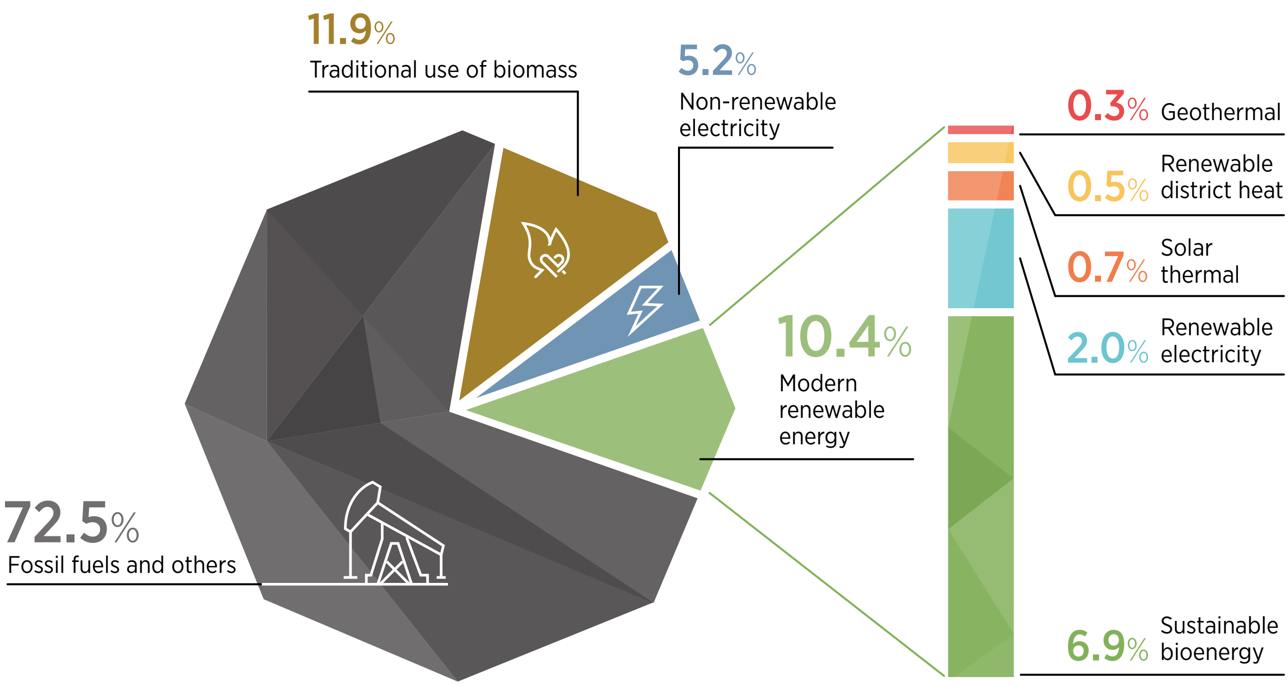
The recent annual review of SDG 7 underlined that objectives for energy access, energy efficiency and renewable energy will not be met unless policy attention is dramatically increased. This includes high-level political commitment, ambitious national and local strategies, mobilised investment, and policy frameworks that support the rapid deployment of distributed renewables to expand access to energy.

Most of the energy used for heating and cooling continues to be produced from fossil fuels (Figure 1.2). In 2019, fossil fuels and non-renewable electricity met more than 77% of heating and cooling demand, with the traditional use of biomass meeting 11.9% (IEA, 2020a, 2020b).

In recent years, the use of modern renewables to meet heating and cooling needs has remained limited to some 10% of global demand. The direct use of modern renewables – including sustainable bioenergy, solar thermal and geothermal heat – met 8% of demand for heat and cooling, with renewable electricity accounting for an additional 2% (IEA, 2019c).[4] Electricity supplied most of the cooling needs through residential air conditioning appliances and district cooling systems.

The weight of heating and cooling needs in final energy demand means that the rapid decarbonisation of the energy used to meet those needs is critical for the achievement of climate, environmental and sustainable development goals. Despite this reality, energy use for heating and cooling has continued to rise and remains largely based on fossil fuels. As a result of the Covid-19 crisis, renewable heat consumption for 2020 is expected to show a drop of 0.4% from its 2019 level, as industrial and commercial activity has been dramatically reduced (IEA, 2020d). The need is urgent, then, to reduce and even reverse growth in energy demand for heating and cooling, while rapidly scaling up the deployment of renewables. Although the climate crisis is the most commonly cited argument for deploying renewable energy for heating and cooling, there are many other complementary reasons to do so.

Figure 1.2 Share of energy sources in total final energy consumption for heating and cooling, 2019



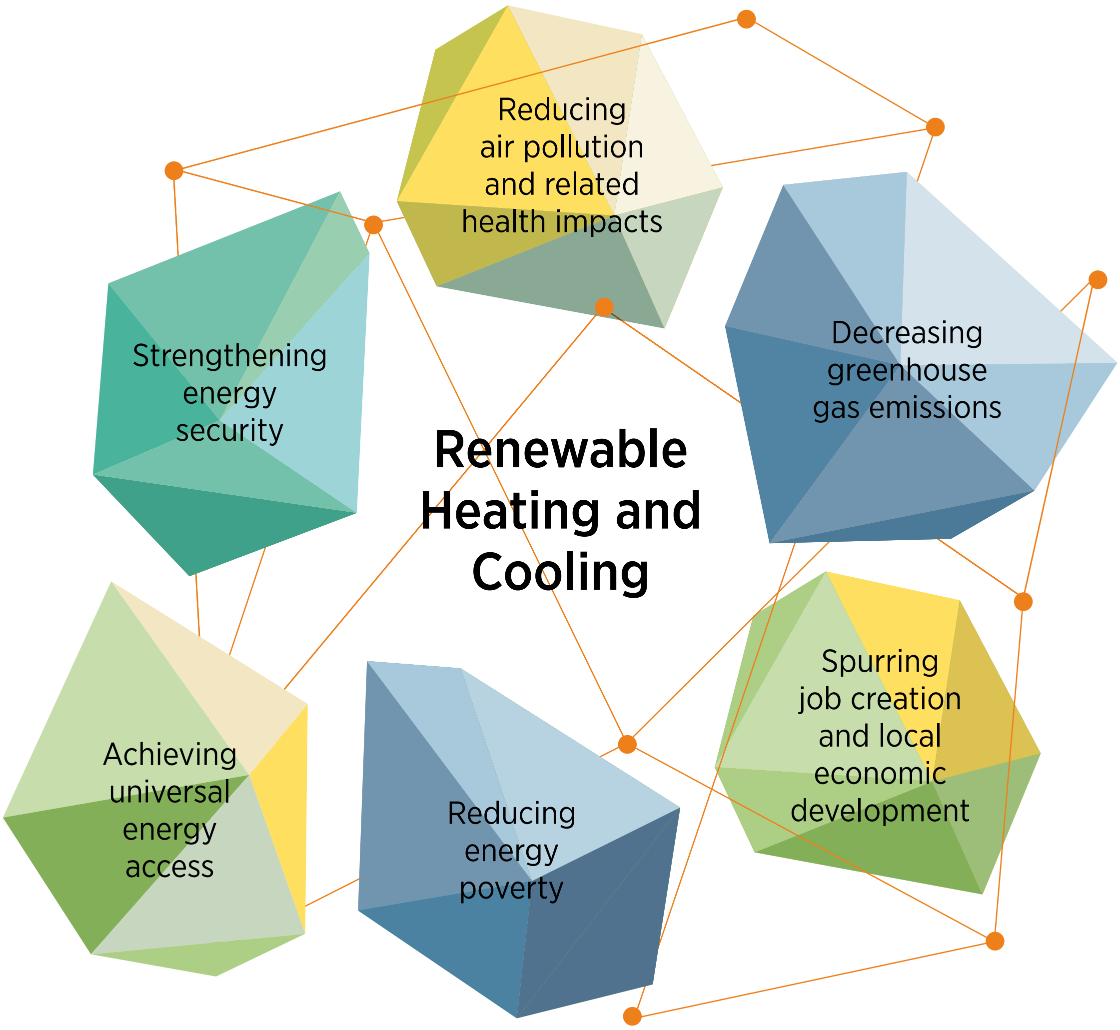
Source: IEA, 2020a, 2020b.

4 Bioenergy is considered to be sustainable when its use reduces greenhouse gas emissions compared with the use of fossil fuels in similar applications, and when its use avoids significant negative environmental and social-economic impacts (REN21, 2019). Sustainable bioenergy is also distinguished from the traditional use of biomass. Consumption of renewable electricity for heating and cooling is estimated based on electricity consumed for heating and cooling uses and on the national annual average share of renewables in electricity generation.

1.2. THE BENEFITS OF RENEWABLES IN HEATING AND COOLING

A number of objectives are driving the transformation of heating and cooling. These include efforts to reduce air pollution and its health impacts, decrease GHG emissions to meet climate goals, improve energy access and address energy poverty, and increase energy security (Figure 1.3). Renewables also help maximise socio-economic benefits, which leads to local economic development and jobs (REN21, 2019). While the relative importance of the drivers is the convergence and mutual benefit of such diverse objectives underlines the far-reaching potential of renewables in heating and cooling.

Figure 1.3 Benefits of deploying renewable heating and cooling



Reducing air pollution and related health impacts. The contribution of heating and cooling to air pollution is primarily associated with burning fossil fuels and biomass (inefficiently) for heating and cooking. In 2018, around 91% of urban dwellers worldwide were regularly exposed to air pollution. Although a portion of this pollution is particulate emissions from the transport sector, a significant contributor is the use of fossil fuels for heating and cooling (REN21, 2019). Coal combustion, for example, can emit numerous toxic gases, including sulphur dioxide, nitrogen oxides and particulate matter into the air, and coal still accounts for a substantial share of heat production for district heating in China, Poland, Russia, Kazakhstan, and other Eastern European and Eurasian states where it is cheap and readily available.

Air pollution has significant negative consequences for public health. It can cause respiratory infections, pulmonary disease, and higher mortality rates overall. The World Health Organization estimates that every year, some 3.8 million deaths are attributable to indoor air pollution, mainly from burning biomass inside, affecting mostly women and children; another 4.2 million deaths are from ambient air pollution through exposure to fine particulate matter (WHO, 2020). Household air pollution from traditional cookstoves is linked to 4 million premature deaths annually in developing and emerging economies, also disproportionately affecting women and children (IEA, IRENA, UNSD, World Bank and WHO, 2020).

Decreasing GHG emissions. Heating and cooling accounted for 40% (13.2 $GtCO_2$) of energy-related CO_2 emissions worldwide in 2018 (IEA, 2019a), a share that has remained almost unchanged for the past decade, owing to the continued dominance of fossil fuels (IRENA, 2020a).

Along with improvements in energy efficiency and energy sufficiency behaviours,[5] shifting to modern renewable energy sources is key to mitigating climate change and limiting the rise in global temperatures, as stipulated under the 2015 Paris Agreement on Climate Change and the Sustainable Development Goals.

Expanding access to energy. Renewable energy facilitates access to energy for various forms of heating and cooling. For example, it can play an important role in providing access to safe, modern cooking facilities – a significant end use in developing countries – and thus improve health. In 2018, around 125 million people used biogas for cooking, primarily in China and India, and demand for biogas cookstoves has increased in other Asian countries such as Bangladesh, Nepal and Viet Nam (REN21, 2020). In addition, electric cookstoves in remote areas are becoming an increasingly cost-competitive option (Couture and Jacobs, 2019).

In other uses, such as agriculture, distributed renewables can provide access to various heating and cooling applications, including crop drying, refrigeration and cold chains. This access can improve both incomes and food security by increasing agricultural productivity and reducing food waste (IRENA, 2016a).

Reducing energy poverty. Energy poverty covers a broad spectrum of negative effects on well-being traceable to insufficient access to modern energy technologies. A household struggling with energy poverty is unable to secure a level and quality of domestic energy services sufficient to meet its basic needs in a given socioeconomic context. In the heating and cooling context, an example of energy poverty would be a household that is unable to afford sufficient heating and cooling services, such as hot water or adequate heat for its living space. Situations of energy poverty are usually accompanied by the use of fossil fuels or traditional use of biomass (with household members spending hours each day collecting fuel) and limits on the use of some parts of the home during cold periods (IRENA, 2019a).

Coupled with demand-side energy efficiency improvements in the overall building stock, the deployment of renewables can lower customers' utility bills, thereby lessening energy poverty. For example, solar water heaters can provide affordable household heating while reducing indoor air pollution.

Strengthening energy security. Renewable energy can improve countries' energy security and energy independence by diversifying the mix of fuels and infrastructure in use and reducing dependence on imports (Cox, Beshilas and Hotchkiss, 2019; IRENA, 2019b). Fossil fuels are vulnerable to potential global supply chain disruptions, whereas renewables can have simpler regional supply chains or, depending on the technology, no fuel supply chain at all (*e.g.* in the case of solar thermal).

Countries with diminishing fossil fuel resources can pre-emptively replace existing infrastructure with renewable energy to reduce domestic demand and mitigate increases in future imports. The Netherlands, which became a net importer of natural gas for the first time in 2019 after a stark drop in production in 2013, made plans to increase the share of renewables used in heating and cooling; similar steps have been taken elsewhere in the European Union and in China (European Commission, 2018; State Council of China, 2014).

Spurring job creation and local economic development. Renewable energy uptake offers socio-economic benefits such as more local jobs and welfare improvements (IRENA, 2020a). The sector accounted for 11.5 million jobs[6] worldwide in 2019 – and could reach 42 million by 2050 – with more than 823 000 people employed in solar heating and cooling in 2019, and 764 000 in solid biomass (IRENA, 2020b). Furthermore, energy efficiency measures in buildings and the manufacturing of certain renewable energy technologies are responsible for some of the highest rates of jobs per unit of investment and spending (IEA, 2020e).

5 Energy sufficiency implies changes in the ways energy is used; it corresponds to the action of tailoring energy-related infrastructure, technology choices and behaviours to fundamental needs, in order to allow access to energy for all while keeping the impacts of energy use within environmental limits.

6 The employment figures include direct and indirect jobs in 2019, including 3.75 million for solar photovoltaic, 3.58 million for bioenergy, 1.96 million for hydropower, 1.17 million for wind energy, 0.82 million for solar heating or cooling, and 0.18 million for geothermal, concentrated solar power, ground source heat pumps, ocean energy and others.

1.3. BARRIERS TO RENEWABLE HEATING AND COOLING UPTAKE

Numerous barriers slow down the transition of renewable heating and cooling. They relate to political and institutional frameworks, the absence of a level playing field with fossil heating fuels, high upfront costs of some renewable heating and cooling technologies, technical challenges, weak supply chains, and lack of awareness about the benefits and potential of renewable energy technologies (Figure 1.4).

Political and institutional barriers lie at the heart of the slow transition. The commitments made in the Paris Agreement are seldom translated into concrete action; when they are, they do not cover all end uses. This is especially true for the access context, where international political commitments to ensuring clean, affordable and reliable access to energy are still lacking. The absence of credible long-term policy signals ultimately reduces the willingness of consumers and investors to make upfront investments for fear that future payoffs will not materialise.

In other words, inconsistent, competing and unclear policies further reduce consumer willingness to invest in renewable heating and cooling technologies. To date, countries with a high share of renewable energy in their heat supply have generally set ambitious, proactive policies to achieve this goal – or they have a high natural resource endowment, such as Sweden and Iceland. Those with a lower share typically have not yet prioritised renewable heating and cooling (IEA, 2018b), or they have chosen to develop their abundant fossil fuel resources instead of renewables (*e.g.* the United Kingdom).

In addition, when it comes to institutional structures, heat markets are complex, fragmented and poorly understood, which can be challenging for effective policy making and monitoring. On the supply side, many different space and water heating options are on offer, with numerous actors involved, from large multinational heating equipment manufacturers to small local installers. Renewable heat faces multiple barriers to participate in these markets, which are not always open to competition. The lack of institutional structure also restricts the gathering of data and statistics, as such information does not fall under the jurisdiction of a single responsible body.

Figure 1.4 Barriers slowing the uptake of renewable heating and cooling

Political and institutional barriers

- Lack of political commitment, including to universal access to energy
- Weak institutional structures (heat markets are complex, fragmented and not well understood)
- Inadequate data and statistics on types and amounts of energy required to meet heating and cooling needs
- Little awareness among decision makers of impact about the effects on the climate and the environment of using fossil fuels for heating and cooling
- Policy frameworks built around a fossil fuel-based energy system

Economic and financial barriers

Playing field with fossil fuels is still not level, owing to:	High upfront costs, including:
• Externalities not accounted for • Persistent fossil fuel subsidies in many parts of the world	• Capital costs • Cost of and access to finance • Unbalanced tax burden

Other

Weak supply chains, including:	Consumer inertia and behaviour, resulting from:	Technical barriers, including:
• Infrastructure and renewable fuels • Shortages of trained personnel • Lack of economies of scale	• Lack of awareness about potential and benefits • Distressed purchase • Disruption and "hassle costs" • Split incentives	• Building suitability • Industrial heat requirements • Reliability of technology

Source: Adapted from IEA (2018c).

Such data are needed for the selection of favourable technologies and locations for installations, for the development of supply chains, and for mapping heat demand and planning district energy networks.

Partly due to the lack of political commitment to the transition, and with an energy regulatory framework built around fossil fuels, the **playing field on which renewables compete with fossil heating fuels remains far from level**. Externalities such as the impacts of fossil fuels on air quality, climate change or other socio-economic metrics are not counted towards their costs. In fact, fossil fuels continue to benefit from government support in many parts of the world. Subsidies for consumption of fossil fuels reached USD 400 billion in 2018, 30% higher than the previous year (OECD, 2019). Although fossil fuel subsidies can help support access to affordable energy, they distort the market, delay the transition and prevent the channelling of public funds into more sustainable and effective solutions, compromising the ability of future generations to meet their basic needs.

The playing field becomes even more tilted during periods of low fossil fuel prices, such as those experienced in 2020 as a result of the Covid-19 crisis. Achieving cost savings to pay back higher capital costs becomes more challenging in such times. In addition, the cyclical nature of fossil fuel prices and the resulting price uncertainty casts doubt on the long-term competitiveness of renewable solutions, affecting the attractiveness of such investments.

The cost-competitiveness of renewables is further impeded by the **higher upfront costs** of some renewable technologies compared with fossil fuel alternatives, in addition to the lack of access to affordable finance and capital for renewable heat investments. This is especially the case in the access context, where clean energy solutions are not affordable and access to finance is less available.

Whether real or perceived, higher upfront costs depress demand for clean heating and cooling solutions and reduce the attractiveness of investing in strengthening **supply chains for renewables** in early stages of market growth, thus locking in energy systems based on fossil fuels. This includes the infrastructure needed to ensure a reliable supply of renewable fuels (*e.g.* biomass from agricultural waste) or heat (*e.g.* district heating and cooling networks). In addition, the lack of a skilled workforce needed to develop, install, operate and maintain renewables-based solutions impedes their uptake. As such, the penetration of renewable heat solutions in the market remains minimal, and the lack of economies of scale prevents costs from falling further.

Another factor that limits the demand for transition-related solutions is **inertia among consumers**. This can proceed from lack of awareness about the benefits of adopting new technologies or low confidence in their overall potential. Consumers, sellers and lenders face informational barriers if they have limited knowledge about renewable heating and cooling options or inaccurate perceptions about their costs or complexity. These barriers may also be intensified by negative prior experiences with poorly designed or improperly installed systems. Consumer inertia with respect to transitioning may also be related to circumstances of distress, as when a boiler breaks down and owners tend to favour its replacement with the same technology. Another factor that can sustain consumer inertia is disruption, or "hassle". The installation of renewable heat systems may entail disturbances related to retrofitting (*e.g.* underfloor heating, biomass fuel storage). Finally, in renter-occupied dwellings, high upfront capital costs are further complicated by split incentives, where the investor (building owner) does not receive the direct financial benefits of using renewables. The split incentive barrier is especially important in countries with relatively low rates of home ownership, such as Germany (around 47%, compared with 61% in Italy) (OECD, 2019).

Finally, **technical barriers** persist. On the demand side, they can relate to building suitability. Heat demand in buildings varies immensely according to factors such as climate, building fabric efficiency, occupancy and behaviour. Some renewable heat options may not be suitable in certain buildings (*e.g.* apartments). In addition, low energy efficiency in building stock results in higher peak loads and increased capital costs, while also reducing system efficiency, as in the case of heat pumps. Technical barriers also affect industry, as a multitude of processes have a range of heat requirements. It can be challenging for some renewable technologies to fully meet the temperature, pressure and quantity of heat required by some industrial users. Finally, some technologies are not yet fully developed or wholly reliable.

All of these barriers combine to deter investments in renewable solutions. Some are shared with energy efficiency (*e.g.* split incentives, fossil fuel subsidies), another key tool for heat decarbonisation. Accordingly, trends in renewable heating and cooling will likely be contingent upon political will and the extent to which national and local governments undertake policy interventions to address these longstanding barriers.

1.4. POLICY LANDSCAPE

1.4.1. TRENDS IN NATIONAL TARGETS AND POLICIES

Policy attention and support for the uptake of renewables in the sector remains remarkably limited on a global scale. Only 49 countries – most within the European Union – had national targets for renewable heating and cooling at the end of 2019, compared with 166 countries with targets for renewables in the power sector. Of these, only one (Denmark) had a target for 100% renewable energy in heating and cooling (REN21, 2020).

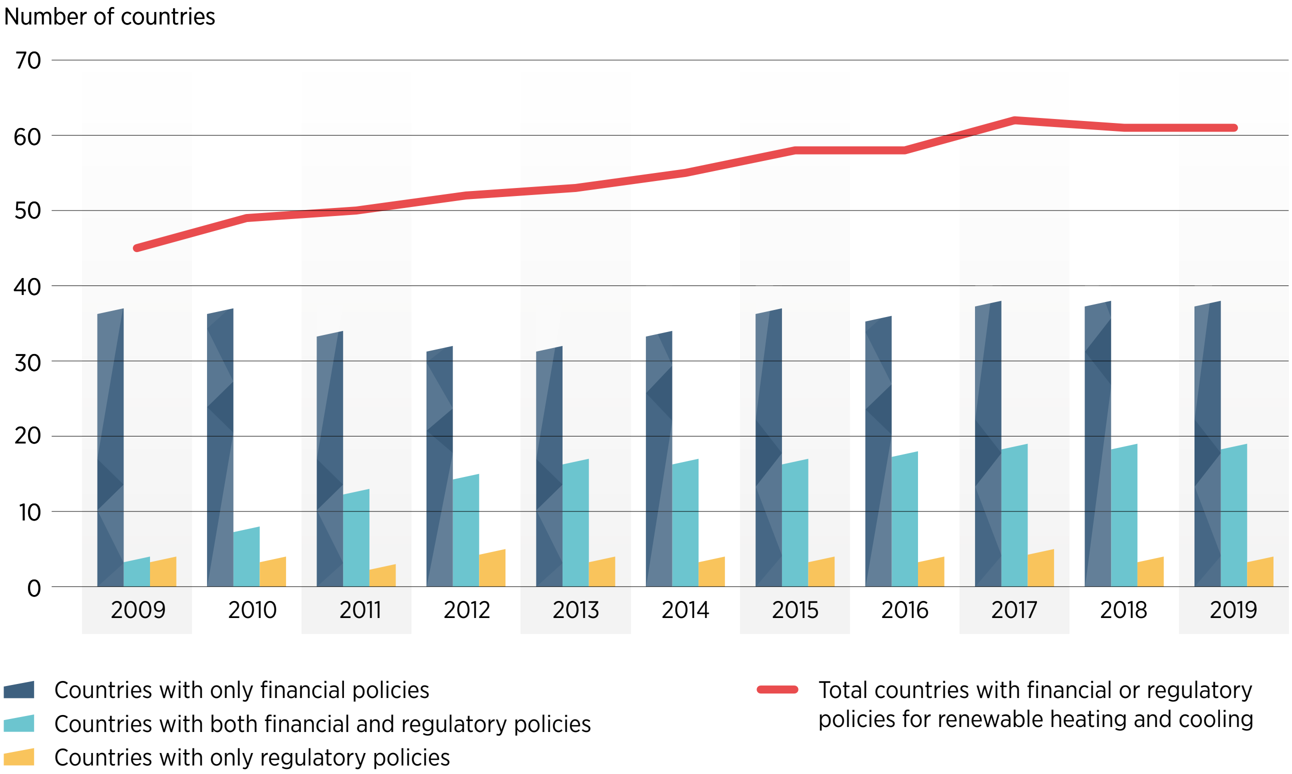
The slow pace of development is also seen in supportive regulatory policy. By the end of 2019, national regulatory policies for heating and cooling were in force in just 23 countries, and the number has changed very little in recent years (REN21, 2020). Under the European Union's Clean Energy for All Europeans package, all EU-27 countries have submitted plans to increase the share of renewables in heating and cooling by 1.3 percentage points each year until 2030, though not all include regulatory measures (European Commission, 2019a).

Financial policies[7] for renewables in heating and cooling are slightly more common than regulatory policies, although their effectiveness varies with the market environment. Fifty-seven countries had a financial policy in place in 2019, 19 of which also had a regulatory policy. In total, 61 countries had either a regulatory policy, a financial incentive or both (Figures 1.5 and 1.6).

1.4.2. TRENDS IN LOCAL TARGETS AND POLICIES

Given the context-specific and decentralised nature of heating and cooling needs, local governments play a key role in scaling up the use of renewables. Increasingly, these governments have made ambitious commitments, often at higher levels than their national counterparts. As of mid-2019, globally, thousands of city governments had adopted renewable energy targets and action plans, and more than 250 cities had reported at least one sectoral target for 100% renewable energy. These include at least 110 cities and municipalities that are targeting 100% renewable heating and cooling either in municipal energy use or city-wide (REN21, 2019). Many are located in northern Europe, the United States or Canada, but some are found in Brazil (Curitiba), China (Foshan and Shenzhen), Japan (Fukushima and Yokohama), and South Africa (Msunduzi).

Figure 1.5 Countries with policies for renewable heating and cooling, 2009-19



Source: REN21, 2020.

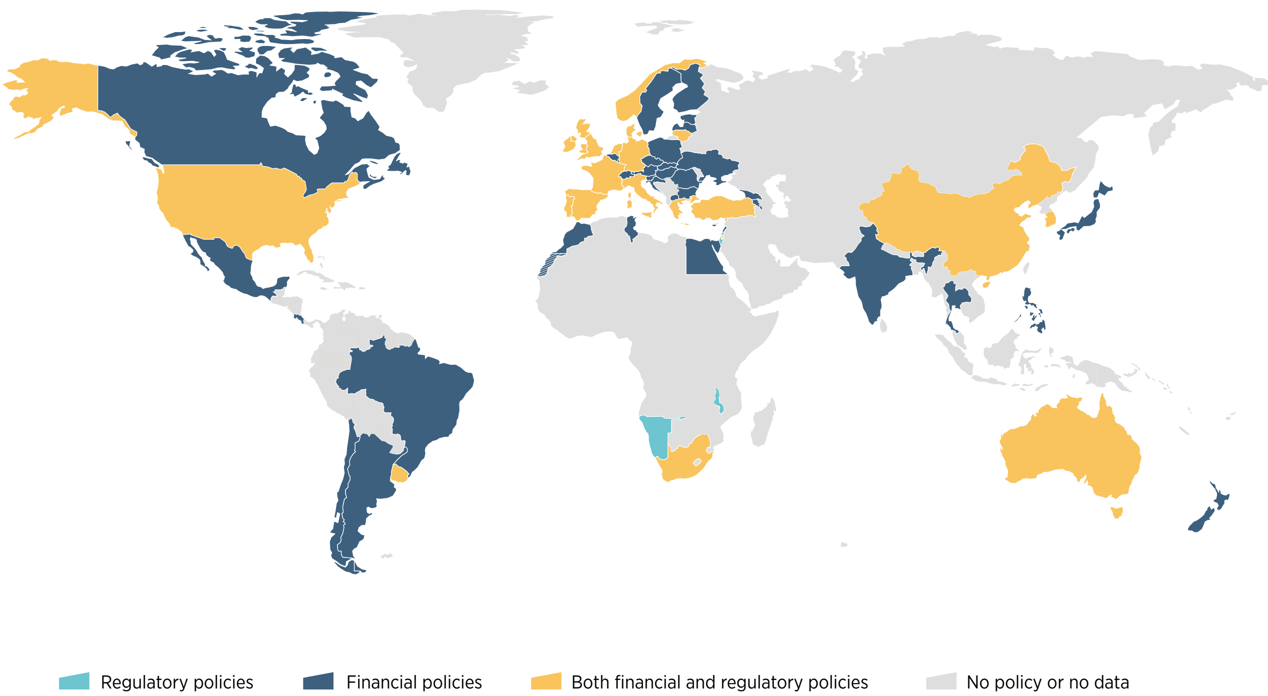
7 Financial policies include investment subsidies, grants, rebates, tax credits, tax deductions and exemptions, and loans. Regulatory policies include solar heat obligations, technology-neutral renewable heat obligations, renewable heat feed-in tariffs, and bans on the use of fossil fuels for heating and cooling at the national or state/provincial level.

To achieve their targets, cities are using their regulatory and purchasing authority to support the use of renewables through municipal mandates and policies for buildings, through the practices they use to manage municipal infrastructure and buildings, and by installing supportive infrastructure, such as urban district energy networks. Cities also provide financial incentives such as grants, rebates and low-interest loans. They adapt permitting practices, building codes and zoning and planning procedures, convene stakeholder groups, establish bulk-buying programmes and take steps to connect consumers with suppliers, in some cases inspiring similar legislation at higher levels of government (IRENA, 2016b, forthcoming-c; REN21, 2019). For example, in 2000, Barcelona was the first city to implement a solar thermal ordinance, which required new and renovated buildings to meet at least 60% of their hot-water needs through solar energy. This has since inspired similar legislation in other Spanish cities as well as a national policy in 2006.

Some municipalities have banned the use of fossil fuels for heating; others have phased out (or plan to phase out) heating systems fed with coal, fossil gas or oil in favour of renewable alternatives. For instance, Krakow (Poland) banned coal and fuelwood in boilers, stoves and fireplaces in 2019, and Helsinki (Finland) intends to ban the use of coal in the city's heating and electricity system by 2029. In Berkeley, California (United States), most new residential and commercial buildings have been barred from connecting to natural gas lines since January 2020 (REN21, 2019).

Some national and local governments have taken political action to support the uptake of renewables in heating and cooling. On a global scale, however, policy measures are insufficient to ensure a rapid transformation that takes full advantage of the potential benefits. In order to address the urgent need to decarbonise the energy used for heating and cooling, governments should implement aggressive and comprehensive policy packages that prioritise efficiency and renewable energy while carefully phasing out the use of fossil fuels and ultimately paving the way to meet the goals for climate, energy access and sustainable development.

Figure 1.6 National policies for renewable heating and cooling, by country, 2019



Source: REN21, 2020

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA, OECD/IEA or REN21.

02 **Transformative approaches** and cross-cutting policies

2.1. THE TRANSFORMATION OF HEATING AND COOLING

The transformation of heating and cooling for a decarbonised energy future requires a combination of context-specific solutions that is responsive to heating and cooling needs, resource availability, level of development of the renewable energy sector, existing infrastructure, and macroeconomic conditions, among other factors. The available solutions vary greatly in many respects, including temperature levels,[1] fuel dependency and supply chains. Various pathways to the energy transformation are introduced in Section 2.1.1.

A first step in the transformation entails improvements in energy efficiency to cut down on demand and waste wherever possible (IEA, 2018c). For example, for heat pumps to work effectively, some buildings may require major energy efficiency upgrades (Section 2.1.2). Another essential element for all pathways is the availability of enabling infrastructure (Section 2.1.3).

In most transformation pathways, renewables may still need to be complemented with fossil fuel heat options. For example, solar thermal systems for water heating may require backup (*e.g.* from a gas boiler). It is therefore necessary to consider a broad strategy for the decarbonisation of heating and cooling.

2.1.1. PATHWAYS TO THE TRANSFORMATION OF HEATING AND COOLING

There is no simple, single solution for decarbonising a country's heating and cooling supply; instead, a combination of options will have to be deployed.

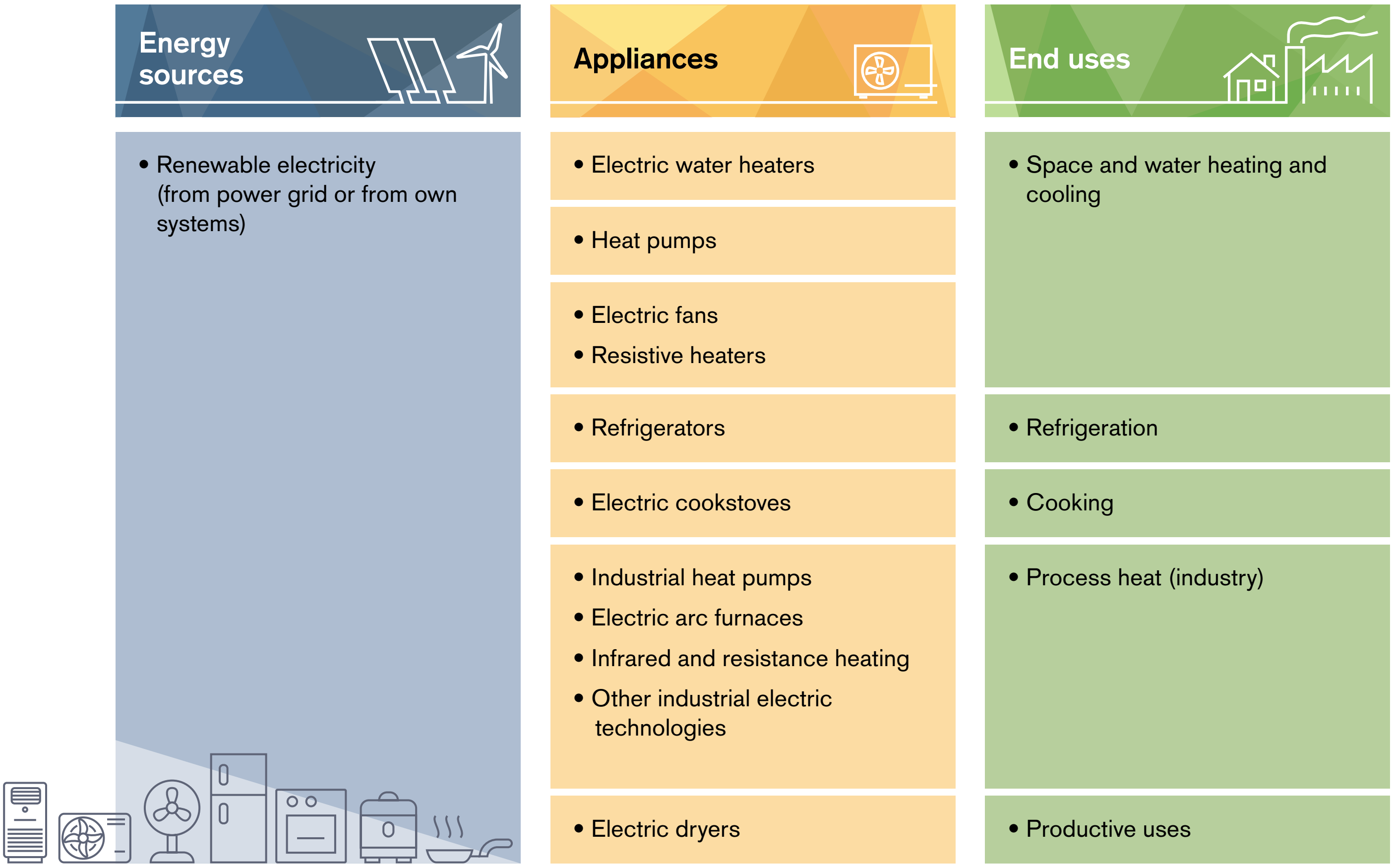
Electrification using renewables. The electrification of heating and cooling entails the use of efficient electric technologies powered by renewable electricity, primarily in buildings and industrial processes. This pathway combines efforts to increase the share of renewables in the power sector, together with electrifying heating and cooling using efficient appliances. In buildings, these include heat pumps, improved water boilers, and cookstoves for heating purposes; fans, air conditioners, and refrigerators for cooling purposes; and radiators, air-source pumps, and geothermal heat pumps for both purposes (Gassera, *et al.*, 2017). In industry, a wide array of electrification technologies exists for industrial process heating. These include industrial heat pumps, electric arc furnaces, infrared and resistance heating, and many others (NREL, 2018; Nadel, 2019) (Figure 2.1)

In the context of widening access to clean, modern forms of energy, electrical appliances can be used for efficient cooking and water heating and for productive uses, with access to electricity made possible through off-grid technologies such as solar home systems and mini-grids. Efficient electrification with renewable electricity provides opportunities to supply clean heat where other renewable options are unsuitable or unavailable.

Electrifying heating and cooling will significantly increase overall electricity demand, which is already rising fast. Together with electric vehicles, it could raise the share of electricity in total global energy consumption from 20% in 2018 to 49% by 2050 (IRENA, 2020a).

1 See Annex I.

Figure 2.1 Electric heating and cooling technologies available for different end uses



As such, greater deployment of renewables-based electricity, mostly variable renewable energy (VRE, such as solar and wind) is required. A high share of VRE in the power system often presents challenges that require greater system flexibility. Policy interventions are needed to accommodate higher shares of VRE and facilitate sector coupling. More details about barriers and enabling policies for this transformation pathway are provided in Chapter 3.

Renewable gases. Renewable gases can replace the use of fossil gases to produce heat for industry, buildings and other end uses. Renewable gases, for the purpose of this report, include biogas, biomethane, and green hydrogen produced from renewable electricity (electrolysis). Renewable gases can replace fossil gas in all its uses, leveraging existing gas networks.

The injection of biomethane into the gas grid has already been adopted in many countries, while a few have begun to explore the feasibility of injecting blended hydrogen into the gas grid or to upgrade the entire gas grid to be ready for 100% hydrogen (IRENA, forthcoming-a). For example, Denmark has set a target to achieve 100% renewable gas injection into the grid by 2035 (REN21, 2019). Still, barriers are slowing the deployment of renewable gas; policies and technical innovations to address those barriers are discussed in Chapter 4.

Sustainable biomass. Bioenergy is presently the largest renewable source of heating, accounting for 21% of total global heat needs in 2018 (REN21, 2020). Two-thirds of that involved the traditional use of biomass – that is, the usually inefficient use of wood, crop residues and animal dung as fuel for cooking and heating in developing economies, which was estimated at 26 EJ in 2018 (REN21, 2020).

The remaining third of bioenergy use provides heating solutions that do not cause the indoor pollution or pose the health threats associated with the traditional uses of biomass. Biofuel boilers can be used directly in buildings, in district heating systems, or to produce industrial process heat. Biofuels (solid biomass, biodegradable wastes, liquid biofuels or biogas) are often sourced locally, but international trading in wood pellets and other biofuels is also taking place. Biofuel cogeneration systems can produce heat for district heating systems and industrial heat needs, as well as electricity. These solutions can meet environmental standards and yield decarbonisation benefits beyond those possible with fossil energy sources.

Although the energy density of solid biomass is lower than that of fossil fuels, it can be improved through pre-treatment such as pelletisation (IRENA, 2015a). The transition to sustainable biomass in both the access and modern energy contexts is discussed in Chapter 5.

Direct use of solar thermal. Solar thermal energy can be used for water heating, space heating (including through district heating networks), industrial processes, food drying, and wastewater treatment and desalination. When solar collectors are paired with an absorption or adsorption chiller, solar energy can be used for cooling.

In 2018, almost 53% of operational solar thermal capacity globally consisted of domestic solar water heaters installed in single-family homes. Large systems for multi-family homes, tourism and public buildings accounted for 37% of the total, followed by swimming pool heating systems at 6%. Only 4% of the applications were destined for district heating networks (led by Denmark), industrial processes, or space heating and cooling (IEA-SHC, 2020). Chapter 6 discusses the current status, benefits and barriers to the direct use of solar thermal energy for heating and cooling, in addition to the policies needed to support its deployment.

Direct use of geothermal. Geothermal energy is heat derived from the subsurface of the earth. Water or steam carry the energy to the earth's surface, where it can be directly used for a variety of heating needs.

Bathing and swimming were the largest direct uses of geothermal heat in 2019, comprising some 44% of total use and growing at an annual rate of about 9%. In second place was space heating (around 39% of direct use); space heating is the fastest-growing category, with annual growth of about 13%. The remaining 17% of direct use was divided among greenhouse heating (8.5%), industrial applications (3.9%), aquaculture (3.2%), agricultural drying (0.8%), snow melting (0.6%) and other uses (0.5%) (Lund and Toth, 2020).[2] Chapter 7 discusses the current status, benefits and barriers to the direct use of geothermal heat, in addition to the policies needed to support deployment.

2.1.2. ENERGY EFFICIENCY AS AN ENABLER FOR COST-EFFECTIVE AND SUSTAINABLE HEATING AND COOLING SOLUTIONS

Energy efficiency has a significant role to play in the energy transition. It is a cost-effective, ready-to-go solution ripe for scaling up.[3] By combining renewable energy with energy efficiency, decarbonisation objectives can be much easier to achieve. Accompanying the electrification of end uses with increases in renewable power generation and direct uses of renewables would deliver around 75% of the reductions in energy-related CO_2 emissions needed by 2050 to set the world on a path to meeting the targets of the Paris Agreement on Climate Change. When energy efficiency is added, the share exceeds 90% (IRENA, 2020a). The switch from fossil fuels to high-efficiency heat pumps, for instance, is expected to be the main driver of GHG reductions in the buildings sector from 2020 to 2070 (IEA, 2020e).

Developments in energy efficiency are particularly critical in the buildings sector, where total energy use has continued to rise as growth in population and floor space and cultural changes in comfort standards have more than offset reductions in demand achieved through energy efficiency (GlobalABC, IEA and UNEP, 2019). Energy savings delivered by high-efficiency cooling, for example, could deliver cost savings of USD 1.2 trillion to 2050 through avoided spending on generation capacity (IEA, 2018a).

Greater energy efficiency can be achieved in buildings through more efficient appliances, better insulation and smarter energy management, while in industry, more efficient industrial processes are key (IEA, 2018c).

In China, equipment efficiency could reduce by an estimated 205 terawatt hours (TWh) the energy required to meet cooling needs in 2030, while improved building envelopes could save another 100 TWh, avoiding around one-third of the projected energy demand (IEA, 2019f). Efficient buildings suitable for low-temperature heating (or high-temperature cooling) are a prerequisite for the application of many renewable technologies.

2 All shares are based on energy use. The direct use of geothermal excludes the use of ground-source heat pumps, which are accounted for in the pathway of electrification with renewables (Chapter 3).

3 Harvesting synergies between heating and cooling is also important. An example would be using waste heat from refrigeration and AC systems (data centers, supermarkets, malls etc.).

In built environments, energy efficiency interventions also improve the quality of life of inhabitants. Finally, greater energy efficiency in energy-poor and off-grid areas reduces inhabitants' energy expenses and the need for energy subsidies.

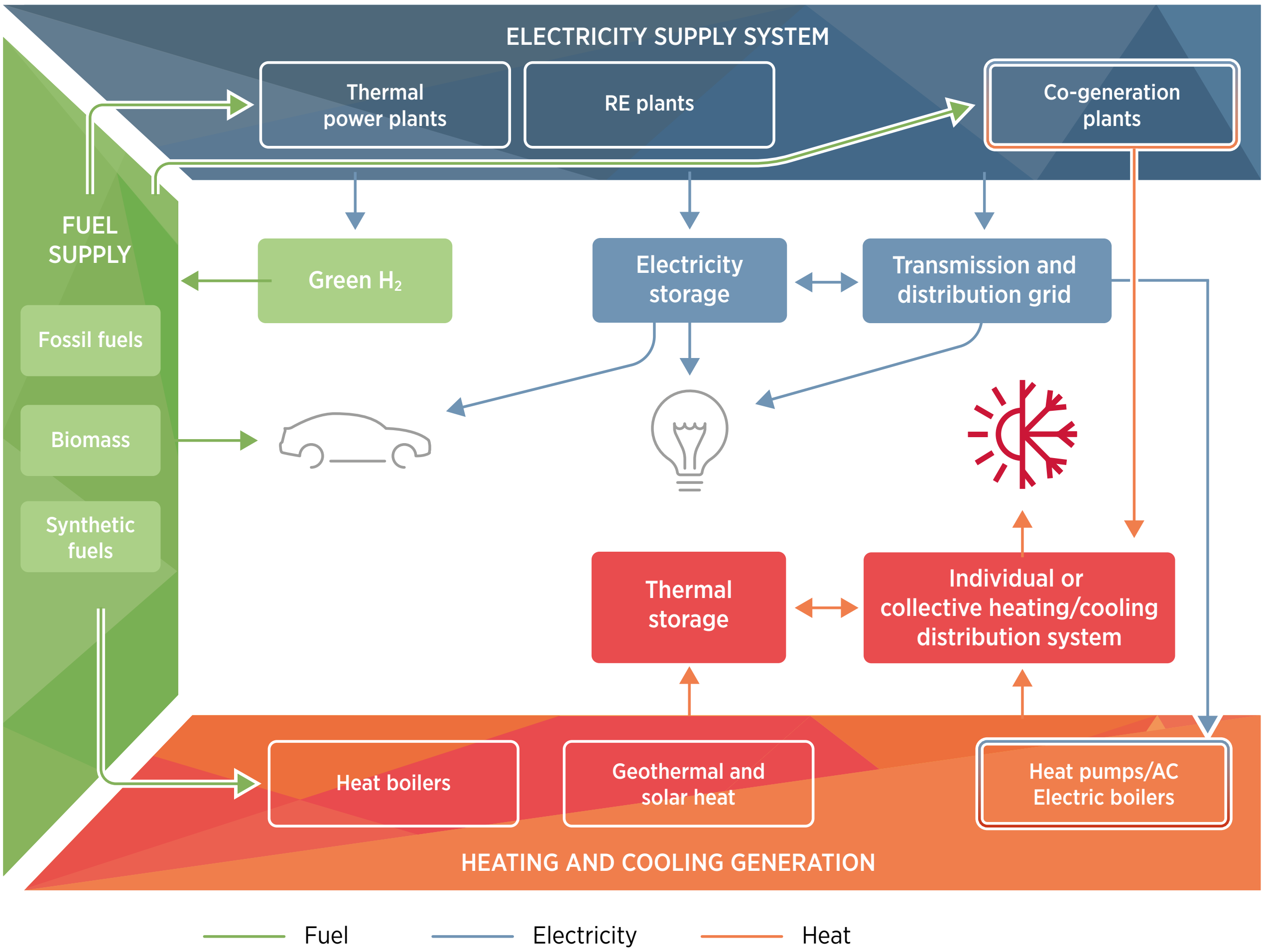
However, the rate of improvement in energy intensity (energy consumption per unit of gross domestic product) slowed in 2018. The 2019 improvement was just 1.2%, less than the annual average of 1.8% recorded over the previous decade (IEA, 2019a). To achieve the targets of limiting global warming to below 2 degrees Celsius (°C) and closer to 1.5°C during this century, the rate of energy intensity improvement must increase to 3.2% per year. Clearly, more effective policies and measures are needed to put the world on track to improving energy intensity (Section 2.2).

2.1.3. PLANNING AND INVESTING IN ENABLING INFRASTRUCTURE

Transitioning to renewable heating and cooling will require investments in new infrastructure and in updating existing networks. Ideally, major investments should be guided by long-term national energy planning to ensure that investments will not result in stranded assets and will not lock consumers in to fossil fuels.

Power grids. With increased electrification of heating and cooling, electricity grids around the world may need to be upgraded to manage growing demand and flexibility requirements. While some countries will need to build new distribution networks, at least over the long term, they can, in the meantime, better manage the existing grid and distribution networks using digital control and monitoring technologies. Smart grid technologies will be needed to provide the increasing flexibility allowed by sector coupling (IRENA, 2019c). For renewables-based electrification, investments in thermal storage are also needed (Box 2.1). Figure 2.2 illustrates the process of coupling power generation with heating and cooling.

Figure 2.2 Coupling power with heating and cooling



Source: IRENA, IEA and REN21, 2018.

BOX 2.1. THE ROLE OF THERMAL STORAGE IN THE ENERGY TRANSITION

Thermal storage is the process of stocking thermal energy so that it can be used after the source stops generating. Because demand for heating and cooling for a given end use tends to vary throughout the day, from one day to the next, or from one season to another, storage is needed to balance demand and supply over time, particularly when the supply is variable (*e.g.* solar and wind energy). In solar thermal applications, thermal storage is an essential component. In general, it is not a complex technology, with water being the most common storage medium. Other solutions include sand, molten salts, rocks and ice (for cooling).

Thermal energy storage systems can be centralised or decentralised. Centralised applications can be used in district heating and cooling systems, coupled with a variable source of energy. Underground seasonal hot water storage systems are already applied for small solar district heating and cooling systems, like the one in Munich (Germany), where a 6000 m^3 thermal storage facility enables solar energy to meet about half of the heat demand for 320 apartments. Decentralised (distributed) systems are applied in buildings to capture solar energy for water and space heating, but they could become more common as more heat pumps are installed. Ice-based thermal energy storage for cooling is also promising. Underground ice storage has been applied throughout history, with ice stored in centrally located ice houses.

When coupled with electric heating and cooling applications, thermal storage can increase system flexibility by allowing for the consumption of electricity when variable resources are available (and power prices are lower). Thermal energy storage has a particularly important role to play in cities where the population density is high enough to permit the use of district heating and cooling systems. Thermal energy storage technologies that enable the decoupling of energy generation from consumption can accommodate a range of timescales (from hourly to seasonal), equilibrate supply with demand, reduce curtailment and avoid the need for costly electricity network reinforcement.

IRENA's "Innovation Outlook: Thermal Energy Storage" discusses thermal energy storage technologies and user cases for heating and cooling systems, and projects development and innovation needs over the coming decades (IRENA, forthcoming-b).

Thermal Storage, Alperia, Bozen, Italy

Gas grids. Investments in gas grid infrastructure, additional hardware (*e.g.* gas cleaning units) and storage are key for the deployment of renewable gases (biogas, biomethane, green hydrogen). Biomethane is compatible with the prevalent gas grids and can be injected into the the grid. Biomethane sourced from household waste has been injected into the network of the French town of Chagny since 2015 (GRTgaz, 2015), while more than 60% of Swedish municipalities collect food waste to produce biomethane that can be injected into local gas grids (Green Gas Initiative, 2016; REN21, 2020).

Green hydrogen can be injected into existing gas grids at rates of up to 20% to reduce the consumption of fossil gas (IRENA, 2019d). For that, the existing network must be assessed for durability, integrity and safety and upgraded as needed to accommodate green hydrogen. Gas service companies will need to deploy adequate storage to meet seasonal variations in heating demand. Renewable gases can provide seasonal storage solutions, especially in countries where renewable energy generation varies widely by season.

District heating and cooling infrastructure. District heating and cooling networks are systems through which a hot or cold fluid generated from one centralised location or multiple decentralised locations is supplied to multiple buildings or industrial consumers through a pipe network. These systems are generally more energy efficient than individual appliances and offer a cost-effective way to heat and cool urban areas. Currently, the supply of district heating and cooling is dominated by fossil fuels such as coal and fossil gas. However, these systems provide opportunities for network operators to shift significant volumes of consumption from fossil fuels to renewables such as bioenergy, geothermal energy, heat pumps using renewable electricity, and solar thermal energy. In countries with high demand for cooling, district cooling networks can also play a role in supporting system integration, with electric heat pumps supplying cooling at times coinciding with abundant solar resources. This type of coupling is still at an early stage in most countries but is becoming more important in, for example, Denmark, Germany and Singapore (IEA, 2018c; Othman, 2016). The barriers and policies needed to attract investment in district energy networks are discussed in the "In Focus" segment of this report (Chapter 8).

2.2. CROSS-CUTTING ENABLING POLICIES FOR ALL PATHWAYS

Although the benefits of decarbonising heating and cooling are well known, longstanding barriers have impeded that goal for decades. This section focuses on what is required to lower the barriers and speed up the transition to a decarbonised future, regardless of the specific pathway to transformation.

Needed are actions to align long-term planning with decarbonisation objectives, an enabling institutional structure, and policies to level the playing field with fossil fuels, address upfront costs associated with adopting renewables, strengthen supply chains, overcome market barriers and increase energy efficiency.

Specific policies needed to support each of the identified pathways are analysed in subsequent chapters. Annex II presents an updated classification of the policies needed for the transition of heating and cooling, including direct, integrating and enabling policies.

2.2.1. LONG-TERM PLANNING FOR DECARBONISATION

Political commitment is a key factor in lowering institutional barriers and driving the energy transition. It takes the form of clearly defined targets for renewable energy and energy efficiency that are expressed in nationally determined contributions (NDCs) and in comprehensive long-term planning aligned with decarbonisation objectives. Long-term planning for decarbonisation can significantly improve policy certainty and guide investment in needed infrastructure and other technologies.

NDCs and renewable energy heating and cooling targets are important planning mechanisms for national, regional and subnational authorities. They demonstrate commitment to the deployment and development of renewables along specific pathways. However, as of 2020, the NDCs and targets are not yet ambitious enough to guide the energy transition to achieve the objectives of the Paris Agreement. Moreover, current NDCs do not reflect the rapid growth of renewables over the past decade. For example, if renewable energy deployment in the power sector were to grow at the same rate experienced from 2015 to 2018 (8.6% per year), global renewable power targets for 2030 would be met by 2022 (IRENA, 2019e).

Heating and cooling uses offer a vast untapped potential for increasing countries' NDCs. While heat accounts for the bulk of energy use in buildings and industries, only 25 of nearly 200 countries have formulated commitments related to renewables-based heating and cooling. Additionally, fewer than 10 countries have added clean cooking to their NDCs (REN21, 2020).

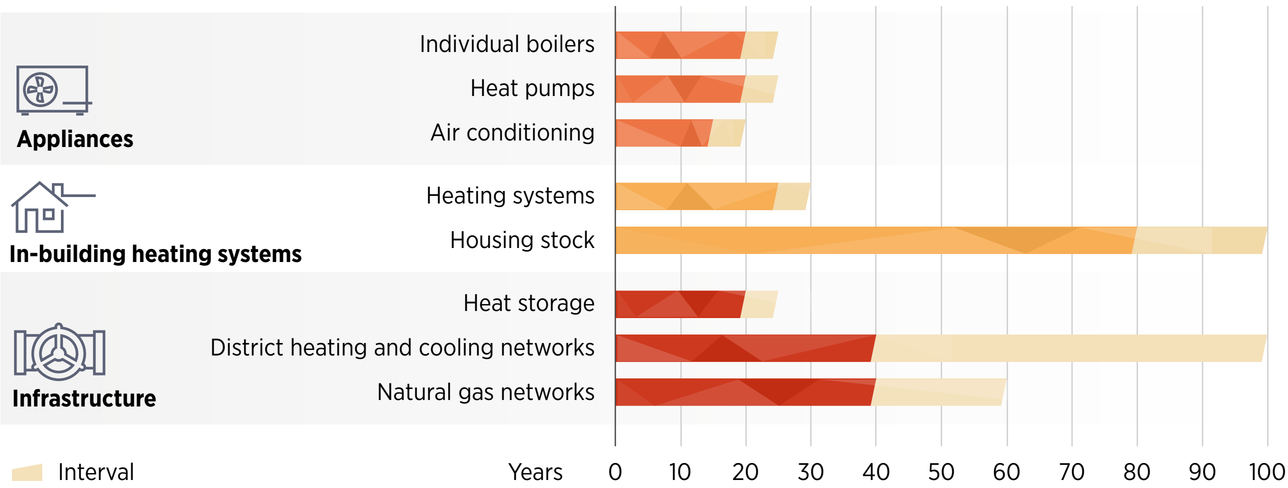
To encourage the transition to a more efficient and renewables-based energy system and to meet global climate goals, the ambitions expressed in NDCs, particularly for heating and cooling, should be raised. Setting ambitious targets consistent with long-term national strategies and plans can send a strong signal to investors and help attract needed capital. Renewable heating and cooling targets can provide important signals for investors and industries and engage stakeholders by revealing future opportunities. In addition, targets serve important functions throughout the policy-making process (IRENA, 2015b).

Whereas most countries around the world have now established targets for the use of renewable energy in the electricity sector (166 countries), relatively few have adopted targets to increase renewables in heating and cooling uses. In 2019, 49 countries had national renewable heating and cooling targets, up from just two in 2005 (REN21, 2020). These targets frequently specify incremental changes, without taking necessary long-term structural changes into account. Often, the perspective covers only the next few decades – which in many developing countries includes the period until the emissions peak is reached – but does not extend to the period when rapid carbon reduction is required in all sectors. Yet under the Paris Agreement, the entire energy sector – worldwide – needs to be decarbonised.

Integrated long-term planning is necessary to coordinate the deployment of renewables-based heating while attracting investment in the necessary infrastructure and avoiding conflicting solutions and stranded assets. For example, an integrated plan that accounts for the widespread use of heat pumps requires an upgrade of the power grid, while a plan that relies on the use of district heat in a high-density urban area requires the development or expansion of district heating networks. Long-term integrated plans for heating and cooling uses are especially important since the operating lifetime for assets and infrastructure range from 15 to over 80 years (Figure 2.3). Integrated long-term planning must cover a time period longer than the economic lifetime of heating and cooling infrastructure and the housing stock. An integrated long-term plan should outline the various pathways adopted, the infrastructure needed, and accompanying energy efficiency plans. Investment decisions made today will affect the long-term strategy for deep decarbonisation beyond 2050.

Public investment in infrastructure. Public investment in renewables-based heat infrastructure supports the growth of related supply chains. The United Kingdom's Heat Networks Delivery Unit programme, for example, provided funding to enable local authorities to develop their heat networks, as described in Section 2.2.4, stimulating the development of a local supply chain that includes heat interface components, heat meters, and valves (Department for Business, Energy and Industrial Strategy, 2018). More examples of public infrastructure that has enabled local authorities, cities and industry to invest in efficient, low-carbon district heating schemes can be found in the In Focus segment (Chapter 8).

Figure 2.3 Operating lifetime of heating and cooling infrastructure, systems and appliances



Source: Adapted from Agora (2020), Nowacki (2020), EHPA (2014), and Connolly *et.al.* (2012).

Note: in this report, the values correspond to those referred to in the upper corner of the bars.

2.2.2. INSTITUTIONAL STRUCTURE TO ENABLE COORDINATION BETWEEN SECTORS

Supportive governance and institutional architecture are crucial to the implementation of integrated long-term plans. This is especially true for heating and cooling plans and policies, which cut across many sectors (*e.g.* energy, agriculture).

Improving intersectoral exchanges. Transitioning heating and cooling towards renewable sources requires a robust institutional structure that clearly defines the roles and responsibilities of various governing bodies and stakeholders in translating targets into actionable initiatives. The importance of further integrating the electricity sector with energy use for heating and cooling, for example, will require additional coordination, notably between the ministry or ministries responsible for energy and power and those responsible for buildings. Coordination of energy, agriculture, and forestry is also important with respect to the uses of bioenergy. The extensive coordination of targets, pathways, and infrastructure planning can be handled by national energy agencies.

At the same time, there is a clear need for coordination with entities at the subnational level. Municipalities play a crucial role in the transition of heating and cooling in cities, and a structure of institutions that defines the role of different levels of governance and entities is required.

Streamlining permitting procedures is key to facilitating investments in large-scale projects and enabling infrastructure for all of the transformational pathways. Clear and transparent permitting procedures are also important for decentralised solutions. Users in residential and industrial establishments are more likely to adopt heat pumps and solar water heaters, for example, when the rules for their installation are clear and transparent.

Reinforcing data collection and statistics. Build capacity for the collection and standardisation of data an statistics and for conducting heat mapping and zoning.

2.2.3. POLICIES TO LEVEL THE PLAYING FIELD

Levelling the playing field has two distinct but related aspects. The first is the need to level the playing field for different energy sources in the same sector. Here, the careful phaseout of fossil fuel subsidies and fiscal policies (*e.g.* carbon pricing) are crucial policy instruments. The second is to level the field between sectors to allow for cost-effective sector coupling.

Phasing out fossil fuel subsidies. Existing subsidies for fossil fuels in the energy sector distort the market, blocking the entry of clean energy solutions. In many cases, what policy makers or industries considered temporary subsidies have persisted for decades.

Direct and indirect subsidies to fossil fuels – created by underpricing negative externalities such as health costs from local pollution and climate change – were estimated to exceed USD 2.5 trillion in 2017 (Coady *et al.*, 2019). The total amount is estimated at around 19 times the support provided for renewables, which came to approximately USD 166 billion in 2017 (IRENA, 2020a).

The International Monetary Fund identifies unlevied negative externalities as fossil fuel subsidies, categorising them as pre- or post-tax. Pre-tax subsidies are estimated based on the difference between supply cost and consumer price. In some countries, subsidised and low-cost fuels (especially for residential use) are intended to offset energy poverty. However, such measures are generally not targeted (or not well-targeted), and much of the subsidy tends to go to higher-income groups that use more energy. Social support directed specifically at low-income families can be more effective. Post-tax subsidies also include estimations of the monetary cost of environmental and social externalities such as global warming, local air pollution, forgone consumption revenues, congestion and other externalities (Coady *et al.*, 2019).

Adjusting and implementing fiscal policies. Fiscal policies can help to create a more level playing field for the various technological options for heating and cooling. Fiscal policies such as carbon pricing can help, as they internalise the negative external costs of fossil fuels (IPCC, 2018). Fiscal policies that require economic actors to pay for their emissions, based on the principle that "polluters pay", can be pivotal in the transition.

In Sweden, the taxation of fossil fuels has been a major driver for renewable heat, whereas low gas prices (reflecting low taxes) hobble the competitiveness of renewable heat options in the United Kingdom and the United States (IEA, 2018c). Alternatively, a well-functioning emissions trading scheme, for example, can cap emissions within a given perimeter of activities and drive their reduction. Canada, Japan, and some EU member countries have applied emissions trading and carbon taxes in a complementary way (World Bank, 2020).

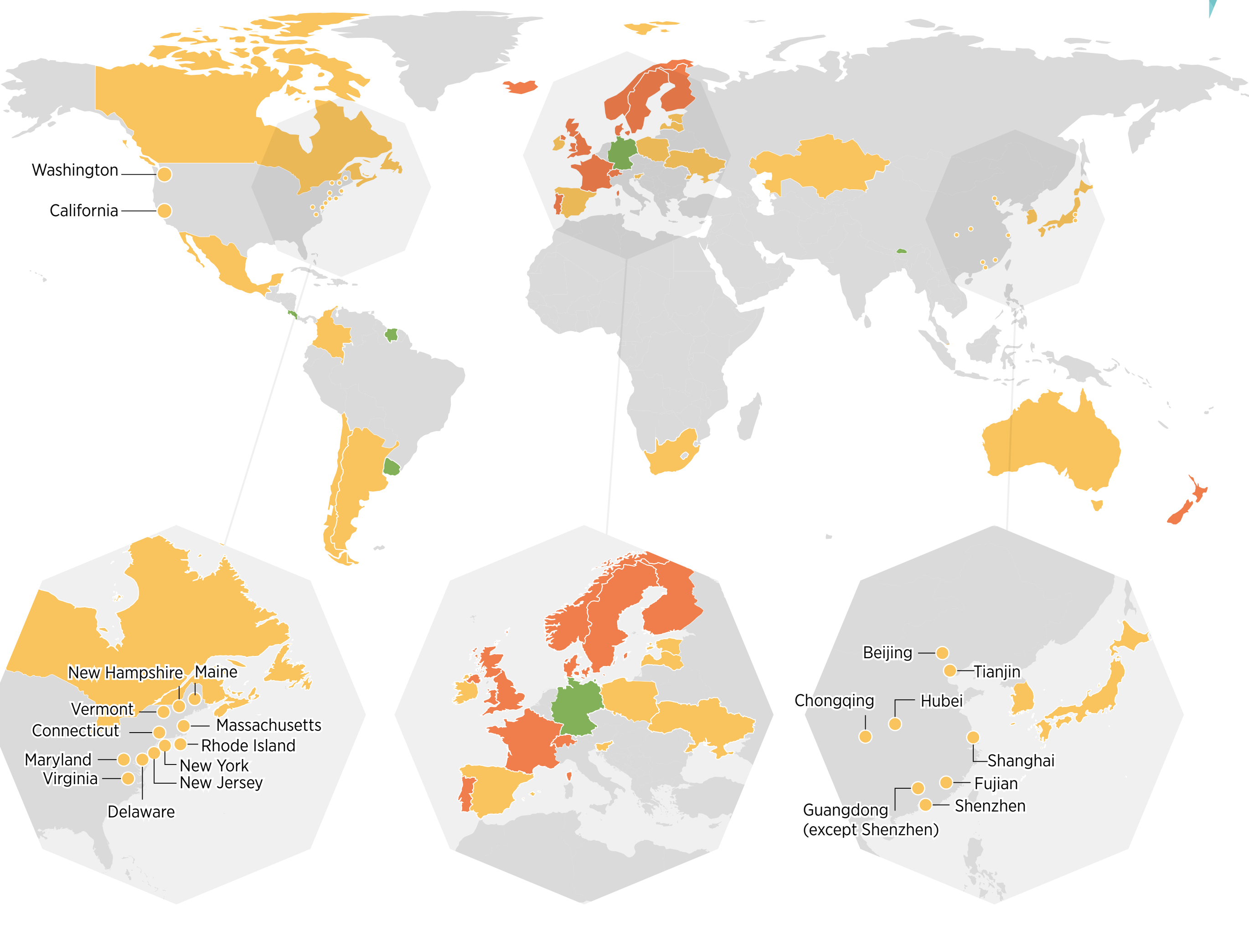
However, carbon pricing policies require careful consideration of broader social and equity issues, particularly for low-income populations, for whom energy constitutes a larger share of household expenditures and whose budgets do not leave many options. Many carbon pricing schemes exempt household heat or provide additional support for low-income consumers. But others exempt energy-intensive industries, which can compromise the effectiveness of such schemes.

By 2019, 20% of global GHG emissions were covered under 58 carbon taxes or emissions trading schemes at the regional, national or subnational level (Figure 2.4). This coverage reflects a rapid increase over the past 15 years. Before 2005, only a handful of European countries practiced carbon pricing, covering less than 1% of global emissions (World Bank, 2020). However, most of those schemes (especially emissions trading schemes) are targeted at power and industry; only in some cases are buildings included. In addition, the price of carbon has so far not been high enough to promote the optimal uptake of renewable heating. Carbon prices need to be in the range of USD 40-80/tCO_{2e} in 2020 and USD 50-100/tCO_{2e} by 2030 to meet the goals set by Paris Agreement on climate change (High-Level Commission on Carbon Prices, 2017). However, less than 5% of GHG emissions are currently priced accordingly, the highest being in Sweden, with USD 119/tCO_{2e} as the upper bound.

Clear policy signals such as carbon pricing can reduce uncertainty and encourage investment in renewable solutions, including infrastructure. By putting a price on the negative externalities associated with producing heat from fossil fuels, policy makers can level the playing field for renewables and send a clear signal to providers of heat services to seek out alternative low-carbon heat sources to ensure the future economic viability of their systems (Box 2.2).

Creating a level playing field between electricity and other energy carriers. To ensure the cost-effective integration (or coupling) of the electricity sector with heating and cooling energy uses, the same types of taxes and levies must apply to all energy carriers in both sectors. In some countries, fossil fuels used for heating and cooling are subsidised, whereas subsidies in the electricity sector have already been eliminated, sometimes as part of market liberalisation. This may impede the use of electricity for heating purposes (*e.g.* heat pumps). Phasing out

Figure 2.4 Jurisdictions with selected climate change policies, early 2020



Source: REN21, 2020

Disclaimer: Boundaries and names shown on these maps do not imply any official endorsement or acceptance by IRENA, OECD/IEA or REN21.

BOX 2.2. CARBON PRICING POLICIES

Carbon pricing policies can be an important source of public revenue. Global revenues from carbon pricing, including carbon taxes on fossil fuels and auctions of emissions allowances through emission trading schemes were USD 44 billion in 2018, a 22% rise over 2017 (World Bank, 2020). Carbon pricing policies provided 3% of the government revenue of British Columbia (Canada), and 2% of the tax revenues of Sweden, with the potential to increase.

Government revenues from carbon pricing policies are becoming one of the main sources of funding for other policies aimed at increasing the uptake of renewables. In 2016, 15% of global revenues from carbon taxation supported such spending, including for heating and cooling (Carl and Fedor, 2016). France and Japan, which rank first and third in carbon tax collection among countries, spend all their carbon tax revenues on "green" spending, such as increasing efficiency and innovation in renewables. In the Canadian province of Alberta, 90% of revenue from emissions trading auctions went to support projects related to energy sufficiency, renewables, climate and sustainability. In the European Union's emissions trading scheme, the same percentage was 80% from 2013 to 2017. Carbon taxes can therefore generate double dividends. The first benefit is the pollution reduction generated by the price signal; the second stems from the use of the tax revenue to achieve environmental or social objectives.

fossil fuel subsidies from all sectors can support the switch to cleaner sources of heat, including electrification.

In Germany, for instance, electricity (which is now primarily produced from renewable energy sources) is facing higher surcharges and tax burdens than the oil and natural gas used for heating and cooling. On a per-kilowatt-hour basis, electricity prices include 18.7 Euro cents/kWh of surcharges and taxes, compared with 2.2 Euro cents/kWh for natural gas and 0.6 Euro cents/kWh for heating oil (Agora Energiewende, 2017). This tilts the playing field for the different sectors, incentivising the use of fossil fuels for heating and disincentivising the use of heat pumps powered by renewable electricity. Accordingly, a longer-term rationalisation of taxes, surcharges and subsidies for the various energy carriers is important for the transition, regardless of the pathway. But the rationalisation must be accomplished without negative distributive effects on low-income households or on industries. This is because the implementation of policies should be based on not only their impact on the future energy system, but they should be viewed as part of the broader socio-economic structures upon which the energy system is built and with which it interacts (Figure 2.5).

2.2.4. POLICIES TO ADDRESS HIGH UPFRONT COSTS

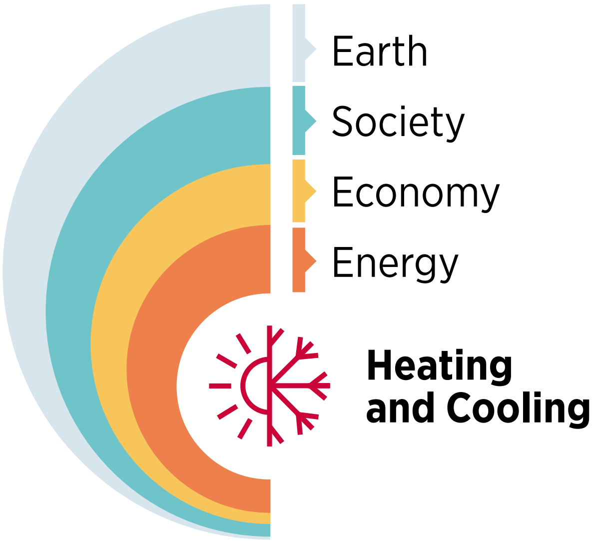
The competitiveness of renewable heating and cooling options depends on capital, fuel and operating costs, as well as on necessary infrastructure investments.

Fiscal incentives. Fiscal incentives such as tax credits, reductions and accelerated depreciation are commonly used to incentivise the adoption of renewable energy technologies for heating and cooling. For instance, Denmark intends to keep district heating prices low by **reducing the tax** paid on electrically produced heating (McLaughlin, 2019) – part of the country's plan to be fossil fuel free by 2050. Examples of wind-to-heat applications can already be found in Denmark (see Box 3.3). The synergies between heat demand and power supply are discussed in Sections 3.3 and 3.4.

Financial incentives. The most common support policies for heating and cooling solutions are direct subsidies and grants, as well as specific loan schemes. Decentralised solutions such as heat pumps and solar water heaters installed in buildings are typically supported by financial incentives that can be provided either as a **single-payment subsidy, grant or loan**. Alternatively, support can be based on the amount of renewable heat generated by the system. Such incentives are typically complemented by mandates and revised building codes (Deason *et al.*, 2018). Examples of financial incentives to support renewable heat are presented in Box 2.3. When designing such policies, a just transition must be kept in mind, especially in contexts of energy poverty (Box 2.4).

A different approach was taken in the United Kingdom, where a subsidy akin to a feed-in tariff supports heating and cooling solutions. One problematic aspect of such a subsidy for heat is that it can inadvertently subsidise the inefficient operation of heating systems or thermally inefficient buildings and industrial processes. To this end, a specific incentive scheme with integrated feed-in tariffs to raise energy efficiency could

Figure 2.5 The broad dimension of renewable energy policy making



be helpful, depending on the scheme's design. The British government has announced the end of the current scheme, known as the Renewable Heat Incentive; it will be replaced by a grant for heating and cooling applications and a feed-in tariff for the injection of green gas (Ofgem, 2020a).

For centralised systems using heat networks, such as district heating and cooling systems, various types of incentives can be implemented. These include ensuring stable demand for the heat produced to reduce investment risk (see the discussion in Chapter 8) and providing capital subsidies and grants.

BOX 2.3. FINANCIAL INCENTIVES FOR RENEWABLE HEAT IN CHINA AND GERMANY

In China, government subsidies encouraged the uptake of decentralised electric heat pumps as part of a strategy to eliminate coal-fired boilers. Eligible buyers could receive subsidies of USD 42 to 84 (CNY 300 to 600), around 10% of the total retail price, depending on the rated heating capacity and efficiency. As a result, over half million air-source heat pumps for water heating were sold in 2018 (CHPA, 2019; Zhao, Gao and Song, 2017).

Germany's Market Incentive Programme offers grants for small-scale renewable heat systems. The overall programme, which also includes low-interest loans for industry and district heating, offers EUR 300 million per year in grants and loans. More than 1.8 million systems were funded between 2000 and 2020, about 100 000 units per year (BMWI, 2020). However, in comparison, more than 600 000 fossil fuel boilers (oil or gas) were sold in 2019 alone. Indeed, in Germany, heat pumps and biomass boilers made up just 15% of the annual boiler market (BDH, 2020).

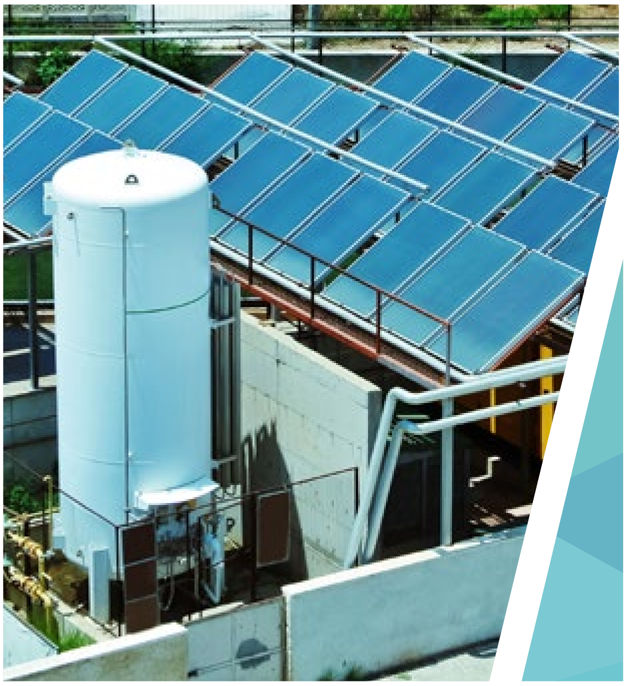
BOX 2.4. ENERGY POVERTY CONSIDERATIONS IN THE DESIGN OF SUPPORT SCHEMES

Given their capital-intensive nature, transition-compatible solutions such as heat pumps have usually been adopted first by higher-income households (Gaigalis et al., 2016). This is not uncommon in the power sector; it has been the case for residential photovoltaic across the globe (Lukanov and Krieger, 2019; Coffman, Allen and Wee, 2018; Barbose *et al.*, 2018; Macintosh and Wilkinson, 2011).

The rapid uptake of such appliances and other aspects of electrification can strain power systems, requiring upgrades of facilities that generate, transmit and distribute power. Although the costs of such upgrades are typically borne by all users, the share allocated to the fixed part of the electricity bills falls disproportionately on lower-income households – including those that are not able to afford the appliances that necessitated the upgrade.

The situation may intensify if direct policies, such as fiscal incentives, capital grants and schemes akin to feed-in tariffs benefit the middle- to high-income households that are able to invest in the technology. Under such circumstances, and depending on the source of the subsidy, there may be the risk of indirect and unfair cross-subsidisation. In the long term, this can exacerbate energy poverty and create transitional barriers, as low-income households become even less able to afford modern heating and cooling technologies.

Proper policy making should pay special attention to the energy poverty dimension and tailor clean technology measures so that their benefits can be realised by those who stand to gain the most from them. Favouring areas where energy poverty is more common (Bouzarovski, 2018) or conditioning subsidy amounts on household income and financial resources can reduce the inequality of support schemes.



2.2.5. POLICIES TO STRENGTHEN SUPPLY CHAINS

Strengthening domestic supply chains is crucial to ensuring the reliability of technology, avoiding disruptions of supply, and maximising local value creation. The development of supply chains for renewable heating and cooling technologies requires long-term planning that is robust and credible enough to ensure investment security and market confidence (see Section 2.2.1). Strengthening those supply chains requires industrial policies that encourage collaboration between industry and research clusters, support for research and development, and support for education and training.

Industrial policies. Industrial policies aim at harnessing, leveraging and enhancing domestic capabilities in support of economic development and diversification. They may encompass initiatives and programmes to incubate new businesses, develop the capabilities of existing firms in the supply chain (by incentivising technological learning and cross-sectoral spillovers), provide low-cost loans, and promote local or regional industry clusters that bring together relevant actors, including government agencies, industry associations and companies, universities, and others. In 2020, having approved its national hydrogen strategy, Germany started an initiative to develop a domestic green hydrogen supply chain based on a partnership with Australia (Lewis and Radowitz, 2020).

Encouraging collaboration between industry and research. To further promote technology diffusion, governments can establish industry clusters for heating and cooling technologies and encourage collaboration between industry and research institutes. The Danish district heating market benefits from a high level of cooperation and knowledge exchange, which helps companies in the supply chain to integrate advanced technologies and operational models (Galindo Fernández *et al.*, 2016). In the city of Dezhou (China), the local government promoted collaboration with renewables research institutes and built a local knowledge hub on solar

water heaters to address the shortage of expertise (ICLEI and IRENA, 2013). Growing supply chains can also have a positive effect on reducing heat costs due to the increased competition (Business Sweden, 2016).

Research, development and demonstration (RD&D). Most renewable heat solutions still face technological or commercial challenges, resulting in low consumer confidence and slow uptake. RD&D are necessary to promote commercialisation and wider deployment of new technologies and to increase the ability of those technologies to compete with other options. Even in smaller markets, RD&D can be especially useful for supporting domestic industries that create domestic value and meet local needs (IRENA, 2015c). For example, the city of Helsinki (Finland) offered EUR 1 million to an individual or group that could propose a technological solution to replace coal-fired heating (REN21, 2019). The activity was kicked off in early 2020 and will select winners by end of the year.

Education and training policies. Government policies to encourage a focus on science, technology, engineering and mathematics in the educational system can strengthen technological learning and know-how in heating and cooling technologies and solutions, as well as in the wider economy. Imparting the same focus to degree programmes in universities, short-term and evening certificate courses, and specialised training courses can give workers more opportunities to gain new skills. Regional programmes can be effective in spreading technology certification among countries. The Heat Pump Keymark is a certification scheme for heat pump quality across Europe. The scheme has been accepted by dozens of European countries (Heat Pump KEYMARK, 2020).

Transition policies. In addition to the aforementioned industrial policies and education and skill policies, a just transition of heating and cooling can be supported by labour market and social protection policies. Those policies can also smoothen the transition for workers in incumbent industries by developing opportunities in new industries and providing re-skilling options for affected workers. Labour market and social protection policies are key.

The coal industry has become one example. Banning coal burning for heating in countries with rich coal resources and high residential heating demand like China and Kazakhstan in the near term would provide a powerful signal to the related heating providers and appliance manufacturers. But it would also threaten jobs in coal mining and related supply chains. Policies to support reskilling for coal workers and others who lose their jobs, paired with interim financial support for income stability, could help the impacted communities and ensure a just energy transition.

In part, this can mean developing policy incentives for employers to retain (and retrain) workers where possible. Flexible, longer-term employment contracts can promote job stability and employee welfare in a manner consistent with the needs of employers. Unemployment insurance and other programmes that offer social protection to those laid off are also crucial for affected individuals and their communities, so that they do not shoulder an unfair share of the burden of the energy transition (IRENA, 2020f). For example, the German Commission on Growth, Structural Change and Employment (also known as the Coal Commission) released a roadmap to ensure a just transition for coal regions and employees affected by the country's plan to phase out coal mining by 2038 (Agora Energiewende und Aurora Energy Research, 2019).

2.2.6. POLICIES TO OVERCOME MARKET BARRIERS

Measures to ensure the high quality of equipment and technical support can help to lower market barriers, particularly if accompanied by mandates to ease market entry for zero-carbon heating and cooling solutions. New business models can help to overcome the challenge of high upfront investment costs.

Certification schemes, standards, quality assurance and technical support for operations and maintenance. Standardisation policies should set requirements for the design, building and operation of the renewables-based heating and cooling supply chain. Available policy options include equipment certification, codes of practice and related regulations to ensure qualified installation and maintenance for operation.

Poorly designed systems, technologies, appliances and settings can sap consumer confidence and create reputational damage. To prevent this, quality assurance schemes should cover the appliances and equipment that use renewable heat; they should extend to the design, installation, operation and maintenance of equipment. Tying support to systems procured from qualified suppliers and designed and fitted by qualified installers is essential.

Technology standards and quality assurance comprise four key steps: 1) standards; 2) testing; 3) accreditation and certification; and 4) metrology and calibration. Setting effective standards for solar water heaters, for example, depends on the development of product standards, test labs, human capacity for auditing and inspection, and equipment and procedures for calibrating and testing devices (IRENA, 2015d). In the United Kingdom, the Microgeneration Certification Scheme certifies renewables-based heat products and installers of heating systems that receive government funds (Ofgem, 2015).

Industry associations can adopt codes of practice to guide and monitor performance. The Chartered Institution of Building Services Engineers in the United Kingdom has issued a code of practice for heat pumps (among other technologies) that promotes the standardisation of renewables-based heating and cooling (CIBSE, 2019).

Mandates for renewables-based heating and cooling solutions. Mandates are key policies to transform targets for the use of renewable energy into concrete actions (IRENA, IEA and REN21, 2018). Mandates for solar water heaters and for connections to district energy networks have already been widely adopted by countries and cities. In some cases, governments have set the heat tariff to an appropriately low level to avoid disadvantaging end users (UNEP, 2015). More could do the same. Chapters 6 and 8 present more cases of mandates.

Bans and forced replacements of fossil fuels aligned with long-term decarbonisation plans. Policies that ban or restrict the use of fossil fuels for heat can be applied at the national and subnational level, and they can fundamentally accelerate the transition away from coal, fossil gas and oil-fired heating to other renewable heat options. For example, the United Kingdom is banning gas connections to new developments starting in 2025 (Ofgem, 2020b). China banned coal-heating in Beijing-Tianjin-Hebei in 2017 to address air pollution (Liu *et al.*, 2019a). New oil-fired boilers in residential properties are banned in Denmark, Norway and Sweden (IRENA, IEA and REN21, 2018)

The Chinese city of Suzhou banned the use of boilers to burn coal and other highly polluting fossil fuels, encouraging their replacement with biomass boilers and other cleaner fuels (IRENA, forthcoming-c). Requirements to replace boilers address consumer inertia and the problem of distressed purchases. Many other cities across the world have also announced or begun to impose bans on the use of certain fossil fuels for heating (REN21, 2019). Such bans are often complemented by policies to support consumers and promote an equitable energy transition, such as subsidies for low-income households to reduce the cost of renewables-based heating.

Programmes and initiatives to raise awareness. Raising public awareness of renewable heating and cooling is essential for increasing consumer interest and engaging politicians and installers in facilitating and promoting renewable options. Public awareness programmes and initiatives are already common at all levels: regional (European Solar Days Campaign), national (Morocco's PROMASOL) and subnational (UNEP, ESTIF and GEF, 2015).

Cities can conduct public campaigns to raise awareness of renewables-based heating and cooling. Vancouver (Canada) organised public consultations and awareness campaigns on renewables-based heating to engage local communities in energy planning. Cape Town (South Africa) launched a marketing campaign in 2014 to raise public awareness and promote installations of solar water heaters (ICLEI and IRENA, 2018). Energy agencies can help facilitate partnerships to provide information and raise knowledge about renewables. In Barcelona (Spain), a local energy agency collaborated with the neighbourhood association and organised an education campaign "Porta a Porta" (Door to Door) to raise awareness of solar technologies, including solar water heaters (C40, 2011a). Additional examples can be found in subsequent chapters.

2.2.7. POLICIES TO INCREASE ENERGY EFFICIENCY

Measures are needed to support the uptake of efficient heating and cooling applications to deliver the same quality of end-use services while reducing energy demand in buildings, industry and agriculture. Such measures should provide information and incentives. They should also introduce regulations to improve the efficiency of buildings and processes and raise the performance of heating and cooling appliances.

Energy performance codes for buildings. Energy performance codes for buildings can be designed to support the uptake of renewable heat by requiring full or partial adoption of modern renewables or by requiring buildings to be compatible with new technologies. Such codes are relatively uncommon worldwide. By 2019, only 41 countries had implemented building energy codes mandating the deployment of renewable energy technologies and energy efficiency measures (REN21, 2020).

Building codes are widely used as a way of improving the energy performance of new and refurbished buildings. Standards are based either on energy performance or, increasingly, on emissions of greenhouse gases or carbon footprints. New regulations in France, for example, aim to account for supply chain emissions from buildings and from equipment manufacturing. When the requirements are demanding, they often can be achieved at a reasonable cost only if renewable options are deployed to meet the residual energy demand once energy efficiency measures have been applied. For example, all Scandinavian countries have coupled the shift to renewable heat with strict energy efficiency standards in new buildings using building code requirements. Finland's building code, for example, considers the carbon intensity of a building's heating supply (Hannon, 2015). On the local level, the signatory cities of the Covenant of Mayors for Climate and Energy have committed to municipal building codes that are stricter than those in force at the national level (REN21, 2019).

In buildings, financial programmes for energy efficiency retrofits can improve energy performance. Codes requiring specific levels of energy efficiency or renewable energy for new buildings – and for existing buildings awaiting refurbishment or alteration – are becoming increasingly common. Key measures include standards for retrofitting, refurbishment and renovation, and for more restricted energy consumption and emissions (IRENA, 2020a). Energy performance codes for buildings can shape heating and cooling loads by setting performance levels for building fabrics, imposing renewable energy requirements, and regulating the performance of fixed appliances such as lighting, heating, cooling and ventilation systems.

Properly monitored, performance codes provide the opportunity to take a census of the national or regional built environment to identify where future action should be focused. High-income countries generally have programmes in place, whereas most developing countries, where demand for new construction is greatest, have made only limited progress. The European Union requires all new buildings to be nearly zero-energy buildings by 2021, while building codes in Singapore apply a "zero energy building" standard to both new and existing construction (REN21, 2019). In addition, measures to decrease energy demand for cooling include the utilisation of nature-based and passive technologies (*e.g.* shade plants, green and white roofs, natural ventilation).

Minimum energy performance standards in industry. Minimum energy performance standards have been widely used to support the uptake of efficient appliances (Section 3.3.2). The combination of energy efficiency and renewable heat is equally important for decarbonising industrial heat, but the industrial sector generally has received much less policy attention. In industry, minimum energy performance standards and labelling schemes are effective policies to improve the energy efficiency of heating and cooling appliances and equipment. Overall, both renewable heat and energy efficiency face a complex and often overlapping set of economic and noneconomic barriers, which can be addressed through policy intervention. Examples are provided in subsequent chapters of this report.

03 Renewables-based electrification of heating and cooling

Renewables-based electrification refers to the use of efficient electric technologies powered by renewable electricity to provide heating and cooling services for buildings and industrial processes.[1] As such, the path to electrification based on renewable energy combines efforts to increase the share of renewables in the power sector with concurrent efforts to electrify heating and cooling using highly efficient appliances.

Electricity can power various end-use applications in residential and commercial buildings, through appliances that are sometimes already widespread, such as fans, refrigerators, water boilers, space heaters, air conditioners, cookers and heat pumps. Other applications include cold storage warehouses, process heat and steam for industrial applications.

In the access context, electric appliances can be used for efficient cooking and water heating, and for productive uses. This is true whether access to electricity is made possible by the arrival of the grid or by off-grid technologies such as solar home systems and mini-grids.

In both contexts, electrification enables the cost-effective decarbonisation of heating and cooling. It can also help integrate higher shares of variable renewable energy (VRE) within power systems. The electrification of heating and cooling has therefore been widely recognised as a viable path towards decarbonisation goals (IEA, 2020b; IRENA, 2020a).

The current status of renewables-based electrification of heating and cooling is discussed in Section 3.1, with equal attention devoted to the benefits of, and barriers to electrification. The remaining sections of the chapter discuss policies to address the identified barriers. Section 3.2 focuses on policies that address financial barriers; Section 3.3, technical and infrastructure-related barriers; Section 3.4, barriers related to consumer behaviour. Section 3.5 explores policies and measures to support the uptake of decentralised, off-grid solutions for heating and cooling in the access context.

1 Electricity from renewable sources can also be used to produce energy carriers, such as green hydrogen, which can be used in thermal applications. This type of "indirect electrification" is discussed in Chapter 4.

3.1. STATUS, BENEFITS AND BARRIERS

3.1.1. THE PATH TO EXPANDED ELECTRIFICATION OF HEATING AND COOLING IN BUILDINGS AND INDUSTRY

In 2019, more than 60% of the electricity consumed in buildings (excluding refrigeration) went for heating and cooling (Figure 3.1). Space heating in buildings consumed around 43 EJ, 13% (5.8 EJ) of which was from electricity. Water heating (17 EJ) and cooking (10.7 EJ) were also an important part of final consumption in buildings, with electricity providing around 17% of the energy needed. Electricity provided nearly all of the energy consumed for space cooling (6.7 EJ), which is set to increase over the next several decades (IEA, 2020b).

Cooling is already the fastest-growing end use in buildings, as electricity demand more than tripled between 1990 and 2018, rising to some 2 000 terawatt-hours (TWh) (IEA, 2020h). Without significant cultural and behavioural change, this figure could more than triple by 2050, with the residential sector driving nearly 70% of demand, much of it in a handful of emerging economies in the tropical and subtropical climates of India, Indonesia and China (IEA, 2018a, 2020b).

In industry, electricity supplied about 28% of the energy used in 2019 for many uses globally, but it provided less than 4% of industrial heat processes (IEA, 2020b). Electro-technologies that can be used to produce process heat include resistive heating in the glass and ceramic industry, induction and plasma torches in the steelmaking and metallurgic industry, and microwave ovens in agriculture (NREL, 2018; Nadel, 2019). Over the past decade, the electrification of steel production has become dominant in the United States, with about 70% of production using electric arc furnaces, thanks to iron scrap recycling (Nadel, 2019). Industries that currently use heat pumps for their low-temperature needs include paper and pulp, food and beverages, textiles, automobiles, and chemicals (Box 3.1).

Heat pumps could play a major role in the energy transition by electrifying heating and cooling in both buildings and industry. Yet they still meet only a small share of residential heat demand – around 5% in 2019 (IEA, 2020g). Worldwide, an estimated 38 million heat pumps were installed in 2019 (IRENA, 2020a) and global sales rose by nearly 10% between 2017 and 2018. Four-fifths of household heat pumps were installed in China, Japan and the United States (IEA, 2020g). In 21 European countries, some 12 million units had been installed as of 2018. That same year, ten EU countries accounted for 88% of the market, with France (where 275 000 units were installed), Italy (200 000) and Spain (120 000) being the leading countries (EHPA, 2019). According to IRENA's Transforming Energy Scenario, heat pumps will have to exceed 334 million units installed in order to achieve the energy transition (IRENA, 2020a).

BOX 3.1. CORPORATE PRACTICES FOR THE TRANSITION TO RENEWABLE HEATING AND COOLING

While an increasing number of companies have turned to renewables for their electricity supply – with some even going up to 100% renewables – fewer have managed to transition to renewables for their heating and cooling operations. To date, companies cannot easily procure renewable heat through external sourcing models such as the case for renewable electricity, i.e. renewable energy certificates and corporate power purchase agreements. In light of the challenges to integrating the direct use of renewables into industrial processes, more and more companies are looking at electrifying various end-uses and applications, including for higher-temperature processes.

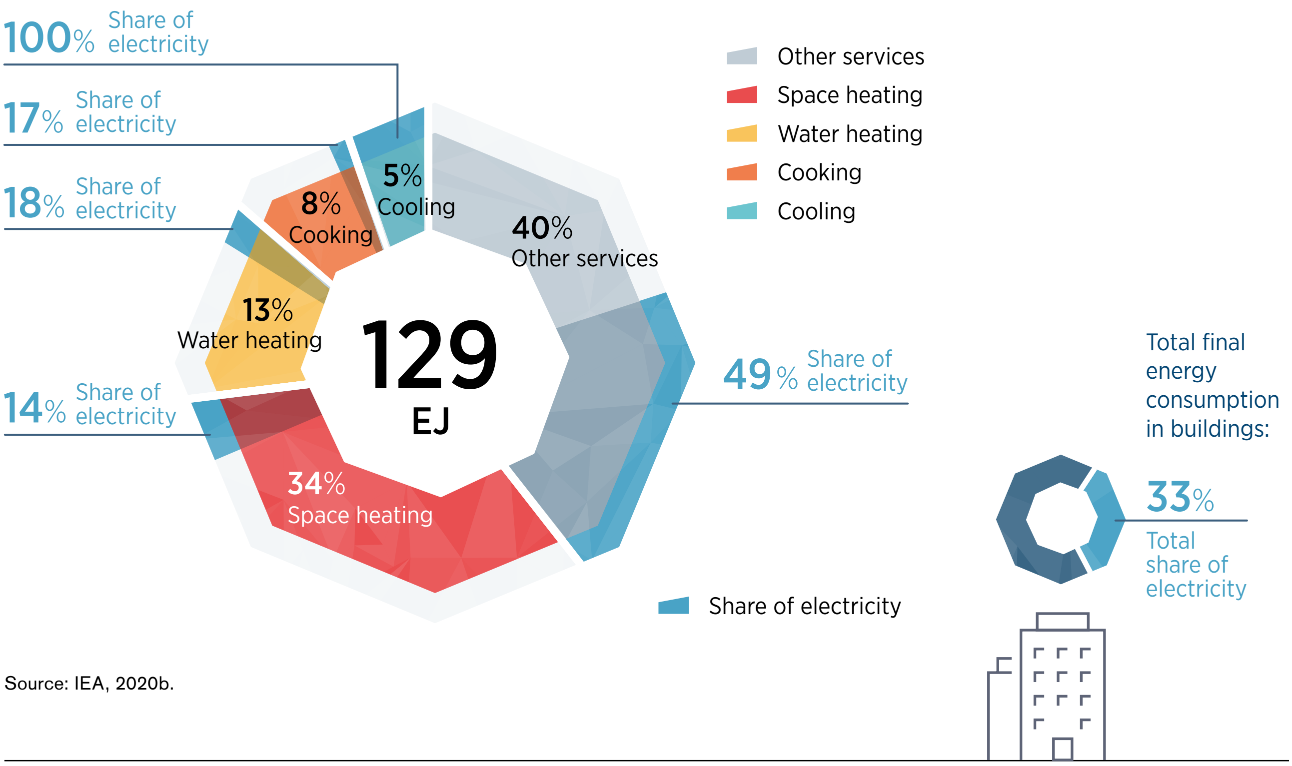
The **TINE Group's dairy facility in Bergen, Norway** is one of the first dairies to have already achieved 100% renewable energy for all production processes, including through electrified heat pumps and cooling machines to supply heating and cooling requirements at all temperatures.

Combined with waste-heat recovery, heat pumps offer significant cost reductions, as Kraft Foods in the United States found when it captured waste heat from refrigeration systems and used it to heat water. As a result, the company has saved more than 14 million gallons of water and USD 260 000 annually.

As companies are increasingly decarbonising their heating and cooling operations, several collaborative initiatives have recently emerged in support, such as the Renewable Thermal Collaborative and the Climate Group's EP Cooling Challenge. These initiatives convene industrial players to exchange on best practices and incentivise other businesses to commit, to pool demand and provide policy recommendations that can accelerate the deployment of renewable heating and cooling in companies.

Sources: IRENA Coalition for Action, forthcoming; IRENA, 2018a, 2019c

Figure 3.1. Global share of electricity in buildings by service, 2019



Source: IEA, 2020b.

3.1.2. DRIVERS OF THE ELECTRIFICATION OF HEATING AND COOLING WITH RENEWABLES

Renewables-based electrification supports quick and substantial reductions in carbon emissions. Harnessing ambient heat with heat pumps, for instance, allows for the highly efficient use of electricity for heating (Box 3.2). In addition, electric appliances involve no fuel combustion, so residential buildings have better air quality, a substantial health benefit.

In addition, as the costs of renewable power generation continue to fall, existing infrastructure can be leveraged to further decarbonise heating and cooling in a cost-efficient manner. Moreover, the electrification of heating and cooling can help integrate higher shares of VRE through the use of heat pumps and electric boilers (combined with thermal storage tanks for hot water or ice – see Box 2.1) to provide demand-side flexibility in power systems.[2] Electrified heating and cooling can also aid load shaping by allowing the demand profile to better match variable supply, accommodating both high and low VRE outputs, storing energy, and providing system services. For example, it is possible to rely on a building's thermal inertia and thermal storage to shift demand without affecting the inhabitants' comfort levels.

Industrial processes can also be optimised to meet the power system's need for flexibility. An example is the concept of "virtual battery" for aluminium production process developed by Trimet Aluminium SE (Germany) and Energia Potior Ltd. (New Zealand). Aluminium production requires a constant supply of electricity, and any fluctuation can have dire consequences. The "virtual battery" concept relies on adjustable heat exchangers able to maintain the energy balance in each electrolysis cell despite shifting power inputs. Trimet's trials indicate that the technology can rise or fall by 25% in electricity use, creating a virtual storage capacity of about 1 120 megawatt hours (IRENA, 2019d; Aluminium Insider, 2017; IEA, 2017a).

Finally, electric heating and cooling services can be provided through centralised systems (*e.g.* district heating and cooling, see Chapter 8) or decentralised systems by combining heat pumps with small-scale rooftop photovoltaic power plants. In the latter case, electricity produced from the panels can be used to meet the cooling load in summer, thereby lowering household expenses as well as demand on the power grid. In the former case, heating and cooling services can be paired with hot or cold storage to make the power system more efficient and flexible (Box 3.3). High-density cities have adopted district cooling systems that use electrically chilled water integrated with cold storage. Examples can be found in many parts of the world, from North America (*e.g.* Boston in the United States) to the Middle East (*e.g.* Dubai in the United Arab Emirates) (IRENA, 2019f; Asian Development Bank, 2017).

Successful electrification of heating and cooling using renewables-based power will hinge on the removal of several barriers.

2 In the power systems of the renewable energy era, VRE is expected to dominate the supply side. VRE generation poses increased operational challenges and calls for more system flexibility – defined as the ability of the power system to match demand with supply at all times. Power system flexibility can also be achieved using demand-side resources, such as electric appliances, by adapting their output to varying power system conditions.

BOX 3.2. HEAT PUMP EFFICIENCY

Heat pumps use electricity to transfer thermal energy from a low-temperature source to a higher-temperature sink by means of a process fluid. Depending on the use, heat pumps can provide both refrigeration/chilling and heating services. With capacities between 1 kW and 10 MW, current heat pumps can provide heating and cooling to individual houses or entire districts. In industrial applications, they can be used at temperatures from below -100°C to above 150°C.

Ambient heat can be captured from the air, bodies of water or from the ground.[a] Air-source, water-source and ground-source units differ widely in their installation costs and efficiency. Ground-source heat pumps, in general, are more efficient than other varieties, although they necessitate higher upfront investment in installation and equipment to capture heat from below ground. Most of the additional installation cost for a ground-source heat pump derives from the necessary drilling and from placement of the heat exchanger loop in the ground.

The energy efficiency of heat pumps can be measured in several ways. Common ways are an instantaneous performance index called the coefficient of performance (COP) and the seasonal performance factor (SPF).

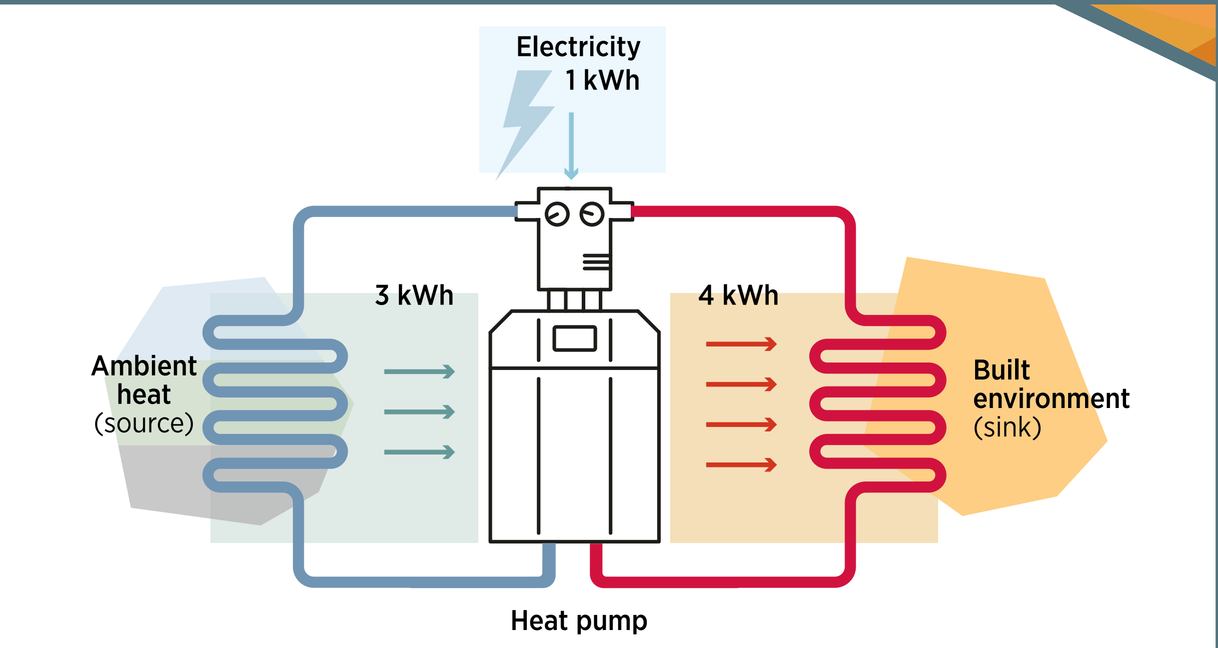
The first is the ratio of the energy output (the heat flow) to the energy input (the electricity consumed) at a given moment. A heat pump with a coefficient of performance of four, for example, is supplying 4 kWh of heat while consuming only 1 kWh of electricity. The 3 kWh of difference comes from the ambient heat extracted from the heat source (Figure 3.2). In comparison, traditional electric resistance heating systems can provide at best one unit of thermal energy for each unit of electricity consumed.

The seasonal performance factor is the seasonal average of the coefficient of performance, expressing the ratio of the total heat supplied to the electricity used by the heat pump over a year. The two measures depend on a number of factors, including the difference in temperature between the heat source and the heat sink, which depends on climatic conditions, as well as building efficiency and temperature requirement for the heat distribution system.

The typical seasonal performance factor has increased steadily since 2010. In well-insulated buildings, a ground-source heat pump can reach factors of 4.5 or higher, especially in the mild climates found in the Mediterranean and southern China.

a Aerothermal, hydrothermal and geothermal energy captured by heat pumps is considered renewable energy in some jurisdictions (including the European Union), and is counted towards the achievement of renewable energy targets (European Commission, 2019a)

Figure 3.2. Example of a heat pump with a coefficient of performance (COP) of 4



Sources: IEA-ETSAP and IRENA, 2013; IEA, 2020g

BOX 3.3. ELECTRIC HEATING USING EXCESS RENEWABLE ELECTRICITY

In many cases, renewable heat production and storage can be used to reduce curtailment of surplus renewable generation. Examples include cities in Denmark, Germany and Scotland.

In 2015, the city of Aarhus (Denmark) expanded the capacity of a combined heat and power plant by adding an 80 MW electric boiler and a 2 MW electric heat pump (expandable to 14 MW) to provide district heating to the neighbourhood. The electric boiler, heat pump and hot storage use excess wind generation in western Denmark, which is typically greatest in the winter months, when the demand for heat is greatest (IRENA, 2019g).

In Berlin (Germany), Vattenfall has connected Europe's largest power-to-heat facility to the district heating grid at its Reuter West power plant. The purpose of the 120 MW power-to-heat unit is to produce and store heat from excess electricity generated from renewable energy sources. The installed capacity of 120 MW is equivalent to about 60 000 household water boilers (DBDH, 2019).

In Scotland's Orkney Islands, a power-to-heat project is fuelled by wind. Households are provided with energy efficient heating devices that draw excess power generated by the community-owned wind turbine, which otherwise would have been curtailed. The household heating devices are connected to the internet and switched on when the wind turbine receives a curtailment signal (IEA, 2018b).

3.1.3. BARRIERS TO ELECTRIFICATION BASED ON RENEWABLE POWER

Renewables-based electrification solutions face cost and financial barriers, in addition to challenges related to technology, the infrastructure market, and regulations.

Cost and financial barriers. Electric solutions such as domestic heat pumps may face relatively higher upfront costs compared with fossil fuel options, thus discouraging consumer uptake. Operational costs may also be a barrier in specific contexts, depending on the price of electricity, especially compared with fossil fuels (Gudmundsson, Thorsen and Zhang, 2013).

The economic attractiveness of electric appliances is related to their payback period, which is context-specific and can vary according to the technology, the fossil fuel alternative and the presence or absence of support schemes. In industry, the economic feasibility of electric heating and cooling processes may be affected by low fossil gas prices (Nadel, 2019).

Moreover, split incentives can compound the problem of the high upfront capital costs of technologies such as heat pumps. In rental buildings, for example, the building owners who invest in the technologies are generally not the ones benefiting from the energy savings.

This underscores the need for policy support to address the high upfront costs of installing efficient electric systems (Chapter 2) and to limit their operating costs in comparison with other sources of energy (Section 3.2).

Technical and infrastructure-related barriers. The electrification of heating and cooling increases the strain on the infrastructure that supplies and transports electricity. Countries with cold winters or hot summers face particular challenges in electrifying high demand if they do not invest in expanding or upgrading their power system's infrastructure, including additional generation capacity. In France, for example, the typical peak demand for electricity and gas combined is four times greater in winter than in summer (IRENA, 2019c). In the countries of the Gulf Cooperation Council, the peak summer demand for electricity for air conditioning can be twice the off-peak demand, and three times the demand in winter (Al-Badi and AlMubarak, 2019). These energy demands can be mitigated by ensuring that equipment and the built environment meet strong energy efficiency standards, and by changes in consumer behaviour, but long-term solutions to the problem of peak demand will require additional measures, research and investment (IRENA, 2019c).

In addition to increasing generation capacity to meet peak demand, the grid must be able to deliver the electricity produced. In particular, the electrification of industrial loads or the full electrification of buildings in given areas may require upgrades of the transmission and distribution networks (Hopkins *et al.*, 2017; Mullen-Trento *et al.*, 2016). While grid operators may already be equipped to deal with increased load, system planners and policy makers must consider its impacts and associated costs. In the absence of a properly developed power system, extensive electrification of heating and cooling could create constraints on the network, halting further deployments of electrified heating and cooling technologies. Proper planning and investment in infrastructure are required, along with the uptake of digital monitoring and control technologies and support for research, development and demonstration projects. These are discussed in sections 3.3.1 and 3.3.2.

Moreover, problems linked with appliances can cause reputational damage. For example, from the 1970s to 1990s, the reputation of heat pumps in Sweden suffered because of poor performance of products (Johansson, 2017). Besides, heat pumps may not be able to meet the heating requirements of very poorly insulated buildings; their effectiveness relies on the thermal performance of the buildings in which they are installed.

Market and regulatory barriers. The electrification of heating and cooling can be hindered by various market and regulatory barriers. This includes the absence of price signals for demand-side flexibility, outdated power market design and an uneven playing field with fossil fuels.

The traditional electricity tariff design provides no price signals for system-friendly electricity consumption or demand-side flexibility. Demand is often viewed as passive and inflexible. But flexibility from the consumer side – which will be crucial in energy systems characterised by sector coupling and large-scale power demand for heating and cooling – is not yet adequately incentivised. Overcoming those barriers will require a rethinking of how electricity tariffs are structured to support the electrification of heating and cooling. This topic is discussed in Section 3.4.1.

In addition, the traditional design of power markets may impede the increased deployment and integration of VRE, which is central to renewables-based electrification (IRENA, 2020c). Minimum volume requirements for participation in wholesale power markets can hamper integration into the system of smaller-scale power consumers, including electric heating and cooling applications. Often, small-scale actors do not have access to auxiliary services markets. To promote and facilitate integration power markets must be redesigned, a topic discussed in Section 3.4.2.

3.2. POLICIES TO ADDRESS COST- AND FINANCE-RELATED BARRIERS

Specific policies are needed to overcome barriers tied to upfront (capital) costs and financing costs (as discussed in Chapter 2), as well as operating costs – notably the efficiency of appliances (Section 3.3.2) and the price of renewables-based electricity.

At the generation level, policies that support deployment (*e.g.* competitive procurement) could be designed to reduce the price of renewables-based electricity.[3] Other measures can be considered to reduce electricity prices at the retail level.

In some contexts, increased electrification may cause electricity prices to rise, particularly if new consumption occurs during the same peak periods as other electrical loads. But if new consumption is shifted to off-peak hours, using time-of-use tariffs, for example (Section 3.4.1), electricity infrastructure would be more cost-effective, and overall operating costs might fall. A German case study found that the use of devices to shut off heat pumps during periods of peak demand, if homes were sufficiently heated, could reduce peak loads and associated costs for end users by 25% (Romero Rodríguez *et al.*, 2018). Shifting consumption to off-peak hours can be achieved through the use of thermal storage, including hot water tanks and the thermal inertia of well-insulated buildings, among other forms of storage.

Another option is to provide preferential, discounted tariffs for the user of electric appliances. Hungary has adopted the "H tariff", a preferential tariff for the electricity consumption of renewables-based heating equipment in buildings, including heat pumps. The tariff is available only in the heating season (Nádor, Kujbus and Tóth, 2019). One weakness of preferential tariffs is the risk of cross-subsidies and of exacerbating energy poverty (Box 2.4).

Finally, making electric solutions cost-competitive with fossil fuels options in buildings and industry will require policy makers to address certain market barriers, as explored in Section 3.4.2.

3 Specific design elements of auctions are analysed in IRENA's series of studies of auctions: https://www.irena.org/policy/Renewable-Energy-Auctions. For self-generation, corporate sourcing can be used (IRENA, 2018a).

3.3. POLICIES TO OVERCOME TECHNICAL AND INFRA-STRUCTURE-RELATED BARRIERS

Policies that overcome technical and infrastructure-related barriers include long-term planning, policies to attract investment in infrastructure, and support for innovation, research, development and demonstration projects. Such policies are discussed in Chapter 2. In addition, technical barriers can be addressed through measures to support the uptake of digital monitoring and control technologies, and through regulations to encourage energy efficiency.

3.3.1. MEASURES TO ENCOURAGE THE UPTAKE OF DIGITAL MONITORING AND CONTROL TECHNOLOGIES

Thermostatically controlled loads (air conditioners, heat pumps, water heaters, refrigerators and freezers) have a great potential for servicing the system. Exploiting that potential requires smart meters, sensors and digitalisation. The digitalisation of thermal appliances is supported chiefly through research and development programmes and assistance to startups, but as digital devices are deployed to control and monitor electrified loads, appropriate regulations must be in place covering data protection, data ownership and grid codes. Equally important are communications procedures, standards and protocols to allow the rapid and responsive exchange of data between devices. At the same time, incentives or funds are needed to support the widespread adoption and use of smart meters and appliances. For some digital devices – notably smart meters – government mandates may be necessary to force the replacement of outdated devices.

Advanced digital devices bring new opportunities to shape the load imposed by heating and cooling systems in a cost-effective manner. In the Isles of Scilly (United Kingdom), air-sourced heat pumps and batteries are installed and connected to digital solutions for home energy management, keeping supply and demand in balance. The installation was made possible by an investment of GBP 10.7 million (USD 13.2 million), which doubled the installed renewable energy capacity on the islands (IRENA, 2019d).

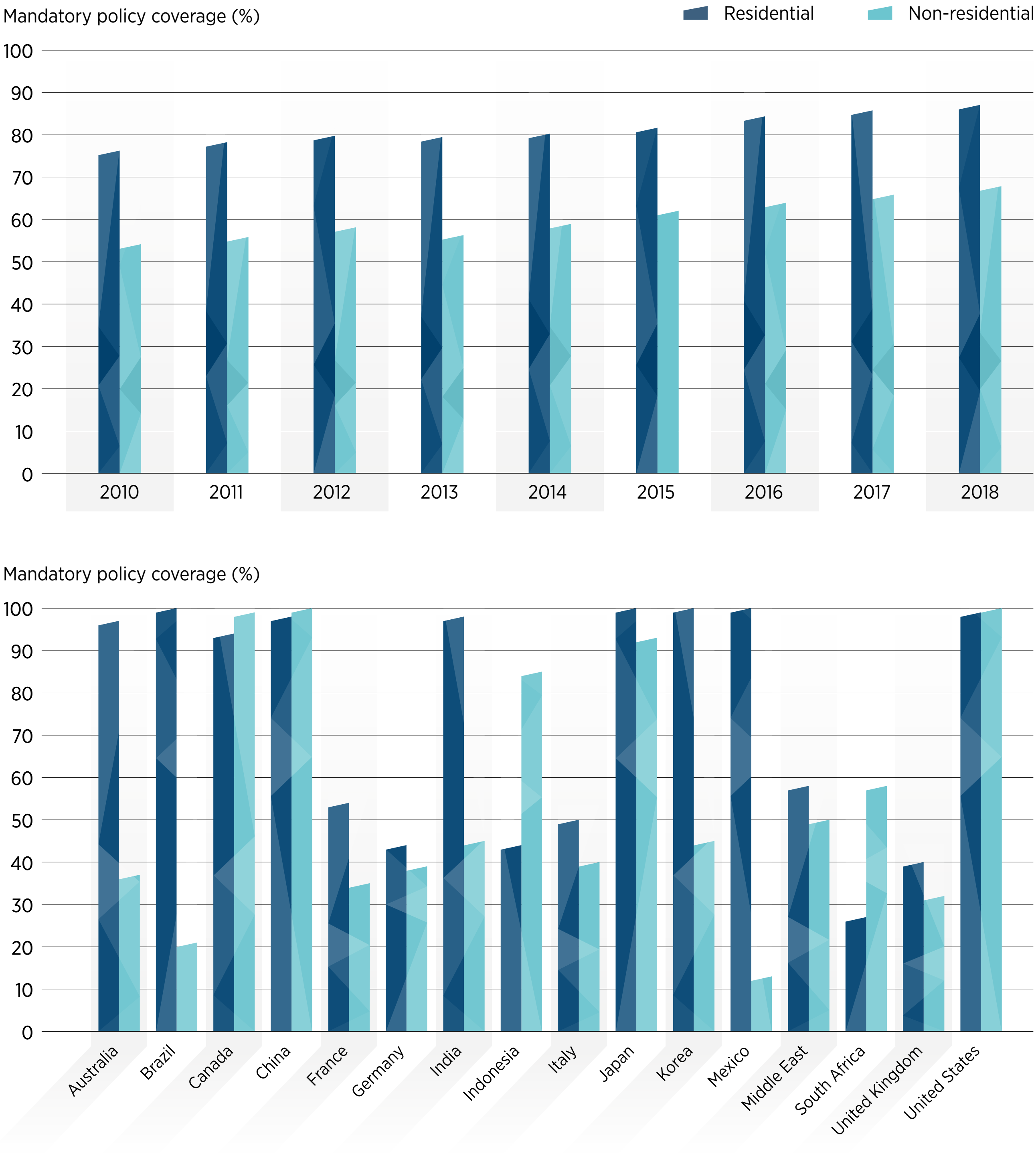
Digitalisation offers solutions for self-consumption as well. In Uruguay, the Lavadero de Lanas Blengio, a wool-washing plant, installed a 1.8 MW wind turbine for its own use. The factory consumes large amounts of hot water, which had been heated by two steam boilers fueled by oil and wood. An electric boiler optimised to follow power generated by the wind turbine is now operational, thanks to a robust and reliable data network. Using continuous data collection, an adaptive control strategy forecasts generation. By the end of 2019 the system had been running for several months, with over 100 MWh consumed per month without resorting to fuel oil or wood (IRENA, 2020d; Castelli and Garmendía, 2019).

3.3.2. MEASURES TO ENCOURAGE THE UPTAKE OF EFFICIENT APPLIANCES

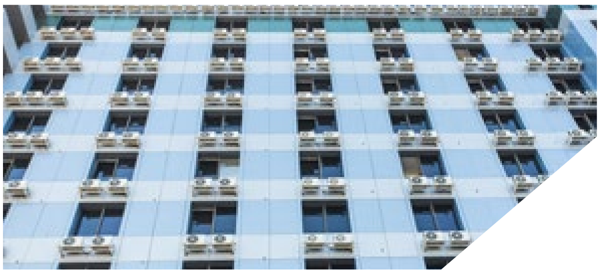
Measures to increase efficiency can help overcome some of the technical and infrastructure barriers of electrifying heat (in addition to barriers related to operating costs). More efficient appliances lower the demand for electricity by delivering the same amount of heat from a smaller amount of power, thereby reducing peak loads and the need to build new generation capacity. Policies to increase the efficiency of buildings are discussed in Chapter 2; this section focuses on policies that support the uptake of efficient appliances.

Minimum energy performance standards (MEPS) are the principal policy mechanism for driving appliances and markets towards higher levels of efficiency. In 2017, MEPS covered energy use for more than 80% of residential and 65% of commercial space cooling in the world, reflecting policies implemented in major cooling markets, such as Australia, Japan and the United States (Figure 3.3).

Figure 3.3. Global energy use for space cooling covered by MEPS, 2010-18 (top) and in selected countries, 2018 (bottom)



Source: IEA, 2019g.



In some countries where policies were implemented early and the turnover rate of equipment is high, almost all energy use for space cooling is covered by MEPS. Australia provides an example of a country with a warm climate and an extensive history of implementing and strengthening MEPS for air conditioners (Box 3.4). It should be noted that MEPS may not always realise the full potential of currently available technology to deliver efficiency gains. Specifically, the minimum levels of energy-efficiency performance may fall well below that provided by the best available technology, or even below the market average.

Efficiency can also become a competitive advantage if properly marketed, as demonstrated by Japan's "Top Runner" programme (Box 3.5).

BOX 3.4. AUSTRALIA'S EQUIPMENT ENERGY EFFICIENCY PROGRAMME

Australia's Equipment Energy Efficiency (E3) programme applies minimum energy performance standards (MEPS) and energy rating labels to a range of air conditioners sold in Australia and New Zealand. Energy labels have been in place since 1987 and MEPS since 2004, with several subsequent revisions. These policy interventions, together with a competitive market environment, have resulted in significant improvements in air-conditioners' efficiency.

At the end of 2018, Australia extended its MEPS to cover larger equipment and single-ducted portable equipment, revising the underlying efficiency metrics and amending the energy label. Australian regulation also requires air conditioner labels to indicate whether the air conditioner has demand-response capability. Such capability means that the air conditioner meets the technical requirements needed to participate in an electricity demand management program. This means that its operation can be remotely controlled by a third party to provide demand-side flexibility.

Source: E3 Program, 2015; Commonwealth of Australia (Department of the Environment and Energy), 2018

BOX 3.5. JAPAN'S TOP RUNNER PROGRAMME

Introduced in 1999, Japan's Top Runner Programme consists of a set of energy-efficiency standards for energy-intensive products. The programme involves 23 product categories characterised by high energy consumption, widespread use or a substantial scope for improving energy efficiency.

Energy-efficiency targets are set to be achieved within a certain number of years on the basis of the most efficient model on the market – the so-called Top Runner. A Top Runner label is bestowed on products that meet energy-efficiency targets; those that do not are labelled differently. Top Runner appliances sell well, and companies compete to make ever more efficient models so as to earn the Top Runner label.

The Ministry of Economy, Trade and Industry (METI) is allowed to disclose the names of companies that fail to meet targets, as well as to issue fines. To date, targets have been systematically met or exceeded. In Japan, manufacturers are the biggest supporters of the Top Runner programme, as they are directly involved in setting the targets.

Source: Future Policy, 2020.

3.4. POLICIES TO ADDRESS MARKET AND REGULATORY BARRIERS

Policies and measures to address market and regulatory barriers include restructuring electricity tariffs to enable increased electrification, and redesigning power markets to enable electrification using higher shares of variable renewable energy while ensuring that consumers interact with the system.

3.4.1. RESTRUCTURING TARIFFS TO SUPPORT ELECTRIFICATION

To incentivise users to adopt electric appliances for heating and cooling, the structure of electricity tariffs must be reexamined.

Applying time-of-use (ToU) tariffs. In many countries, electricity tariffs are designed to reduce peak loads by charging higher tariffs during hours of peak demand, when heating or cooling is most needed.

ToU tariffs can support flexible electric heating and cooling by exposing consumers to cost-reflective price signals. ToU tariffs can incentivise customers to adjust their electricity consumption voluntarily (either through automation or manually) to reduce their energy expenses. As the name indicates, the price signals vary with time, depending on the season, time of day or day of week (weekdays, weekend or holidays), and they are determined based on system operators' models or on short-term wholesale market price signals. Retailers or distributors billing consumers with a ToU tariff require smart meters to monitor consumption and match it with the tariff (IRENA, 2019h).

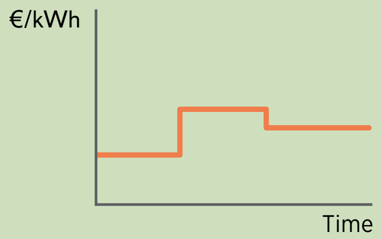
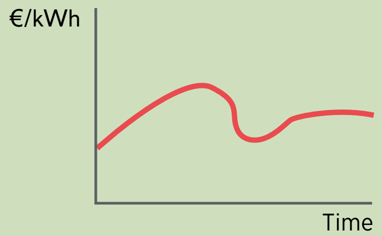
ToU can be static (with tariffs determined in advance) or dynamic (with tariffs determined close to real time, based on actual system conditions). A combination of static and dynamic tariff structures can be used, such as variable peak pricing, with the periods defined in advance. Table 3.1 provides an overview of time-based demand-response pricing options.

ToU tariffs can incentivise electrification if end users have the option of shifting their heat load so as to benefit from lower electricity prices. The availability of thermal storage greatly facilitates load shifting (see Box 2.1). ToU tariffs can also provide an incentive for investment in electrification in industry in cases where electric processes can be shifted to take advantage of the times when electricity prices are lowest.

One example of how ToU tariffs can positively affect energy use for heating and cooling comes from the U.S. state of Illinois. Consumers there were given the opportunity to participate in an hourly pricing programme in which electricity prices reflected the actual electricity load. Consumers were incentivised to pre-cool their residences in the early morning hours, when prices are lower, setting the cooling systems to an idle mode when prices are higher. The programme has allowed consumers to save about 15% on their electricity bills (USD 15 million from 2007 to 2016) (IRENA, 2019h).

Most households in France already benefit from ToU tariffs, which incentivise consumers to heat water during off-peak hours. Over the course of five decades, the deployment of electric water heaters, together with simple on/off controls, encouraged a gradual shift in hot-water demand to off-peak periods, progressively flattening the demand curve (IRENA, 2019i; Béjannin *et al.*, 2018).

Table 3.1. Examples of time-of-use tariffs

Type of tariffs	Illustrative graphical representation	Features
Static ToU pricing		This typically applies to usage over large time blocks of several hours, where the price for each time block is determined in advance and remains constant. It can use simple day and night pricing to broadly reflect on- and off-peak hours, or the day can be split into smaller segments, allowing several slack periods. Seasonality can also be taken into account.
Dynamic ToU pricing		Prices are determined close to real-time consumption of electricity and are based on wholesale electricity prices. Electricity prices are calculated based on at least hourly metering of consumption, or with even higher granularity (*e.g.*, 15 minutes). Such tariffs are mostly composed of the wholesale price of electricity plus a supplier margin.

Source: IRENA, 2019h.

Redesigning progressive tariffs. Some jurisdictions (*e.g.* Italy and the United States) apply progressive tariffs, which rise with each additional tier of electricity consumption. The objectives of progressive tariffs in some contexts are to encourage energy efficiency and reduce electricity waste. Where electricity is subsidised, progressive schemes can be used to ensure that subsidies are limited to lower-income households. But even so, progressive tariffs can create a disincentive to electrification.

Designing progressive tariffs so as not to discourage electrification requires adopting a systematic and holistic socio-economic perspective. In the summer of 2016, the government of the Republic of Korea reformed its progressive tariff in response to high electricity bills for air conditioning. The government introduced incentives and lowered tariff rates for households that made eco-friendly investments in energy. Before the reform, the progressive residential power tariff had had six price stages (per kWh), the final one being eleven times more expensive than the first. Since 2017, the tariff structure has had only three stages, the top one being three times more expensive than the first (Kim and Eunju, 2017; Kim, 2018; So, Jo and Yun, 2020).

Redesigning demand charges. In other jurisdictions, demand charges are levied on commercial and industrial users' electricity bills, based on the highest demand in any given time period. Demand charges are usually designed to reflect transmission and distribution system costs imposed by a specific consumer (Wood, *et al.*, 2016). Demand charges may disincentivise electrification if potential consumers foresee a peak hourly demand higher than the typical peak.[4]

Redesigning demand charges hand-in-hand with electrification policies – in ways that account for actual system costs while introducing a time value to the demand charge – could be beneficial for the deployment of electricity solutions (Deason *et al.*, 2018).

3.4.2. REDESIGNING POWER MARKETS TO ENABLE ELECTRIFICATION WITH HIGHER SHARES OF VARIABLE RENEWABLE ENERGY

Among the advantages of electrification is the prospect of expanding the shares of flexible load in the power system, thereby enabling greater deployment of VRE. Today's power markets, however, generally treat demand as passive and inflexible. They do not create the price signals that incentivise consumers to shape load according to system resources and needs (IRENA, 2020c).

To become more system-friendly, the operations of the electric heating and cooling load should be governed by explicit demand-side management schemes.[5] Such schemes allow consumers to participate, on their own or through aggregators, in power markets (wholesale, intraday, ancillary or capacity). They call for new market regulations and grid codes.

For example, minimum-volume requirements as a condition for trading electricity in the wholesale power market may not be consistent with electric heating and cooling applications. This could be solved by either lowering the required minimum volume or allowing aggregators to participate (Agora Energiewende, 2016). Overcomplicated permitting and prequalification requirements for trading also impede participation, especially for small consumers. Lighter administrative burdens could ease entry into power markets. Finally, the regulation of power markets prevents the participation of certain technologies or small consumers; if this changes, the full participation of all power grid assets would yield the best possible outcome for the system (IRENA, IEA and REN21, 2018).

Although heating and cooling appliances can offer limited system services to the grid in some cases, aggregated loads could operate in the market as a flexible resource. Aggregators should therefore be allowed to operate in the wholesale markets. For instance, by 2017, the Swiss company Tiko was able to connect more than 10 000 electric heat pumps and hot water boilers, providing flexibility to the Swiss national grid (Geidl *et al.*, 2017).

Finally, it should also be noted that the participation of heating and cooling technologies in the power market, with the consequent profits and savings for firms, institutions and households that deploy renewables-based heating and cooling technologies, can lower their operation costs and improve their business case, making their deployment more attractive, particularly in industry.

Table 3.2 provides a summary of barriers and policies for renewables-based electrification.

4 Peak demand for space and water heating may not coincide with peak system demand, so these peaks may not be directly related to actual system costs, possibly posing undue burdens on consumers.

5 These differ from implicit demand response, as they are the voluntary changes consumers make in their electricity consumption patterns in response to ToU tariffs, as discussed in the previous section.

Table 3.2. Barriers and policies for renewables-based electrification

Targeted barriers	Policies	Examples	Comments
High upfront costs to purchase and install electric heating appliances; difficulty accessing finance	Grants/capital subsidies	**New Zealand**'s Warmer Kiwi Homes program	Feasibility depends on competing budget requirements. Care must be taken to avoid the risks of cross-subsidisation and aggravation of energy poverty.
	Loans	**Germany**'s Market Incentive Programme	
	Rebates	Residential rebate programme in **Boulder, Colorado** (United States)	
High operational costs	Subsidies for electricity	**China**'s Clean Winter Heating in Northern Regions pilot program	Targeting subsidies to low-income households helps reduce the cost of the policy while contributing to social equity.
	Heating tariffs	**United Kingdom**'s Renewable Heating Incentive (non-domestic scheme)	Payment per kJ requires a specific metering device for heat consumption.
High operational costs for large power consumers	Redesigning demand charge		Feasibility depends on infrastructure capacity to deal with peak demand.
High operational costs, peak demand issues, network constraints	Time-of-use (ToU) tariffs	**Illinois** (United States)	ToU needs to be adjusted to evolving system conditions.
	Redesigning progressive tariffs	**Republic of Korea**	Feasibility depends on capacity for cost recovery. Attention needed in policy design to avoid energy poverty aggravation.
Network constraints and peak demand issues	Support for digitalisation (assistance to start-ups, regulation, research and development, etc.)		Effectiveness will depend on the relevance of given technologies to the country context.
Technical barriers to quality resulting in low consumer confidence	Quality standards including minimum energy performance	**Australia**'s MEPS program	There is strong evidence of international success. MEPS should be adjusted to capture technological advancement.
	Labelling	**Japan**	Labelling definition should be adjusted to capture technological advancement.
Fossil fuel–oriented regulatory framework	Redesign of power markets	**Spain**	Effort is part of a larger reform of power market for the renewable energy era.

3.5. POLICIES TO EXPAND ELECTRICITY ACCESS WITH DECENTRALISED RENEWABLES

Modern heating and cooling technologies, in addition to services such as refrigeration and electric cooking, are inaccessible to many people because they lack access to reliable electricity and have to rely on fossil fuels (*e.g.* kerosene) and the traditional use of biomass such as charcoal and fuelwood. Renewable off-grid technologies and appliances are helping bridge that gap, having already provided access to electricity to close to 500 million people (Lighting Global and GOGLA, 2020).

Designed to accommodate energy-constrained environments, the latest high-performing appliances can be used in both off-grid and weak-grid contexts.[6] Off-grid appliances are compatible with direct current (DC) systems but include alternating current (AC) appliances equipped with inverters. Appliances like DC refrigerators, electric pressure cookers and fans have positive impacts on the health, income and livelihoods of smallholder farmers and households in contexts of low energy access (Efficiency for Access Coalition, 2019; Lighting Global, ESMAP and Dalberg Advisors, 2019).

3.5.1. STATUS AND BENEFITS OF DECENTRALISED ELECTRIC-POWERED HEATING

Despite having access to electricity, 1.8 billion people still use biomass to cook, out of a total 2.8 billion people without access to clean cooking (IEA, IRENA, UNSD, World Bank and WHO, 2020; MECS, 2020). Historically, electricity was not considered a viable cooking fuel because of its high cost, the inefficiency of appliances such as hotplates, and the difficult behavioural changes required (Batchelor *et al.*, 2019; Couture and Jacobs, 2019). Only 8% of households in developing countries use electricity as their primary cooking fuel (IEA, 2017b).

But as the costs of appliances and solar photovoltaic power have declined and become cost- and time-competitive with fossil fuels, electric cooking could become a viable, clean option. Since 2016, the cost of solar modules and lithium-ion batteries has decreased by 30–50%, and electric cooking appliances have become more efficient. The average peri-urban or urban African household spends USD 150–350 on charcoal or kerosene annually, while electric pressure cookers cost USD 22–110. (Efficiency for Access Coalition, 2019; Couture and Jacobs, 2019).

As with cooking, the productive use of heat for smallholder farmers has been dominated by biomass (GIZ, 2013). Heat

6 “Weak grid” refers here to distribution grids highly sensitive to fluctuations in load (IRENA, 2018b).

is required to reduce post-harvest losses to contamination and spoilage through milk pasteurisation, food drying, and sterilisation (FAO, 2000). Electrified agro-processing can help smallholder farmers transform their raw produce into more valuable products, thus increasing their income (Lighting Global, ESMAP and Dalberg Advisors, 2019; FAO, 2015).

There is little to no data about the potential of off-grid appliances to meet the heating needs of smallholder farmers. This is partly because using off-grid appliances for heating is costly for smallholders and solar-powered units are not yet on par with diesel units (Lighting Global, ESMAP and Dalberg Advisors, 2019). Other renewables, such as sustainable bioenergy, geothermal and solar thermal (see Section 6.6.), may be better positioned to address this gap (IRENA, IEA and REN21, 2018; FAO, 2015).

3.5.2. STATUS AND BENEFITS OF DECENTRALISED ELECTRIC-POWERED COOLING

The 800 million who live without access to electricity can be used as a proxy for the cooling-access gap worldwide (IEA, IRENA, UNSD, World Bank and WHO, 2020). The practical gap is even wider, however, because low-income consumers with energy access do not have the capital to own and maintain cold chain technology. The nutrition, income and health of over 1 billion rural and urban poor living in the 52 most vulnerable countries are at risk because they lack access to cooling (Sustainable Energy for All, 2019).

Climate change has rendered access to sustainable electric cooling a pressing challenge in sub-Saharan countries across a number of key sectors (Sustainable Energy for All, 2019). In Africa, households and smallholder farmers could save USD 4 billion worth of food annually through the use of proper cooling technologies and cold chain management (FAO, 2016).

The cost of obtaining and using refrigerators and cold storage prevents access to these cooling benefits (Efficiency for Access Coalition, 2019). As a result, of the 10 million smallholder farmers in sub-Saharan African who require cooling services, only 3.6 million have access to electricity, while 6.26 million can not afford cooling products (Lighting Global, ESMAP and Dalberg Advisors, 2019). At the household level, only 17% of Africans have refrigerators (Efficiency for Access Coalition, 2019).

A lack of cooling in health facilities in sub-Saharan Africa poses a huge threat to the provision of preventive and curative services (Gavi, 2019; WHO, 2015). One billion people in developing countries are without access to adequate health care services due to energy poverty (WHO, 2015). Data from low-energy-access countries show the importance of cooling services in healthcare facilities: 28% of electrified health centres in these countries use electricity for air cooling systems while 40% use it for vaccine refrigeration (IEA, IRENA, UNSD, World Bank and WHO, 2020).

3.5.3. BARRIERS TO DECENTRALISED ELECTRIC-POWERED HEATING AND COOLING

Cost and financial barriers. Critical to access is ensuring that electricity and heating and cooling technologies are affordable to low-income consumers. Many last-mile customers cannot pay the high upfront costs of off-grid solutions and electric appliances (Efficiency for Access Coalition, 2019). For example, solutions such as milk-chilling and cold rooms benefit larger, commercial farmers who can afford the space (rented or purchased), electricity and technologies required for cold chain management (GIZ, 2016).

On the supply side, off-grid companies and appliance manufacturers have limited space to decrease their prices, especially in the dire economic conditions brought on by the Covid-19 pandemic. Especially during the early stage of development and deployment, many cannot access finance from commercial banks because their business model and/or technology has yet to be proven. These companies must instead vie for international grants, funding challenges and incentives (Sustainable Energy for All, 2020).

Technical barriers. Access to cooling and heating cannot be guaranteed if consumers do not have efficient appliances (Efficiency for Access Coalition, 2019; Abagi *et al.*, 2020). Inefficient appliances consume more electricity and increase the costs of use. In addition, the energy demand from inefficient appliances can overload weak electrical systems, resulting in power outages (Abagi *et al.*, 2020). This may cause appliance owners in both off-grid and weak-grid areas to use the appliances sparingly or engage in fuel stacking (Mekonnen *et al.*, 2009), adversely affecting time and cost savings and prompting the reintroduction of carbon emissions, which a complete transition would address. In addition, a lack of timely maintenance for off-grid technologies in rural areas can disrupt access.

Market and regulatory barriers. At the national level, off-grid appliances are not always explicitly included in the tax policies that can ease financial commitments (Lighting Global, ESMAP and Dalberg Advisors, 2019). Appliance distributors and manufacturers often encounter high import duties or value-added taxes, which can increase their costs by up to 50%. In addition, unclear regulations for off-grid companies can delay deployment and increase overhead costs that may be passed on to low-income consumers (Agenbroad *et al.*, 2018).

Cultural and information barriers. To justify their cost, consumers must understand the tangible benefits of heating and cooling applications, know the best appliances to meet their needs, and learn to use those appliances effectively (Efficiency for Access Coalition, 2019). This information can be disseminated through consumer-awareness campaigns highlighting benefits such as time savings, reduced drudgery and income generation for women (ENERGIA, 2020). Without such information, cultural and behavioural norms can prevent low-income consumers from reaping the advantages of efficient technologies.

3.5.4. POLICIES TO PROMOTE DECENTRALISED RENEWABLE ELECTRIFICATION

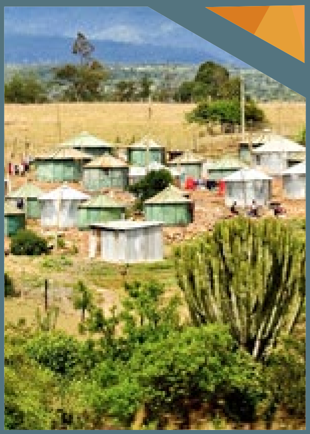
Rural communities with an interest in heating and cooling applications are budget constrained, and lower electricity and off-grid systems prices can stimulate their demand (Box 3.6). To address affordability, **fiscal and financial incentives** such as subsidies and tax exemptions can reduce costs for end users (Agenbroad *et al.*, 2018; Lighting Global, ESMAP and Dalberg Advisors, 2019). **Regulatory measures** such as clear tariff-setting and licensing processes can also enable faster, less-expensive deployment of decentralised renewables (Agenbroad *et al.*, 2018). These measures and incentives have to be targeted to technology providers who service off-grid and weak-grid populations in low-energy-access countries.

Even with targeted financial and fiscal incentives, off-grid deployment is still limited by a lack of access to finance. New and **innovative financial mechanisms** for renewable electrification of off-grid areas have begun to take hold. Projects funded through special purpose vehicles, results-based funding (Box 3.7) and pay-per-service models can go beyond electrification and include productive and residential use appliances (MECS, 2020; Sustainable Energy for All, 2019).

BOX 3.6. REDUCING MINI-GRID TARIFFS TO STIMULATE PRODUCTIVE USES

Mini-grids have the capacity to meet the needs that rural communities have for residential and productive use of heating and cooling. Unlike rural grid customers, mini-grid customers must pay cost-reflective tariffs without subsidies from larger consumers or the government (Crossboundary and Energy 4 Impact, 2019). However, survey data suggest that more than 30% of poor households in developing countries have had difficulty paying for electricity to meet their most basic energy needs (Efficiency for Access Coalition, 2019).

Early market research from Crossboundary suggests that the power consumption of rural mini-grid customers is price constrained – and that tariff reductions immediately increase electricity consumption. Of every dollar saved after tariff reductions, 93 cents are spent to increase energy consumption. This research suggests that a calculated decrease in mini-grid tariffs could assist in moving rural consumers up the energy ladder and encourage the use of appliances while still yielding roughly similar revenues for operators (Crossboundary and Energy 4 Impact, 2019).



BOX 3.7. GLOBAL LEAP: RESULTS-BASED FUNDING FOR OFF-GRID APPLIANCES

Only 4% of rural African households have refrigerators, yet a third of annual food losses occur at the household level (Sustainable Energy for All, 2019; Efficiency for Access Coalition, 2019). Three issues prevent widespread penetration of refrigerators in sub-Saharan Africa: 1) their high upfront cost, 2) the inefficiency of units available in the local market, and 3) intermittent power supplies (Abagi *et al.*, 2020).

Initiated in 2013, the Global LEAP Awards identifies, tests and promotes the best-in-class off-grid appliances that can meet these challenges (Global LEAP Awards, 2019). One beneficiary of Global LEAP results-based financing and a finalist for the award in 2019 manufactures AC and DC refrigerators that can be powered by a low-voltage grid or photovoltaic systems. Depending on the ambient temperature, the units can chill their contents for over 36 hours when there is no solar power, or during a blackout or brownout.

Through energy savings, consumers can offset the total cost of the units by up to 30% in Bangladesh, Kenya, Tanzania, Rwanda and Uganda (Efficiency for Access Coalition, 2018; Lighting Global, ESMAP and Dalberg Advisors, 2019).

To address technical barriers, **quality assurance frameworks** for off-grid technologies would reduce the sale of low-quality products unable to support off-grid appliances (IRENA, IEA and REN21, 2018). VeraSol (formerly the Lighting Global Quality Assurance Programme) tests the durability and quality of solar home systems (10–350 watts) and the ability of these systems to power household appliances (Lighting Global, 2018). These frameworks can also signal product quality to investors and distributors in the sector and qualify companies for financing schemes. Governments can use them as a foundation for product regulations and policies (Lighting Global, 2016). After-sale maintenance standards may be used to extend the life span of off-grid appliances and technologies, protect low-income consumers, and provide jobs for local technicians (Efficiency for Access Coalition, 2018).

Policies to expand access to renewables-based heating and cooling services in countries where access to energy is low will depend on a coordinated and **integrated approach**. Many low-access countries now have electrification targets for mini-grid and stand-alone systems (IRENA, 2018c). Countries like Kenya have established clean cooking policy frameworks. Through the Kigali Cooling Efficiency Programme, 25 countries are working on their national cooling plans (IEA, IRENA, UNSD, World Bank and WHO, 2020) (Sustainable Energy for All, 2020). However, to improve access to heating and cooling, there must be synergy between new and existing policies targeted at off-grid and weak-grid populations.

3.5.5. POLICIES TO PROMOTE THE UPTAKE OF ELECTRIC APPLIANCES

Improving the affordability and efficiency of electric appliances such as electric cookstoves, electric fans, and refrigerators is essential for improving access in off-grid and weak-grid areas. As with solar home systems and mini-grids, **tax incentives and duty exemptions** for manufacturers and distributors can reduce the cost of appliances for consumers. But the uptake of efficient electric appliances running on off-grid renewables also depends on research and development sponsored by donors and roll-out programmes that can increase economies of scale. National energy policies must explicitly cover weak-grid and off-grid appliances to ensure that financial and fiscal incentives are applied consistently (Efficiency for Access Coalition, 2019).

The evolution of **consumer financing models** has also improved access to appliances. In East Africa, increased mobile money penetration allows low-income consumers to break down payments into manageable amounts through pay-as-you-go business models. Loans from micro-finance institutions and subsidies that target off-grid, low-income populations can also help consumers acquire appropriate appliances (Efficiency for Access Coalition, 2019) and address gender disparities in modern appliance ownership and usage (ENERGIA, 2019).

Low-income consumers must be protected through mandated quality standards and post-sale services for weak-grid and off-grid appliances (Efficiency for Access Coalition, 2019). Policy mechanisms like **minimum energy performance standards**

and appliance labels (see Section 3.3.2.) can ensure access to quality appliances and protect against overloading weak-grids (Sustainable Energy for All, 2020; Abagi *et al.*, 2020). Buying guides can also assist distributors in identifying affordable and efficient heating and cooling appliances in their region and/or country (Global LEAP Awards, 2019).

Appliance deployment needs to be paired with **informative campaigns, user training and manuals** in local languages to raise awareness among new users and to encourage behavioural change (Efficiency for Access Coalition, 2019; Couture and Jacobs, 2019). In 2019, Kenya introduced its first energy label for refrigerators to differentiate efficient appliances from the low-efficiency units in the market. Kenya's Energy and Petroleum Regulatory Authority and Collaborative Labelling and Appliance Standards Program have initiated a consumer-awareness campaign to ensure that consumers understand the energy labels and make informed purchases (Blair, 2020).

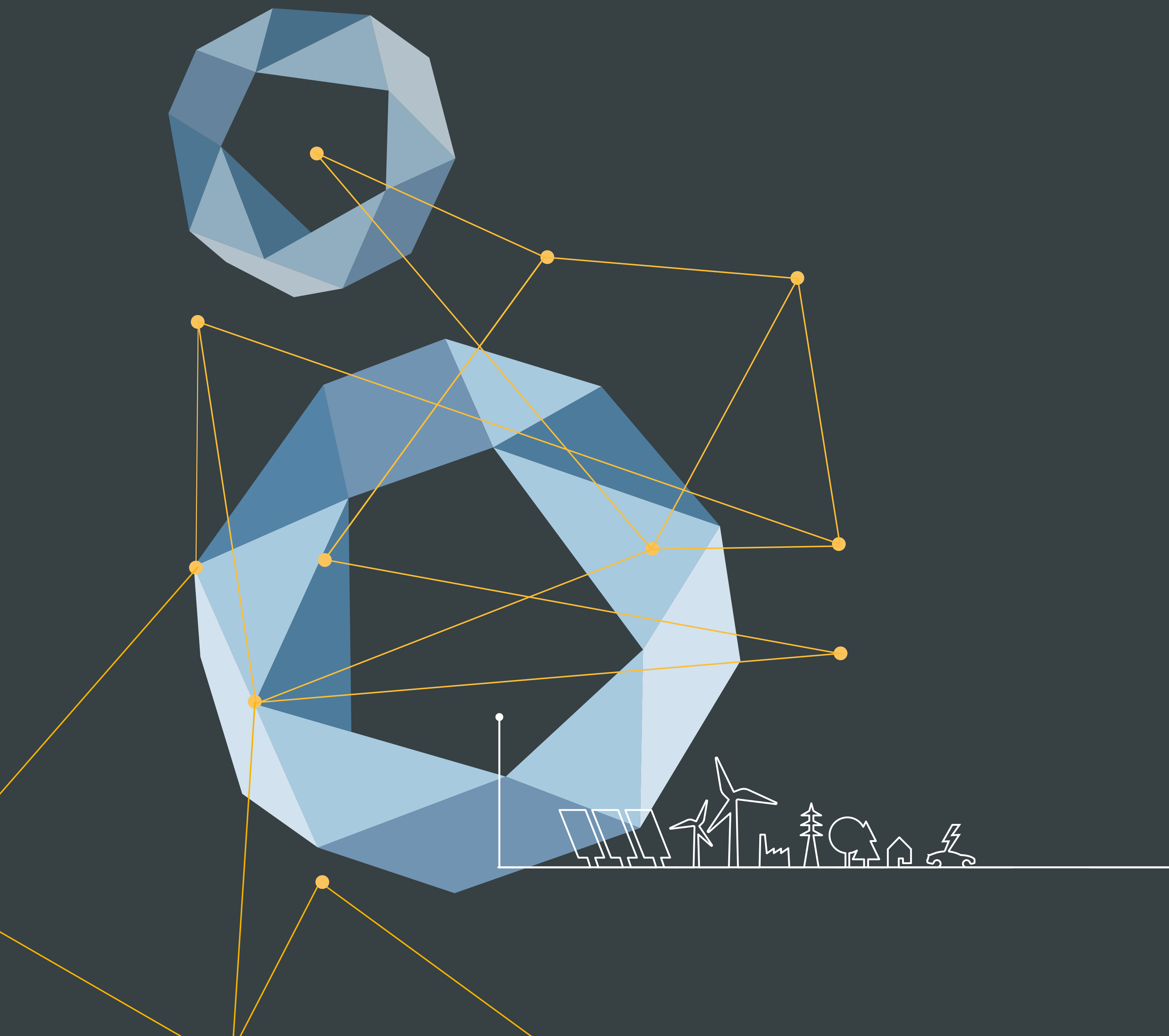
Table 3.3 summarises barriers and policies to support decentralised electrification of heating and cooling in the access context.

Table 3.3. Barriers and policies to support decentralised electrification of heating and cooling for energy access

Targeted barriers	Policies	Examples	Comments
Access to decentralised renewable electricity	National electrification targets	**Kenya**'s Off-Grid Solar Access Project	Effectiveness depends on interministerial co-ordination and implementation.
	Heating and cooling plans	**Rwanda**'s National Cooling Strategy	
High upfront costs to purchase and install off-grid technologies and difficulty accessing finance	Tax incentives		Effectiveness depends on clear and specific regulations to avoid benefitting competing fuels and technologies.
	Policies encouraging alternative financing mechanisms	Global LEAP results-based financing program	Policy attention required to increase low-interest financing for operators and distributors.
High upfront costs for low-income consumers	Policies encouraging micro-finance institutions, pay-as-you-go business models and targeted subsidies	Pay-as-you-go businesses in **East Africa**	Policy attention required, as access depends on the affordability of off-grid technologies, electricity tariffs and electric appliances.
Technical barriers related to the quality of appliances and off-grid solutions	Performance and quality standards	Minimum energy performance standards through Kigali Cooling Efficiency Programme	
	Quality-assurance frameworks	VeraSol Quality Assurance Programme	Policy attention required to improve the quality of off-grid technologies.
	Appliance labelling	**Kenya's** Energy and Petroleum Regulatory Authority	Effectiveness depends on consumer awareness and understanding of energy labels.
Off-grid technologies require behavioural change	Information (*e.g.* awareness campaigns, local user manuals)	Global LEAP buying guides	Consumers may not be interested in changing behaviour.

04

Renewable gases as a heat source



Renewable gases are low-carbon options that can produce heat for industry and buildings, replacing the use of fossil fuels. They also offer an alternative to electrification and the direct and indirect use of other renewable sources. This chapter outlines a range of policy options for consideration by governments and other stakeholders to facilitate the use of these renewable gases for heat provision. Renewable gases can also be used for electricity generation and transport, although these uses are not a focus of this publication and not discussed in this chapter. Box 4.1 explains the principal types of renewable gas.

Natural gas[1] provides just over a fifth of current energy demand in both buildings and industry, and gaseous energy carriers will likely continue to play a prominent role in providing large-scale, flexible energy supply over the long term. Replacing a large share of natural gas demand with "renewable molecules" can reduce greenhouse gas (GHG) emissions, enhance energy security and support sustainable development goals. This transition can also harness existing natural gas infrastructure and industry knowledge.

However, the transition to a higher renewable share of gas supply is at an early stage, and governments and the private sector must overcome economic, infrastructural and technological challenges to scale up deployment. Supportive policies and effective market design from governments are therefore vital if the potential of renewable gases for decarbonising heat demand is to be realised.

BOX 4.1. RENEWABLE GASES DEFINED

Biogas is a mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. The energy content of biogas varies between a lower heating value (LHV) of 16 and 28 megajoules per cubic metre (MJ/m^3).

Biomethane ("renewable natural gas" in North America) is a near-pure source of methane produced either by upgrading biogas (in a process that removes CO_2 and other contaminants) or through the gasification of solid biomass followed by methanation. Biomethane has an LHV of around 36 MJ/m^3 and a chemical composition similar to natural gas. Natural gas infrastructure, end-user equipment and vehicles can accommodate biomethane with no or minimal modification.

Renewable hydrogen is hydrogen produced from the electrolysis of water using renewable electricity to split water into hydrogen and oxygen. Four electrolyser technologies exist today: alkaline electrolysis, proton exchange membrane electrolysis, solid oxide electrolysis cells, and anion exchange membrane electrolysis – the last being at an earlier stage of development than the others. Biomass gasification or fermentation followed by gas conditioning processes can also produce renewable hydrogen, although this is yet to be demonstrated at scale.

Hydrogen can also be upgraded to synthetic methane through methanation to combine it with CO_2. Multiple sources of CO_2 are available. However, for synthetic methane to be classed as renewable, the CO_2 must come from biomass, direct air capture or another renewable source. Renewable hydrogen can also be combined with nitrogen to produce renewable ammonia. Hydrogen from renewable electricity and hydrogen from biomass are two subsets of low-carbon hydrogen, which also includes electrolysis using nuclear electricity or from steam methane reformation of natural gas with carbon capture and storage. This chapter does not discuss these production routes. In gaseous form at ambient conditions, hydrogen has an LHV of around 10 MJ/m^3, around one third of the LHV of natural gas.

1 All references to natural gas in this chapter refer to fossil natural gas.

4.1. STATUS, BENEFITS AND BARRIERS

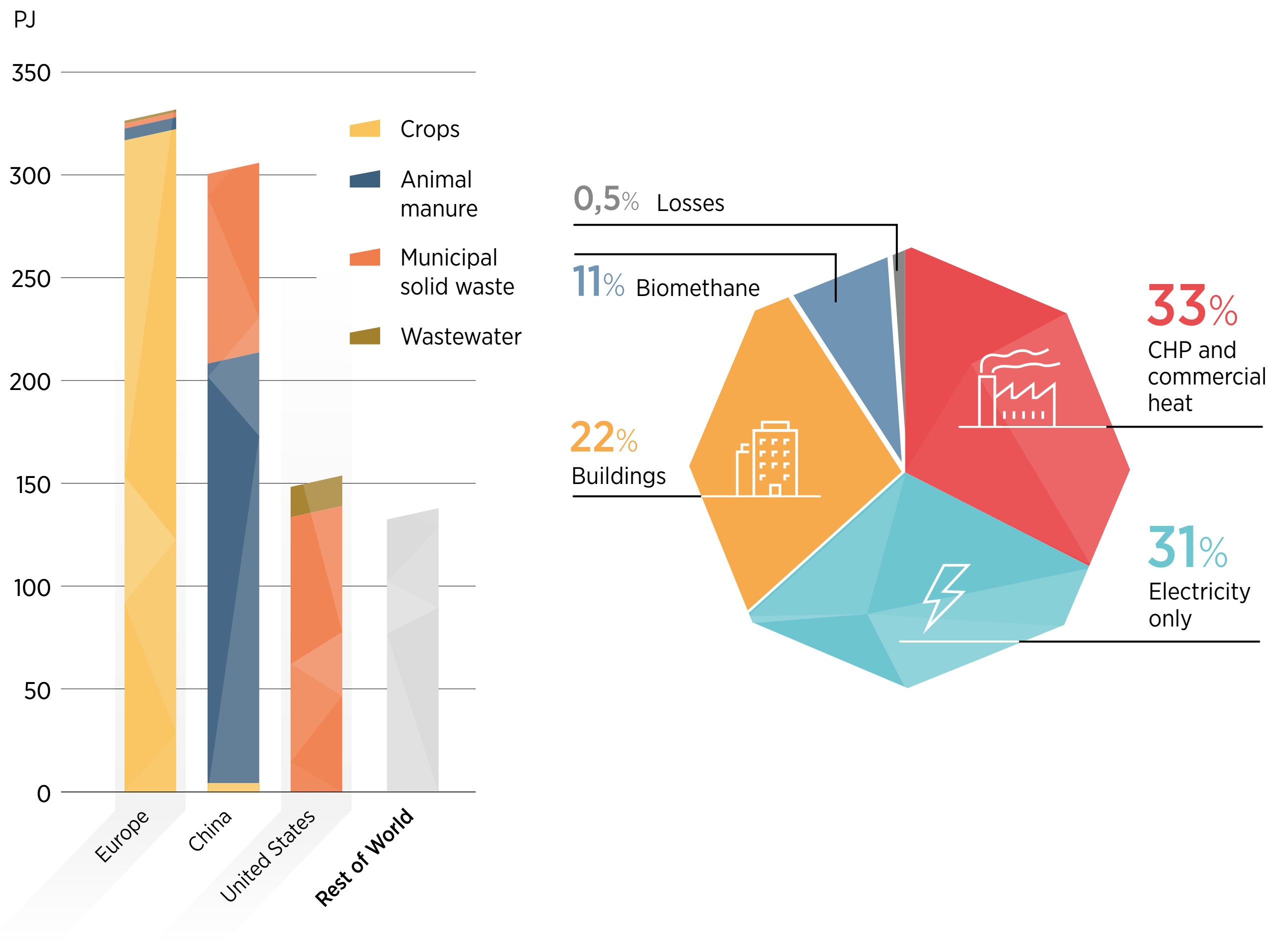
4.1.1. CURRENT DEPLOYMENT STATUS

Biogas and biomethane. Two-thirds of current biogas production is used for electricity and heat generation, with an approximately equal split between electricity-only and co-generation output. China, Europe and North America were responsible for over 80% of biogas production in 2017, and there is still sufficient feedstock availability for established biogas and biomethane industries to continue to grow (Figure 4.1). There is also significant untapped potential to scale up biogas production in the Asia-Pacific and Latin American regions that are barely exploiting their abundant feedstock potential.

In 2017, biomethane accounted for 8.5% of biogas production (by energy), and the number of biomethane plants, worldwide, passed the 700 mark (Cedigaz, 2019). Nevertheless, biomethane represents less than 0.1% of natural gas demand today. There will likely be more than a thousand operational biomethane plants by the end of 2020, representing around 600 000 m^3 per hour capacity.[2]

Deployment is also spreading from pioneering European and North American markets to a wider array of countries (*e.g.* China, India and Brazil). Around 60% of plants currently online and in development are dedicated to injecting biomethane into gas distribution networks, with a further 20% dedicated to providing biomethane for road transport. The remainder have mixed end uses; overall, three-quarters of biomethane plants inject all or a proportion of their output into the natural gas grid.

Figure 4.1. Biogas production by region and by feedstock (left), and end use (right), 2017



Sources: IEA, 2019a, 2019b.

Note: On the left, "Crops" include energy crops, crop residues and sequential crops. On the right: Consumption of biogas in industry and agriculture is included within "CHP and commercial heat" category. CHP = combined heat and power. Consumption in buildings is predominantly for cooking and heating.

2 Actual biomethane production levels are determined by the in-feed of feedstock and digester conditions

Hydrogen. The use of hydrogen is already established in oil refining and chemicals production, with current demand for pure hydrogen around 70 million tonnes (Mt) per year[3] (IEA, 2019d), equivalent to around 13.8 exajoules (EJ). Hydrogen is an energy carrier produced via different pathways. Current hydrogen production is almost entirely from fossil fuels, with 6% of the world's natural gas and 2% of coal consumption dedicated to hydrogen production. Natural gas is currently the primary source of hydrogen production. This dependence on fossil fuels means that hydrogen production today generates about 830 $MtCO_2$ per year (IEA, 2019d), similar to the combined CO_2 emissions of Indonesia and the United Kingdom.

Hydrogen can contribute to decarbonisation efforts only when produced in a low-carbon manner. Only around 0.7% of hydrogen produced today is low-carbon (IEA, 2019d). This is mostly from plants producing hydrogen from natural gas with carbon capture, utilisation and storage. Today, about 2% of global hydrogen supply and less than 0.1% of dedicated hydrogen production worldwide comes from water electrolysis, which is mostly for applications requiring high-purity hydrogen (*e.g.* electronics and polysilicon).

Momentum for renewable hydrogen is growing; with more countries introducing polices that directly support investment in hydrogen technologies. By mid-2019, the number of targets, mandates and incentives in place globally to support hydrogen reached around 50. But the policies focusing on hydrogen in industry and buildings currently lag transport initiatives. The EU's European Green Deal designated hydrogen a priority, and in July 2020 the European Commission launched its Hydrogen Strategy. Australia, Chile, France, Germany, Japan, the Netherlands, Portugal and the United Kingdom, among others, also have national hydrogen strategies and plans (IRENA, forthcoming-a).

Additional funding from economic stimulus measures to combat the economic effects of the Covid-19 pandemic are also set to boost hydrogen development. Stimulus packages from Denmark, France and Spain, among others, pledge financial support to grow hydrogen production and use.

4.1.2. BENEFITS OF RENEWABLE GASES

The beneficial characteristics of biogas, biomethane and renewable hydrogen could support the transition to a more secure and sustainable energy system. These renewable gases offer:

- **Versatility:** they can serve as an energy source for transport, electricity and heat generation. Offering a potential energy source for heat demand from industry and buildings, where solutions to cut CO_2 emissions are challenging or costly – that is, hard-to-abate.
- **Flexibility:** they can be stored, potentially over long periods of time, when renewable resources mean production exceeds demand. They can then be consumed during periods of high heat demand, *e.g.* the winter heating season in colder climates. Biomethane and hydrogen can also be transported over long distances via pipelines or shipping.
- **Enhanced energy security:** countries without extensive fossil fuel resources can produce renewable gases to offset a share of natural gas and/or other fossil fuel imports.
- **Reduced emissions:** they can displace fossil heating fuels, reducing CO_2, and air pollutant emissions, *e.g.* renewable gases emit little to no particulate matter on combustion.
- **Infrastructure compatibility:** biomethane is fully compatible with gas network infrastructure. Hydrogen is compatible with some elements of gas infrastructure; upgrading and adaptation would be needed for widespread use.

Biogas and biomethane offer benefits beyond their value as a fuel. First, their production supports enhanced waste management and sanitation, which in turn delivers environmental benefits such as reduced groundwater pollution or odours. Second, the decomposition of the organic feedstocks used to produce biogas would emit methane directly to the atmosphere if not managed, resulting in a far greater climate impact. Third, their production can deliver job creation in rural areas. These benefits are obtained whether or not biogas is upgraded to biomethane.

A simple cost comparison with natural gas does not reflect these wider benefits, so they are often overlooked. Policy makers are therefore encouraged to first recognise these benefits and then to design polices that harness them as levers for biogas and biomethane deployment.

Renewable hydrogen has the potential to offer additional flexibility in energy systems and pathways to reduce GHG emissions from industry, as well as from transport and possibly buildings, although to a lesser extent.

Converting electricity to hydrogen, which can subsequently be stored and transported, supports the integration of greater amounts of variable wind and solar generation[4] in the electricity system, and indirectly into industry and transport, by helping to tackle mismatches of resource availability and demand, where they occur. Realising this potential (*e.g.* long-term energy

3 A further 45 Mt of hydrogen is used without prior separation from other gases in the industry sector.

storage to bridge major seasonal changes in electricity supply or heat demand) would require large-scale infrastructure (*e.g.* salt caverns).

Hydrogen offers a route to harness the potential of renewable electricity where direct electrification is difficult. The decarbonisation of industry is one of the biggest challenges in the transition to a sustainable energy system, and renewable hydrogen offers several avenues to reduce emissions in the hard-to-abate industry sector. These are:

- Replacing hydrogen produced from fossil fuels in existing applications: Ammonia and methanol, both important primary chemicals, require large quantities of hydrogen for use as feedstock. Hydrogen is also used to remove sulphur and other contaminants in refineries.
- Using hydrogen as a feedstock or reducing agent: Hydrogen is consumed for steel production via direct reduction of iron-electric arc furnace (DRI-EAF). But this now accounts for only a small share (around 7%) of primary steel output worldwide. Hydrogen consumed by DRI-EAF is based on synthesis gas produced from fossil fuels and is subject to an upper limit of around 30% without a major adaption of equipment (IEA, 2019d). A modified DRI-EAF process using 100% hydrogen is now being demonstrated by the HYBRIT project in Sweden. Tests of the use of hydrogen in blast furnaces for primary steelmaking are also under way.
- Substituting for fossil fuel: Hydrogen, as well as biogas and biomethane, can produce high temperature (> 400°C) industrial heat (*e.g.* for melting, gasifying, drying) for which renewable alternatives to fossil fuels are currently limited.

- Renewable hydrogen could possibly help to mitigate CO_2 emissions from buildings as well by partly replacing natural gas in domestic heating settings where direct electrification is challenging, as in old buildings with poor energy performance and connections to the gas network.

4.1.3. CHALLENGES TO SCALING UP RENEWABLE GAS DEPLOYMENT

Several barriers impede the uptake of renewable gases.

Production costs. The most prominent challenge in expanding the uptake of biogas, biomethane and renewable hydrogen for heat provision is that these renewable gases currently have higher production costs than natural gas. Consequently, most applications are not now cost-competitive without support policies.

The production cost of biogas depends on the feedstock used. Regional variations in production cost stem from variable costs for feedstock, labour, equipment and financing. Global average costs are in the region of USD 11 per gigajoule (GJ) (IEA, 2020i).

The global average cost of biomethane is around USD 20/GJ (IEA, 2020i). There are two reasons for the cost differential relative to the global average for biogas. First, upgrading carries an additional cost, typically between 15% and 20% of the total cost of biomethane production. Second, biomethane production is less widespread than biogas, which comprises a higher proportion of output in Europe and the United States and lower production in countries with minimal feedstock costs. Considering regional variations in natural gas prices, biomethane competitiveness varies drastically (Figure 4.2); developing Asia has the strongest economic case for biomethane production.

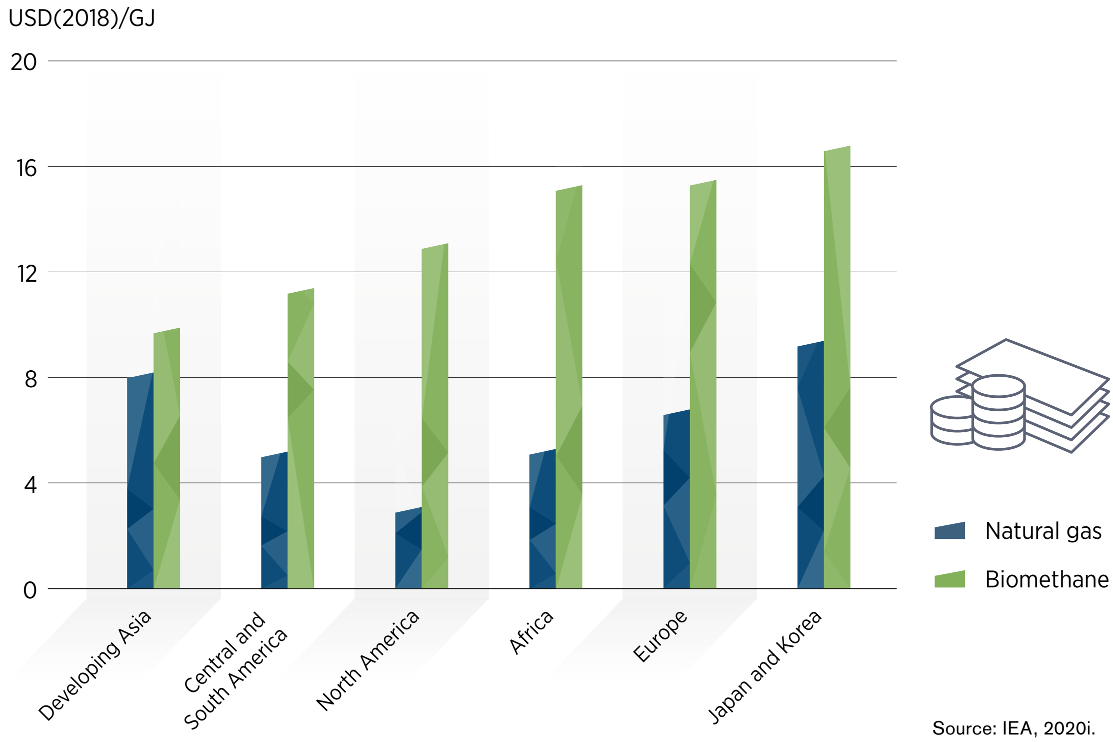
Producers could lower costs through economies of scale and standardisation. Anaerobic digestion technologies are relatively well established, however, so considerable cost reductions are unlikely. Biomass gasification is less technically mature and biomethane production via this route has a higher estimated cost (about USD 20-25/GJ). Nevertheless, with technology development and greater commercialisation, lower costs are a possibility. Biomass gasification at commercial scale over an extended period has yet to be demonstrated. Sweden has showcased one large-scale gasification project using solid biomass, but this is no longer operational.

Technical and economic factors – including the capital cost of the electrolyser, electrolyser efficiency, electricity costs and annual operating hours – determine the production costs of hydrogen from the electrolysis of water. However, the current production cost of renewable hydrogen is still two to four times higher than the cost of hydrogen produced from fossil fuels, in theory, ranging from USD 20 to 55/GJ. The lower end of this range requires renewable electricity costs of around USD 25/MWh[5] (USD 2.4/kg H_2) and depends on high load factors for electrolyser operation (Figure 4.3). Delivery of the necessary power requires wind and solar electricity plants dedicated to hydrogen production, operating in high-resource regions.

The production cost of renewable hydrogen is driven largely by operating expenses. The cost of electricity is the single most significant determinant of the overall cost of production. Renewable electricity generation costs vary widely, depending on technology, region and market conditions.

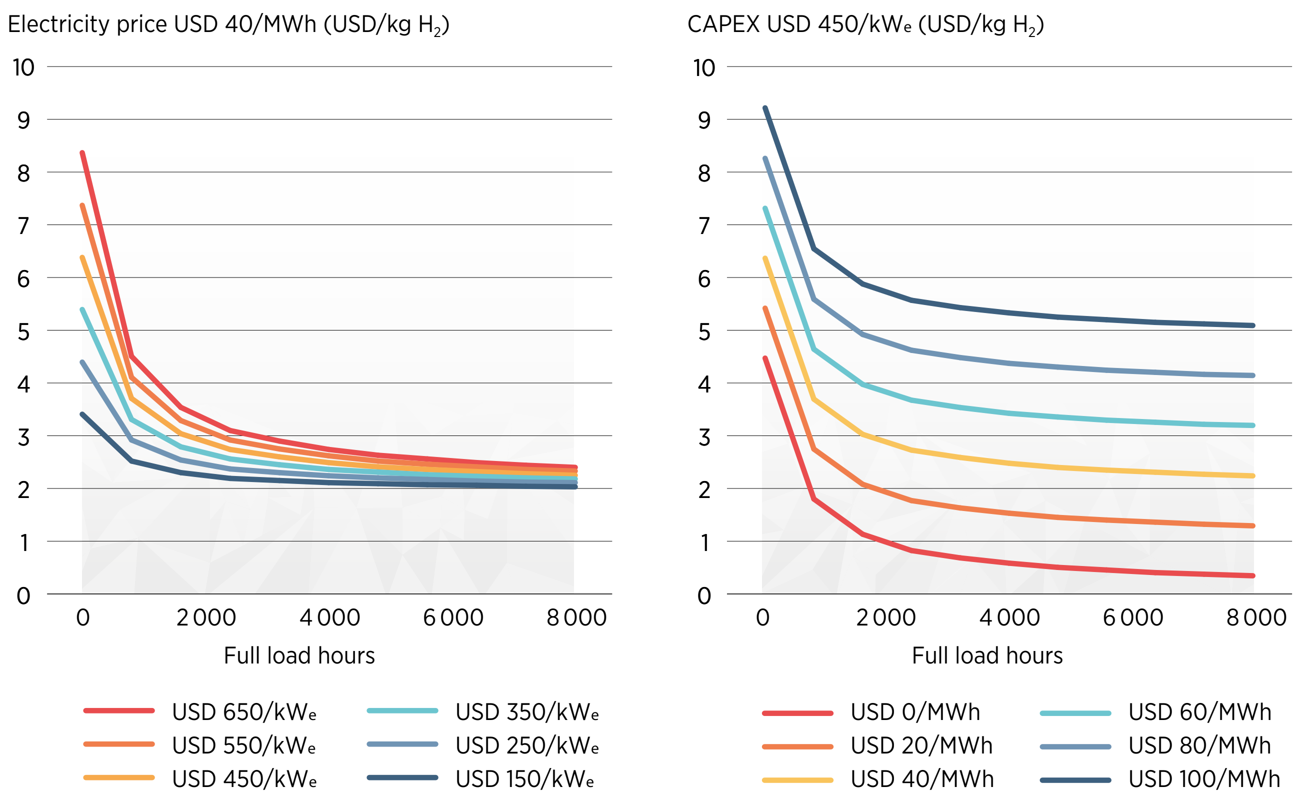
5 Assuming an efficiency of 64% and 5 000 full-load hours' operation, as well as an electrolyser investment cost of USD 883/kWe, which corresponds to the current average cost of proton exchange membrane and alkaline electrolysers.

Figure 4.2. Cost of introducing biomethane to meet 10% of gas demand, and natural gas prices in selected regions, 2018



Source: IEA, 2020i.

Figure 4.3. Future levelised cost of hydrogen production by operating hour for different electrolyser investment (left) and electricity costs (right)



Source: IEA, 2019d.

Note: CAPEX = capital expenditure; kWe = kilowatt electric; MWh = megawatt hour. Based on an electrolyser efficiency of 69% lower heating value and a discount rate of 8%.

The cost of renewable electricity production from wind and solar photovoltaic technologies has dropped significantly in many countries and regions through the application of well-designed and competitive auction frameworks for government Power Purchase Agreements.[6] This in turn has lowered the expected production cost of large-scale renewable hydrogen.

A balance still needs to be struck, however, between electricity prices high enough to make investments in renewable electricity capacity viable, but low enough so hydrogen is competitive with other fuels, notably natural gas. The cost of hydrogen transport to the point of demand also needs to be factored in, as long-distance transport costs might cancel out lower production costs. Consumer natural gas prices in 2018 were much lower than renewable hydrogen production costs.

The relatively high capital costs of electrolysers are also a factor in currently high production costs. Consequently, economic renewable hydrogen depends on attaining suitable load factors for electrolyser operation (*e.g.* 40% and above). More widely, the production of renewable hydrogen has considerable room for cost reduction through technology learning (*e.g.* to improve the durability of electrolysers) and deployment at scale (*e.g.* which should lower electrolyser capital costs). Depending on the pace of market development and on the electrolyser technology used, capital costs could fall between 10% and 60% by 2030 (IEA, 2020f; IRENA, 2020e). This will be achieved, however, only with effective policies and market design.

Figure 4.4 outlines the average production costs of three types of renewable gas, and also the average consumer prices of fossil fuels in member countries of the Organisation for Economic Co-operation and Development.

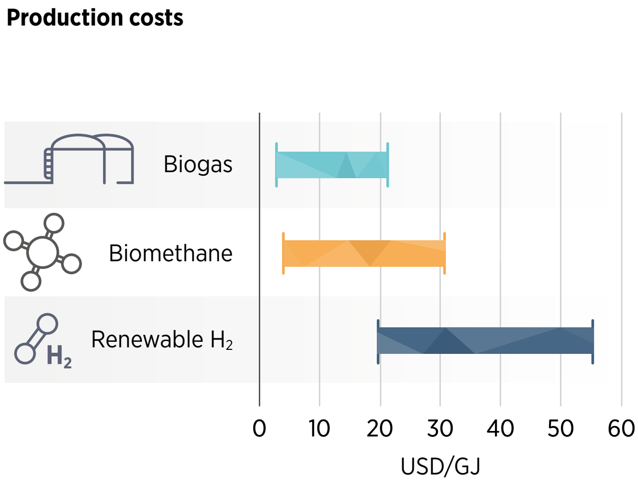
Policy uncertainty. Policy uncertainty remains a key barrier in many markets. Regardless of the policy mechanism, stable and long-term frameworks are necessary to realise the potential of renewable gases.

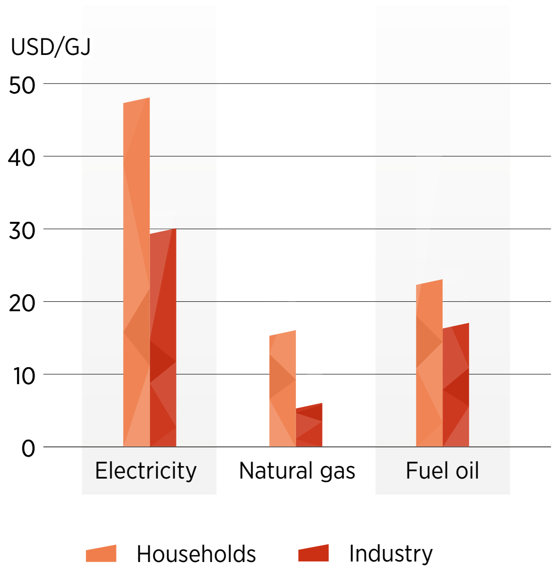
Many countries have long-term goals of lowering their GHG emissions. Often, however, the speed with which these goals are achieved and can then drive the transition to low-carbon energy sources remains uncertain. In the absence of clear, binding commitments to sustainable and resilient energy systems over the long term, major investment in renewable gas technologies and infrastructure will be difficult. Legally binding requirements to reach net zero GHG emissions are an example of the kind of commitment that could enable renewable gas investment. Such commitments are in place in France, New Zealand, Sweden and the United Kingdom, and are central to the EU European Green Deal.

Policies and regulations related to renewable gas deployment range from renewable energy incentives to regulations governing injection into natural gas networks. In some cases, these may need to be reassessed. Are they unnecessarily inhibiting the scaling up of renewable gases? Do they offer scope for streamlining (*e.g.* permitting requirements)? Biogas and biomethane cut across a number of policy areas. So there is a need to ensure that policy making is coordinated across government departments responsible for agriculture, waste management and energy.

Many markets lack mechanisms to track and balance the production and consumption of renewable gases, as well as to identify their characteristics (*e.g.* origin and lifecycle emissions). Such mechanisms are required to underpin support policies for the use of renewable gases and to ensure suitable pricing that

Figure 4.4. Renewable gas production cost range (left) and average OECD consumer prices for selected fuels (right), 2018





Sources: IEA, 2020i, 2020j.

6 For instance, in regions with large wind or solar potentials, such as the United States, the United Arab Emirates, Brazil and Portugal, prices for power purchase agreements have already reached levels as low as USD 20/MWh.

reflects the lower GHG emissions of renewable gases compared with fossil natural gas.

Ensuring the compatibility of hydrogen with natural gas infrastructure. Scaling up consumption of biomethane and hydrogen raises important questions about the future of gas infrastructure and how best to ensure the integration of renewable gases. Integrating hydrogen into natural gas networks faces barriers that are not applicable to biomethane. Its energy density is around a third that of natural gas. This reduces the energy-carrying capacity for hydrogen relative to a given pipeline capacity and requires higher energy demand for compression.

Today's 3 million kilometres of gas-transmission pipelines were designed to transport natural gas. Therefore, thorough assessments are needed to assess their suitability to accommodate hydrogen. Elevated hydrogen concentrations together with high and variable pressure might weaken the steel used in transmission pipelines (a condition called embrittlement) and damage compressors and valves. Polyethylene-distribution pipelines generally have a high tolerance for hydrogen blending and could potentially accept 100% hydrogen. Introducing hydrogen into gas distribution networks requires consideration of constraints associated with the tolerance of downstream appliances, vehicles and connected equipment. Liquefaction or further conversion to ammonia are other means of permitting hydrogen to be transported over long distances to points of demand.

Another potential barrier to the injection of hydrogen into gas infrastructure is related to the suitability of regulatory limits on injection levels. Thorough compatibility assessments are needed to ascertain maximum levels of hydrogen that can be injected. Where mismatches in permitted blending limits exist between countries, this could represent a barrier to the international trade of gases. For example, France has a blending limit up to 6% (by volume) for its gas network, while Belgium's is far lower (IEA, 2019d).

Hydrogen technology and market development. Other challenges must be overcome to increase renewable hydrogen production and consumption.

- Slow development of the relevant infrastructure to accelerate widespread adoption.
- Compatibility, *e.g.* with energy appliances in buildings, industrial energy plant and equipment, and processes feedstock specifications in industry.
- Potential safety risks and consumer inertia for some applications.
- Elevated investment risk in hydrogen production unless demand for hydrogen is scaled up in parallel. In this perspective, ensuring long-term off-takers for hydrogen-based commodities is essential.
- Mismatched seasonal variation in supply and demand. For example, in regions with excellent solar resources, hydrogen output could peak during the summer, when demand for building heat is lowest.

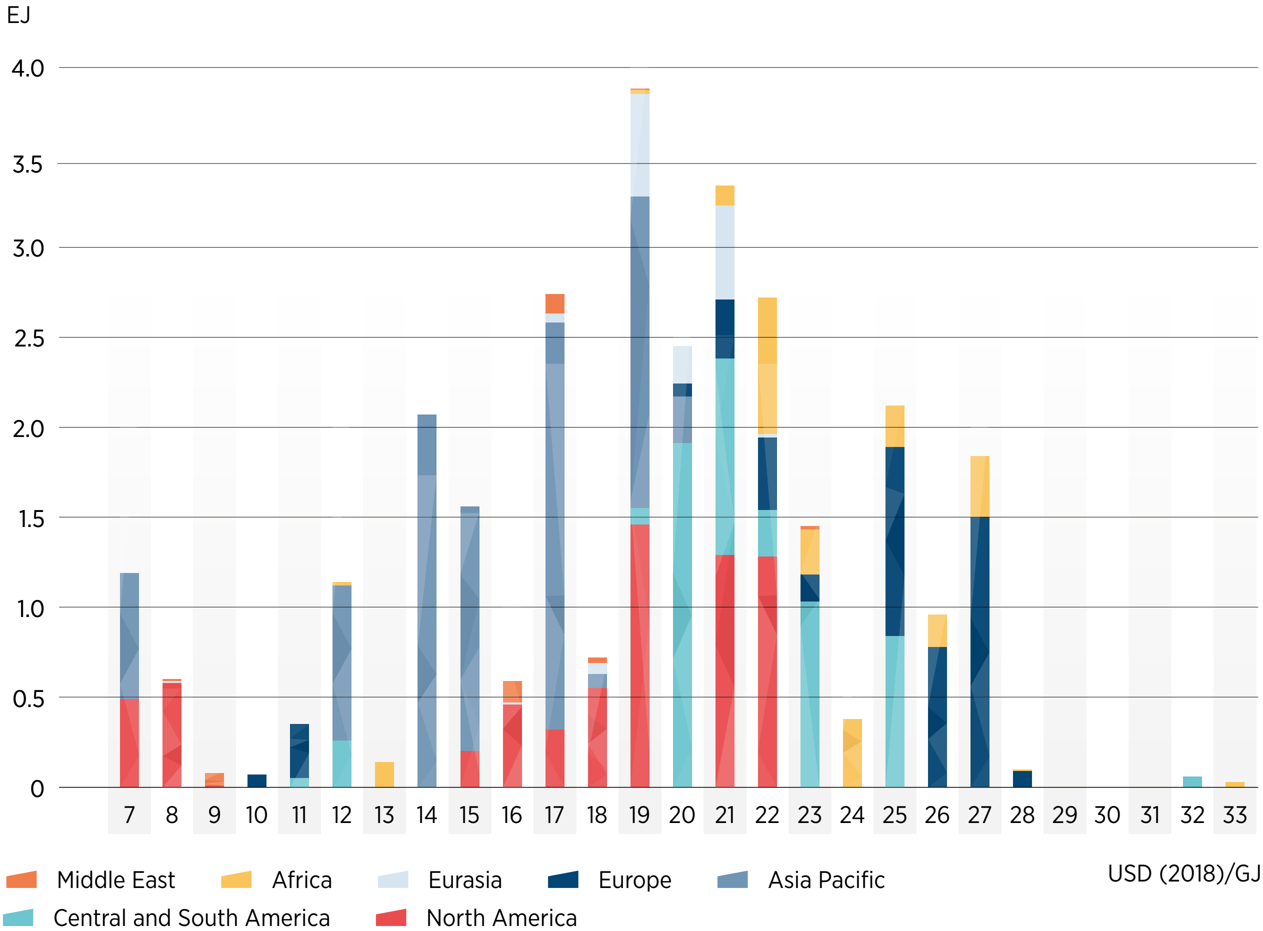
In addition, technology development must be sustained if electrolyser technologies are to progress along a learning curve and thereby bring capital costs down, raise efficiency and extend stack lifetime. While progress is evident in this respect, only sustained development will make renewable hydrogen an economically competitive heating fuel.

Mobilising feedstock supply for biogas and biomethane. Global feedstock resources today are sufficient to produce around 30.5 EJ of biomethane (Figure 4.5),[7] equivalent to over 20% of global natural gas demand (IEA, 2020i). With production standing at just 6% of estimated global feedstock potential, these resources are underexploited, and there is enormous potential to grow biogas and biomethane outputs.

Building supply chains for these widely dispersed feedstocks for biogas and biomethane production can be challenging. Their low value and bulky nature mean transport over long distances is difficult. This favours localised use. Seasonal

7 Approximately 80% from anaerobic digestion and upgrading and 20% from thermal gasification. This value excludes energy crops.

Figure 4.5. Technical potential for biomethane by cost and by world region, 2018



Source: IEA, 2019a.

production, *e.g.* for agricultural residues, requires adequate storage. Should hydrogen production from the gasification of solid biomass resources reach commercial scale, feedstock supply chains will need to be mobilised.

Not all feedstocks face these challenges. Agriculture and certain industrial processes produce a steady stream of feedstock that can be used to produce biogas or biomethane. This is also the case for municipal waste streams – *e.g.* the organic fraction of municipal solid waste, or urban green waste. The concentrated nature of the organic fraction of municipal waste streams aids in supply chain development.

Policy makers must link policy support to criteria for biomass sustainability. Robust oversight can help to ensure compliance with policies and regulations. This allows policy makers to devise measures to confidently support the production of biogas, biomethane and hydrogen using biomass gasification, knowing that monitoring and control mechanisms will ensure beneficial outcomes. Mechanisms include third-party certification of the entire supply chain to ensure sustainability. Assessments of CO_2 emissions for different production pathways should cover the entire lifecycle, from the origin of biomass feedstocks to the generation of electricity (in the case of renewable hydrogen).

4.2. POLICIES TO STIMULATE INVESTMENT IN RENEWABLE GAS PROJECTS

Establishing an ambitious, clear and long-term framework for the development of a renewable gas industry will be vital to grow the market for biogas, biomethane and hydrogen. This framework can come in the form of roadmaps, industrial strategies and economy-wide emissions targets. Such measures provide the necessary policy signals to stakeholders, giving them confidence in the market for renewable gases and unlocking private sector investment in manufacturing and infrastructure. This is particularly important for hydrogen, since investments and policies need to be synchronised in scale and time to harmonise renewable gas production, supply chains and end-use demand. For example, the EU's hydrogen strategy targets 40 GW of renewable electrolyser capacity across member states by 2030, and 10 million tonnes of renewable hydrogen production. Germany's strategy targets 5 GW for the same year.

Demand-pull policy instruments that facilitate the consumption of renewable gases can come in the form of targets specifying a set share of overall gas consumption from renewable gases. For example, France has established a target of 10% of gas consumption (measured in energy terms) to be renewable by 2030. Alternatively, the policy instrument may be a renewable blending mandate for gas supply.

In either case, these targets provide direction regarding the desired growth of the industry. Demand-pull measures can also focus on hard-to-abate sectors such as domestic and industrial heat. Binding quotas or renewable portfolio standards go a step further by creating a known offtake level. This captive demand lowers investment risk and financing costs, facilitating investment in production capacity. Setting targets and quotas at an achievable level requires robust assessment – for example, comprehensive national and regional assessments of feedstock availability for biogas and biomethane.

Investment support can ease the delivery of expensive renewable gas projects during the early stages of market development when higher levels of investment risk are prevalent. De-risking measures can help to reduce financing costs and stimulate private sector investment. These include capital grants, public-private partnerships, loan guarantees, or soft loans from development banks. Examples include Australia's Advancing Hydrogen Fund from the Clean Energy Finance Corporation, and support through the InnovFin Advisory programme of the European Investment Bank to provide strategic financial advice and assistance to companies deploying large-scale hydrogen projects.

Public procurement rules that encourage the use of renewable gases is another means to promote consumption. **Fiscal benefits** – for example, accelerated depreciation for the purchase of equipment and exemptions from excise duty for imported equipment – also support the investment case for renewable gas projects.

4.3. POLICIES TO ENHANCE THE ECONOMIC FEASIBILITY OF RENEWABLE GAS PRODUCTION

Production subsidies for each unit of renewable gas produced (Nm^3, MWh or other) can be utilised to strengthen the economic case for renewable gas projects. Examples include tariffs for biomethane injection under the United Kingdom's non-domestic Renewable Heat Incentive, and Denmark's 20-year feed-in premium for biomethane injection.[8] Such policies require a robust assessment of the required level of subsidisation (both in terms of duration and level of support) to ensure competitiveness with market prices for fossil fuel alternatives, while also retaining flexibility to react to evolving renewable gas production costs.

The **award of policy support based on CO_2 abatement cost** is a means to ensure technology neutral competition between different decarbonisation solutions. Considering that multiple sectors can consume renewable gases, ranking decarbonisation solutions based on CO_2 abatement cost would also direct renewable gases to where they can reduce emissions in the most cost-effective manner.

The Netherlands is introducing the Sustainable Energy Transition Incentive Scheme (SDE++) in 2020, which includes renewable gases. The SDE++ will comprise a technology-neutral phased tender in which renewable gases can compete with other decarbonisation options. While biomethane and hydrogen combined with carbon capture and storage may be able to compete for funding via the SDE++, it will be challenging for renewable hydrogen to compete with other decarbonisation options on a technology-neutral basis until production costs decrease. Therefore the government of the Netherlands is establishing a dedicated support scheme to scale up renewable hydrogen and lower its costs.

Technology-neutral **policies that establish targets to reduce the carbon intensity, or GHG emissions, of fuels** used within in a particular sector can increase demand for renewable gases. These frameworks can also provide an additional revenue stream in the form of tradable credits or certificates. Policy support based on certified carbon intensity is an objective means to support deployment and impartially compare the range of options available to reduce emissions. Such mechanisms are already established for transport on both regional (California) and national (Germany, Sweden) levels. Canada is also in the process of developing a cross-sectoral low-carbon fuel standard.

Recognition of avoided methane emissions to the atmosphere from biogas and biomethane in policy frameworks strengthens the case for these as a means to reduce GHG emissions. The decomposition of many organic feedstocks releases methane directly to the atmosphere, with a far greater climate impact[9] than utilising them in a controlled manner for anaerobic digestion. Policy design that remunerates this benefit through lifecycle accounting of reductions in GHG emissions makes biogas and biomethane more cost-effective (Figure 4.6).

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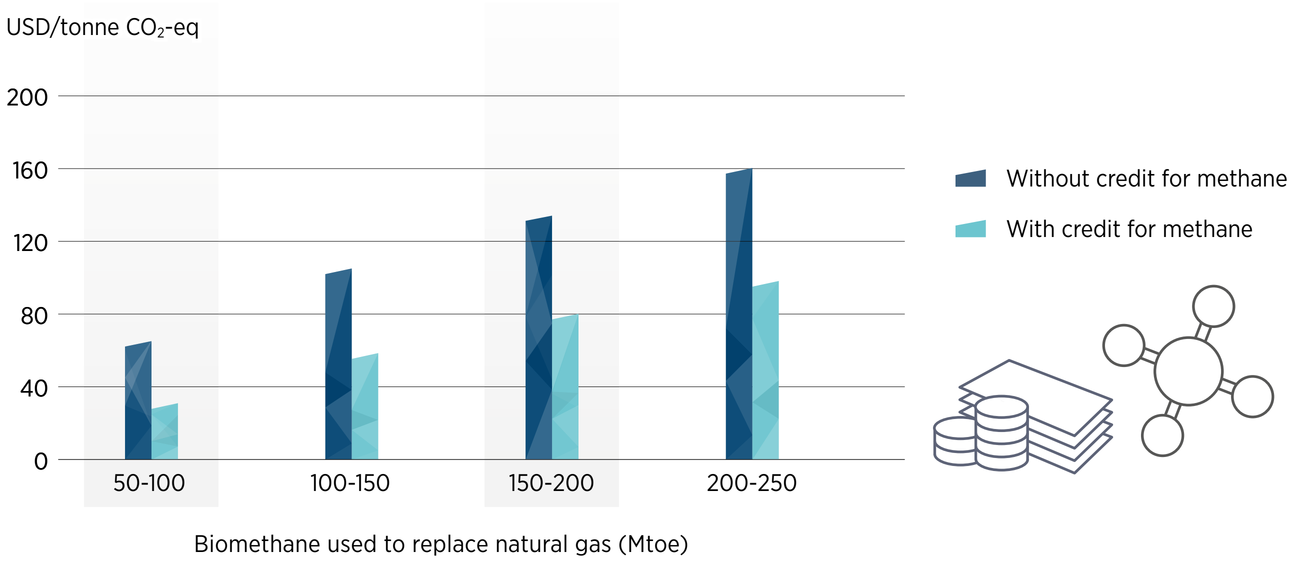
8 Closed to new applicants at the end of 2019.

9 Methane has a global warming potential 28 times higher than CO_2 over a 100-year timescale (UNFCCC, 2016). Quantification of avoided methane emissions should also consider methane leakage.

Figure 4.6. Global marginal abatement costs for biomethane to replace natural gas, with and without credit for avoided methane emissions, 2018



Source: IEA, 2020i.

Note: 1 Mtoe = 41.9 petajoules. The chart shows the biomethane potential starting from the cheapest production options that would require a GHG price; the first 30 Mtoe of the global biomethane potential costs less than regional natural gas prices (and so should not require a GHG price to be cheaper than natural gas).

CO_2-eq = carbon dioxide equivalent; Mtoe = million tonnes of oil equivalent.

Enabling revenue generation from co-products, such as CO_2 and digestate, maximises the overall value proposition from biogas and biomethane. Pure CO_2 is separated from biogas during upgrading to biomethane. Around 230 million tonnes (Mt) of CO_2 are used each year, and although the quantities required by large industrial users (*e.g.* fertiliser production) may be far in excess of what individual biomethane producers can provide, the food and drink industry, food processing and agriculture sector also use CO_2 (IHS Markit, 2018). Facilitating its purchase provides an additional source of revenue for biomethane plants. In the long term, biogenic CO_2 may also be in demand as an input to the production of synthetic liquid fuels for use in transport or certain industrial applications.

Biogas production results in a residue of fluids and fibrous materials called 'digestate'. Depending on the feedstock used, digestate can serve as a fertiliser or soil improver and represent a sustainable alternative to inorganic fertilisers. However, producers find digestate hard to monetise. It is generally not transported over large distances due to its relatively low value, meaning sales rely on local farmers willing to purchase it. Policy makers can support market development by facilitating the trade and appropriate use of digestate, *e.g.* through suitable regulations, standards and approvals for its use. In the agriculture sector, depending on soil conditions, farm-based biogas plants could use digestate on their own land, offsetting fertiliser purchases.

4.4. POLICIES TO INTEGRATE BIOMETHANE AND HYDROGEN INTO GAS NETWORKS

Many of the countries working on GHG emissions reductions in compliance with the Paris agreement on climate change will likely see long-term demand in buildings for gaseous energy carriers decline as building stock becomes more energy efficient. Natural gas demand for electricity generation could fall in some countries and regions as the share of renewables in electricity generation portfolios grows. Yet the pace of this change also needs to consider that natural gas capacity may substitute the retirement of other fossil fuel (*e.g.* coal) and nuclear generating capacity in some markets over the medium term.

Even so, there will be ongoing demand for gaseous energy carriers in buildings, industry, power generation and transport; gas transmission and distribution infrastructure will therefore need to be maintained (Box 4.2). The International Energy Agency's Sustainable Development Scenario sees the demand for gaseous energy carriers increasing by a fifth by 2040, with consumption driven by developing countries and emerging economies, with a 20% share of global gas supply deriving from low-carbon sources in 2040.

The time frames for gas grid upgrade and conversion programmes are long, as are those for the turnover of consumer appliances designed for use with gas. Therefore, a **clear long-term vision** (*e.g.* in the form of a roadmap, target or policy signal) decreases the obstacles to integrating renewable gases

BOX 4.2. HARNESSING EXISTING GAS INFRASTRUCTURE TO ADVANCE THE COMMERCIALISATION OF RENEWABLE GAS

Injection into gas pipeline networks can support the commercialisation of renewable gases. Gas grids could provide the most cost-effective means of renewable gas transportation, as well as lower GHG emissions than other transport modes, such as liquefaction. In addition, gas pipelines and related network infrastructure enable renewable gases to be stored and used when and where needed – and in applications where they have the greatest value.

When gas networks are close to a renewable gas production site, offtake is made easier, regardless of the location and timing of demand. Demand may be far from the biomass feedstock and renewable electricity generation resources (biomethane and hydrogen, respectively) that dictate the location of production. This allows producers to avoid the costs of on-site gas storage. Blending with natural gas could help to lower renewable hydrogen costs through economies of scale in production, which will be critical in the early phase of market development.

With the exception of close to 5 000 km of dedicated hydrogen pipelines in industrial clusters (IEA, 2019d), no infrastructure has yet been dedicated to hydrogen transport. That being so, transporting hydrogen could be done at a lower unit cost by repurposing existing gas infrastructure than by building new, dedicated hydrogen pipelines. Analysis has indicated that, in Europe, repurposed pipelines could have capital costs per kilometre that would be just 10-20% of those of new hydrogen pipelines (Gas for Climate, 2020).

into existing networks and allows investors in renewable gas production to assess the size of future markets. Incorporating renewable gases into existing gas networks, and thereby lowering the overall CO_2 emissions of gas consumption, would also prevent gas infrastructure from becoming stranded assets in the transition to a low-carbon energy system.

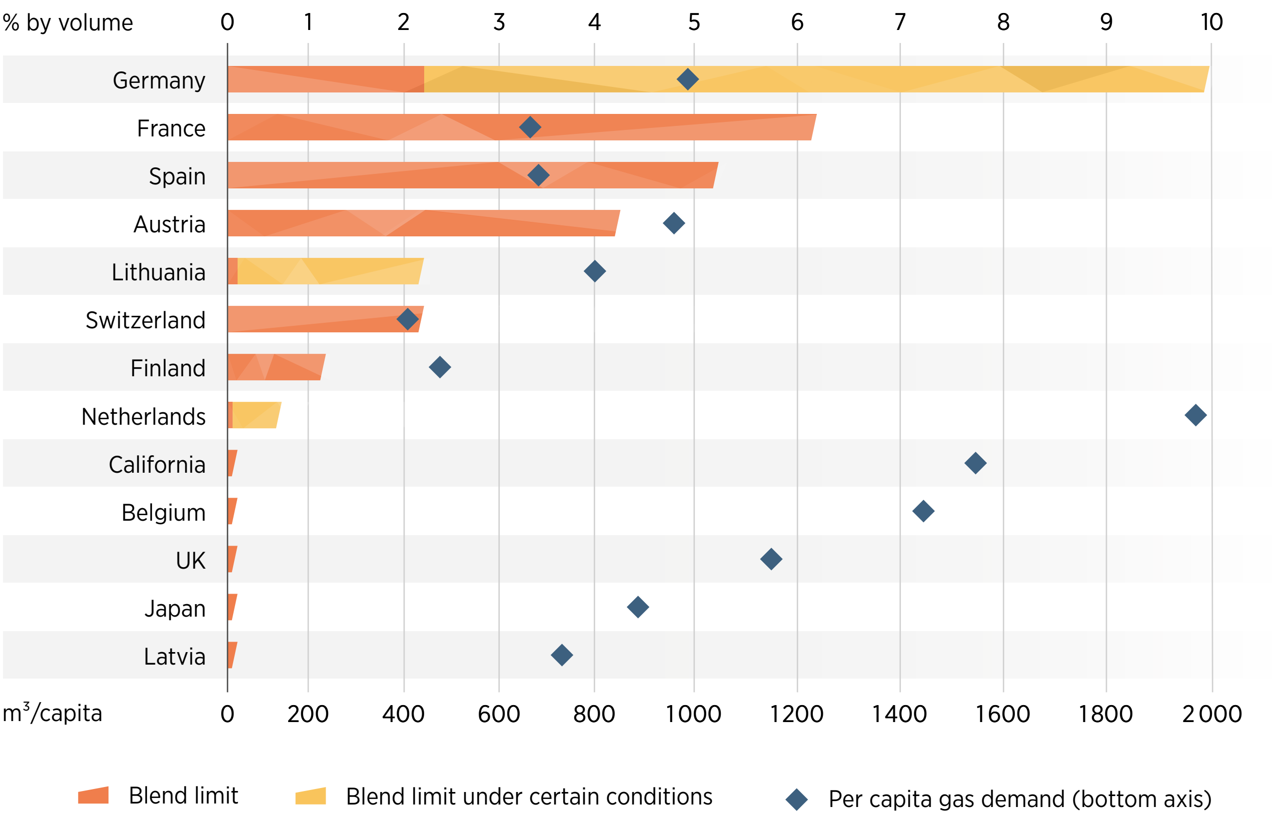
A "European hydrogen backbone" proposal has been developed by a pan-European group of gas infrastructure companies. This vision outlines networks connecting European hydrogen supply and demand centres across Europe. The proposed pipeline network would extend to around 23 000 km by 2040, with 75% of the network consisting of retrofitted natural gas pipelines (Gas for Climate, 2020).

To enable the potential of gas networks to transport hydrogen, policy makers need to provide network operators with a regulatory framework that enables either upgrades to networks and equipment so they can accommodate higher blending levels or the full repurposing of infrastructure. Modifications that adapt elements of the gas network (*e.g.* compressors), and connected equipment, could help transmission networks cope with hydrogen blends of 15–20% (by volume), depending on local context. Full conversion would require either investment in pipeline-integrity management systems and compression stations or the replacement of some pipework. These options may not be possible in all cases.

Given this context, **hydrogen demonstration projects** have an important role. These early stage investments can deliver major longer-term benefits for technology learning and highlight technical feasibility. There are about 40 such projects around the world at both the transmission and distribution levels. In the United Kingdom, for example, the H21 Leeds City Gate project aims to demonstrate the feasibility of hydrogen transport through the gas distribution network to provide heat for households and businesses.

An expanded regulatory framework may be required to ensure the compatibility of gas networks with long-term decarbonisation goals. Accommodating hydrogen will require regulatory adjustments and updated standards. Many countries strictly limit concentrations of hydrogen in natural gas networks, *e.g.* a maximum of 2% blending or below, with a few specifying between 4% and 6% (Figure 4.7). Some of the countries with the highest per capita gas demand have low <1% regulatory limits of hydrogen tolerance.

Figure 4.7. Current regulatory limits on hydrogen blending in natural gas networks and gas demand per capita in selected locations



Source: IEA, 2019a

In order to stimulate market development, governments and grid operators will need to perform a balancing act: **removing needless regulatory barriers while ensuring safety standards** for end users and associated equipment. Existing specifications for natural gas supply commonly determine regulations governing the injection of renewable gases; the upper limit of the most sensitive piece of equipment connected to grid supply often determine regulatory limits. In France, an assessment by the operators of the gas transmission and distribution network indicated that hydrogen can be blended at a rate of 6% (by volume) in most networks, which could then be increased to 10% and ultimately 20%, with targeted upgrades to adapt equipment, particularly downstream. Harmonising requirements across national borders would also be beneficial for the large-scale adoption of renewable gases.

Equipment manufactures will also need to assess the suitability of their products for hydrogen use. Exploring tolerances for higher hydrogen blending requires evaluation on a case-by-case basis with rigorous testing to ensure system safety, as well as certification processes to allow upward adjustment of permitted hydrogen bending limits. Without testing, the tolerance of natural gas vehicles and gas engines to higher hydrogen blends cannot be automatically assumed. There are strict limitations on the extent to which hydrogen can be used in existing gas turbines (Altfeld and Pinchbeck, 2013).

The effect of hydrogen blending on domestic appliances (*e.g.* boilers, cookers, heating appliances etc.) has been extensively assessed. Many domestic heating and cooking appliances in Europe are already certified for up to 23% hydrogen. The Ameland project in the Netherlands demonstrated that blending hydrogen up to 30% posed no difficulties for household appliances (Hermkens, Kippers and De Laat, 2011). Nevertheless, long-term effects remain unknown and further testing on a variety of appliances would be beneficial. Higher blending levels could be achieved with regulations requiring new gas appliances connected to the gas distribution network to be labelled “hydrogen ready”. For example, Worcester Bosch has produced a 100% hydrogen-compatible boiler.

The injection of renewable gases into the gas network requires **certification of CO_2 intensity and provenance in order to obtain policy support.** Certification is essential to prevent mislabelling or double-counting environmental benefits. Registries of so-called “guarantees of origin” (GoO) can track and balance the volumes of biomethane injected into the gas network and subsequently consumed.

The United States is developing a certification programme for biomethane, due for introduction in 2020 (Green-e, 2020). These certification programmes already exist in several European countries, including Germany, France and the United Kingdom. The EU Renewable Energy Directive outlines that member states should establish GoO registries for renewable gases; once widely established, they should support a more harmonised European market.

Harmonised GoO registry requirements enable the cross-border trade of biomethane. They also increase deployment and opportunities to link areas with renewable gas resource potential and demand. **It is important that hydrogen certification considers both carbon intensity and origin,** since the carbon intensity of hydrogen production varies according to production method (*e.g.* SMR, electrolysis), and even within electrolysis, carbon intensity depending on the source of input electricity.

Other policy considerations related to the pipeline injection of renewable gases include:

- Relevant technical specifications, for example, the European EN 16723-1 (2016) standard for the injection of biomethane in the gas grid, and standards to guarantee the mechanical stability of gas grid materials in the case of hydrogen injection.
- Cooperative infrastructure to support biomethane upgrading and gas network injection among project developers so they can deliver economies of scale and lower the investment and operational costs for biogas producers in the same location.
- Frameworks that guarantee grid injection for biomethane and, as established in France, clarity on how associated costs are shared costs between producer and grid operator.

4.5. POLICIES TO STIMULATE RENEWABLE GAS TECHNOLOGY DEVELOPMENT

Research and development (R&D), accompanied by scaled-up deployment, are fundamental to reducing costs for renewable gases. There is scope to **stimulate innovation through ongoing research, development and deployment support for less mature technologies** such as electrolysers for hydrogen production and biomass gasifiers. This provides a means to reduce costs and accelerate commercialisation. For example, electrolysers could benefit from less costly materials for electrodes and membranes and by economies of scale in the manufacturing processes. R&D focused on hydrogen applications for high-temperature industrial heat is also critical, as most applications are yet to be demonstrated. Although anaerobic digester units are more technically mature, there is still scope for standardisation, technical solutions to reduce methane leakage, and the development of new technologies for small upgrading plants.

Governments have a central role in setting the research agenda for renewable gases. This can take the form of funding for the specific aspects of R&D required to accelerate development. Multilateral research collaboration initiatives are also valuable in this respect. Active research programmes to identify and harness new feedstocks could also increase biogas and biomethane output. Examples include algae, new agro-industrial feedstocks and crops suitable for sequential cropping to increase agricultural feedstocks without additional demand for land area. Governments can employ a range of measure to support early-stage projects, including grants, tax incentives, concessional loans and equity in startups.

Support for demonstration projects to incrementally grow the scale of deployment can also play an important role. Proving technology concepts makes it is easier to attract private finance for replication projects that take into account key lessons learned and enable a policy shift from direct support to market-based incentives. For example, demonstrating large-scale electrolyser deployment with improved performance is a crucial first step to unlock the replacement of fossil-based hydrogen for ammonia and methanol production with renewable hydrogen.

The average unit size of electrolyser additions was just 0.1 MW in 2000-09, but increased to 1.0 MW between 2015 and 2019, indicating a shift from small pilot and demonstration projects to commercial-scale applications (IEA, 2019d). Several projects under development have electrolyser sizes of 10 MW or above. A 10 MW renewable hydrogen demonstration project entered into operation in Japan in 2020, with support from the Japanese government's New Energy and Industrial Technology Development Organisation in collaboration with private sector partners. EU funding has supported a 10 MW electrolyser demonstration project in Germany to provide hydrogen to a refinery. A number of announcements have signalled future projects with even higher electrolyser capacity: a 20 MW project is expected to come online in 2020 in Canada, for example, and another dedicated to ammonia production in 2021 in Spain.

Nationally appropriate mitigation actions offer a means of delivering technology transfer, financing support and capacity building between developed and developing countries in order to harness the GHG emissions reduction potential of biogas, biomethane and renewable hydrogen. Such actions can support the achievement of a country's nationally determined contribution within the context of the COP21 global climate agreement.

4.6. POLICIES FOR DIRECT USE OF RENEWABLE GASES IN BUILDINGS

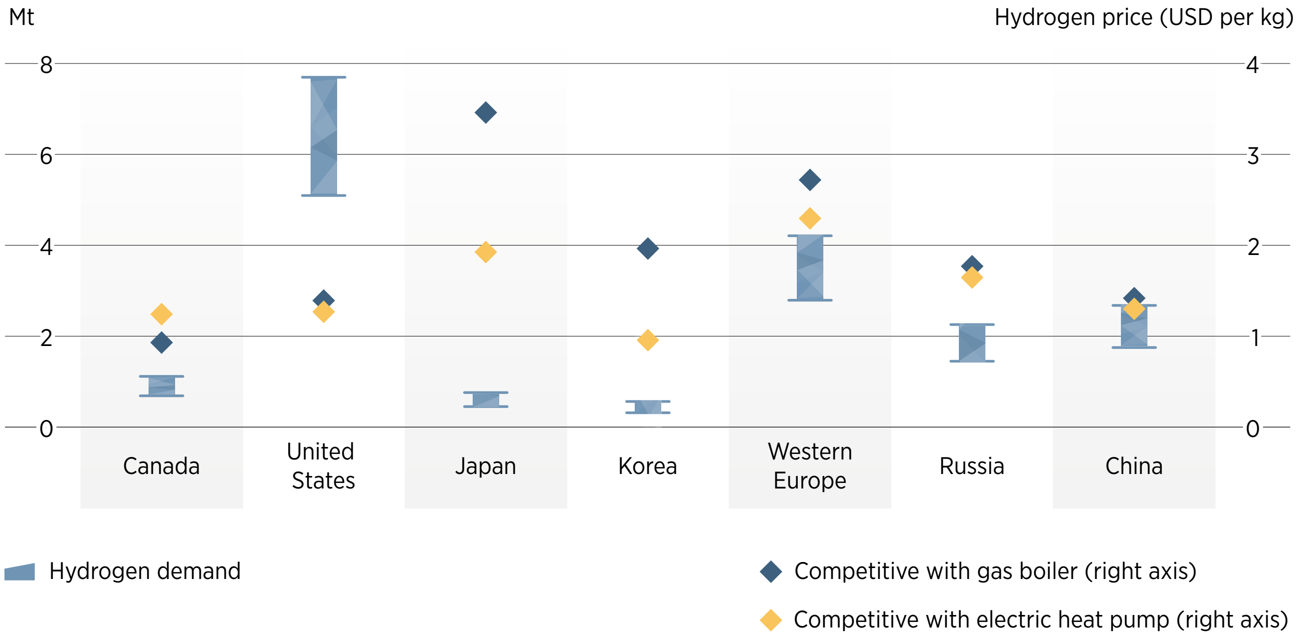
Buildings require low-temperature heat, which can be provided by a number of sources that may be more technically or economically feasible than direct hydrogen. Therefore, **technology-neutral strategies and policies for building-heat decarbonisation are advisable** given that heat pumps, low-carbon district heating or solid biomass heating may be more cost-effective solutions for space heating. In this context hydrogen appears to have the greatest potential in multifamily and commercial buildings, particularly in dense cities, where conversion to heat pumps and access to biomass fuel supply are challenging.

Using hydrogen directly in buildings will require sharp cost reductions in production. It may be that the use of hydrogen for building heat (either through dedicated boilers or fuel cells) will not be economically competitive with other low-carbon options until economies of scale are realised through consumption of hydrogen in other end-use sectors (Figure 4.8). Prices of hydrogen delivered to consumers would likely need to be in the range of USD 1.5-3.0/kg H_2 (USD 12.5-25/GJ H_2) in many major heating markets to compete with the running cost of natural gas boilers and electric heat pumps. Energy utilities could offer **renewable-gas tariffs** to increase demand, for example, from corporate customers wishing to improve their social responsibility credentials.

The prospects for hydrogen in the longer term will also depend on technology cost. As dedicated hydrogen heating appliances enter the market, it is probable they will initially incur higher capital costs than natural gas boilers. This, alongside the potential for increased energy prices for consumers, are barriers that will require policy support in order to scale up hydrogen as a heating fuel for buildings.

Hydrogen use in buildings will **require greater engagement with consumers and the equipment service sector.** Installers, for example, may require training or specific skills. Governments can help to facilitate dialogue and improve the evidence base for hydrogen applications for building heat. Safety is paramount, and it will be necessary to implement safeguards to address consumer concerns along with information campaigns to reassure the public.

Figure 4.8. Potential hydrogen demand for building heat and spread of competitive energy prices in selected markets, 2030



Source: IEA, 2019d.

Note: Prices are average retail prices, including taxes, in USD 2017. Natural gas demand is for space heating and hot-water production and includes building envelope improvements to 2030, on a pathway compatible with the Paris agreement. Competitiveness of electric heat pumps assumes their typical seasonal efficiency in the counties listed. Price competitiveness does not include capital costs of the equipment. Potential hydrogen demand assumes that all gas boiler equipment installed or replaced at expected stock turnover rates between today and 2030 will be hydrogen-ready. kg = kilogram; Mt = million tonnes.

10 The cost of delivery should not be overlooked. For pipelines, it is estimated that the cost of transporting hydrogen in gaseous form over 1 500 km would be around USD 1/kgH_2 (IEA, 2019d).

4.7. POLICIES TO RENEWABLE GAS USES IN INDUSTRY

Clusters of industrial activity offer a major opportunity for ramping up the deployment of renewable hydrogen. Locating electrolytic hydrogen production at the point of industrial demand reduces upfront investment in transmission and distribution infrastructure. Electrolysers are modular, which means that units can be stacked to adapt to the capacity required by industrial processes. Consequently, where low-cost renewable electricity resources are available near industrial plants, there is little incentive for centralised production and distribution networks. If the hydrogen has to travel a long distance before consumption, transportation costs can outweigh those for production. In addition, the concentration of demand facilitates project scaleup, helping to unlock cost reductions and efficiency improvements. Co-utilisation of infrastructure also allows cost and risk sharing. Industrial uses are outlined as a key leading application for renewable hydrogen in the European Commission's hydrogen strategy, alongside mobility.

Industrial strategies should assess high-temperature industrial heat demand suitable for hydrogen use, and opportunities to co-locate hydrogen production (*e.g.* on-site electrolysis). Bespoke sector planning will be key, both in surmounting the major barriers to uptake in industry and in achieving deployment among industry's many types of energy-conversion devices (*e.g.* kilns, furnaces, boilers, reactors). Tailored sector planning is especially important in view, first, of the capital-intensive and durable nature of heavy industrial equipment and, second, that certain industries have strict feedstock specifications. As the pace of low-carbon transitions will differ by country and region, international competitiveness will be vital if carbon leakage is to be avoided – i.e. the transfer of industrial activity to countries with less stringent climate policies and therefore lower production costs.

Demand-pull measures for low-carbon materials (like green labelling, sustainable procurement policies and fiscal advantages, *e.g.* for third-party certified sustainable steel) could support the uptake of green hydrogen in the iron and steel industry.

Awareness-raising initiatives and project development support (*e.g.* subsidised feasibility studies) could unlock the potential of biogas in key industry sectors. Certain industry subsectors produce residues on-site that can be used for biogas production in a co-located anaerobic digester, with the corresponding biogas used to meet or offset on-site energy demand. In such cases, the economic case for biogas is strong. Agriculture, food and drink as well as certain chemical industries produce suitable feedstocks for biogas and have untapped potential to scale up its utilisation. Furthermore, opportunities exist in chemical industries to use anaerobic digestion to treat wastewater sludge with high levels of organic pollutants.

4.8. POLICIES TO UNLOCK WASTE FEEDSTOCK POTENTIAL FOR BIOGAS AND BIOMETHANE

Assessments of biogas production potential from waste and sanitation infrastructure can be undertaken. Over one billion tonnes of organic waste are thrown away or abandoned every year. Its decomposition leads to methane emissions and, if left unmanaged, can cause land and groundwater contamination. For example, landfills are the third-largest source of methane emissions from human activity in the United States (US EPA, 2020). Gases emitted by landfills and water treatment sites present ready opportunities for biogas development, bypassing the need to establish feedstock supply chains. Commissioning targeted feasibility studies can determine the scale of this potential.

Landfill gas offers a bridging solution for managing methane emission from existing municipal waste disposal and it has some of the lowest production costs of all biogases. In all regions, landfills equipped with a gas recovery system could provide biogas for around USD 3/GJ or less (IEA, 2020i). Landfill disposal sits at the bottom of the waste management hierarchy,[11] so a shift towards more sophisticated and sustainable waste management practices should be encouraged. However, many developing countries will likely use landfill disposal for years to come given the rapid growth of municipal solid waste production caused by rising populations and economic development. Regulations can mandate landfill gas collection and subsequent treatment and use, *e.g.* for energy recovery. For example, the EU Landfill Directive requires landfill gas collection and treatment for landfills receiving biodegradable waste.

Enhanced waste management practices and regulations would boost biogas production by increasing the availability of sustainable feedstocks. Comprehensive waste management policies and regulations that lead to higher levels of collection and source-segregation of organic wastes mobilise feedstock for biogas production in urban areas. Other measures include restricting the disposal of organic waste in landfills, landfill taxation and separate food-waste collections for business and the public. Where there is a cost for waste disposal, biogas and biomethane producers can charge for the receipt of feedstock. This revenue stream would sidestep the need to subsidise energy produced.

Moving away from landfilling naturally limits the long-term potential for landfill gas; but source separation of wastes creates feedstock for biogas production in mechanical biological treatment waste processing facilities. EU legislation requires member states to ensure that biomass wastes are separated and recycled at source or are collected separately and not commingled with other waste by the end of 2023. Good progress has already been made in some member states in this respect. In Sweden more than 60% of the municipalities collect food waste for energy purposes to produce biomethane for gas grid injection.

Policy options for the development of renewable gases, are summarised in Table 4.1.

11 The waste-management hierarchy comprises prevention, preparing for re-use, recycling, energy recovery and landfill disposal.

Table 4.1. Barriers and policies for scaling up renewable gases

Policy objective	Policies	Examples	Comments
To close the cost gap with fossil fuel alternatives	Renewable gas injection subsidies	The **United Kingdom**'s Renewable Heat Incentive for biomethane	Tariff flexibility is important to react to evolving renewable gas production costs.
	Recognition of avoided methane emissions from biogas / biomethane production	**California**'s low-carbon fuel standard (for transport only)	Policies that remunerate avoided methane emissions heighten the cost-effectiveness of biogas / biomethane versus other means of reducing emissions of greenhouse gases.
To stimulate investment in renewable gas production by lowering investment risk	Establishment of a clear long-term framework for development of the renewable gas industry	The **European Union**'s Hydrogen Strategy National hydrogen strategies and plans, *e.g.* in **Australia, Germany** and **Japan**	Clarity about the future market for renewable gases is needed to unlock private sector investment.
	Setting of targets for renewable gas consumption	**France**'s target to make 10% of gas consumption (in energy terms) renewable by 2030	Targets provide an indicative level of future demand and therefore of needed production capacity.
	Measures for financial de-risking, such as capital grants, loan guarantees and soft loans	**Australia**'s Clean Energy Finance Corporation's Advancing Hydrogen Fund	Scaling up hydrogen production is key to reducing production cost, but in the early stage of market development capital-intensive projects entail high investment risk.
To harness the potential of gas grid infrastructure for transporting renewable gas.	Hydrogen demonstration in gas transmission and distribution networks	The H21 **Leeds City** Gate project in the United Kingdom	These early-stage investments can deliver major longer-term benefits for technology learning and highlight technical feasibility.
	Creation of "guarantee of origin" registries to identify, track and balance volumes of renewable gas injected into gas networks	The **European Union**'s Renewable Energy Directive stating that member states should establish registries of origin for renewable gases (Several European countries already have biomethane registries.)	Provision of policy support hinges on certification of CO_2 intensity and provenance of supply.
To deploy renewable gases in industry	Development of hydrogen projects in industrial clusters	The Port of **Rotterdam**'s ambition to become a hydrogen hub	Concentrating demand facilitates project scale up to unlock cost reduction. Co-utilisation of infrastructure also allows for the sharing of costs and risks.

4.9. POLICIES TO EXPAND ENERGY ACCESS WITH SUSTAINABLE BIOGAS

4.9.1. STATUS AND BENEFITS

Rural households in developing countries require energy access for heat, mainly for cooking, water heating and productive activities. Most of these needs are now met with the inefficient use of solid biomass. For example, in sub-Saharan Africa, population growth meant that those without access to clean cooking grew from 750 million in 2010 to 890 million in 2018 (IEA, IRENA, UNSD, World Bank and WHO, 2020).

Small-scale domestic biogas digesters have the potential to meet the heating needs of rural households and smallholder farmers. There are three types of biogas technologies for domestic use: fixed-dome digesters, floating drum digesters, and polyethene tubular digesters (also known as balloon digesters). These biogas systems usually supply cooking, water or space heating. Fixed-dome digesters are constructed at the point of use, while floating drum and tubular digesters are prefabricated and are easy to transport and assemble.

Globally, there are around 50 million small-scale biogas digesters serving about 125 million people. Almost 95% of the systems are in China and India (REN21, 2020; Jain, 2019). Biogas use for heating in Africa is at an early stage and evident mostly in countries that belong to the Africa Biogas Partnership Programme – Ethiopia, Kenya and Tanzania. Several international donor organisations support deployment, with a focus on small-scale, domestic digesters fed by organic waste and animal manure.

The use of biogas brings multiple economic, social and environmental co-benefits, these include:

- Creating skilled jobs and a skilled workforce related to construction, installation and maintenance of systems.
- Reducing labour associated with fuel collection, especially of solid biomass, a task that disproportionally falls on women and children
- Reducing indoor air pollution through a move away from the inefficient use of solid biomass.
- Supporting better sanitation and enhanced waste management *e.g.* of animal manure.
- Reducing deforestation and GHG emissions.
- Producing digestate, which can be used as a fertiliser that is easier than animal dung to spread on fields, and that could also be sold.

4.9.2. CHALLENGES IN THE ACCESS CONTEXT

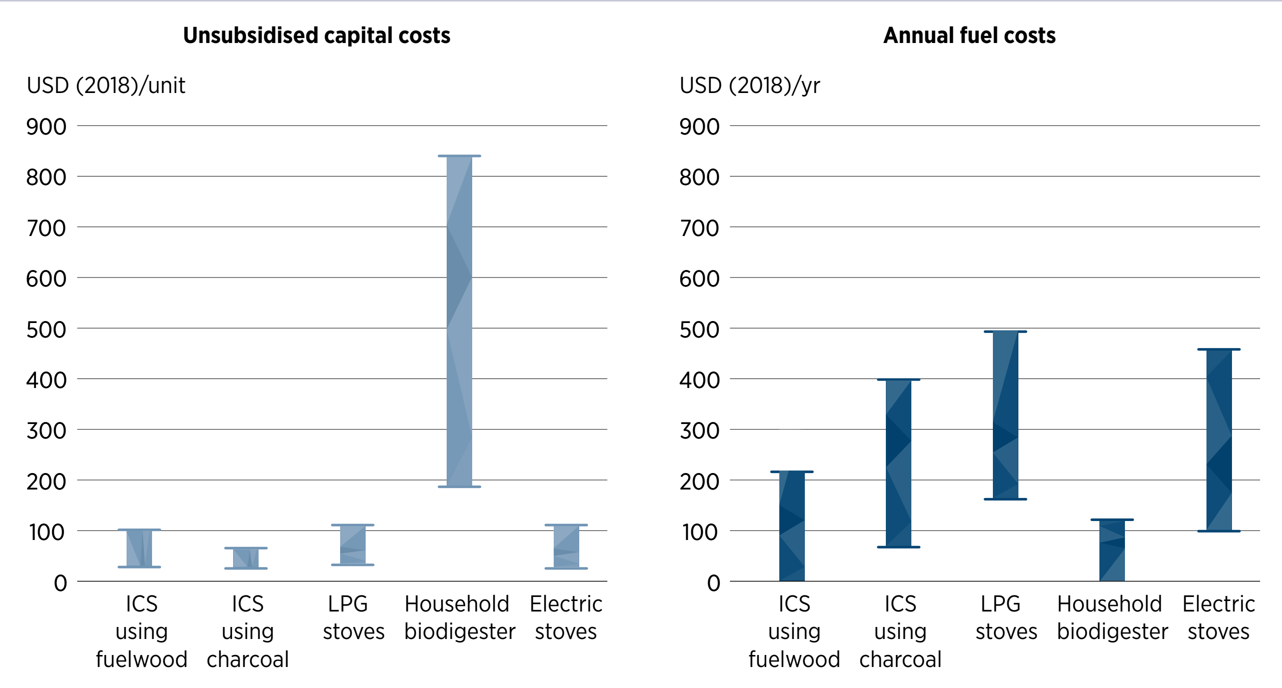
Despite the potential to deliver energy access and these multiple wider benefits, most biogas potential has not been utilised. For example, currently Africa has exploited less than 0.5% of its significant biogas potential, which could be as high as 18.5 million digesters since challenges related to technology and installation quality, capital costs and access to affordable financing limit uptake (World Bank, 2019).

Technical challenges abound, affecting areas from design, installation and construction to the daily operation of biogas applications. Biogas digesters can function for more than a decade if they are well-designed, installed and maintained. However, operations and maintenance challenges often arise from insufficient supplies of animal manure, inadequate knowledge of water and feedstock ratios, labour shortages, difficulties in obtaining replacement parts, and lack of after-sale technical support, among other matters (Puzzolo *et al.*, 2016). The quality and efficiency of digesters is inconsistent due to the absence of related regulations and technical standards (Puzzolo *et al.*, 2019).

High cost and limited financing access remain key barriers. On average, an unsubsidised small-scale biogas digester costs around USD 200-800 (see Figure 4.9), and in Africa an average-size household digester can range between USD 500 and USD 800 (IEA, 2020i). Despite the ability of digesters to offer cost-savings over the lifetime of the system, most rural households or smallholder farmers do not have the disposable capital required for such an investment (Putti *et al.*, 2015).

Although installation costs for other clean cooking technologies are lower, biogas digesters have low or nonexistent fuel costs, and basic digesters can therefore pay back initial investment in as little as two years. However, experiences based on Kenya's biogas programme have proven it is difficult to engage micro-finance institutions or savings and credit cooperative societies in financing biogas digesters due to the lack of awareness and, in the case of a fixed-dome digester, the lack of collateral (Clemens *et al.*, 2018). Box 4.3 provides more on biogas use in poultry farming in Kenya.

Figure 4.9. Global ranges of capital and fuel costs for different clean cooking technologies in developing economies, 2018



Sources: IEA (2020h), based on data from Politecnico di Milano (2016), Kammila *et al.*, (2014), and Hivos (2019)

Note: ICS = improved cookstoves; LPG = liquefied petroleum gas. Electric stoves are considered for households connected to the centralised grid or mini-grids.

BOX 4.3. BIOGAS USE IN POULTRY FARMING AROUND NAIROBI, KENYA

In Nairobi (Kenya), some farmers are using biogas digesters to supply heating for poultry farms and chicken brooding. The key driver for poultry farmers is to improve waste management and odour from chicken manure. For commercial farmers, an investment of around USD 10 000 for a biogas digester is generally feasible. Typically the payback from energy cost-savings is roughly six years.

However, the capital cost of biogas systems is a barrier for small-scale poultry farmers. Smallholders have less disposable income available, which calls for shorter payback periods. For some, even a payback period of two to three years may be too long. As a result, despite the numerous benefits of biogas, most smallholder poultry farmers find it difficult to purchase systems.

This may soon change. Kenyan smallholder farmers are highly dependent on savings and credit cooperative societies (Bwana, 2013), and these were established in the poultry farming sector in 2019 (Waweru, 2019; Kamau, 2019).

4.9.3. POLICIES FOR THE DEPLOYMENT OF BIOGAS IN THE ACCESS CONTEXT

Focused development assistance programmes can play a role in facilitating household biodigester uptake through supporting programmes to make system purchases more affordable. These should balance upfront and lifetime costs to households. Governments can use, and complement, development finance to promote uptake through subsidy programmes, community grants and favourable financing. This is crucial for attracting private-sector participation, particularly of independent energy companies and private equity and infrastructure funds, which can help scale up the supply chain while benefiting from lower-cost financing afforded by government-backed investment programmes.

Viet Nam's biogas programme, a joint initiative between the Dutch government, the Vietnamese Ministry of Agricultural and Rural Development and the SNV Netherlands Development Organisation, has resulted in the installation of 250 000 domestic biogas digesters. The programme offered a flat rate subsidy per digester unit of around 10% of total investment costs, before being replaced by results-based financing (IRENA, 2018d).

Financial incentives could support biogas deployment. Countries, including Burkina Faso, Ethiopia and Kenya, have successfully introduced policies and incentives to build a functioning domestic biogas value chain. Kenya has introduced new taxes on kerosene and an import-tax exemption that greatly improve the cost-competitiveness of biogas systems (Wachira, 2018). This fiscal benefit, however, is available only to biogas suppliers that import prefabricated digesters (Clemens *et al.*, 2018).

International and national clean cooking policy frameworks could make biogas competitive with alternatives such as charcoal and kerosene. Biogas's GHG abatement potential means it can help fulfil climate change policies. Projects enacted under the Clean Development Mechanism, which permitted GHG emission reduction projects in developing countries to produce certified emission reduction credits that could subsequently be sold, saw a wave of biogas project installations, particularly in Asia, although uptake has significantly slowed in recent years.

Coordinated policy measures that support good end-user practices, high-quality design and after-sale service, coupled with a continuous push for innovation from the private sector, are key to the success of biogas as a renewable heating solution. Biogas benefits transcend health, environment, gender and the rural economy, so a **holistic approach with inter-departmental policy coordination is required.**

Installer training programmes are also a key to ensure that a qualified local workforce is available to install and maintain biogas digesters. These programmes would involve local communities in the construction of biogas production plants and create durable employment opportunities while ensuring the optimal use of biodigesters over their full technical lifetimes. Biogas construction enterprises composed of local tradespeople have acted as a bridge to rural biogas access in Kenya, Tanzania and Uganda. The enterprises market, install and maintain various biogas technologies as part of their revenue streams while often operating other construction businesses (Clemens *et al.*, 2018). Training is also a key element of success. In Viet Nam, the successful National Biogas Programme, supported by the Netherlands Government provides training for manufactures and government technicians. Manufacturers must be certified before they are able to build digesters, and trained officials provide quality assurance and training for users (SNV, 2017).

Policies to promote biogas in the energy-access context are summarised in Table 4.2, along with related barriers.

Table 4.2. Barriers and policies to promote biogas for energy access

Targeted barriers	Policies	Examples	Comments
Technical barriers related to the design, installation, and maintenance of systems	Capacity building (*e.g.* installer training)	The National Program of Biodigesters of **Burkina Faso** (through the Africa Biogas Partnership Programme, ABPP	Coordinated policy measures required to extend the life span of biogas digesters.
Technical barriers related to the quality of biogas digesters and appliances	Quality and performance standards	**Kenya** Biogas Program (an ABPP affiliate)	Adoption of financial penalties can improve adherence.
	Appliance labelling		
High upfront costs of biogas digesters and appliances	Tax incentives (*e.g.* exemptions from value added tax)	**Kenya** Biogas Program	These early-stage investments can deliver major longer-term benefits for technology learning and highlight technical feasibility.
	Access to loans, grants, subsidies, micro-finance institutions and savings and credit cooperative societies		Effectiveness depends on consumer awareness and ability to provide collateral.
	Development assistance to increase the affordability of household biogas digesters.	The biogas programmes of **Viet Nam** and SNV Netherlands Development Organisation	These should balance upfront and lifetime costs to households.
Fossil fuel oriented financial incentives	Fossil fuel subsidy reforms	Government of **Kenya**	Effectiveness depends on clear and specific incentives to prevent competing fuels from benefiting.
	Tax incentives (*e.g.* import-tax exemptions)		

05 Sustainable use of biomass

Bioenergy contributes the largest share among renewables used for heating, providing 21% of total global heating needs – some 40 exajoules (EJ) in 2018. Most of this (65%) involves the "traditional use of biomass" – which refers to the use of local solid biofuels (wood, charcoal, agricultural residues, and animal dung) burned with basic techniques, such as traditional open cookstoves and fireplaces (IEA, IRENA, UNSD, World Bank and WHO, 2020) – estimated at 26 EJ in 2018[1] (Figure 5.1) (REN21, 2020).

The remainder provided almost 14 EJ of heat consumption in industry and in buildings, mostly in developed economies, including some 0.7 EJ provided through district heating. Bioenergy provided some 9% (8.9 EJ) of heat requirements in industry in 2018 and has been growing by around 2% per year in recent years and it provided 4.6% of heat needed in buildings in 2018 (4.3 EJ). The contribution to building energy needs has been falling slightly in recent years (REN21, 2020).

This chapter discusses the socio-economic and environmental issues associated with the use of biomass in areas with and without access to clean, affordable and reliable energy. It then focuses on the barriers to transitioning to a more sustainable use of biomass and on policies to overcome those barriers.

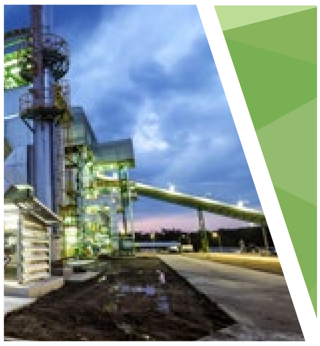
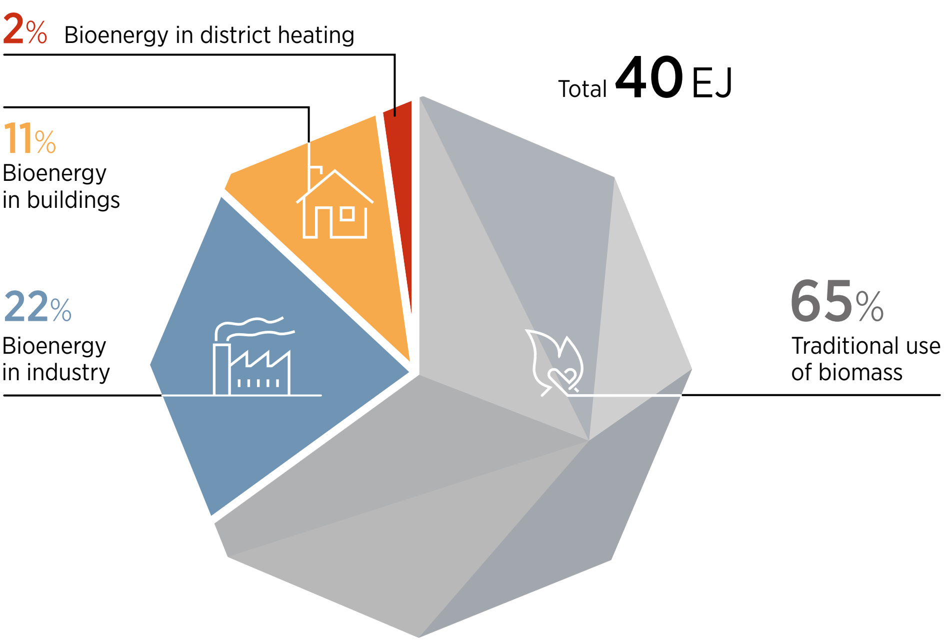


Figure 5.1. Bioenergy used for heating, 2018



Source: REN21, 2020 based on IEA, 2019c.

Note: EJ = exajoule.

1 Owing to their informal and noncommercial nature, it is difficult to estimate the energy consumed in such practices, which remain widespread in households, mostly in the developing world.

5.1. EXPANDING ENERGY ACCESS WITH SUSTAINABLE USE OF BIOMASS

5.1.1. CURRENT STATUS AND BENEFITS OF THE USE OF BIOMASS FOR ENERGY ACCESS

Even though biomass as it is traditionally used is, in principle, renewable, it leads to significant indoor and outdoor air pollution, which has severe health consequences along with other environmental and socio-economic impacts. Resulting household air pollution is directly linked to 2.5 million premature deaths annually (IEA, IRENA, UNSD, World Bank and WHO, 2020). In addition, the low energy efficiency of cooking stoves means that fuel requirements are high and often exceed local sustainable supply, leading to pressure on local forestry resources and damage to local forests. As of 2018, 27–34% of all wood-fuel harvesting in tropical regions was classified as unsustainable (FAO, 2018). Conventional charcoal production is also inefficient (8–20% efficiency) and polluting; moreover, it puts pressure on local wood resources. Several countries have tried unsuccessfully to ban the use of charcoal or wood fuels, but those attempts have encouraged black-market production and driven up prices.

The collection of biomass such as firewood for cooking is very time consuming and has a high opportunity cost, as it takes time away from other income-generating activities and education. These issues disproportionately affect women and children, as they are the ones often tasked with cooking and fuel collection (IEA, IRENA, UNSD, World Bank and WHO, 2020).

Given these negative consequences, one target of the United Nation's Sustainable Development Goals (SDGs) – target 7.2.1 – is to ensure universal access to clean cooking solutions by 2030. Despite worldwide efforts, nearly 3 billion people, accounting for almost 40% of the world's population, currently lack access to modern cooking facilities and instead rely on biomass (used inefficiently), kerosene or coal (Box 1.1). The access deficit is more pronounced in rural rather than urban areas and while progress has been made in providing clean cooking solutions in Asia and South America, the situation is not improving in sub-Saharan Africa (IEA, IRENA, UNSD, World Bank and WHO, 2020). Fossil fuel based solutions – such as those centring on liquefied petroleum gas and natural gas – are being deployed widely as part of national and regional strategies to ensure access (Box 5.1).

BOX 5.1. CLEAN COOKING ACCESS: ONLY WITH FOSSIL FUELS?

The share of the population with access to clean fuels and technologies for cooking increased from 57% in 2010 to 61% in 2017, an average annual increase of 0.5 percentage points. Some improvements in access are being achieved as countries use a variety of strategies, most of which rely on increased use of liquefied petroleum gas (LPG) and natural gas, electricity and cleaner biomass solutions. For example, in Asia 525 million people gained access to clean energy solutions since 2011. Access rates in China and India reached 70% and 47%, respectively, with natural gas infrastructure improving clean fuel access in China and LPG replacing biomass and kerosene in India. In Africa, 68 million people achieved clean cooking access since 2000, mostly in Ethiopia, Ghana, Kenya, Nigeria, South Africa and Sudan. LPG use has grown strongly in Sudan and Kenya. Governments in Ghana, Cameroon and Kenya are promoting LPG as a better alternative especially for urban areas. In Ghana, 24% of the population relied on LPG after 15 000 LPG cookstoves were distributed by 2017.

Source: IEA, 2019a; IEA, IRENA, UNSD, World Bank and WHO, 2020.

Renewable energy technologies provide an opportunity to leapfrog fossil fuel solutions. The priority is to provide universal access to modern cooking and heating solutions that avoid the negative environmental and socio-economic impacts of fossil fuels. Such a transition uses a range of solutions including electricity from renewable sources (Section 3.5), household and community biogas systems (Section 4.9), improved cookstoves, and ethanol fuelled cookstoves.

Improved cookstoves can increase combustion efficiency and lower air pollutant emissions. Many programmes to roll out such improved designs have been undertaken, but the stoves are sometimes unable to perform in ways that lead to acceptable emissions performance (IEA, 2019a). More promising results are achieved when improved stoves are coupled with solid biomass in the form of pellets or briquettes produced from wood or from agricultural residues which have higher energy densities and better combustion properties. In urban areas where charcoal fuels are commonly used, mainly in Africa, improved charcoal production systems can reach 35–40% efficiency (IEA, 2019a).

Modern forms of bioenergy, such as bioethanol and biomethanol cooking fuels, can provide an efficient and clean source of energy to displace the inefficient use of biomass. Sophisticated biomass stoves can offer a high degree of automation and efficiencies of up to 90%. The use of ethanol is found to reduce particulate matter by more than 98% compared with traditional charcoal or three stone fire stoves and is two to three times more efficient (Benka-Coker *et al.*, 2018). In addition, it is cost competitive. In Kenya, the use of ethanol instead of charcoal can reduce the average household's expenditure on cooking fuel by 40% (Collins, 2019). In Nigeria, ethanol cooking gel costs about USD 1.15 per litre; this is in the range of the cost of kerosene, which fluctuates between USD 1 and USD 1.55 per litre (IRENA, 2016c).

While efforts to increase clean energy access using different fuels and energy carriers are ongoing, a number of biomass-based options are likely to continue to play an important role. This is especially true in more remote communities where access to modern fuels is difficult, and in countries where the price of fossil-based alternatives is prohibitive. Furthermore, when other fuels are promoted and adopted, resulting in a gradual transition towards cleaner fuels, users tend to move to multiple energy sources for cooking, one of which is often biomass (a practice referred to as stacking). Experience in Mexico and China shows that the use of multiple energy sources for multiple purposes is not just a short transition phase but can last for decades (FAO, 2018). Many clean cooking initiatives therefore include improved biomass options along with alternative solutions. But their deployment is still subject to barriers.

5.1.2. BARRIERS TO THE TRANSITION TO SUSTAINABLE AND EFFICIENT BIOMASS FOR ENERGY ACCESS

The principal barriers to the adoption of improved clean cooking solutions – including the use of improved stoves and biomass fuels – are related to lack of policy attention, cost and financing constraints, appliance and fuel standards, quality and skills, supply chains and sustainability issues, in addition to cultural barriers and a lack of awareness in local communities. Barriers to households adopting ethanol as a cooking fuel appear throughout the supply chain, from feedstock cultivation, fuel production and distillation, to distribution, cookstove design, cookstove fabrication and cookstove distribution.

Lack of political will and policy attention. The lack of political will to address energy access, or of a coherent strategic approach to clean cooking, has been a major impediment to progress in many countries. The issues relating to clean cooking cut across many parts of government – including ministries responsible for energy, environment, forestry, and social and financial matters – which may not accord priority to access, making coordination difficult (FAO, 2017). In addition, national and international funding is still not in line with that required to meet the SDGs. It is estimated that an annual investment of at least USD 5 billion is needed to achieve universal access to clean cooking; however, financing for residential clean cooking was only USD 32 million in 2017 (IEA, IRENA, UNSD, World Bank and WHO, 2020). Only USD 2 million in private sector equity is invested in companies in the clean cooking sector – 0.01% of what is required to bring clean cooking solutions to scale (IEA, 2019a).

Cost and financing constraints. One major barrier is the higher cost of the improved equipment and fuels which replace what is essentially a "free" resource of wood fuels and other collected residues (although their collection requires considerable time and effort and therefore has a significant social cost) (Hosier *et al.*, 2017). This cost barrier is reinforced by a lack of access to capital to finance the purchase of clean equipment and fuels. In Nigeria, where the cost of ethanol cooking fuel is similar to that of other energy sources that are more polluting, the affordability of ethanol cooking stoves may pose a challenge for low-income consumers. Ethanol cooking requires specialised stoves, generally priced at between USD 40 and USD 80, though in some areas they can cost as little as USD 20 (Hosier *et al.*, 2017). Still, this is more than double the cost of a traditional biomass stove. Policy options to address these barriers are discussed in Section 5.1.4.

Challenges related to standards, quality and skills. Many improved bioenergy cookstoves still have low efficiency and often fail to meet appropriate, environmental and health performance standards unless associated with improved fuels (such as briquettes, pellets, or ethanol-based fuels) (Hosier *et al.*, 2017). In many countries where cookstoves are not produced in a standardised manner, efficiency levels are often not certified. Moreover, potential entrepreneurs wanting to set up companies in the supply chain often lack the necessary skills. In cases where skilled labour is scarce along the supply chain, there is a risk of improper assembly or installation. Inappropriately designed and built systems which do not conform to quality standards generally perform badly, reducing users' confidence and potentially causing safety problems.

Supply chains and sustainability issues. Programmes to promote improved biomass solutions often do not address either the need for user solutions or for sustainable fuel supplies. Improved cooking fuels, such as biomass briquettes and pellets, or ethanol-based fuels, and suitable cooking stoves, have immature distribution channels, which can prompt concerns about the security of supply or price volatility. Distribution to remote rural areas is especially challenging (as it is for fossil fuels as well).

In addition, the supply of ethanol cooking fuel often falls short, as it competes with demand from the beverage industry and the transport sector (*e.g.* sugarcane ethanol in Malawi) and very few countries have an ethanol cooking fuel sector at scale (Gasparatos *et al.*, 2018a). It was estimated that 28 billion litres of ethanol cooking fuel would be needed each year to displace biomass, more than twice the current global production of bioethanol (IRENA, 2016c). To put this into perspective, fewer than 6 million litres of ethanol and 8 million litres of ethanol gel were sold in 2017 to serve the households in sub-Saharan Africa that use ethanol for cooking, which number less than 1 million (Hosier *et al.*, 2017).

The production of ethanol fuel is a land-intensive activity (Gasparatos *et al.*, 2018b). When agricultural and natural areas are converted for feedstock production, the change can directly and indirectly affect local food security, the ecosystem and other aspects of rural livelihoods (Gasparatos *et al.*, 2018a). This is less of a challenge when the feedstock source is sugarcane molasses, which is considered a waste material, or when feedstocks are grown on contaminated lands. In sub-Saharan Africa, ethanol production is often tied to sugar factories. For these ethanol distilleries, the availability of molasses is a determining factor in the volume of ethanol production. In Kenya, for example, although domestic production capacity from the sugarcane-based ethanol industry is as high as 83 million litres, the distilleries at the sugar factories often operate below capacity for lack of enough molasses (Trindade, 2016).

In addition to supply shortages, last-mile distribution of ethanol cooking fuel is also a challenge. For ethanol fuel to reach households for use in cooking, a good distribution network is needed, similar to that for kerosene. This is especially true in sub-Saharan Africa, where ethanol production is centralised (Hosier *et al.*, 2017). In a centralised production model, finished ethanol is moved from the distilleries in tanker trucks of 30 000–50 000 litres. Denaturants and thickening agents (for ethanol gel) are added before further distribution to retail points (Puzzolo *et al.*, 2019). This process limits the consumption of ethanol fuel to urban and peri-urban households that are close to the retail points. For rural households, a decentralised production model can improve access and empower local communities (Practical Action Consulting, 2011).

Issues related to information, culture and gender. A lack of knowledge and understanding of the economic, social and health benefits of clean cooking serve as a barrier to the adoption of clean household energy. There is also misinformation – for example, that wood smoke repels insects and so protects against malaria (IEA, 2019a). In addition, clean cooking solutions often do not reflect user requirements, for example, to reduce cooking time. It is therefore critical to consider various factors, particularly consumer preferences and needs, to ensure the long term adoption of clean cooking solutions. Although women are usually responsible for cooking, they are often disadvantaged in household investment decision making and in gaining access to finance for clean cooking.

5.1.3. MEASURES TO SUPPORT THE TRANSITION TO A MORE SUSTAINABLE AND EFFICIENT USE OF BIOMASS FOR ENERGY ACCESS

Measures to address the lack of policy attention

The inclusion of clean cooking in the SDGs has prompted greater attention and international efforts to address the issue. The development community in particular has made significant investments in clean cooking over the past five years, under the leadership of the Clean Cooking Alliance.

International and national programmes and strategies can have an important catalytic effect on efforts to deploy clean cooking solutions including improved bioenergy-based heating and cooking appliances. Some examples include the West African Clean Cooking Alliance, which aims to provide clean, efficient and affordable cooking fuels and devices to all citizens in the Economic Community of West African States by 2030 (IEA, 2019a).

In addition, there is a strong need from national governments to become less dependent on international fuel prices. While many countries have yet to create a policy framework for ethanol cooking fuel, the adoption of domestically produced ethanol can mitigate fluctuating fuel prices, and potentially meet the growing international demand of ethanol that comes from governments' fuel mixing mandates.

Policies to address barriers related to cost and finance

Policies can play an important role by directly offsetting the cost differences of competing solutions and by providing financial options, including subsidies, that make clean solutions more affordable to users.

National cookstove programmes supported by development finance are being launched or scaled up in many sub-Saharan countries, including Ethiopia, Ghana, Malawi, Nigeria, Rwanda, Senegal and Uganda (Hosier *et al.*, 2017). In Benin, Burkina Faso and Ethiopia, governments have provided **subsidies** of up to half of the investment cost of anaerobic digesters. The World Bank Clean Cooking Fund provides results based **grants** and technical assistance for clean cooking solutions. **Relief of taxes and duties** such as value added tax (VAT) have an important influence on relative pricing. For example, in 2015, the Kenyan government removed the excise duty on denatured ethanol to increase affordability and stimulate investment.

Examples of policies to tackle the finance barrier can be found, among others, in Kenya, where financing is provided through a **lease-to-own** arrangement which transfers ownership to the operator at the end of the loan period (IEA, 2019a). In Kenya and Tanzania, private companies have implemented **pay-as-you-go** electronic financing models for cookstove equipment and renewable fuel, which allow consumers to pay in instalments, improving access to clean cooking in rural, low-income communities by mitigating the high upfront capital costs of clean cooking solutions.

To alleviate capital shortages, the U.S. Agency for International Development funded **loans** under the Micro Enterprises Support Programme Trust (MESPT) programme in Kenya to increase cookstove adoption rates by creating a revolving loan facility for cookstoves and also **supported micro-finance** institutions to offer credit to potential customers for small loans for cookstoves (Winrock International, 2017).

In terms of policies that address the cost and finance of ethanol, successful policy measures to improve affordability include levelling the playing field between ethanol and other cooking fuels by lowering the VAT and adjusting import tariffs.

Policies to address barriers related to standards, quality and skills

Regulation and standards backed up by certification and testing can make the difference in procuring the best technology available in order to avoid inefficiencies and consequent abandonment of clean cooking solutions. For example, Ghana's comprehensive clean cooking programme includes the development of national standards for cookstoves and efforts to expand the use of biogas and alcohol fuels at the household level.

Training is also a key element of success. In Senegal, Sudan, Mali, Niger and Kenya, there is support for sustainable biomass fuel supply demonstration projects, training and market development along with support for co-operatives and producer associations (FAO, 2017).

Kenya has established clear regulatory guidelines for the ethanol cooking industry, with a coherent model that merits replication elsewhere. Its regulations include clear registration, certification, licensing and permitting processes for ethanol producers and distributors. **Safety and quality standards** for the fuel and stoves are monitored, documented and provided to the public. The challenge of Kenya's ethanol cooking fuel policy design, however, lies in the distinction between ethanol for beverage uses and for fuel. Historically, ethanol has been produced and taxed for the beverage market, and these taxes are often higher than taxes on fuels (Puzzolo *et al.*, 2019). Until recently, Kenya's import tax on ethanol, whether denatured or undenatured, was 25% (Dalberg, 2018). To promote the use of ethanol cooking fuel, a zero-VAT rating was adopted by the Kenyan government in 2019 (Deloitte, 2019).

Policies to bolster supply chains and address sustainability issues

Programmes for improved biomass solutions often do not address both the need for sustainable fuel supply and for user solutions. A number of policy measures promote sustainable forestry management. Programmes can also promote the use of non-forestry biomass sources such as crop residues (although it is important to avoid overexploitation of these resources, often used as animal fodder).

The supply of sustainable biomass is being regulated by providing secure forest tenure and rights in exchange for responsibility to manage and conserve forest areas (Chad, Niger, Madagascar, Uganda, Ethiopia and Kenya). **Licences, permits and quotas for production or transportation** of wood or charcoal are being imposed and they work best when they are made simple and affordable and are best under local management (communities or local authorities with communities having enforceable rights over forest resources (FAO, 2017).

Direct financial and fiscal measures also have an important role to play in improving the sustainability of wood fuel supply. For example, in Burkina Faso, Chad and Niger, taxes are levied on wood extracted from forests, but a lower rate is applied to wood extracted from managed forestry. The revenue is shared between communities and the local treasury, an important factor in securing local buy-in. In Latin America, subsidies are provided for small-scale plantations and wood lots, including free seedlings and grants for the establishment and maintenance of lots. This is financed from taxes on the wood fuel produced (FAO, 2017).

As mentioned in Section 5.1.2, weak points in the supply chain are among the key challenges to the greater uptake of ethanol cooking fuel. Policies to address production gaps can promote small-scale production. For example, the Madagascar government set forth a decree to promote ethanol cooking by lowering taxes for fuel production and stove imports, setting performance and quality standards for ethanol fuel, and clearly designating responsibility for approving ethanol micro-distilleries. This decree has boosted private sector interest in this emerging sector of economic development. The government received applications from four distilleries (World Bank, 2016). The rationale for a small-scale production model is further developed in the case study in Box 5.2.

Policies to address issues related to information, culture and gender

Education and awareness programmes can play a key role in encouraging the uptake of clean cooking solutions. Kenya has several initiatives underway to raise awareness about the benefits of clean cooking among the general population. Likewise, in Rwanda, Sudan and Ethiopia, the governments are working to increase the uptake of cleaner renewable fuels like biogas and processed biomass fuels which can offer higher efficiency when used in improved appliances.

Table 5.1 summarises policies and barriers related to the pursuit of a more sustainable use of biomass and ethanol to widen access to energy.

BOX 5.2. CASE STUDY: SMALL-SCALE PRODUCTION OF ETHANOL COOKING FUEL IN ETHIOPIA

As of 2017, about 90% of the biofuel businesses in sub-Saharan Africa were pursuing centralised production models, which feature medium- to large-scale distilleries whose capacity is in the order of millions of litres (Muniz Kubota *et al.*, 2017). Medium-scale plants usually produce 15–25 million litres per year using sugar factories' waste molasses as their main feedstock. The ethanol fuel is then transported by tanker trucks to nearby depots for denaturing and colouring before further distribution to consumers. An ethanol micro-distillery (EMD), on the other hand, typically produces less than 5 000 litres per day.

While small-scale production has found little success in early biofuel markets, such as Brazil, it has shown potential in sub-Saharan Africa where cooking fuel needs are strong (Muniz Kubota *et al.*, 2017). Despite the many obstacles to EMDs in sub-Saharan Africa – obstacles that include fossil fuel based economies, a lack of infrastructure for biofuel distribution and a lack of skilled labour – there is still great potential for small-scale production to take off due to a large gap in access to clean cooking.

In Ethiopia, ethanol is mainly produced by the state-owned sugar factories. The introduction of a biofuel policy resulted in competition between the ethanol cooking fuel market and transport fuel blending programmes, leaving ethanol stove users without affordable fuel (Practical Action Consulting, 2011). To address this supply shortfall, Project Gaia, an association promoting ethanol-based clean cooking, invested in an EMD of 1 000 litres-per-day capacity, tied to a small sugar factory close to Addis Ababa, Ethiopia. Although its profit margin is small, the EMD has since proven financially viable. With a capital investment of roughly USD 300 000, Project Gaia was able to sell the fuel at an affordable price of USD 0.55 per litre, serving 4 500 people in Addis Ababa. In addition to the benefits of clean cooking, this project brought alternative livelihoods and sources of income to members of the Former Women Fuelwood Carriers Association (FWFCA) as distributors of ethanol cooking fuel.

With the success of this project, Project Gaia, in collaboration with a bean processing plant, sought to replicate this model in Adama, Ethiopia. The plant produces 10 000–20 000 tonnes of beans every year, out of which 4 000 tonnes are rejected in the quality control process. By setting up a protein extraction processing plant and an EMD at the bean factory, the project can supply 480 tonnes of protein extract and 1.5 million litres of ethanol per year. This can provide clean cooking access to 300 000–400 000 people in Adama.

The key enablers of a wider adoption of EMDs include: 1) better access to dedicated loan facilities by international donors for potential EMD owners, and 2) clear policies that encourage private investment in EMDs for cooking fuel. For example, providing loan guarantees to small ethanol producers were proven successful in the United States in the late 1970s and 1980s, through the Energy Security Act (Practical Action Consulting, 2011). In 2014, the Madagascar government lowered the taxes for fuel production, set performance and quality standards for ethanol cooking fuel and provided clear guidance for approving EMDs (Sustainable Energy for All and Catalyst Off-Grid Advisors, 2019).

Table 5.1. Barriers and policies for more sustainable use of biomass and ethanol for energy access

Targeted barriers	Policies	Examples	Comments
Higher costs of improved cooking equipment and fuels	Grants/capital subsidies	Government subsidies of 50% for anaerobic digestion plants in **Benin**, **Burkina Faso** and **Ethiopia** Grants from World Bank Clean Cooking Fund for clean cooking solutions	Designs and fuels receiving support must achieve significant emissions reductions and be compatible with local cooking practices.
	Tax and duty relief	**Kenya**'s removal of excise duty on denatured ethanol to improve affordability	
Lack of access to capital to finance equipment purchases	Policies encouraging pay-as-you-go (PAYG) model for equipment purchases	PAYG model in **Kenya** and **Tanzania**	Appropriate loans are for small capital sums only, which discourages lenders who face significant administrative costs.
	Low-interest loans	The U.S. Agency for International Development's revolving loan system and support for micro finance institutions in **Kenya**	
Lack of policy attention	International and national programmes and strategies	The West African Cooking Alliance's goal to provide clean and efficient cooking devices and fuels to all citizens of the Economic Community of West African States by 2030	Clean cooking's inclusion in the Sustainable Development Goals has stimulated attention and investment in clean cooking programmes.
Poor standards and quality; lack of appropriate skills	Regulations and standards	**Ghana**'s clean cooking programme, with national standards for cookstoves and for the use of biogas and ethanol fuels	Standards must be backed up with certification and testing to ensure compliance.
	Training programmes	The National Biogas Programme in **Viet Nam**, which provides training for manufacturers and government technicians	Manufacturers must be certified before being allowed to sell systems.
Supply chains and sustainability issues	Promotion of sustainable forestry practices and efficient use of non-forestry resources	Secure forest tenure rights in **Chad**, **Niger**, **Madagascar** and several other African countries, along with licences for production and transportation of wood fuels, all to encourage conservation and management of forest areas	Regulations must be simple and affordable and are best left under local management.
	Taxation policy	In **Burkina Faso**, **Chad** and **Niger**, a lower rate of tax on wood extracted from managed forestry	Extraction tax revenue can be shared with local communities to secure local buy-in.
	Subsidies for sustainable plantations	In Latin America, subsidies for small-scale plantations and wood lots	Grants are financed by a tax on the wood fuel produced.
Lack of information; gender and cultural issues	Education and awareness programmes	In **Kenya**, programmes to promote the benefits of clean cooking solutions	Cooking solutions must be well adapted to local practices.
Ethanol competition with the transportation and beverage industries; application of beverage-industry regulations to ethanol used for cooking	Policies to promote ethanol micro-distilleries	**Madagascar**'s Ethanol Clean Cooking Climate Finance Programme	Policy attention is needed to address the lack of financing for ethanol micro-distilleries.
	Clear regulations	**Kenya**'s interagency approach to permitting, licensing, registration and certification.	Effectiveness depends on legal frameworks, pricing structures, and quality standards specific to cooking ethanol.
High upfront cost of ethanol cookstoves	Policies encouraging PAYG business models		Adoption depends on the affordability of both fuel and appliances.
Technologies requiring behavioural change	Capacity building and information (*e.g.* local manuals, awareness campaigns)	Initiatives in **Rwanda**, **Ethiopia** and **Kenya** to raise awareness of clean cooking	Consumers may not be willing to change their behaviour.
Fossil fuel oriented financial incentives	Tax relief or exemption on ethanol fuels	Tax incentives decreed by **Madagascar**'s government	Effectiveness depends on clear and specific incentives to keep competing fuels from benefitting.

5.2. SUSTAINABLE USE OF BIOMASS FOR BUILDINGS AND INDUSTRY

Biomass fuels can be used in modern, efficient combustion devices to produce heat for industry and buildings. As part of the transition to a low-carbon energy economy, sustainable biomass for heating in industry and in buildings offers immense potential.

5.2.1. CURRENT STATUS AND BENEFITS OF THE USE OF BIOMASS IN BUILDINGS AND INDUSTRY

Solid biomass can be efficiently used for heating for buildings and industry by producing hot water as steam in boilers and in stoves, using wood chips and pellets as well as agricultural residues such as bagasse and straw. The extended use of solid biomass can help reduce GHG emissions without increasing demand for low-carbon electricity and the associated infrastructure. It can also help provide important rural employment opportunities through the development of local fuel supply chains, while also providing additional income streams to the forestry and agriculture sectors.

In buildings, modern small- and medium-scale devices can efficiently provide heat for the residential sector, but also for commercial and public buildings and industrial heat loads, where the larger scale makes applications more competitive. Such devices can meet stringent environmental standards and achieve high efficiency, thermal comfort and automation especially when used with standardised wood fuels such as pellets. Such fuels are taking an increasing share of the heating fuel market, with pellet sales of nearly 16 million tonnes in Europe and 2.7 million tonnes in North America (REN21, 2020). There is room for further expansion of this market, complementing the growing use of bioenergy in district heating systems (Chapter 8) and of biomethane in gas grids (Chapter 4). Solid biomass heating is particularly helpful as a route to decarbonise heating needs for users who are not connected to the gas grid. It is also a useful option for houses which are difficult to insulate to high levels and for which heat pumps are a less suitable alternative (REA, 2019).

In industry, biomass is currently mostly used in the bioeconomy,[2] such as the pulp and paper, forestry, wood products, sugar and other foodstuff industries where heat is produced with electricity in combined heat and power (CHP) plants. Within these industries, biomass waste and residues are produced on site and are subsequently used as fuels. Sri Lanka's Elpitiya Plantations PLC, for example, uses estate-grown sustainable biomass for the thermal energy required for tea and rubber production processes, in addition to also operating at 100% renewable electricity (IRENA Coalition for Action, forthcoming). Currently, biomass is not widely used in other industries including high temperature industry applications due to technical suitability, consumer acceptance and cost and supply barriers. Exceptions include the cement industry, where solid biomass fuels (mostly from waste) are used as a replacement for coal and represent around 6% of energy used. In Europe, as a result of favourable waste management regulations, the share of biomass in energy for cement has reached 25% (REN21, 2020). Brazil has some use of charcoal fuels for iron production.

There is scope to increase the use of biomass and the efficiency with which it is used in the industries that use biomass feedstocks, and to extend its use for producing low-temperature heat to other sectors. It is also possible to consider the use of biomass in high-temperature applications, but some adaptation will often be needed to ensure compatibility with production processes, along with the supply chain development required for the very large quantities of fuel that would be needed.

5.2.2. BARRIERS TO THE WIDER UPTAKE OF BIOMASS FOR HEAT PRODUCTION IN BUILDINGS AND INDUSTRY

The main barriers to using biomass for heat in buildings and industry relate to costs and markets; immature supply chains and sustainability issues; policy and regulatory limitations; lack of skilled workers and cultural barriers.

Cost and market barriers. In many cases, since the negative environmental and health impacts of fossil fuel combustion are not reflected in prices, they remain more cost-competitive than bioenergy. The difference in costs between biomass and fossil fuel options depends on factors including fluctuating oil and gas prices, taxes and duties on fossil fuels, among others (see Chapter 2 for a discussion of fiscal policy).

For domestic heating systems, the capital cost of a modern and efficient biomass boiler is around USD 720–750/kilowatt thermal (kW_{th}) compared with USD 80–120/kW_{th} and USD 120–150/kW_{th} for a gas or oil boiler, respectively (REA, 2019). Fuels costs depend on local supply. The delivered cost of wood pellets for domestic use in Europe was around EUR 240/tonne in 2018 – *i.e.* USD 16/gigajoule (GJ) (Bioenergy Europe, 2019). This compares with residential gas prices in Europe between USD 14 and USD 35/GJ, depending on the levels of VAT and other taxes (BEIS, 2020).

Larger-scale systems which can be used for heating commercial and public buildings can benefit from lower operating and fuel costs. They also tend to have longer operating periods (IEA, 2017b). Heating costs for biomass wood chips and pellets can be competitive versus a range of fossil heating fuels, especially compared with heating oil.

For industrial users, bioenergy feedstocks which can be used at or close to their source may be available at lower costs (*e.g.* residues in the forestry and timber industry and agricultural residues such as sugar cane bagasse). Where fuels must be collected, stored and transported, costs rise and can exceed those of fossil fuels, becoming prohibitive for large-scale operations such as high-temperature industrial processes. For industrial production of steam or hot water, with high utilisation factors and using locally available fuels such as wood chips,

2 The European Union defines the bioeconomy as follows: those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisms – to produce food, materials and energy.

costs can be competitive.

Many high-temperature industrial processes currently use large amounts of low-cost coal or coke as an energy source. For example, a typical large-scale steel plant producing 5 million tonnes a year would use some 2.5 million tonnes of coal (around 65 petajoules). Replacing significant proportions of the fuel with biomass would need up to 4 million tonnes of biomass and therefore a very extensive supply chain. The delivered costs of such fuels for power generation and industrial uses averaged USD 11/GJ in 2018, compared to coal prices of around USD 3/GJ (Bioenergy Europe, 2019). Significant policy initiatives will be needed to bridge this cost gap – by reflecting the real cost of coal through removal of subsidies, and levying externalities or other taxes and duties (see Chapter 2), by placing CO_2 emission limits on processes, or by supporting biomass based fuels in other ways. Moreover, regarding **financing**, bioenergy heat projects are capital intensive and are perceived as high-risk investment, due to risks associated with the reliability of fuel supply. Section 5.2.3 presents policies to address barriers related to cost and finance.

Policy and regulatory limitations. The sustainable and efficient use of biomass in buildings and industry depends on a strong and supportive policy and regulatory regime that provides for investor certainty in terms of the income streams that projects will receive. The challenges lie in designing a coherent policy framework for a complex topic that touches upon diverse policy areas, including energy, environment, biodiversity, agriculture and forestry. Section 5.2.4 discusses measures to address policy and regulatory limitations.

Supply chain issues. Bioenergy systems rely on a reliable and consistent supply of feedstock. While in many cases this can be provided locally – for example, within a site where wood products are handled, or in a sugar mill – many other projects require more extensive supply chains. Developing these may involve many actors (in the forestry, agriculture and waste management sectors) who may not have been engaged in the energy industry before, and who may be reluctant to change their current practices until they see successful examples of sustainable, stable and profitable outlets for their resources. Similarly, energy producers may be unfamiliar with these upstream bio-industry players. These problems are most acute when there is a need to produce new energy crops, which may require significant changes in their production and rotation patterns, including a shift from annual crop production to perennial crops such as miscanthus and other grasses or short rotation forestry (*e.g.* coppiced willow or poplar), along with the use of novel planting and harvesting machinery. Unless farmers are confident that there will be a sustained and profitable market, they are unlikely to switch production from their traditional crops. Measures to increase farmers' confidence are discussed in Section 5.2.5. Finally, although no special infrastructure provisions are needed, bioheat installations require considerable space for fuel storage and handling and this may not be convenient in urban contexts, constraining deployment.

Sustainability issues. If bioenergy supply chains are not carefully developed and operated, there may be negative and unsustainable environmental, social and economic consequences. The extent to which bioenergy contributes to GHG emission reduction targets, and whether its widespread development would have positive or negative environmental, social or economic impacts – for instance related to biodiversity or landscape preservation – remains controversial for some forms of bioenergy, making it difficult for policy makers to take actions in this area. Sustainability of bioenergy sourcing and use is an important requirement for its widespread development – without this creteria, policy makers are wary of including bioenergy in national GHG reduction programmes, and associated policy uncertainty discourages investment by industry players, who also risk reputational damage. Section 5.2.5 presents policies to address barriers related to supply chain and sustainability issues.

Skills and quality of products. Developing successful bioenergy projects is complex and requires skilled and experienced people to plan, design, execute and provide continued operations and maintenance. In some cases, lack of skilled personnel can be a barrier to deployment. For example, in Germany where there is a strong drive to decarbonise heating and high levels of grant support for new biomass installations, a lack of qualified biomass boiler installers is currently considered an impediment to faster development of the sector, despite strong policy drives and incentives. Deployment can also be held back where poor-quality systems are used, or where the biomass fuel quality does not meet a specification which matches that used in designing the furnace or fuel. Section 5.2.6 presents policies to ensure the availability of the required skills and quality of products.

Cultural and information barriers. Given the wide range of bioenergy technologies, potential users and other actors in the supply chain may not be aware of the potential solutions. For example, households, communities and public sector building managers may not consider using wood fuels and may be unaware of clean solutions such as pellet boilers and stoves. Industrial players may either be unaware of potential bioenergy opportunities or lack reliable information on the benefits and risks of specific bioenergy options. Section 5.2.7 discusses measures to address cultural and information barriers.

5.2.3. POLICIES TO ADDRESS COST, FINANCE AND MARKET BARRIERS

Policy mechanisms that can address the cost and market barriers to the wider uptake of biomass for heating include fiscal and financial measures to reduce operational costs, bridge the gap with fossil heating fuels, and provide low-cost financing for projects. Those include capital grants, subsidies, fiscal benefits, tradeable certificate schemes which put a value on the GHG mitigation and other benefits associated with bioenergy, and feed-in tariffs or premiums which guarantee a firm price for energy supplied.

Capital grants and subsidies reduce the upfront investment and have the benefit of simplicity – especially for small-scale projects such as those in residences. But grant-based systems may also be used for larger-scale systems, including those associated with district heating schemes. Capital grants have also been provided to improve efficiency and reduce operation cost, such as those profiled in Box 5.3.

Fiscal policy relating to bioenergy systems, such as lower rates of VAT on biomass boilers and fuels and other low-carbon energy systems for residential customers, can also significantly influence consumer choice. Favourable regimes allowing more rapid depreciation for low-carbon heating options, can have an important impact on industrial investments.

Renewable heat schemes are also sometimes included in schemes designed to promote renewable electricity generation, such as **renewable portfolio standards**. For example, the renewable portfolio standards in 12 U.S. states include renewable heat technologies. Electricity ratepayers fund thermal renewable energy certificates and have compliance costs that are lower than those for electricity (Alliance for Green Heat, 2020).

Schemes for heating that operate like feed-in tariffs are less common. In the United Kingdom, the Renewable Heat Incentive has led to biomass heat uptake in commercial and residential buildings and in industry by providing a guaranteed tariff for every unit of heat produced, rewarding renewable heat on a per kilowatt hour basis with a 20-year price guarantee (Ofgem, 2020c). While open to a range of renewable heating options, biomass-based systems are those most widely supported under the Renewable Heat Incentive, especially at a larger scale, where 96% of projects supported involved biomass (REA, 2019).

Measures can also help improve access to financing for bioenergy projects. For example, the Brazilian Development Bank provides loan support to expand biomass cogeneration capacity, typically fuelled by renewable biomass, such as bagasse or wood chips (Morais, 2019).

BOX 5.3. CAPITAL GRANTS TO SUPPORT BIOENERGY AND ENERGY EFFICIENCY IN BUILDINGS AND INDUSTRY

France's *Fonds Chaleur* (Heat Fund), in place since 2009, offers subsidies for residential, commercial and industrial renewable heat, including small-scale biomass applications (Observ'ER, 2020). The subsidy aims to increase the uptake of renewable heat by pushing the price 5% lower than fossil fuel alternatives. On a local level, Grenoble augmented the Fonds Chaleur by adding local financial aid to small-scale projects, including bioheat technologies (REN21, 2019).

In Italy, the uptake of pellet boilers has been supported by the *Conto Termico* (Heat Account), a grant scheme that supports renewable heat and thermal efficiency improvements in buildings. The incentive has an annual budget of EUR 900 million (of which EUR 200 million is destined for the public sector) and provides grants of up to EUR 5 000 depending on technology capacity, reductions in GHGs and particulate matter, and heating degree days in the region (IEA, 2017c).

India's Ministry of New and Renewable Energy has also introduced a grant scheme for biomass cogeneration in industrial steam boilers, with incentives paid when the plant operates successfully (IRENA, IEA and REN21, 2018).

5.2.4. POLICIES TO ADDRESS INSTITUTIONAL AND REGULATORY BARRIERS

A **consistent and long-term policy approach to bioenergy** within an overall renewable energy or low-carbon strategy provides confidence to investors and project developers. This strategy should be developed with a wide range of stakeholder input, including from industry, and co-ordinated with the different policy areas. Indicative targets for bioenergy as a whole and for contributions in specific sectors also provides certainty about the future direction. Such plans and targets must be backed by concrete policies addressing the barriers.

Policies and regulations on bioenergy tend to be complex, given the many issues involved, including sustainability (see Section 5.2.5). This complexity calls for sufficient resources and qualified **institutional capacity** to develop, implement, monitor and enforce appropriate regulations, which may not be available, especially in emerging and developing markets where many important bioenergy opportunities may exist. Institutional capacity building is necessary to put in place effective policy and regulatory portfolios to enable bioenergy deployment and to ensure sustainable development and operation. Resources and expertise are also needed in the agencies which permit projects and monitor long-term performance. Development and other multilateral banks, and international agencies can play a key role in providing advice on best practice policy guidance and institutional capacity building.

Bioenergy heat projects are also subject to **planning and regulations that are set by non-energy related sectors such as agriculture and environment**. A clear set of regulations which establish the criteria that projects must meet to achieve permitting and for ongoing operations, sets clear design parameters for projects and reduces developer risks (and costs). For example, regulatory requirements must clearly establish what levels of emission to air and water are permitted and what other sustainability criteria must be achieved. Publishing guidance on the permitting framework explaining the necessary steps is very helpful and can be handled by one stop shops to reduce permitting time and transactional costs.

Building codes and constraints on fossil fuel use can provide a powerful push for renewable solutions including bioenergy, complementing energy efficiency measures (discussed in Chapter 2). For example, all Scandinavian countries have coupled the shift to renewable heat with high energy efficiency standards in new buildings using building code requirements.

Finally, **supplier obligations** can set a requirement for fuel distributors to provide a percentage of renewables-based fuels or involve a requirement to reduce the carbon intensity of fuels. Such measures are especially being considered to promote the inclusion of biomethane and other low-carbon gases in the natural gas grid (see Chapter 4), but are also being considered more widely for the supply of heating fuels (REA, 2019; REN21, 2020).

5.2.5. POLICIES TO ADDRESS SUPPLY CHAIN AND SUSTAINABILITY ISSUES

Providing secure long-term and profitable market opportunities is key to the establishment of reliable supply chain. The effectiveness of this is demonstrated by the very large-scale supply chains established to provide wood pellets for power generation, secured by long-term power purchase agreements that have allowed supply chain players to invest in the necessary infrastructure.

The growth of energy crops can be incentivised by providing additional financial support to projects which use these fuels. Planting grants and other measures designed to reduce the upfront costs of establishing energy crop plantations have also been used but have not always been effective when other measures designed to stimulate long-term markets are absent. But sustainable practices must be taken into consideration.

Bioenergy encompasses a very wide range of options – feedstock sources, conversion routes and energy products – and the environmental, social and economic benefits depend on many factors and can vary depending on location. Therefore, sustainability assessments need to consider the risks associated with specific bioenergy routes in detail and general statements are generally unhelpful (IEA, 2017b).

A better understanding of the potential benefits and risks of bioenergy has been developed in recent years and has formed the basis for sustainability regulations intended to prevent unsustainable practices and to only incentivise sustainable bioenergy (IEA, 2019h). National schemes for bioenergy stipulate **sustainability conditions** that need to be met to qualify for support, and a number of **certification bodies** provide detailed sustainability audits to check that the conditions have been met. Issues relating to water quality, land use tenure and labour rights, including the role of child labour and safe working conditions, are already included in many **bioenergy certification schemes** (GBEP, 2011).

Bioenergy certification schemes are often aligned with systems already put in place in other biobased industries. For example, sustainability of forest products is receiving more attention since the development of internationally recognised certification schemes such as those of the Forest Stewardship Council and the Sustainable Forest Initiative (FSC, 2020; PEFC, 2020; SFI, 2020).

Some of the key issues which need to be considered for specific bioenergy heat supply chains include:

- **GHG benefits.** Many bioenergy support systems build in minimum GHG savings criteria as a condition for support under the scheme, calculated according to a prescribed methodology, often with the limit tightening over time. The European Union's Renewable Energy Directive sets a minimum of 70% savings for bioenergy options for heat and power compared with fossil fuel use from January 2021, rising to 80% in 2026 (European Commission, 2019b).
- **Land use and food security issues.** Bioenergy governance regimes often prohibit the use of materials associated with such "indirect land-use emissions" or with the impacts in biodiversity or food security. For example, Europe's Renewable Energy Directive excludes support for bioenergy from raw materials produced on land which have high carbon stocks (or land with high biodiversity value) (European Union, 2019a).[3]

- **Bioenergy and air quality.** This is particularly an issue for residential-scale systems, although with more modern systems stringent air quality standards can be met even at this scale (Austria Environment Agency, 2018). At a larger scale – for heating commercial and public buildings, industrial systems and district heating, and electricity production – it is easier to meet air quality requirements economically (Thornley *et al.*, 2009).
- **Other environmental and social issues.** These issues can be managed by relevant national legislation which usually sets conditions that have to be met as part of the permitting process, with post project monitoring to ensure continuing compliance. Issues relating to water quality, land use tenure and labour rights (including the role of child labour and safe working conditions) are also included in many bioenergy certification schemes (GBEP, 2011). For example, the Sustainable Biomass Programme, a certification system designed for woody biomass, includes air and water quality and labour rights in its criteria (SBP, 2019). The Roundtable on Sustainable Bioproducts includes criteria relating to soil, air and water quality; human labour rights and land rights along the whole value chain (as well as issues relating to GHG and biodiversity) (RSB, 2016).

5.2.6. POLICIES TO ADDRESS TECHNICAL ISSUES RELATED TO QUALITY AND SKILLS

Issues related to a lack of required skills or insufficient product quality can be offset by measures to ensure that only well-designed systems are installed, and by qualified personnel. This can be achieved, for example, by restricting financial support to projects where the systems and the installers have attained suitable quality standards or qualifications.

Industry-led standards can play an important role. The QM Holzheizwerke programme, a joint Swiss-Austrian-German initiative that was first implemented in Switzerland in 2000, is one example (BIOS, 2015). It covers the entire process of designing, procuring, installing and operating a biomass heating system, until its end of life and disposal. It has been successful in raising performance (and thereby reducing greenhouse gas emission) across the biomass sectors in Switzerland, Austria and Germany by providing clarity of responsibilities across the supply chain and measurable minimum standards. Using and being measured against QM Holz is a requirement for securing public investment in a biomass plant in most Swiss cantons and in some regions of Austria and Germany.

With the exception of the cement sector, biomass is rarely used to produce high-temperature process heat at commercial scales of operation. Some technologies – such as gasification – are established and can be used to provide high-temperature heat sources (*e.g.* for mineral processing), but further technology development and demonstration will be needed to show how bio-based systems can be adapted for high-temperature applications while not affecting process efficiency and product quality.

5.2.7. INFORMATION AND CULTURAL BARRIERS

Governments at the national and subnational levels have an important role to play in providing **clear and reliable information** on bioenergy to consumers and potential investors. This can help improve awareness of the benefits and challenges associated with bioenergy and encourage adoption of the technology.

Local governments can play an important role in promoting the use of biomass fuels (along with other low-carbon alternatives). For example, the local authority in Grenoble (France) disseminates information about national support programs to encourage their citizens to engage (Lametro, 2017). The governments and other public bodies can also assist project developers by providing information needed to locate and develop projects. These can include the availability and location of bioenergy resources, in addition to fuel-trading platforms that can improve the liquidity of fuel supply and improve confidence mapping of heat loads.

Table 5.2 summarises policies and barriers related to the sustainable use of bioenergy for heat in buildings and industry.

3 That limit consists of a 7% maximum contribution of such fuels towards the final consumption of energy in rail and road transport in each Member State.

Table 5.2. Barriers and policies for the sustainable use of biomass for buildings and industry

Targeted barriers	Policies	Examples	Comments
High costs compared with fossil fuel alternatives	Capital grants for biomass heating systems	**France**'s heat fund scheme of subsidies for biomass heating systems The grant scheme for industrial-scale biomass co-generation introduced by **India**'s Ministry of New and Renewable Energy	The relative costs of biomass and fossil fuel heating are very sensitive to fuel taxes and duties. Carbon-based fiscal policies and incentives can play an important role in stimulating the uptake of biomass heating.
	Tax incentives	Lower rates of value added tax on biomass boilers and fuels designed to influence consumer choice.	
	Inclusion in renewable portfolio standards	Renewable portfolio standards in 12 **U.S.** states to accommodate renewable heat technologies.	
Unavailability of finance for biomass heating projects	Creation of specific investment funds for biomass heating	Loan support for biomass co-generation projects from **Brazil**'s development bank	Such schemes can catalyse additional funding from commercial lenders.
Absence of clear and supportive policy and regulatory framework	A consistent and long-term policy approach for bioenergy heating	Inclusion of renewable heat in the **European Union**'s Renewable Energy Directive to stimulate the use of biomass for heating in EU member countries	Biomass heating can be the most cost effective source of renewable heat in many settings.
Lack of clear regulations on sustainability	Clear sustainability guidelines	The minimum level of greenhouse gas reduction for biomass heat and power projects specified in the revised EU Renewable Energy Directive, which also excludes support for projects using feedstocks having biodiversity value or produced with high-carbon components	Biomass certification schemes are often aligned with systems in place for other bio-based industries, such as Europe's Forest Stewardship Council and Sustainable Forest Initiative.
	Clear and strict emission limits and equipment standards	Exacting eco-design standards for new small-scale installations in the European Union after 2022	Sustainable biomass combustion systems can meet stringent emission requirements when operated properly.
Quality of installations and biomass fuels	Standards for systems and installers	Requirements in **Switzerland** and parts of **Austria** and **Germany** that projects satisfy design, installation and performance standards in order to receive public financial support	Certification of systems, installers and fuels can play a key role in improving system reliability and environmental performance.
Cultural and information barriers related to the use of wood fuels	Clear and reliable information on bioenergy	Dissemination by the local authority in **Grenoble** (France) of information on national support programmes to encourage local investment	Households, especially in regions without a history of using wood fuels, may not consider using them and may be unaware of clean solutions such as pellet boilers and stoves. Industrial players may either be unaware of potential bioenergy opportunities or lack reliable information on the benefits and risks of specific bioenergy options.

06

Direct use of **solar thermal heat**

Solar thermal technologies use solar collectors for heating and cooling purposes, including water and space heating, space cooling (when collectors are paired with an absorption or adsorption chiller), industrial processes, and wastewater treatment and desalination. Some large-scale projects using solar thermal for industrial processes and district heating could reach a capacity scale at the megawatt level (Solar Thermal World, 2020).

This chapter starts with an overview of solar thermal heat's benefits, current status and the most prominent barriers to deployment. The remainder of the chapter explores the policies that can be adopted to overcome these barriers. Section 6.2 focuses on policies that can address cost and finance barriers, given the high upfront costs of solar thermal technologies. Section 6.3 discusses policies and measures to address the barriers related to markets and regulation, especially given the competition with other sources of heat, and Section 6.4 addresses the technical barriers. Section 6.5 explores policies and measures that can support the uptake of decentralised solutions for heating and cooling in contexts where expanding access to energy is a priority.

6.1. BENEFITS, CURRENT STATUS AND BARRIERS

6.1.1. BENEFITS OF SOLAR THERMAL HEAT

The benefits of directly using solar thermal for heating and cooling are manifold.

Solar thermal technologies can be used in both centralised systems, through district energy networks (see Chapter 8), and decentralised applications.

Solar thermal heat can be used to heat greenhouses, creating environments suitable for food production in locations where natural conditions would not normally allow it. Greenhouses can increase the efficiency of production, reduce losses and improve commitments to sales. In the Netherlands, solar thermal systems are built to help flower farming (Solar Thermal World, 2018a).

Solar thermal heat can also be used for sterilisation as well as for drying purposes in the agri-food industry, which helps preserve a wide range of agricultural products. It contributes to mitigating product waste and results in a substantial reduction in drying space and time requirements (Liu *et al.*, 2019b).

Solar water heaters (SWHs) can lower households' energy bill while cutting carbon emissions. For example, in South Africa, solar water heating can replace water heating with electricity and gas which can account for 30–40% of the energy bill for a typical South African household (Hohne, Kusakana and Numbi, 2019).

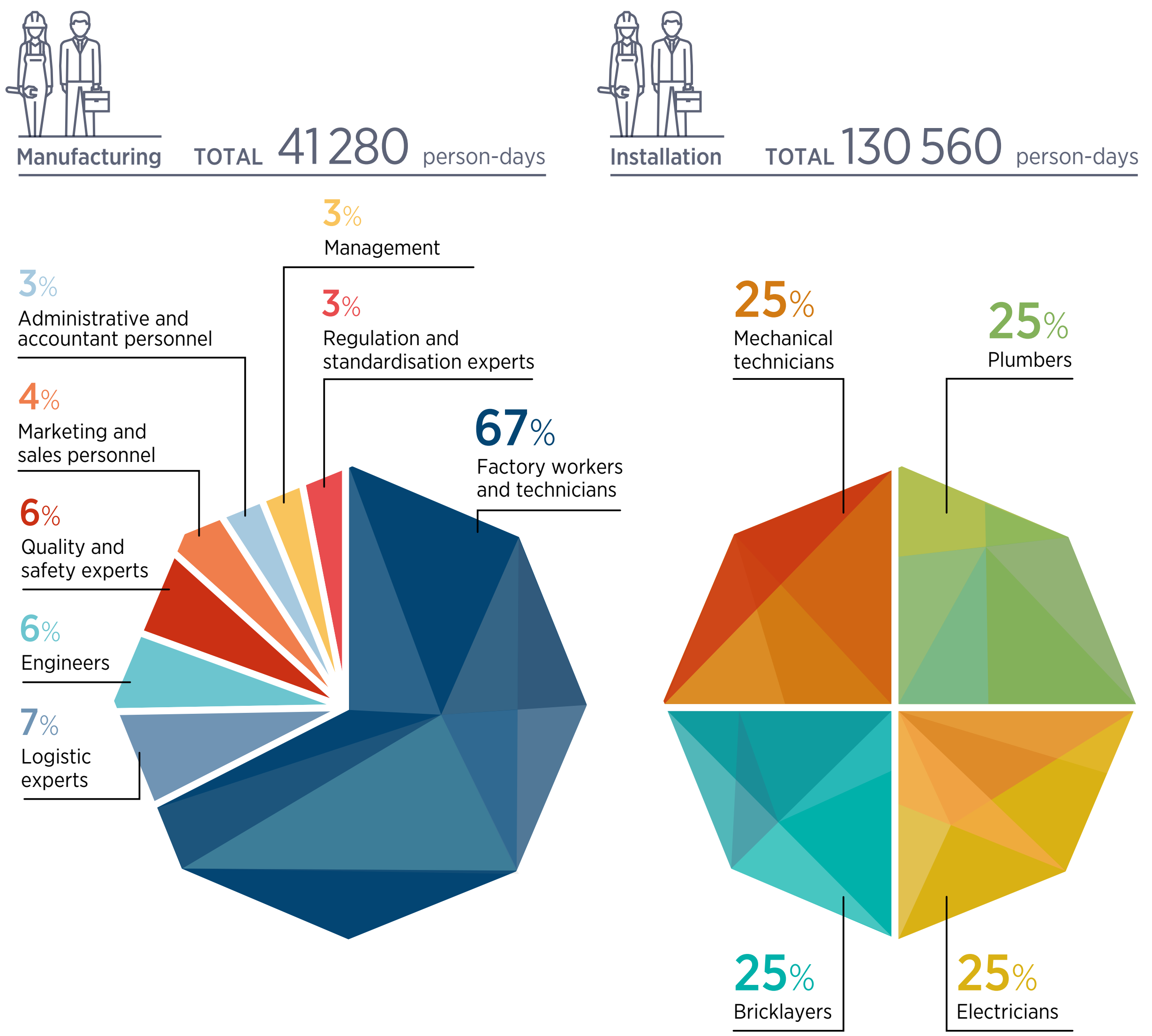
Solar cooling offers great potential to decarbonise space cooling, especially since the greatest demand coincides with the highest solar potential, reducing the load of electric air conditioners at peak times during summer months.

Solar thermal technologies can create local jobs. SWHs and other solar thermal collectors are a relatively accessible technology for local enterprises to produce, install and maintain, and therefore can help develop local industries and provide jobs (Box 6.1). In 2018, the SWH industry provided more than 810 000 jobs (IRENA, 2019j).

BOX 6.1. LEVERAGING LOCAL CAPACITY FOR SOLAR WATER HEATERS

Solar water heaters (SWHs) are a relatively simple technology, and the bulk of all labour requirements are mostly low to medium technical skills. The skills needed to manufacture, install and maintain a system are easily transferrable from existing occupations, such as plumbers and electricians, and are readily available in any country's workforce. However, training and retraining programmes are required to build up the necessary aptitudes for the installation and maintenance of these systems, ensuring their safety and building up their reputation. Figure 6.1 shows the labour requirements for the manufacturing and installation of SWHs for 10 000 single-family households and the distribution of occupations needed.

Figure 6.1. Human resources required for the manufacturing and installation of SWHs for 10 000 single-family households, by occupation



Source: IRENA, forthcoming-d

For a country deploying SWHs, the potential to generate income and create jobs will depend on the extent to which industries along the different segments of the value chain can employ people locally, leverage existing economic activities or create new ones. The opportunity to create value mostly lies in the manufacturing or import of equipment, the wholesale distribution of technology, the sales and installation of SWHs and their maintenance and operation.

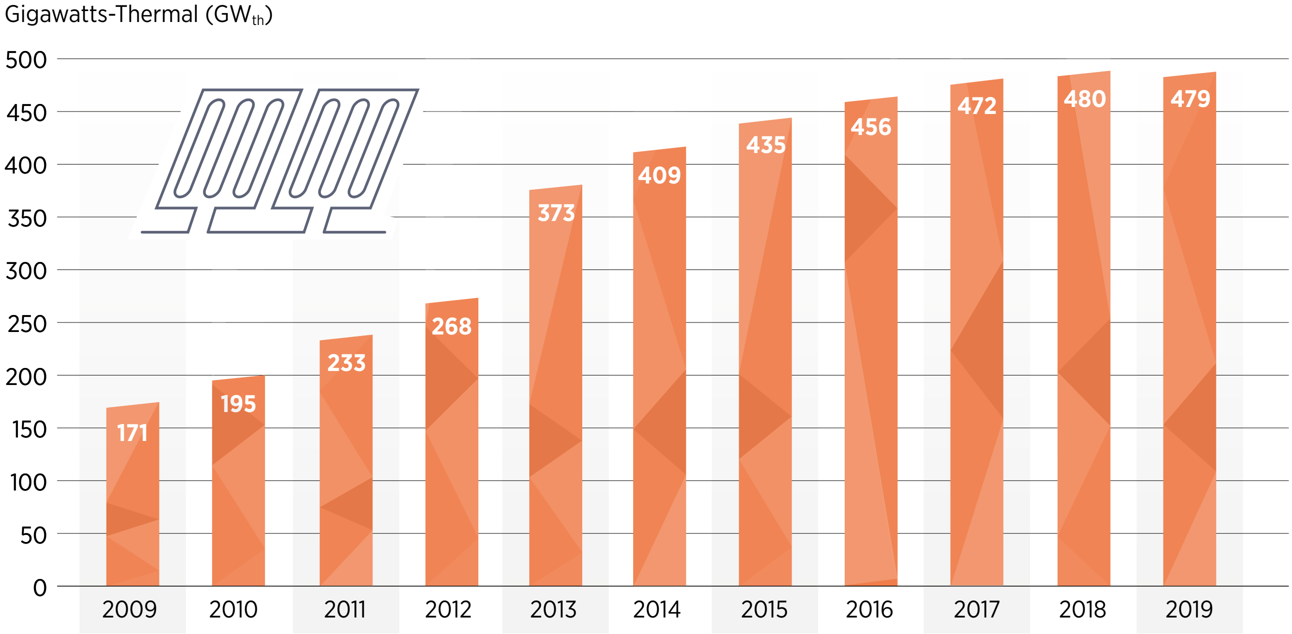
In order to maximise the domestic value created from the development of an SWH industry, policies and measures are needed both to stimulate demand and to ensure that the necessary capabilities along the value chain are able to meet this demand. In countries where relevant industries and services already exist, efforts to develop a domestic supply chain for SWHs should leverage such capabilities. To ensure that the contribution of existing businesses is maximised, countries can introduce measures such as industrial upgrading programmes and supplier development programmes; create associations and networks among importers, producers and sellers; and develop export markets.

6.1.2. CURRENT STATUS OF THE DIRECT USE OF SOLAR THERMAL HEAT

Over the last decade, the global capacity of solar thermal heating collectors in operation rose steadily and grew by a factor of 2.8, from 171 gigawatts thermal (GW_{th}) in 2009 to 479 GW_{th} in 2019 (Figure 6.2), corresponding to 244 and 684 million square meters (m^2) of installed collector area, respectively. This is estimated to be equivalent to 389 terawatt hours of solar thermal heating in 2019 (IEA-SHC, 2020).

In 2018, almost 53% of operational solar thermal capacity globally was domestic SWH systems for single-family houses. Barbados, Cyprus, Austria, Israel and Greece had the highest level of solar water heating capacity per capita in 2017 (IEA-SHC, 2020). Large systems for multi-family houses, tourism and public sector establishments accounted for 37% of the total, followed by swimming pool heating systems with 6%. Only around 4% of the applications were destined for district heating networks (led by Denmark), industrial processes, and space heating and cooling (IEA-SHC, 2020). An example of the use of solar thermal in industrial processes comes from the Gaby copper mine in Chile, which uses a solar system of 34 megawatt-thermal to heat water used in copper electrowinning (Solar Thermal World, 2014). The solar thermal system has replaced 80% of the fossil fuels consumed by the electrowinning process, saving 15 gigatonnes of carbon dioxide ($GtCO_2$) emissions annually (Perez, 2015).

Figure 6.2. Global solar thermal capacity in operation, 2009-19



Source: IEA-SHC, 2020.

Note: These figures include unglazed water collectors, flat plate collectors, evacuated tube collectors and unglazed and glazed air collectors.

As shown in Figure 6.2, the total global capacity in operation kept rising until 2018, but the gross annual capacity additions have declined for the past six years. This decline is attributed mostly to China, which still dominates the market and where market saturation and competition with electric systems (*e.g.* heat pumps) are reducing demand for new systems. China was the largest market for solar thermal water heaters in 2018 and had around 70% of cumulative world capacity, followed by Turkey (with a 2% decline in gross annual capacity addition in 2018 compared to 2017), India (17% increase), Brazil (1% decrease), the United States (5% decrease), Australia (2% increase) and Germany (8% decrease).

Solar thermal energy accounted for around 7% (1.5 exajoules, EJ) of global renewable heat consumption in 2018, with most applications being small-scale thermal systems for domestic water heating. In 2017, some 99% of total global solar thermal heat consumption was for residential and commercial buildings, around 1% for industry, and less than 0.1% for agriculture, but this varies by country (IEA, 2020a).

In decreasing order, China, the United States, India, Turkey, Brazil, Germany and Australia had the largest solar thermal heat consumption in 2017 (Figures 6.3), mainly for buildings. Figure 6.4 shows the distribution of solar thermal heat consumption by country by sector in 2017.

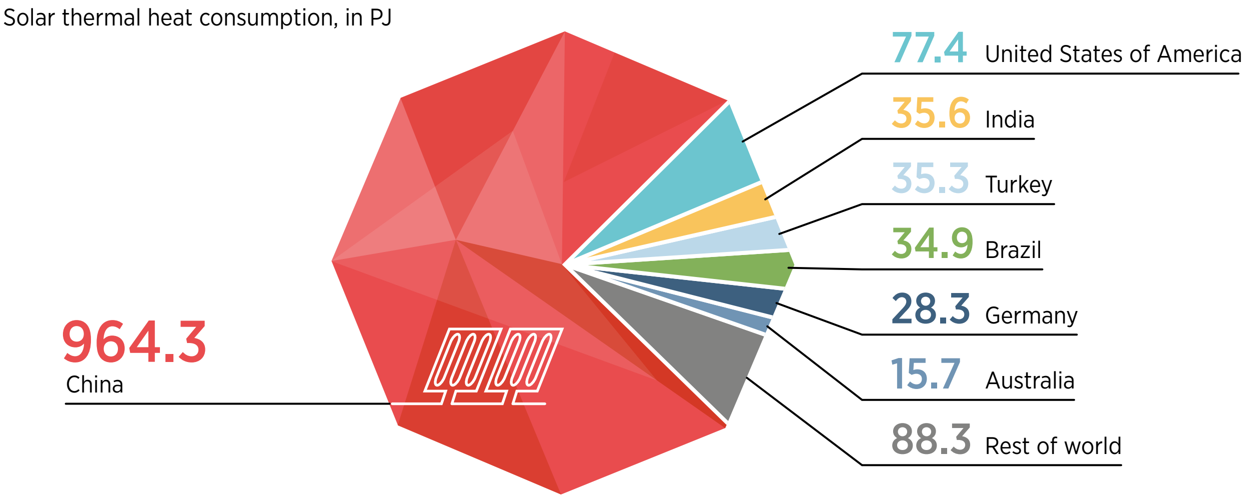
Solar cooling remains a niche market, with less than an estimated 2 000 solar thermal cooling systems deployed worldwide at the end of 2019 (SHC, 2020). The availability of solar resources is an important factor in the attractiveness of solar thermal technologies. However, vast areas across different regions of the world have high solar irradiation but limited deployment. Currently, most solar cooling systems remain at the demonstration stage (Box 6.2) with great potential for technical innovation (Shaheen, 2019).

BOX 6.2. SOLAR COOLING SYSTEMS AROUND THE WORLD

In Arizona (United States), a solar thermal cooling system was built for a high school, meeting up to 100% of the summer cooling load and almost half of the cooling needs for the rest of the year. In Johannesburg, South Africa, a solar thermal cooling system, with a peak cooling capacity of 330 kilowatts (kW), has been built for cooling a data centre of a telecommunication company. In Singapore, demonstration of a solar thermal cooling system, consisting of a 2 475 m^2 collector and an 800 kW absorption chiller, was deployed to meet part of the peak cooling load for a building with commercial and office functions.

Source: Solar Thermal World, 2018b; UNEP, 2017; Fripp, 2014.

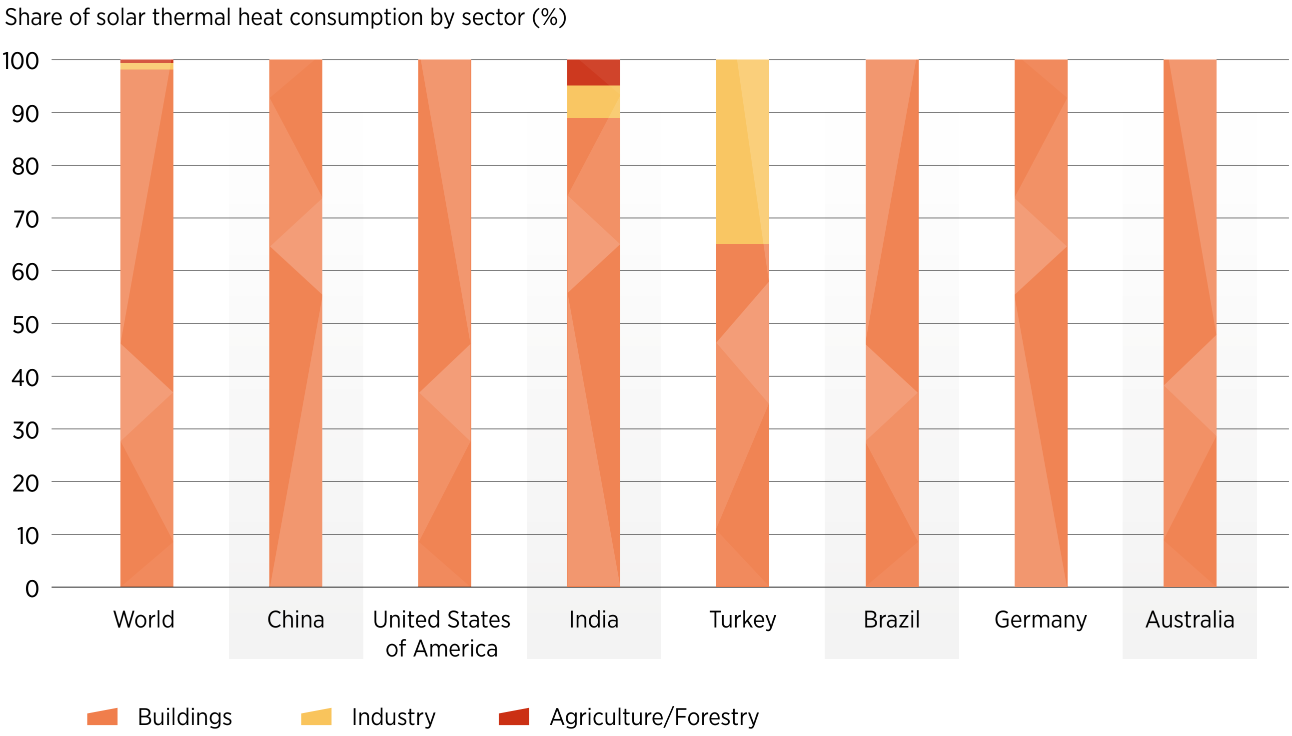
Figure 6.3. Solar thermal consumption in the largest consumer countries, 2017



Source: IEA-SHC, 2020

Note: PJ=petajoule

Figure 6.4. Distribution of solar thermal heat consumption in the largest consumer countries and worldwide, by sector, 2017



Source: IEA, 2019c.

6.1.3. BARRIERS TO THE DIRECT USE OF SOLAR THERMAL FOR HEATING AND COOLING

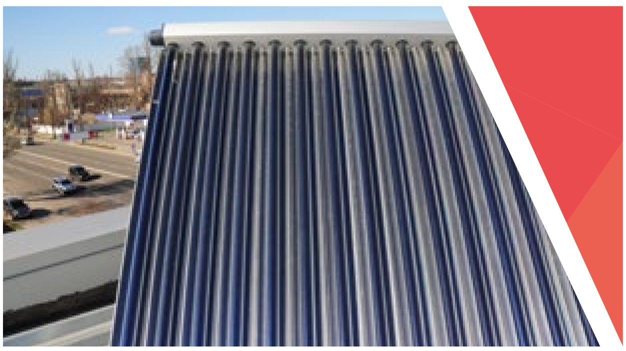
Solar thermal technologies for heating and cooling face multiple barriers, such as high upfront costs and access to finance; legal and regulatory barriers; technical barriers related to a less mature supply chain and a paucity of qualified installers; and lack of public awareness and acceptance (IEA-ETSAP and IRENA, 2015a).

The main limitation to solar thermal includes **high upfront costs**, especially compared to well established conventional electric and gas water heaters in residential buildings. High upfront costs also pose a barrier to the adoption of solar thermal systems for industrial processes, particularly for small- or medium-sized companies. Large, energy-intensive industries are also constrained by risk aversion and expectations of shorter payback times (IEA-ETSAP and IRENA, 2015b). The upfront costs can be an impediment in developing countries especially. In sub-Saharan Africa, the average cost of a domestic SWH ranges between USD 150 and USD 1 500 per unit, which is unaffordable for most households in this region (IEA-ETSAP and IRENA, 2015a).

Other barriers to solar thermal systems include the **lack of an appropriate regulatory framework** to guarantee their quality and ensure their reliable operation, as well as the burdensome authorisation process for new capacity installation, *e.g.* some local-level permitting processes result in additional time and costs (IEA-ETSAP and IRENA, 2015a; European Union, 2019b).

As for solar cooling systems, their uptake remains limited due to various barriers beyond their costs, including **technical limitations** and the need for further research and development. This technology is relatively expensive when compared to most electric alternatives (IEA-ETSAP and IRENA, 2015a). Because of the application-specific nature of benefits and the yet-to-mature supply chain, it remains challenging to establish the cost benefits of solar cooling systems for all applications (Sheldon, Sethuvenkatraman and Goldsworthy, 2018).

Finally, **limited awareness** of available technology options, their maintenance requirements and potential benefits can impede their deployment (Djordjevic *et al.*, 2014). The environmental benefits of solar thermal technologies may not be of interest to potential investors and consumers, limiting market penetration.



6.2. POLICIES TO OVERCOME COST AND FINANCIAL BARRIERS

Fiscal and financial incentives including loans, grants, tax credits and subsidies are instrumental in lowering the upfront costs of solar thermal solutions, both centralised and decentralised, for residential, commercial and industrial applications. In buildings, such incentives are typically adopted together with mandates (Section 6.3) and building codes (Chapter 2) to address market barriers. This is especially the case in countries where options such as gas boilers are more cost-competitive, mainly due to subsidised fossil fuels. Some financial schemes, including the United Kingdom's Renewable Heat Incentive, the Netherlands' Stimulation of Sustainable Energy Transition and France's *Fonds Chaleur* (Heat Fund) support various renewable energy technologies including solar thermal systems for residential and industrial use (ADEME, 2020; Netherlands Enterprise Agency, 2020). Examples of financial incentives that supported the deployment of SWHs in buildings (in the early 2010s when they were less competitive) are found in Box 6.3.

For centralised use, providers of heat need incentives to adopt solar thermal, either to switch from fossil fuels or adopt the technology from the outset. Denmark is an example of how solar thermal energy can be used in district heating, as it hosts most of the world's largest solar thermal based district heating systems. Its largest system was built in 2016 to cover 20% of the total heat demand of Silkeborg, with a 110 MW peak capacity and seasonal thermal storage (Solar Thermal World, 2017). Another large-scale district heating plant was built in Marstal to supply heat for 1 400 households, thanks to tax incentives and an awareness campaign to gain public support (Perlin, 2017).

In France, since 2015, large-scale solar thermal systems (more than 500 m^2 in terms of collector area) for district heating were incentivised using a fund covering between 50% and 70% of the preliminary studies and between 45% and 65% of the total investment (Solar Heat Europe, 2017).

BOX 6.3. FINANCIAL INCENTIVES SUPPORTING SOLAR WATER HEATERS

Tunisia's PROSOL (Programme national de Promotion du solaire thermique en Tunisie) started in 2005 to support solar water heaters (SWHs). The first phase focused on supplier lending with a 20% subsidy of capital costs, a temporary interest rate subsidy (gradually phased out after 18 months) and credit repayable over five years. Individual suppliers acted as indirect lenders and debt guarantors for consumers, while the Tunisian Electricity and Gas Company (Société Tunisienne de l'Électricité et du Gaz, STEG) collected loan repayments through utility bills. In its second phase, focused on consumer lending, it granted direct credit to households (via STEG) for SWH installation, relieving suppliers of debt liability. STEG serves as a guarantor of household repayments. In 2009, through the National Fund for Energy Conservation, bonuses of USD 150–300 replaced the 20% subsidy (CPI, 2012).[a] From 2007 to 2014, approximately 60 000–80 000 m^2 of solar thermal collectors were installed annually under the program. The financial support mechanism, a combination of grants, tax exemptions and reduced interest rates, has cultivated a local SWH manufacturers' network and directly created more than 3 000 new jobs (Baccouche, 2014; SHC, 2017).

In Lebanon, the Ministry of Energy and Water and the Central Bank developed a national financing mechanism for SWHs, offering subsidised loans at a 0% interest rate, in addition to a USD 200 subsidy for the first 7 500 loan applications. By the end of 2017, more than USD 1 450 000 had been injected into the market via the USD 200 subsidies, and more than 14 500 loans had been granted. The mechanism has helped generate investments exceeding USD 135 million (LCEC, 2016).

Barbados has implemented a mix of financial incentives and mandates. The price of fossil fuels in Barbados is notably high; therefore, the upfront costs could be recuperated within a few months. A tax exemption for the materials used to produce SWHs was introduced, reducing their cost by 20%. The government also mandated the installation of SWHs in new government housing developments and a tax benefit was introduced, making the full cost of installation tax deductible up to a maximum of USD 1 750. As a result, installed SWHs covered 40% of households as early as 2009 (U.S. DOE, 2015).

In 2011, Rwanda rolled out its flagship program, SolaRwanda, which provided grants and loans for residential SWHs, resulting in installations of 3 400 units as of 2018 (Solar Thermal World, 2018c). In Kenya, the privately owned Equity Bank collaborated with companies to provide preferential loans with longer tenures to small-scale residential SWH users (Hakeenah, 2018).

On a city level, Mexico City (Mexico) announced MXN 150 billion (USD 7.8 billion)[b] in funding for solar thermal systems for commercial and industrial buildings, while the city of Itabashi in Japan has offered grants for up to 5% of the upfront cost of installing solar thermal systems. Washington, DC (United States), offers a personal property tax exemption for investments in renewable energy technologies, including solar thermal (REN21, 2019).

a. Currency conversion based on an exchange rate of USD 1 = TND 1.33 in 2012.

b. Currency conversion based on an exchange rate of USD 1 = MXN 19.23 in 2018.

6.3. POLICIES TO OVERCOME MARKET AND REGULATORY BARRIERS

Policies to overcome market and regulatory barriers include solar thermal targets and action plans to increase market confidence, SWHs mandates and building codes and public campaigns to raise consumer awareness regarding their potential and benefits.

Policy makers can provide long-term investment signals to overcome market barriers by setting **solar thermal heating targets and action plans**. Targets and roadmaps can push investors away from conventional heating technologies, minimising the risk of asset stranding in the future. Countries and cities have introduced solar thermal heating targets.

India is targeting 14 GW (20 million m^2 of collectors) by 2022 (Gowda, Putta Bore Gowda and R. Chandrashekar, 2014). In West Africa, the Economic Community of West African States adopted the target to deploy solar thermal heating for around 50% of all health centres and schools, 25% of hotels and 25% of the agri-food industry by 2030 (ECREEE, 2015). Cities are also implementing technology-specific targets. For example, Beijing (China) aims to install 9 million m^2 of solar thermal collectors (REN21, 2019).

Targets can be supported by solar thermal **mandates**. Mandates requiring the installation of solar thermal systems in new or existing buildings have proven effective at overcoming split incentives. For example, in response to the oil crisis in the 1970s, Israel mandated the installation of SWHs in new buildings. By 2009, SWHs were installed in 85% of households (Sterman, 2009). Kenya introduced a new building regulation mandating that at least 60% of the hot water supplied in buildings be heated using solar thermal systems. This regulation applies to new, expanded or renovated commercial and residential buildings that use more than 100 litres of hot water per day (REN21, 2019). Since 2006, Spain has also mandated that a share of the hot water supplied in all new buildings to be heated with solar thermal instead of fossil gas and electric devices (IEA-SHC, 2015). This policy was adopted at the national level after Barcelona became the world's first city to mandate solar thermal systems in 2000. Also, at the local level, numerous cities across South America (including Sao Paolo in Brazil, Montevideo in Uruguay and Rosario in Argentina) have introduced solar thermal mandates (REN21, 2019). Similar mandates exist in cities in Asia, Europe and the Unites States.

Combining targets, mandates and financial incentives proves to be the most effective. This combination of policy instruments has helped China become the leader in the SWH industry (Box 6.4).

Market barriers to the deployment of solar thermal technologies can be overcome by increasing consumer awareness. **Public campaigns** and information-sharing activities raising public awareness of SWHs can fill the information gap as well as increase public confidence in these technologies. For example, the municipal government of Rosario (Argentina) facilitates community consultations and participatory workshops, as well as organises events at youth sports centres to raise public awareness on the benefits of SWHs (ICLEI and IRENA, 2018). Accessible platforms to disclose the operational data of large scale industrial and district heating solar thermal systems to the public could improve their visibility. Moreover, the replacement of old and inefficient heating systems could be an opportunity for synergies between the deployment of solar thermal systems and public awareness activities.

BOX 6.4. CHINA'S LEADING ROLE IN SOLAR THERMAL DEPLOYMENT

China leads the world in the deployment of solar thermal systems, hosting around 70% of world capacity as of the end of 2018. Deployment is promoted through a mix of targets, subsidies and mandates. At the national level, China is targeting the installation of 800 million square metres (m^2) of solar thermal by 2020.

Chinese policy support depends on the location and context of the end user. For example, in rural areas, solar thermal systems were eligible for subsidies equal to 13% of the capital cost of the system during 2007–13, while in urban areas, a combination of subsidies and mandates, partially driven by air pollution concerns, have lifted uptake (IEA-SHC, 2019).

China also provides subsidies for solar thermal heating in industry. For example, the Shandong provincial subsidy scheme covers 20–40% of investment costs, which has supported the commissioning of a 4.2 MW system supplying process heat to a poultry factory (REN21, 2019).

6.4. POLICIES TO OVERCOME TECHNICAL BARRIERS

Support for research, development and demonstration (RD&D) can help reduce costs by overcoming technical barriers and production bottlenecks through innovation. Specifically, in industry, RD&D support is needed to improve the integration of solar thermal heat into existing industrial processes and facilities, and the cost-effectiveness of storing steam or hot water.

Given the limited uptake of solar thermal cooling, substantial innovation and demonstration support is still required to reduce costs and increase technological maturity. For example, the IEA's Solar Heating and Cooling Technology Collaboration Programme has supported the development of solar thermal energy since 1977.

Government-funded RD&D projects (see Chapter 2) have supported solar thermal in industry, a fairly less mature application. In Tunisia, the Italian Ministry of Environment and the United Nations Environment Programme provide financial support to a demonstration textile plant that uses solar thermal heating to generate process heat (IRENA, IEA and REN21, 2018).

De-risking policy schemes for large-scale solar district heating and solar heat for industrial processing are needed to support the development of feasibility studies and attract more investment. An EU-funded project, TrustEE, aims to set up a platform to streamline technical assessment and de-risk projects replacing industrial fossil fuel thermal sources with energy efficient and renewable sources, including solar thermal (TrustEE, 2020).

Table 6.1 summarises barriers and policies related to the direct use of solar thermal heat.

Table 6.1. Barriers and policies for the direct use of solar thermal heat

Targeted barriers	Policies	Examples	Comments
Lack of confidence among investors due to long-term uncertainty regarding market development	Technology-specific targets for renewables-based heating	**India**'s targets for the use of solar water heaters	Effectiveness depends on stable long-term commitments, including regulatory instruments and other supporting policies.
Technical barriers related to specific applications (*e.g.* solar heat for industrial processes, solar thermal cooling)	Research, development and demonstration	**India**'s demonstration projects for solar cooling	Demonstration projects, by their very nature, entail uncertainty about costs and the performance of technologies.
Slack demand, partly due to poor public awareness of available options and benefits	Solar water heater mandates	Mandates in **Barbados** for use of solar water heaters	Effectiveness relies on the presence of quality assurance and maintenance regulations. Consumers may oppose uncompetitive markets and obligations.
	Public campaigns, information-sharing activities	**South Africa**'s solar water heater campaign	Campaigns can be more effective when they showcase the results of successful demonstration projects.
High upfront costs to purchase and install technologies, and difficulty accessing finance	Loans, grants and subsidies	**France**'s heat fund *(Fonds Chaleur)*	Feasibility depends on competing budget requirements.
	Tax credits and exemptions	Tax exemptions in **Washington**, DC (United States)	Careful policy design is needed to avoid increasing energy poverty.

6.5. POLICIES TO PROMOTE SOLAR THERMAL HEAT FOR ENERGY ACCESS

Access to direct solar thermal heat technologies can improve resilience and ease the financial situation of low-income communities, including households; micro, small and medium enterprises; and smallholder farmers in countries with low energy access. Uses of renewable heat include food processing, drying and cooking. Some programmes may include broader uses, such as India's programme on Off-grid and Decentralised Concentrated Solar Thermal Technologies for Community Cooking, Process Heat and Space Heating and Cooling Applications in Industrial, Institutional and Commercial Establishments (MNRE, 2019).

6.5.1. SOLAR THERMAL FOR AGRI-FOOD PROCESSING

Harnessing solar heat for agri-food processing is arguably one of the oldest ways to use solar energy. Direct, open-air drying is a common practice in many subsistence farming communities around the world (Belessiotis and Delyannis, 2011). Indirect solar drying using solar thermal collectors, on the other hand, is a technique that is not yet widely commercialised. There are many types of solar dryers with various chamber, air circulation and ultraviolet filtration designs. The most commercialised design so far is a tunnel dryer, which usually consists of a transparent roof and walls, a tube of solar heat collector and trays containing the materials to be dried. The air flows through the tunnel, accelerating the drying process and improving the consistency of dried products. Small-scale applications of solar drying are observed in many low-energy-access countries across South America, sub-Saharan Africa, South Asia and Southeast Asia.

BOX 6.5. SOLAR DRYING IN KADUNA, NIGERIA

Kaduna State, in northern Nigeria, is home to a thriving agriculture sector. Agriculture contributes to about 37% of the state's gross domestic product, supporting the livelihoods of 1.3 million households. Among them, about 10% of farming households are practising dry-season farming, mainly to produce tomatoes. According to the latest data, more than 88 000 tonnes of tomatoes were produced in 2017.

Farmers were subject to 40% postharvest loss, however, due to poor infrastructure, long distance to markets and fluctuating prices (Uzor, 2020). Drying the tomatoes is a common practice that prolongs the shelf life of the product. Traditionally, farmers dry their produce in the sunlight and on the ground. This method takes up to a week and raises hygiene concerns.

In 2017, a local renewable energy company, Sosai Renewable Energies, introduced solar dryers to tomato farmers. With this dryer, it took about 3 days to dry 250 kilograms (kg) of tomatoes per cycle (U.S. African Development Foundation, 2017). The pilot project brought not only an additional 30% revenue for farmers, but also saved them time and significantly improved the quality of the dried tomatoes.

By improving the quality of the product, tomato farmers were able to market to high-end customers in Nigeria or export to other countries. However, tapping into new markets requires sustainable and appealing products that will meet customers' needs. To this end, Sosai Renewable Energies partnered with another company, Farm Innovation Nigeria Ltd., to provide marketing support, introduce measures to reduce pesticides and improve packaging.

In addition to the economic benefits that the project brought to local farmers, Sosai Renewable Energies also put a strong focus on benefiting women. While the majority of the farmers in Kaduna State are men, jobs were created for women who operate the solar dryers. By providing training, raising awareness about solar drying technologies and implementing a rigorous selection process, Sosai Renewable Energies is now actively engaging with 16 women across 3 states to operate its solar dryers.

Despite its high-impact margins, solar dryers can be difficult to finance as a self-sustainable business. At the moment, rural solar drying businesses in Nigeria are still donor funded. The payback period for such a system is estimated to be more than ten years. Smaller-scale models may offer good alternatives at 10% of the cost and 40% of the capacity. This may provide an opportunity for rural communities to adopt solar drying as a self-sustaining business.

In the future, the programme will not be limited to tomatoes. Mangos, peppers, pineapples and onions are all identified as high-potential crops that can benefit from solar drying.

Sources: Kaduna State Bureau of Statistics, 2017; U.S. African Development Foundation, 2017.

While the indirect solar drying technique has many benefits, it is still costly for many. Depending on its capacity, the cost of a solar tunnel dryer that processes 100–800 kg of fresh produce ranges from a few thousand U.S. dollars to USD 15 000 per dryer. The costs of small-scale solar dryers that process 20–100 kg per cycle range from a few hundred dollars to USD 2 000 per dryer. These cost ranges are beyond most smallholder farmers' ability to pay. There are continuous efforts from manufacturers to bring the costs down. The most affordable model to date can cost as little as USD 195 for a 20 kg per cycle tunnel dryer (Better India, 2019).

Having affordable access to solar dryers is also not the only enabler for better-dried outputs. The quality of the dried products is strongly dependent on the experience of the farmers, quality of the crops, monitoring of optimal drying temperatures for each crop, reduction of microorganisms and the desired moisture content for safe storage (Green and Schwarz, 2001). Therefore, the economic benefits of solar drying are also subject to many variables (discussed in Box 6.5).

Policies that support the uptake of solar dryers include **financial support, capacity building** for the use of technology and most importantly **linking farmers with consumers** to ensure a market for the products. The example of Sosai Renewable Energies in Kaduna, Nigeria, showcases how these measures enabled solar drying to increase revenue and save time for farmers, improve the quality and hygiene of product output and create jobs for women (Box 6.5).

6.5.2. SOLAR THERMAL COOKERS

Solar thermal heat for cooking is a technology that has high potential to reach vulnerable populations that do not have access to electricity or clean fuel. Some 3.9 million solar thermal cookers are deployed around the world, serving 14 million people in 2020 (Solar Cookers International, 2020).

The affordability challenge for solar cookers is less pronounced. Solar thermal cookers use cheaper reflectors to collect solar irradiance instead of a direct solar thermal collector, which makes them more affordable for rural, off-grid households. Organisations like Solar Cookers International provide manuals, designs and capacity building which encourage local manufacturing further reducing costs and increasing the potential for local value creation (Solar Cookers International, 2020).

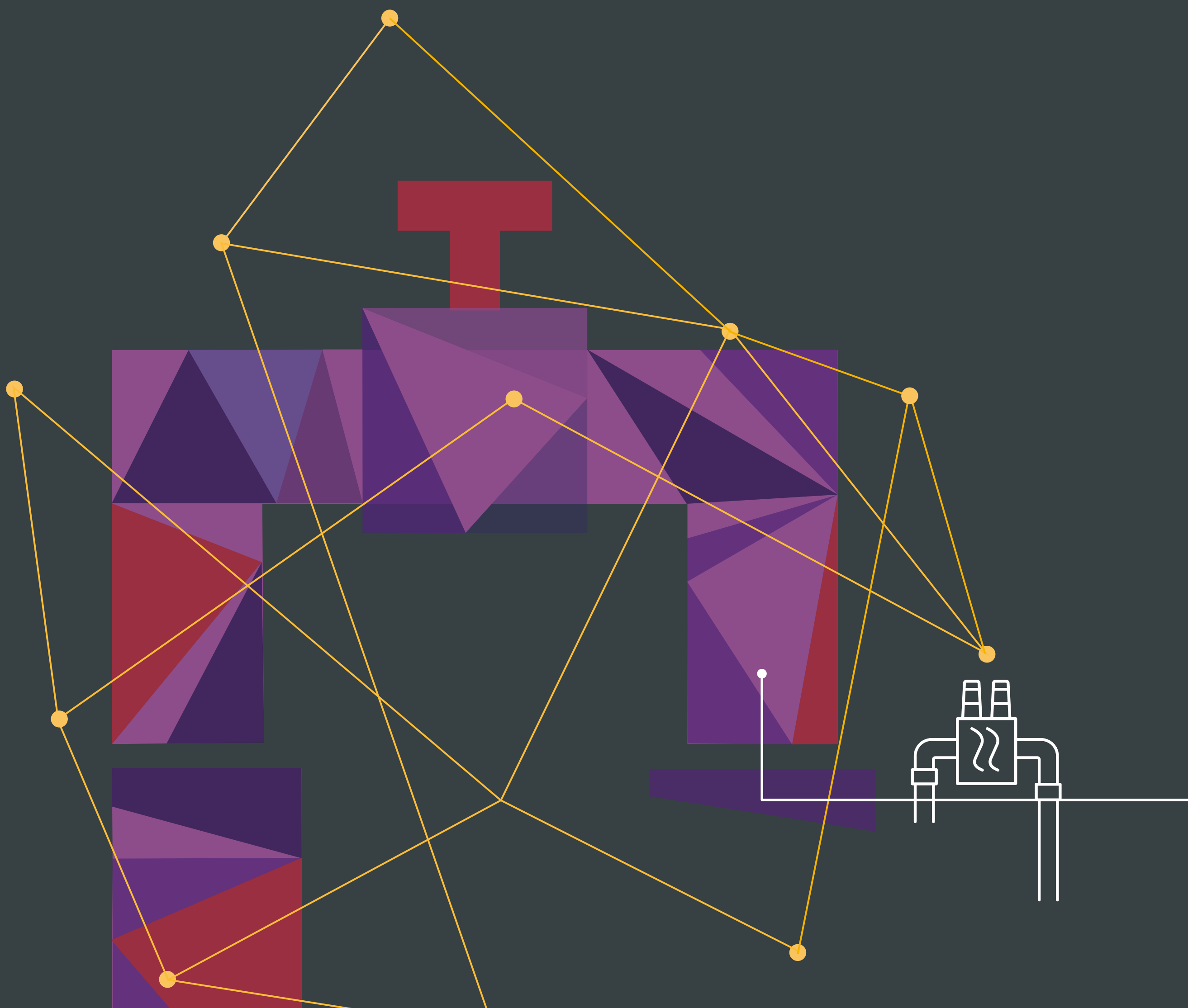
The main challenges to the wider adoption of solar thermal cooking, however, are behavioural. Since most of the solar cookers use simple reflectors to concentrate solar heat, they only work during sunny hours and their efficiency is compromised in the early morning, in the late afternoon and on cloudy days. For end users to adopt solar cooking, they need to adapt their cooking hours and learn to use heat retainers to keep food after sunset. Even in favourable conditions with abundant sunlight, they are reported to meet only 25–33% of their cooking needs (Puzzolo *et al.*, 2013). Therefore, solar thermal cookers need to be paired with other alternatives to provide more suitable and reliable solutions (Brown and Sumanik-Leary, 2016).

Table 6.2 summarises barriers and policies related to the use of solar thermal heat in the context of access to energy.

Table 6.2. Barriers and policies to scale up solar thermal heat for energy access

Targeted barriers	Policies	Examples	Comments
High upfront costs to purchase and install technologies and difficulty accessing finance	Loans, grants and subsidies	**SolaRwanda**'s solar water heater grants and subsidies	Policy attention is needed to accelerate progress on solar water heaters.
Thermal technologies requiring behavioural change	Capacity building and information (*e.g.* awareness campaigns)	Training in solar drying from Sosai Renewable Energies **(Nigeria)**	Consumers may not be willing to change their behaviour.
The success of productive uses depend on multiple variables (*e.g.* farmers' experience, crop quality, market access)	Policies to encourage multisectoral partnerships	**Sosai**'s partnership with Farm Innovation to support farmers using solar dryers	Effectiveness depends on interministerial coordination and implementation.

07 Direct use of **geothermal heat**



Geothermal energy is the thermal energy stored in rocks and trapped liquid or steam within the sub-surface of the earth. Direct-use geothermal applications include space and district heating, greenhouses, aquaculture, bathing and other commercial and industrial processes.

This chapter starts with the benefits, current status and barriers related to the direct use of geothermal heat.[1] The barriers include market and regulatory barriers, technical barriers, and risks related to geothermal exploration. Sections 7.2 and 7.3 explore policies to overcome these obstacles. Section 7.4 discusses policies to support geothermal heat for productive use in contexts where energy access is limited.

7.1. BENEFITS, CURRENT STATUS AND BARRIERS

7.1.1. BENEFITS OF GEOTHERMAL HEAT

Utilising geothermal energy for heating and cooling can bring benefits for buildings, industries and agriculture. Most of the benefits are tied to lower costs and greater productivity, particularly in agriculture.

Geothermal solutions can provide a stable heat supply and be cost-competitive with fossil fuel alternatives. In France, geothermal district heating costs are as low as EUR 15/megawatt hour (MWh), 70% lower than fossil gas (EUR 51/MWh) (EGEC, 2020). In the United States, the use of geothermal heat for home and commercial operations could save up to 80% of costs compared with fossil fuels (NREL, 2004). In Canada, direct geothermal use for district heating and snow melting could also yield savings (Canadian Geothermal Energy Association, 2014).

Geothermal energy is used for heating greenhouses and drying products for the agri-food sector, which increase agricultural productivity, reduce food waste and increase farm owners' earnings. (IRENA, 2019k; NREL, 2004).

Heating greenhouses with geothermal energy can reduce the cost and improve the productivity of agri business industries. Using geothermal resources instead of traditional energy sources can save about 80% of fuel costs. In the case of existing geothermal wells, farmers only need to invest in steel or plastic pipes to transport the hot water to the greenhouse (NREL, 2004).

7.1.2. CURRENT STATUS OF GEOTHERMAL HEAT

Although on the rise, geothermal energy is currently the smallest renewable heat source with around 30 gigawatts (GW) of direct

1 The analysis excludes ground-sourced heat pumps, which are discussed in Chapter 3.

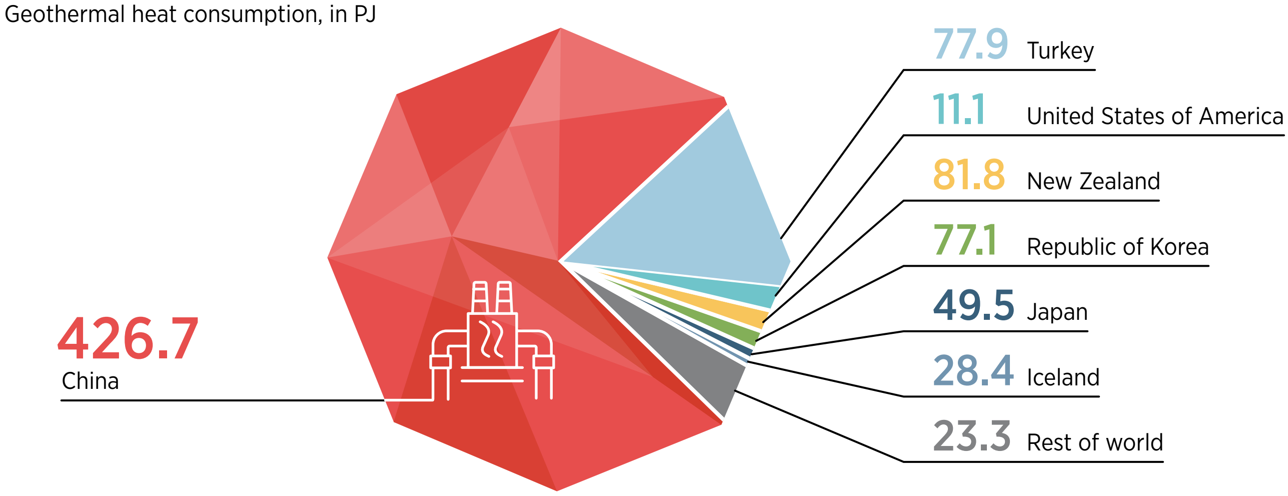
thermal use applications installed by the end of 2019. The largest category of direct thermal use in 2019 was bathing and swimming, comprising around 44% of the total and growing about 9% annually. The second was space heating (around 39% of direct use), the fastest-growing category with around 13% annual growth. The remaining 17% of direct use was allocated to greenhouse heating (8.5%), industrial applications (3.9%), aquaculture (3.2%), agricultural drying (0.8%), snow melting (0.6%) and other uses (0.5%) (Lund and Toth, 2020). Geothermal energy met about 0.3% (0.7 exajoules, EJ) of global heat demand in 2019 (IEA, 2020a).

The top four countries with the most geothermal heat consumption are China, Iceland, Japan and Turkey. Together, these four accounted for 75% of global geothermal heat consumption in 2019. Geothermal heat is also used in New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil (in descending order), as well as many other European countries, though each of these countries represents less than 3% of global geothermal heat consumption (REN21, 2020).

Direct geothermal use is projected to increase more than 40% (+0.3 EJ) globally by 2023, with almost two-thirds of this growth in China (where air pollution concerns are expected to stimulate the development of geothermal district heating) and the United States. In the European Union, direct geothermal energy consumption was 23.8 petajoules (PJ) in 2017 and anticipated to increase, with district heating remaining a key application (IEA, 2019b).

Geothermal heating is typically used in all sectors, with 80% of total final consumption in residential and commercial buildings, 16% in agriculture (for greenhouse heating, aquaculture and drying) and around 4% in industry. Figures 7.1 and 7.2 show the final geothermal energy consumption by end-use sector in 2017, for the countries with the highest geothermal consumption.

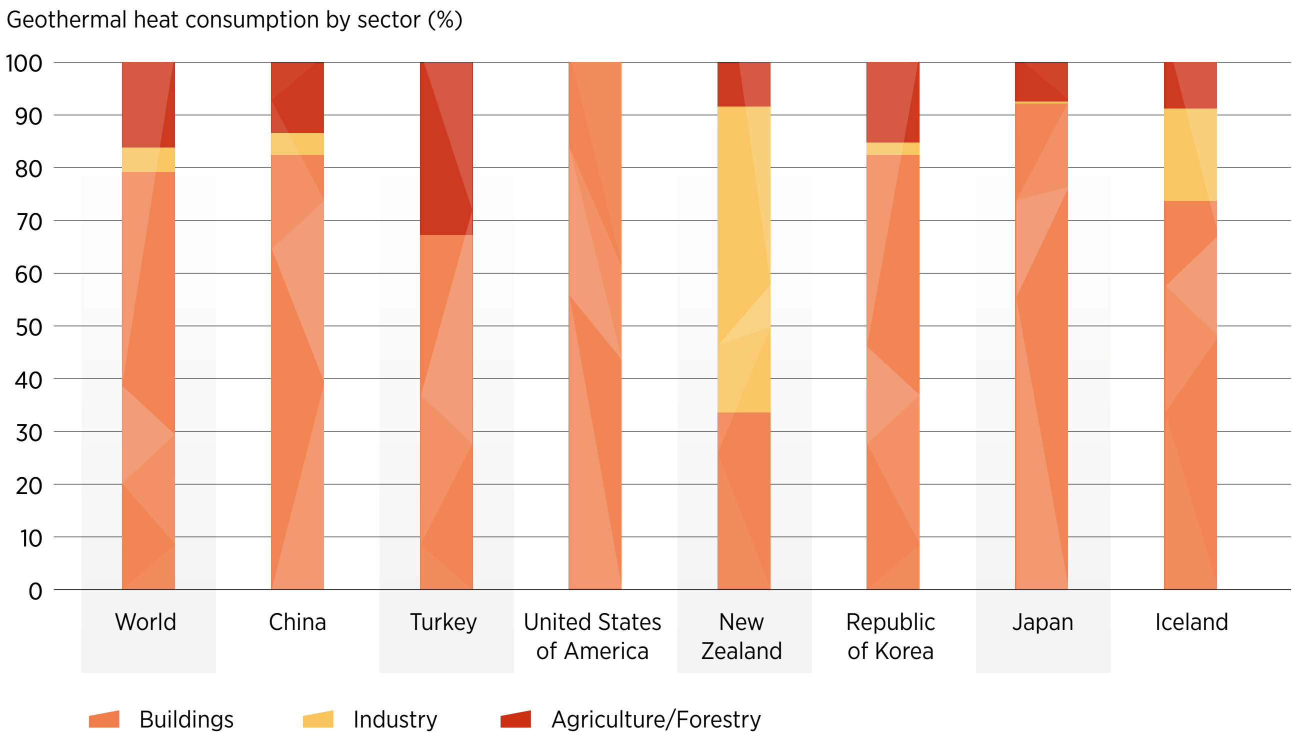
Figure 7.1. Geothermal heat consumption in the largest consumer countries, 2017



Source: IEA, 2019b.

Note: PJ=petajoule

Figure 7.2. Distribution of geothermal heat consumption in the largest consumer countries and worldwide, by sector, 2017



Source: IEA, 2019b.

Geothermal energy consumption varies depending on resource availability and structure of the economy. In China, geothermal energy has been providing heat for over 50 million square meters (m^2) of buildings in the Northern China region. New Zealand has a high share of geothermal heat for industrial processes and agriculture uses, including pulp and paper processing, wood curing, dairy processing and greenhouse heating. Iceland uses geothermal directly for space heating, fish farming, snow melting, swimming pools, greenhouses and industries (National Energy Authority of Iceland, 2013). Box 7.1 discusses the use of geothermal energy for agricultural use in Turkey.

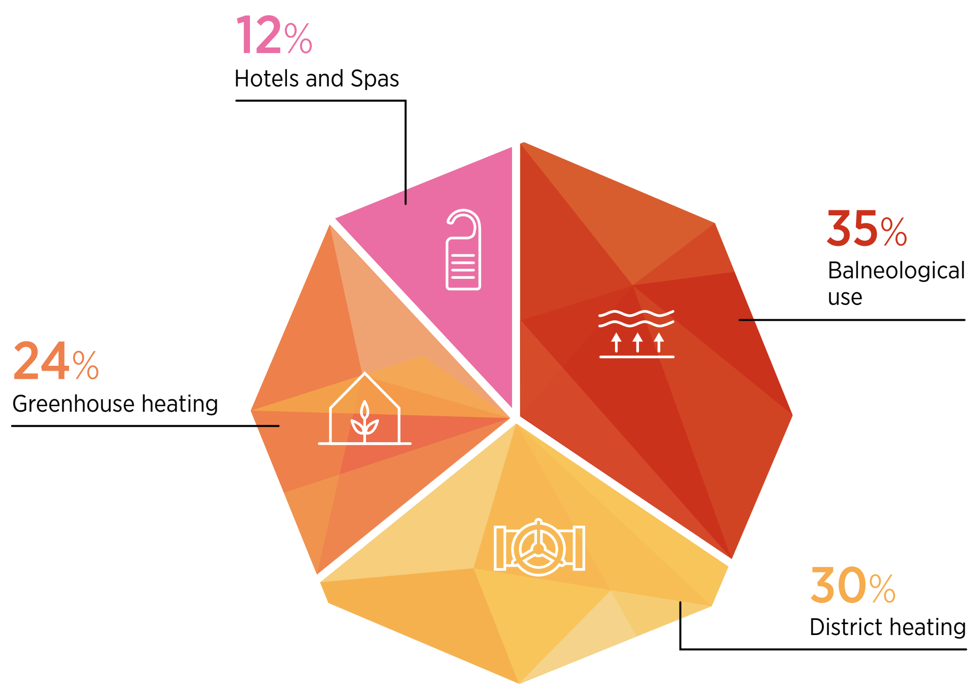
BOX 7.1. GEOTHERMAL HEAT IN TURKEY

Turkey has a theoretical geothermal heat potential estimated at 60 gigawatt thermal (GW_{th}). The use of geothermal resources was initiated in 1987 with the heating of 2 000 square meters (m^2) of greenhouses. As of 2019, about 450 geothermal fields had been discovered and direct-use applications had reached 3 487 MW_{th}, of which 23% was used to heat greenhouses. The distribution of geothermal energy by use is presented in Figure 7.3.

The share of geothermal heat going into agricultural greenhouses is continuously increasing. About 6.6 million tonnes of vegetables and fruits are produced in greenhouses, with revenues estimated at about USD 2.18 billion. Geothermal greenhouse heating has recently become popular in Turkey, especially in western Anatolia, where the government has supported geothermal investments.

Source: Mertoglu *et al.*, 2019.

Figure 7.3. Geothermal heating by use in Turkey, 2018



Note: Agricultural drying (0.04%) and geothermal cooling (less than 0.01%) are excluded from the chart.

7.1.3. BARRIERS TO THE UPTAKE OF GEOTHERMAL HEAT

The wider adoption of all geothermal energy applications is restricted by a variety of barriers. The most common obstacles include high upfront investment cost, risks related to the appraisal of geothermal resources and securing funding for surface exploration and drilling operations, inadequate policy and regulatory frameworks and shortage of a qualified workforce.

In addition, transporting geothermal heat for long distances from geothermal wells may not be economically viable. Hence, the bankability of geothermal direct-use projects may be undermined by the need to find customers nearby (either a single large customer or several smaller ones) that have a demand for heat matching the temperatures of the geothermal resource (IRENA, 2019k).

Other barriers include environmental, social and administrative constraints. For instance, a project might be delayed due to lengthy administrative procedures for the issuance of licences and permits, or due to delayed discussions and negotiations (often complex) with local groups. Another potential difficulty for developers with a portfolio of geothermal projects in different countries is that these countries have different regulations for performing environmental and social impact assessments, which are mandatory in most cases. Transparent government regulations which avoid causing unnecessary project delays are needed (IRENA, 2017a).

Given the different barriers to the use of geothermal energy, a mix of policies may be needed to ensure its uptake. The Netherlands presents an example of a complete set of policies to support geothermal energy for greenhouses (Box 7.2).

For all applications, policy support is necessary to reduce upfront costs and increase technology maturity and reliability, so that geothermal can compete more effectively with fossil fuels. In the remainder of the chapter, each of the financial, technical and regulatory barriers is addressed through direct, integrating and enabling policies that can help promote the direct use of geothermal in buildings, agriculture and industry.

7.2. POLICIES TO OVERCOME MARKET AND REGULATORY BARRIERS

Policy makers can develop **action plans** on direct use of geothermal heat, setting out milestones to achieve **renewables heating and cooling targets**. China's Clean Air Action Plan, released in 2017, aims to phase out coal-fired boilers and utilise cleaner fuels, including geothermal heating in the Northern China region. As a result of this action plan, Sinopec, the leading company in oil refineries as well as the largest geothermal heating developer, launched its Green Action Plan, which includes provisions to expand the company's geothermal heat network to serve 2.1 million urban residents in 20 cities.

Public campaigns can also help customers understand the benefits of geothermal use for heating and cooling and overcome market barriers. In the United States, the Geothermal Resources Council (GRC) has announced funding for a marketing and public relations campaign to highlight the benefits of geothermal energy and raise public awareness of its uses and benefits (GRC, 2020).

7.3. POLICIES TO ADDRESS GEOTHERMAL EXPLORATION RISKS

Policy makers can help address the exploration risk barrier and attract investment by supporting the collection and sharing of data on resource potential, and providing de-risking loan guarantees and grants and risk insurance funds.

Collecting and sharing detailed and comprehensive **data on geothermal resources** can help attract investors to increase the chances of successful exploration. The European Union has supported the development of geothermal resources through the GeoDH project and the VigorThermosGIS code. The GeoDH project assessed the regional potential for geothermal district heating in 14 countries and produced an interactive web map, while the VigorThermos GIS code allows prospective developers to assess the feasibility of geothermal technical and economic potential (Dumas and Angelino, 2015; Gola *et al.*, 2013).

High-quality information on resources is particularly important for developing countries which may lack information on geothermal resources and the technical capacity to improve it. Promoting standardisation in the reporting of geothermal resource estimates could attract financing. The United Nations Framework Classification (UNFC) was adopted by the geothermal industry to develop specifications for geothermal resources. IRENA, together with the International Geothermal Association and the World Bank's Energy Sector Management Assistance Program (ESMAP), piloted the application of the UNFC to geothermal resources in Indonesia, a cluster of eastern Caribbean Islands and Ethiopia between 2018 and 2019. The widespread adoption of the UNFC could enable the comparison of geothermal projects across different countries and against other resources. This is expected to facilitate decision making on investment (IRENA, 2016d).

Dedicated loan guarantees and grants can help de-risk geothermal exploration, especially in regions with large potential that are financially constrained, such as Latin America and Southeast Asia. Development banks and other types of concessional finance can help unlock investment in geothermal heating in these regions. For example, the Inter-American Development Bank approved a USD 109 million loan to stimulate private investment in geothermal energy in Mexico. Although this support is targeted primarily at stimulating the development of geothermal power, it offers a best practice example of how to reduce investment risk at each stage of development, including exploration, construction and operation. The Asian Development Bank is supporting geothermal energy development in China, with an USD 250 million loan for the development of geothermal heating systems (REN21, 2019).

Risk insurance funds can ease the risk of geothermal investors and developers. Most current insurance systems are focused on covering short-term risk, namely of drilling. Risk insurance funds for geological risk have been set up by some European countries, including France, Germany, Iceland,

BOX 7.2. A POLICY TOOLBOX FOR GEOTHERMAL ENERGY IN THE DUTCH AGRI-FOOD SECTOR

In the early 2000s, there was no dedicated policy framework for geothermal energy in the Netherlands. However, the government developed a plan for geothermal heat in the years that followed and put in place a mix of complementary measures to facilitate its implementation. Combined with solid expertise and knowledge of geological conditions, originating from the country's experience in oil and gas extraction, the policy toolbox adopted in the Netherlands facilitated a geothermal energy boom between 2007 and 2017. The country went from not using any direct geothermal energy to consuming 30 PJ yearly.

The enabling environment for geothermal energy in the Netherlands is currently composed of the following supporting instruments:

- The 2011 Geothermal Action Plan was the first white paper setting targets on geothermal energy in the country. The 2014 Acceleration Plan Geothermal Energy in Horticulture sets a target for 5 PJ of deep geothermal heat per year and includes strategies to achieve its target.
- The operating grant SDE+ gives financial support for a fixed number of years for the renewable energy generated. The programme pays the difference between the price of fossil fuels and the cost of renewable fuel as a feed-in premium. The support scheme is open to renewable electricity, renewable heat and biogas.
- The Netherlands oil and gas portal is a public geological database that holds all sub-surface data gathered under a mining permit. These data are made public five years after acquisition and have significantly reduced resource risks for geothermal project developers.
- A post-damage guarantee scheme pays out 85% of well costs if the thermal power output is lower than expected. In the Dutch scheme, participants pay an insurance fee of 7% of the maximum support.
- The energy-producing greenhouse programme is a collaborative venture in which government and industry work together to reduce carbon dioxide emissions from greenhouse horticulture, notably by providing businesses with information.

Source: IRENA, 2019k.

the Netherlands and Switzerland. The German government launched a national revolving fund in 2009, combining project financing and risk insurance to national developers for drilling deeper than 400 metres. The EU-funded project GEORISK also aims to support mitigation of resource and technical risks of geothermal projects, by first assessing the de-risking tools available in the market and then proposing a risk-mitigation scheme that can be applied in Europe and in selected countries in other regions (Dumas and Angelino, 2015).

The World Bank is leading plans for a similar project in Indonesia. The Indonesia Geothermal Resource Risk Mitigation project is planning to provide financing of USD 650 million for risk mitigation for exploration in the country. The project is designed so that up to 50% of any loan will be forgiven if a project fails to discover sufficient steam (REN21, 2019).

Table 7.1 summarises barriers and policies related to the direct use of geothermal heat.

Table 7.1. Barriers and policies for the direct use of geothermal heat

Targeted barriers	Policies	Examples	Comments
Low investor confidence owing to uncertainty about long-term market development	Roadmap and action plans	**China**'s action plans for renewables-based heating	Credibility depends on consistency of the policy system.
Technical barriers related to geothermal applications	Research, development and demonstration	**Switzerland**'s support for research and development to advance its programme on geothermal energy for industrial use	Demonstration projects, by their very nature, entail uncertainty about costs and the proper functioning of technologies.
Lack of demand stemming partly from the lack of public awareness of available options and benefits	Public campaigns, information-sharing activities	Public campaigns on geothermal energy in the **United States**	Campaigns can be more effective when they showcase the results of successful demonstration projects.
Lack of information on geothermal resources	Data collection and sharing	The **European Union**'s geothermal data platform	Synergies with mining industries offer potential benefits.
Risks related to the exploration of geothermal resources	Risk insurance funds or loans	Risk insurance for drilling in the **Netherlands**	Feasibility depends on competing budget requirements.
High operational costs	Heating tariffs	The **United Kingdom**'s renewable heating incentives for non-domestic uses	Payment per kilojoule requires a specific metering device for heat uses. Policy attention is needed to avoid inefficient consumption.

7.4. POLICIES TO ENHANCE ENERGY ACCESS AND BOOST PRODUCTIVITY USING GEOTHERMAL ENERGY

Because of its localised nature and high productive use potential, geothermal heat can reach smallholder farmers and add value to their agricultural activities. However, good policy practices and financial support are needed for local communities to utilise geothermal hot water and steam affordably and sustainably. Kenya is one of the most successful countries in the world in the development of geothermal resources and the only country in sub-Saharan Africa to use it for agricultural purposes on a commercial scale. Box 7.3 showcases the success of one of the main geothermal developers in Kenya in demonstrating the use of geothermal heat for local farming activities.

Kenya's success in leveraging its rich geothermal potential for direct heating for productive use (see Box 7.3) can be attributed to the following reasons: 1) integrated geothermal energy plans and rural development plans; 2) active engagement with local actors and promotion of partnerships; 3) assessment of specific productive use activities in the early stage; and 4) a strong focus on capacity building for end users.

Table 7.2 summarises barriers and policies related to the deployment of geothermal energy for productive use in the context of expanding access to energy.

BOX 7.3. GEOTHERMAL HEAT FOR AGRICULTURE IN THE RIFT VALLEY, KENYA

In 2019, the Geothermal Development Company (GDC) began installing a semi-commercial geothermal grain dryer in Menengai, Nakuru (Kenya), where agriculture was the main economic activity. The crops produced in the area included maize, beans and wheat. After harvesting, a majority of the smallholder farmers dry their maize openly in the sun. The dried product is then either stored or sold to bulk grain handlers who require the produce to have a moisture content of less than 13%. To reach that requirement, farmers dry their maize in the open for about a week till it has a moisture content of 18%, before taking it to a nearby dryer to dry it further to 13%. The dryer charges them at least USD 2 for a bag of maize. This practice is not only time consuming but also costly for farmers.

Since the GDC began its drying services in 2020, early results have shown that farmers can cut their drying costs by at least 50% and dry their maize in a shorter time with the GDC dryer. In addition to savings in costs and time for farmers, geothermal drying also brings environmental benefits by replacing diesel-powered drying services. While drying maize with geothermal heat brings multiple advantages, not every farmer enjoys these benefits. The capacity of the geothermal dryer is 600 kilograms per cycle in three days, while most farmers in the area harvest 90 kg of maize per season. GDC therefore encourages these smallholder farmers to form collectives or groups to process their maize together.

Sources: Ronoh, 2020; Koskei *et al.*, 2020.

Table 7.2. Barriers and policies to enhance energy access and boost productivity through geothermal energy use

Targeted barriers	Policies	Examples	Comments
High upfront costs to purchase and install technologies; difficulty accessing finance	Tax incentives (tax and duty exemptions)	Tax exemptions for companies in the Olkaria geothermal area in **Kenya**	Effectiveness depends on clear and specific regulations to avoid competing technologies and fuels from benefitting.
Technologies may process more than the average smallholder farmer can produce	Farmers' collectives	The Geothermal Development Company in **Kenya**	The desire and ability to create farmers' collectives are country specific.
	Early-stage assessment of productive use activities	Olkaria's geothermal feasibility study	Effectiveness depends on community engagement during the planning phases.
Dependence on multiple variables (*e.g.* farmers' experience, crop quality, market access) to ensure success of productive use activities	Integrated resource management plans	**Kenya**'s integrated geothermal energy and rural development plans	Effectiveness depends on interministerial co-ordination and implementation.

08

IN FOCUS:
District heating and cooling

District heating and cooling (DHC) systems consist of one or more sources of heat and a network of pipes that deliver a hot or chilled fluid to consumption centres. The centre may be a residential block, a neighbourhood, a district or even an entire city and its residential and industrial consumers. DHC is best suited for dense urban areas, which provide the anchor load needed to ensure large and steady heat demand.

DHC systems were developed to achieve fuel savings by replacing decentralised solutions such as residential boilers with more efficient heat generation, often drawing waste heat from a large power plant, industrial processes, or water and sewage treatment plants. To date, most DHC networks have operated on fossil fuels (often linked to combined heat and power plants burning coal or gas), although some have been set up specifically to exploit renewables (*e.g.* geothermal heat in Iceland). Fourth- and fifth-generation DHC systems are more efficient and able to operate with lower temperature heat, thus facilitating the integration of renewables (Buff *et al.*, 2019).

A growing number of DHC networks have integrated some forms of renewable energy. In 2017, renewables represented more than half of the total energy consumed for heating and cooling in Estonia, Finland, Latvia and Sweden, where well-developed DHC systems play a key role (European Commission, 2019c).

DHC infrastructure can be viewed as an enabler of greater renewable uptake and, as such, is expected to play a fundamental role in the wider energy transition. In IRENA's Transforming Energy Scenario, district heat accounts for 5% of total final energy consumption by 2050, with renewables providing 77% of that share (IRENA, 2020a). Expanding the supply of heat through district heating is a major part of low-carbon heat strategies in some countries (*e.g.* the Netherlands and United Kingdom) and some cities (*e.g.* Paris, Munich and Vancouver).

This chapter discusses the benefits and current status of DHC including the shares of renewable heat in existing networks (Section 8.1). It then analyses the barriers to the integration of renewable heat in existing infrastructure and to the development of new infrastructure (Section 8.2). Finally, policy measures are presented to overcome those barriers (Section 8.3).

8.1. BENEFITS AND CURRENT STATUS

8.1.1. BENEFITS OF DISTRICT HEATING AND COOLING

Although capital intensive, well-designed DHC networks are among the most cost-efficient and technically feasible solutions to lower primary energy demand. In the European Union, district heating could efficiently meet at least 50% of heat demand by 2050 (Paardekooper *et al.*, 2018).

In highly populated areas of cold or warm regions with high heating or cooling demand, DHC is feasible and cost-effective. Otherwise, the cost-effectiveness of DHC depends on several factors such as linear heat demand (*i.e.* the ratio of total heat demand to the length of the pipe network) and the availability of low-cost supply (*e.g.* excess heat or geothermal). Even where there is no large district heating potential for the country as a whole, it may well be cost-effective in specific localities. Small-scale district networks are increasingly being deployed to service larger buildings or groups of buildings such as university campuses or hospitals.

DHC systems can reduce emissions and are expected to be an important component of future sustainable energy systems if fuelled by renewables. In that regard, there are many instances where renewables could be used in existing DHC infrastructure. In most urban areas, DHC is potentially more economical than decentralised solutions; fossil fuels could be entirely replaced by renewable sources, including biomass, geothermal, solar thermal, and renewable electricity based heat pumps (Lettenbichler and Provagg, 2019).

In dense urban areas, district heating networks may offer the most effective option for using a significant share of renewables and other low-carbon heat, as the use of individual biomass boilers, solar thermal systems or heat pumps, may be constrained for reasons such as lack of available space or access, or noise restrictions. District heating also provides opportunities for integrating short-term and seasonal thermal storage for using excess heat, and for providing flexibility for variable renewable electricity generation through options such as power-to-gas or electric boilers and heat pumps.

Options for the most cost-effective renewable heat supply for district heating vary between locations. In the Baltic States, district heating systems have switched from imported natural gas to using local wood chips and pellets. In a number of Chinese (*e.g.* Baoding) and European cities (*e.g.* Bordeaux, Munich and Paris), geothermal heat from local hot aquifers is providing a cost-effective option, with the share of heat supply varying according to resource availability. In Denmark, large-scale solar thermal systems are contributing renewable supplies to district heating grids in several towns (*e.g.* Silkeborg). Some district networks also supply cooling based on renewables or natural cooling (*e.g.* Paris uses water from the Seine River).

8.1.2. CURRENT STATUS OF DISTRICT HEATING AND COOLING

District energy currently supplies a relatively small share of heating and cooling demand in the buildings sector, at around 6% of global heat consumption in 2018 (IEA, 2019i), with fossil fuels acting as the primary fuel source in most countries today. Most district heating networks are in operation in China, Europe and North America. In China, district heating network capacity exceeds 462 gigawatts-thermal (GW_{th}), while in Europe an estimated 6 000 district heating systems supply around 12% of heat demand. Investment in infrastructure has been driven by the security of supply concerns or as a means to distribute the waste heat or recovery heat from power generation plants.

District cooling networks are primarily used to supply space cooling to commercial buildings in some countries of Europe and the Middle East, as well as some emerging markets (IEA, 2020c). District cooling systems cover 20% of the total space cooling load of the United Arab Emirates and exist in Berlin and Hamburg (Germany), and Toronto (Canada). New systems are operating in Gujarat State (India) and the city of Manila (the Philippines). In Singapore, solar photovoltaic is also deployed to provide electricity for an electric district cooling system (Eveloy and Ayou, 2019; State of Green, 2020).

Renewable fuel options for DHC include renewables-based combined heat and power, solar thermal and geothermal, renewable electricity-based heat pumps and efficient electric boilers (running on renewables-based power) and modern bioenergy boilers. Only 8% of the energy used in district heating was based on renewables in 2018 (IEA, 2019i).

Among renewable sources, biomass is the most common, accounting for 95% of all renewables in district heating in 2019. Sustainable biomass is a viable option for DHC in countries with a high heat demand and substantial forestry activity or other readily available biofuels. Driven by energy security concerns, Lithuania and other Baltic states have shifted from natural gas to biomass, which yields substantial cost savings (Euroheat & Power, 2019). In Finland, renewables contributed 42% of district heat supply in 2018, including 21% from forest fuelwood, 12% from industrial wood residues and 9% from other biofuels (Finnish Energy, 2020).

Most current geothermal and solar thermal DHC projects are located in Europe – and more are on the way. For example, in 2018, Gyor (Hungary) completed a district heating system that serves more than 24 000 houses. A growing number of projects have been completed or are under way in China, South Africa, North America and elsewhere. In Xiong County (China), geothermal replaced coal to provide 95% of heat demand through district heating networks (Yunong, 2019). The fact remains, however, that renewables still account for a small share of total final energy consumption in those countries (REN21, 2019).

The share of renewables in district heating supply varies greatly between countries, depending on natural resources endowment, market drivers and policies. For example, nearly 100% of Iceland's district heat comes from geothermal sources and recycled heat, driven by the country's abundance of natural resources (REN21, 2019). Sweden has seen a steady increase in the share of biomass in its district heating fuel mix, from less than 30% in the early 1990s to 84% in 2017. Other leading countries include Denmark, France, Lithuania and Norway. Each with more than 50% renewables in its district heat supply. However, in countries with a high reliance on coal such as China and Kazakhstan, the heat in DHC networks is predominantly or fully sourced by coal. In China, renewables currently supply only 1% of thermal energy; with regulations aimed at improving air pollution, this share is expected to increase in the future.

8.2. BARRIERS TO DISTRICT HEATING AND COOLING USING RENEWABLES

8.2.1. BARRIERS TO THE DEPLOYMENT OF RENEWABLES IN EXISTING NETWORKS

Technical, financial and regulatory barriers can slow down the deployment of renewables in existing DHC networks.

Technical barriers include ageing networks with low efficiency and high operating temperatures, which are not compatible with many renewable sources. Some countries with existing infrastructure, especially in Russia and East and Southeast Europe, have highly inefficient networks with significant distribution losses that are not suitable for running on low-temperature renewables (IRENA, 2019a; IRENA, 2017c). Similarly, inefficient heating systems or heat exchangers in buildings may not be compatible with low- and medium-temperature heat (see Annex 1). The optimal integration of renewable and low carbon heat sources into DHC systems requires minimising design temperature in distribution pipes and increasing efficiency of heating and cooling systems at the user end to allow for the use of more low- and medium-temperature renewable sources such as solar thermal, geothermal and heat pumps.

Moreover, there can be a possible mismatch between demand and resource availability, mostly when it comes to solar energy for space heating in winter months. Although the demand for district cooling in summer months matches the availability of solar resources, solar thermal district heating may face seasonality concerns in winter where peak solar irradiance and peak demand are at opposite times of the year, which necessitates complementary heat sources or thermal energy storage (see Box 2.1) (Solar District Heating, 2018).

Limited urban areas for the deployment of renewables heat, in particular for large-scale solar thermal collectors and seasonal thermal storage, remain another challenge for DHC networks switching to local renewable sources. That becomes more intensified in high-density urban areas where heat demand is high, but the available urban area is scarce.

Financial barriers mainly relate to the high capital investments required for the switch to renewables in cases where the infrastructure exists. Renewables are further undermined by fossil fuel costs that are subsidised or which do not account for negative externalities, creating an artificially uncompetitive playing field for renewable fuel sources, as discussed in Chapter 2.

8.2.2. BARRIERS TO THE DEVELOPMENT OF NEW NETWORKS

Barriers to the development of new networks mainly entail **financial barriers** relating to the high capital investments required for the development of infrastructure, the high cost of feasibility studies, and uncertainty surrounding heat demand. New DHC systems face high upfront capital investment requirements, especially in already built cities. For example, the Swedish District Heating Association estimates that the distribution network investment cost for the prebuilt area could be EUR 1 950 per house in the inner city and EUR 2 050 per house in the outer city. The cost could be 13–26% less expensive in unbuilt areas (Gudmundsson, Thorsen and Zhang, 2013).

The high capital intensity of DHC networks increases the investment risk as a result of high sunk costs, long payback periods and the significant risks that a DHC system will fail to achieve economies of scale capable of offsetting the high fixed costs. District energy operators can sell their products to only a set of households or industrial premises connected to the distribution grid. While this may appear obvious, it raises uncertainty about the actual amount of energy that can be sold and the investment return. An estimation of the energy demand in the potentially served area, a process known as heat mapping, permits demand to be measured against the minimum heat demand density needed to make the investment profitable. For example, the British government advised a minimum heat demand of 3 megawatts per square kilometre (MW/km^2) for profitable district heating.

Heat mapping is widely used and affordable, and estimates heat demand with enough accuracy to identify anchor loads. Anchor loads are, in the heat market, the equivalent of baseload consumption in the power market: customers with high and stable heat needs. Industrial facilities or public buildings can provide this anchor load. Though estimates off a snapshot of current heat loads, they do not necessarily suffice to predict future heat demand in the long term, yet the typical lifetime of DHC infrastructure is in the order of a century. Also, predictions and improvements in energy efficiency, although it is also true that energy efficiency in buildings can improve

their compatibility with low-operating-temperature DHC, thus facilitating the integration of renewable sources into DHC systems.

More broadly, **legal uncertainty** and **policy inconsistency** can result in a fragmented and unstable DHC market and undermine investment in new projects. For example, new building codes may be tailored for individual production of heating and cooling without considering the system-wide decarbonisation potential of renewables in DHC. Similarly, building refurbishment may reduce consumers' heating or cooling demand, bringing lower earnings for the operators. As a result, prices for DHC might increase due to lower economies of scale. A proper heat management policy should include these aspects, allowing the extension of DHC systems to capture more load where appropriate.

Achieving the full potential of DHC in the decarbonisation of heating and cooling will require policies to address financial barriers to the deployment of renewables in existing and new networks (Section 8.3), measures to address regulatory barriers to the development of new networks (Section 8.4), and measures to address barriers related to consumer awareness and confidence (Section 8.5).

8.3. POLICIES TO ADDRESS FINANCIAL BARRIERS

Financial incentives, fiscal measures and guarantees can offset the high capital costs and financial risks associated with developing new DHC networks and renovating old ones, something that is essential to the uptake of renewable energy sources. Measures include subsidies, grants or tax credits for private-sector utility providers based on decarbonisation impacts; debt guarantees to minimise risks for potential investors; and concessional finance from a multilateral development bank where it is difficult to secure financing locally or interest-rate buydowns for more accessible finance (IRENA, 2017b). Box 8.1 presents examples of financial incentives supporting the refurbishment of existing networks and the development of new ones.

Direct investment in DHC networks and land value capture strategies can be implemented at the municipal level to support the development of infrastructure. For example, the city of Qingdao (China) is investing USD 3.5 billion to build a district heating network. The system will use heat pumps that transfer heat from the air, the ground and waste heat from industries to buildings in the city. The Qingdao District Heating and Power Company is also investing in upgrading buildings to be compatible with the district heating network. The city aims to use clean energy sources for all its heating needs, which would reduce coal consumption by over 3 million tonnes annually (C40, 2017).

Interconnecting the DHC networks among neighbouring cities could mitigate financial barriers. Collaboration between neighbouring municipalities could make operations more efficient and improve system resilience. In Gothenburg (Sweden), the interconnection of district heating networks with two other municipalities, Mölndal and Kungälv, has lowered costs and improved reliability (Celsius, 2020).

Moreover, deploying DHC networks can be **synchronised with transport construction** to minimise costs, traffic disruptions and administrative burdens. Installation of pipes below roadways can account for 60% of the cost of DHC network construction; coordinating DHC planning with transport construction can reduce that cost dramatically. In St. Paul, Minnesota (United States), a local developer utilised the construction of a light-rail line to extend district energy networks and realise cost savings (UNEP, 2015). Financial schemes can also help with the high cost of feasibility studies and the heat mapping in connection with new DHC systems. In the United Kingdom, the Heat Network Delivery Unit provides grants to local governments for feasibility studies and the related early stages of infrastructure development, including heat mapping, the energy masterplan, techno-economic feasibility and detailed project development (Government of the United Kingdom, 2017).

In addition, **energy efficiency policies** are key integrating policies to increase the cost-effectiveness of DHC, for existing and new networks. Although energy efficiency improvements in buildings may slightly affect the business case for DHC due to reduced heat demand, they can enable district energy systems to be operated at a lower temperature and higher efficiency, making it possible to integrate a greater variety of renewable energy sources. Policies to support **recovering waste heat** from industrial processes and other available excess heat could also improve cost-effectiveness. In Copenhagen, the district heating system has captured waste heat from incineration plants and combined heat and power plants since 1984, which makes district heating more competitive (C40, 2011b).

8.4. POLICIES TO ADDRESS REGULATORY BARRIERS

Fiscal incentives are most effective when they are provided as part of an integrated plan for heating and cooling, which is vital for overcoming regulatory and financial barriers and incentivising investment in DHC infrastructure. This includes target setting at the city level, zoning and mandating connection to networks in areas where they exist.

Given that DHC networks are best suited for urban areas where heat demand density is high, municipal governments can adopt **city-level targets** for renewable DHC that are more ambitious than those on the national level. Renewable DHC targets create certainty about the future path of the district energy market, which can help unlock infrastructure investment. Helsingborg (Sweden) and Munich (Germany) have both set targets for 100% renewable district heating by 2034 and 2040, respectively.

Mandating zones – designated urban areas that mandate the connection of new or existing buildings within the zone to the district energy network – effectively eliminate competition with other heat supply technologies and guarantee an anchor load for developers, reducing investment return risk. Zoning policies can apply to existing city districts for the replacement of heating systems and emerging markets experiencing construction booms. The design flexibility in new housing developments can allow for the optimal integration of renewable resources that face technical and spatial barriers, such as solar thermal and geothermal (IRENA, 2017b). Similarly, **municipal energy zoning** can mandate the use of district energy in specific urban areas. It defines the key characteristics of geographic zones, such as the density and height of buildings, as well as other requirements.

BOX 8.1. FINANCIAL INCENTIVES TO SUPPORT RENEWABLES IN DISTRICT HEATING NETWORKS

Denmark, Germany, Iceland, Norway and Sweden all offer financial incentives for investment in DHC infrastructure. The German CHP Act of 2016 offers subsidies for district heating based on the length and diameter of the pipe, up to an annual maximum of EUR 1.5 billion. The subsidy programme has led to significant investment in new and existing district heating systems. Germany's capital investments in refurbishing existing pipes are aimed chiefly at permitting the use of hot water instead of steam in Dortmund, Hamburg, Leipzig and Munich, among other cities. The use of hot water reduces energy losses and allows for lower operating temperatures. In Munich, this process is expected to increase the share of geothermal heat and help meet the city's goal of 100% renewable district heating by 2040 (BINE Informationsdienst, 2007).

Kazakhstan is currently using development bank loans to refurbish its district heating system. Lack of investment in maintenance and upgrades of heat plants and distribution pipes to date has left Kazakhstan's district heating network highly energy intensive. The investment, therefore, aims at improving energy efficiency and reducing heat losses to enable the integration of renewable sources, as nearly all of the heat in Kazakhstan's district heating networks is currently produced from coal (EBRD, 2016).

For example, in Vienna, zones have been defined where heat has to be supplied by district heating, renewables or waste heat (City of Vienna, 2019).

China, Denmark, Republic of Korea and Sweden have used heat planning and zoning to deploy DHC infrastructure. Denmark's Heat Supply Act on District Heating (1979) designates separate urban zones for district heating and natural gas pipes. This not only ensures that economies of scale are achieved, but also prevents inefficient duplication of infrastructure investment. Similarly, the Republic of Korea's mandate zones serve to minimise energy consumption by eliminating duplicate heat systems; unlike Denmark, zoning systems in the Republic of Korea typically only target construction areas in expanding cities (Nuorkivi, 2016).

Connection mandates in new developments or for public buildings in cities can act as a strong regulative framework to support the expansion of energy networks. For example, Amsterdam (the Netherlands) requires all new developments to have a district heating connection. Oslo (Norway) mandates all municipal buildings to have the ability to connect to district heating, unless they can prove that their current energy use has lower emission intensity (C40 and UNEP, 2016). Since 2012, Belgrade (Serbia) has required all public buildings and all new private buildings to connect to the district heating system (REN21, 2019). The cities of Abu Dhabi and Dubai (United Arab Emirates) and Hong Kong (China) have all used zoning mandates to expand their district cooling networks. Dubai currently has the largest district cooling network in the world, established as a public private partnership between a real estate developer and the public utility company. All new developments and all existing public-sector buildings are required to connect to the system, which has helped the city achieve its goal of reducing electricity consumption from decentralised space cooling. Hong Kong's mandate target is narrower (it only targets the emerging Kai Tak development) but is driven by a similar goal of reducing electricity consumption in buildings (UNEP, 2015).

8.5. POLICIES TO STRENGTHEN CONSUMER AWARENESS AND CONFIDENCE

Policies to regulate the natural monopoly, such as competition oversight, transparent pricing or regulated tariffs can improve consumer confidence in DHC systems. Other policies to facilitate competition in the heating and cooling market, such as **allowing third-party access** to distribution pipes, can incentivise DHC providers to improve their service quality, creating improved outcomes for customers. Policies can also, and in a more direct way, favour public ownership or not-for-profit cooperative structures to avoid monopoly abuses. Box 8.2 discusses examples of policies that support customer protection in Iceland and Sweden.

Finally, demonstration projects and research and development initiatives can improve consumer confidence, and more importantly, lower risk perception from financial institutions. Many emerging renewable heating and cooling technologies are relatively new, which limits the financial sector's ability to assess creditworthiness, as well as the public's familiarity and trust in the technology. Demonstration projects can, therefore, offer relevant actors and decision makers greater awareness of district energy systems as a decarbonisation pathway, as well as confidence in the use of emerging heating and cooling technologies within DHC systems.

BOX 8.2. SUPPORT FOR CUSTOMER PROTECTION IN ICELAND AND SWEDEN

Iceland has both abundant geothermal resources and highly concentrated population zones that are ideal for district energy systems, which has led to the world's highest district heating penetration rate of 92%. In order to protect customers and mitigate reputational damage that could have hindered proliferation, Iceland required district heating providers to obtain a license that stipulated full tariff regulation and at least 51% public ownership of the natural monopoly.

Sweden's Energy Markets Inspectorate (EMI) and the Swedish Competition Authority supervise the country's district heating market. The EMI ensures that private providers comply with the 2008 District Heating Act, which stipulates pricing, customer rights, access to information and third-party access. For example, customers have an unconditional right to access information regarding their tariffs (transparent pricing) and can legally leave the district heating system with no repercussions if their pricing terms change. Providers are also obligated to negotiate with third parties, which improves competition and customer outcomes.

Source: Patronen, Kaura and Torvestad, 2017.

This can be coupled with the engagement of research institutes to lower technology risks. The Indian state of Gujarat, for instance, is using public funds to develop the country's first district cooling system in its International Finance Tec City, a business district on the outskirts of Ahmedabad. The purpose of the project is to show both public and private actors the high potential and technical viability of district cooling in India and is expected to markedly increase investor confidence in district cooling nationwide.

Table 8.1 summarises barriers and policies related to the deployment of district heating and cooling networks.

Table 8.1. Barriers and policies for renewables in district heating and cooling

Targeted barriers	Policies	Examples	Comments
High capital investment required to build new district heating and cooling (DHC) networks and refurbish existing networks	Subsidies, grants, tax credits, debt guarantees and land-value capture strategies	**Germany, Kazakhstan**	Feasibility depends on competing budget requirements.
Low confidence of investors and consumers in DHC	Research, development and demonstration; information campaigns	**India**	Demonstration projects entail uncertainty by their nature.
Traditional fossil fuel based DHC systems	Targets on renewables-based DHC	**Helsingborg** (Sweden)	Effectiveness depends on stable long term commitments, including regulatory instruments and other support policies.
Uncertainty about anchor load, affecting the attractiveness of investments	Guidelines for heat mapping	**United Kingdom**	Effectiveness depends on the availability of data and, given the long lifetime of DHC systems, requires long-term planning for urban development.
	Connection mandates and heat mandate zones	**Vienna** (Austria), **Amsterdam** (The Netherlands)	Mandate zones create natural monopolies, requiring additional regulation and adapted business models and ownership structures.
Monopoly-related issues (*e.g.* pricing, maintenance, service)	Customer-protection policies (*e.g.* monopoly oversight); price transparency; involvement of customers in the business model (through involvement of the public sector); management of networks as not-for-profit companies.	**Iceland**	Universal adoption in countries with extensive DHC systems suggests wider feasibility.

09 THE WAY FORWARD

The urgent need to limit the rise of global temperatures and curtail the lethal consequences of climate change depends on reducing emissions of greenhouse gases. This in turn depends on a successful transition away from fossil fuels and towards renewable energy, combined with greater energy efficiency. The transition must extend to all energy uses across the economy, including heating and cooling.

To that end, policy makers will have to raise ambition by setting specific targets; translating those targets into long-term, integrated energy plans that take into account country-specific resources and requirements; erecting a robust institutional structure; and implementing the plans to meet the targets. Some of the policies stemming from the plans may be targeted towards specific technologies and solutions intended to achieve a specific pathway, whereas others are designed to facilitate all pathways.

NDCs, TARGETS AND PLANS

Achieving the transition to clean, sustainable heating and cooling will require raising the ambition of nationally determined contributions (NDCs) under the Paris Agreement and on setting related renewable energy targets. The ambitions expressed in NDCs, particularly for sectors with large heating and cooling needs, must be raised to encourage the transition to a more efficient and renewables-based energy system consistent with the achievement of global climate goals.

Policy makers should set specific, timebound targets for renewable energy and energy efficiency in heating and cooling uses. These should be expressed in NDCs and reflected in comprehensive long-term strategies aligned with national decarbonisation objectives. This will provide policy certainty, guide investment towards the needed infrastructure and send a positive signal to investors.

A long-term, integrated energy plan for heating and cooling is necessary to coordinate the deployment of renewables-based solutions with measures to raise energy efficiency and develop needed infrastructure, while simultaneously avoiding conflicts among pathways and the stranding of assets. Cross-sectoral planning should integrate the transition of heating and cooling within plans for other sectors (notably power and industry). The energy plan for heating and cooling must be based on specific needs; macro-economic conditions; availability of resources; the infrastructure already in place; and the level of development, accessibility, and cost of technologies.

INSTITUTIONAL STRUCTURE FOR A COORDINATED ENERGY TRANSITION

A robust institutional structure that clearly defines roles and responsibilities for translating targets into actionable initiatives is essential. That structure will have to coordinate various governing bodies and stakeholders, including those responsible for and involved in energy and power, industry, agriculture, and forestry.

Build capacity for the collection and standardisation of data and statistics, and for conducting heat mapping and zoning.

TO PROMOTE UPTAKE OF RENEWABLES IN CITIES, POLICY MAKERS SHOULD:

Coordinate national and local governments to ensure that effective instruments at different levels of governance are complementary.

Work with local stakeholders to undertake a comprehensive resource and infrastructure assessment through heat mapping to identify technologies and transformative approaches of heating and cooling that suitable for local context.

Pursue the strategic phase-out of fossil fuels used for heating and cooling in new and existing buildings.

Recognise the key roles that cities can play in the transition to renewable heating and cooling.

POLICIES AND MEASURES NEEDED FOR ALL TRANSFORMATIONAL PATHWAYS

Chief among the policies and measures that contribute to the success of all pathways are those that increase energy efficiency, level the playing field with fossil fuels, address upfront costs associated with adopting renewables, attract investment in needed infrastructure, strengthen supply chains, and overcome market barriers.

TO INCREASE ENERGY EFFICIENCY IN BUILDINGS AND INDUSTRY, POLICY MAKERS SHOULD:

Introduce energy performance codes for buildings that set requirements on energy efficiency and renewables-based heating and cooling for new construction and for the refurbishment of existing buildings. Together with financial incentives, such codes can raise buildings' energy performance and improve their ventilation systems.

Implement minimum energy performance standards for appliances. Performance standards and labelling schemes are effective instruments to boost the efficiency of the heating and cooling appliances used in buildings and industry.

TO LEVEL THE PLAYING FIELD WITH FOSSIL FUELS, POLICY MAKERS SHOULD:

Phase out existing fossil fuel subsidies to remove distortion in the market and enable the uptake of clean energy solutions.

Implement and adjust fiscal policies, including carbon pricing policies, to enhance the competitiveness of renewables-based heating and cooling against fossil fuels. However, like phasing out fossil fuel subsidies, such interventions should be preceded by a careful assessment of the social dimension to ensure that they will not worsen energy poverty among low-income households.

Adopt policies to ensure that changes in subsidies and fiscal policies do not increase energy poverty or have other socially regressive effects. Exempting households or energy-intensive industries can compromise the viability of schemes designed to level the playing field. Instead, it may be more in line with long-term decarbonisation objectives to provide dedicated support for low-income consumers or other highly affected parties to help them shift towards low-carbon heating and cooling solutions.

Create a level playing field between electricity and other energy carriers. Taxes and levies should be balanced for all energy carriers used for heating and cooling to avoid the case where fossil fuels remain subsidised even after subsidies are removed on electricity.

TO ADDRESS HIGH UPFRONT COSTS OF TRANSITION-RELATED TECHNOLOGIES, POLICY MAKERS SHOULD:

Implement fiscal and financial incentives, including tax credits, tax reduction, accelerated depreciation, subsidies, grants and loan schemes, among others. These incentives can be combined with regulatory policies, such as mandates for the use of solar water heaters, to accelerate deployment of technologies that advance the energy transition.

Introduce fiscal and financial incentives in an equitable way to ensure that low-income households benefit. Policy makers should ensure that recipients of fiscal and financial incentives are not limited to higher-income households who can afford transition-related solutions such as heat pumps. Policies must be tailored to ensure that energy-poor households derive clear benefits, such as by linking funds and subsidies for renewable energy solutions to household income, with the goal of reducing inequality.

TO ATTRACT INVESTMENT IN NEEDED INFRASTRUCTURE, POLICY MAKERS SHOULD:

Ensure the presence of sufficient anchor load for new infrastructure such as district heating and cooling networks and gas grids so that investing in the infrastructure will be seen as profitable. Guaranteed anchor load might include large heat consuming industries and public buildings.

Mandate connections to district heating and cooling networks or renewable gas grids (where these exist) in new urban developments, public buildings, and other opportune locations. Mandates would ensure a stable demand for the network and reduce investment risk.

Make certain that energy efficiency goals, plans and measures are taken into account when assessing the feasibility of district heating networks and other heating and cooling infrastructure.

Refurbish existing distribution networks and improve their efficiency to enable the integration of low-temperature sources, such as solar thermal, geothermal and biomass. This would encourage the switch from fossil fuels to renewable heat.

TO DEVELOP AND STRENGTHEN THE RENEWABLE ENERGY INDUSTRY, POLICY MAKERS SHOULD:

Implement industrial policies that leverage and enhance domestic capabilities for the provision of needed components and services along the renewable energy supply chain. Such policies include initiatives and programmes to incubate new businesses, develop the capabilities of existing firms in the supply chain, (*e.g.*, by incentivising technological learning and cross-sectoral spillovers), provide low-cost loans, and promote local or regional industry clusters that bring together relevant actors – chief among them government agencies, industry associations and companies, universities, and research institutes.

Encourage collaboration between industry and research organisations to fill knowledge gaps. To further promote technology diffusion, governments should establish industry clusters for heating and cooling technologies.

Support research, development and demonstration (RD&D) projects to help overcome the technological and commercial challenges that renewable heat solutions still face and which result in relatively high costs, low consumer confidence and slow uptake. RD&D is necessary to promote commercialisation and wider deployment of new technologies and to increase their ability to compete with other options. Even in smaller markets, RD&D can be especially useful for supporting domestic industries that create domestic value and meet local needs.

Introduce education and training policies to build or augment technological learning and know-how in the energy sector and the wider economy. Efforts can be introduced as part of degree programmes at universities, or in the form of short-term and evening certificate courses that help workers gain additional skills in heating and cooling technologies. Such policies can bridge the skills gaps that often slows the rapid uptake of renewables-based technologies.

TO ENSURE AN INCLUSIVE TRANSITION, POLICY MAKERS SHOULD:

Work to minimise the socio-economic cost of transitioning heating and cooling to modern renewables and away from fossil fuels and inefficient use of biomass.

Adopt a set of labour market and social protection policies. Active labour market measures match the supply of skills in the jobs market with demand, provide employment advisory services, and facilitate relocation where needed. Recognising that the transition may not always be smooth for all affected workers and communities, social protection policies offer financial and other support during an interim period and can be paired with economic diversification programmes.

Smoothen the transition for workers in obsolete industries by developing opportunities in new industries and providing re-skilling options for affected workers. This requires a close examination of where and how skills in old and new industries overlap and what measures must be taken to facilitate reskilling and upskilling.

TO OVERCOME MARKET BARRIERS, POLICY MAKERS SHOULD:

Introduce certification schemes, standards, quality assurance, and technical support for operation and maintenance. Standardisation policies should set requirements for the design, development and operation of renewable heating and cooling solutions across their value chains. These include equipment certification, codes of practice, and regulations to ensure qualified installation and maintenance. Quality assurance schemes should also cover the appliances and equipment that use renewable heat and extend to the design, installation, operation and maintenance of equipment. It is essential to tie support to procurement from qualified suppliers and installation by qualified installers.

Adopt programmes and initiatives to raise public awareness so as to stimulate interest and build confidence among potential consumers and to engage stakeholders (from politicians to installers) in promoting renewable options. To cite just one important example, governments should mount information campaigns to raise public awareness of efficient electric heating and cooling technologies.

POLICIES AND MEASURES FOR SPECIFIC TRANSFORMATIONAL PATHWAYS

The solutions available for renewable heating and cooling vary greatly, ranging from fuelwood for cooking to green hydrogen in industrial applications. They differ in many respects, including temperature levels, fuel dependency and supply chains. Those differences often call for distinct policies and measures to advance the transformation of heating and cooling in its many forms.

TO SUPPORT RENEWABLES-BASED ELECTRIFICATION, POLICY MAKERS SHOULD:

Couple the electrification of heating and cooling with the additional deployment of cost-efficient renewable energy generation. Rising demand for electricity for heating and cooling should be built into targets for renewable energy deployment in the electricity sector, in line with long-term decarbonisation objectives.

Align additional renewable energy deployment in the electricity sector with forward-looking planning for expansion of the grid. The power system must be adapted to handle the additional load imposed by the electrification of heating and cooling. To this end, most power systems will require infrastructure upgrades.

Redesign power markets to support the integration of higher shares of variable renewable energy – for example, by establishing shorter intra-day markets and removing barriers to the participation of renewables in auxiliary services markets. Heat pumps have the potential to become a source of system flexibility, facilitating the integration of higher shares of variable renewable energy. But exploiting that potential will require proactive policies for the upgrade of power networks, supported by smart technologies (for digital monitoring and control, among other things) and dedicated flexibility products, as well as the formation of aggregators of variable power inputs.

Redesign electricity tariffs to meet the growing need for flexibility. By establishing time-of use tariffs and other smart rate-setting options, policy makers can increase demand-side flexibility, thus facilitating the system-friendly integration of additional loads from heating and cooling.

In the off-grid and weak-grid contexts, policy makers should take **actions to support the adoption of efficient electric solutions running on decentralised renewable energy technologies** in a way that improves livelihoods and supports socio-economic development. To this end, they should:

- **Adopt an integrated approach in their electrification and development plans.** Plans for decentralised heating and cooling must be coordinated with rural electrification plans and policies (*e.g.*, regulations, fiscal incentives) to ensure they are implemented synergistically. They should also fit within a broader development plan to ensure that their implementation will support socio-economic development goals.

- **Support the uptake of efficient electric appliances for heating and cooling needs** (*e.g.*, efficient electric cook stoves, electric fans, refrigerators). Measures include fiscal and financial incentives for manufacturers and distributors, donor-sponsored research and development, roll-out programs to increase economies of scale, minimum energy performance standards and appliance labels, information campaigns, user training and manuals, and consumer financing models.
- **Prioritise policies that encourage financial institutions to make available alternative and innovative forms of financing (*e.g.*, results-based financing).** These alternative financing options should be available to small and medium-size companies that provide decentralised heating and cooling solutions for residential and productive use in off-grid and weak-grid settings.

TO SUPPORT THE USE OF RENEWABLE GASES, POLICY MAKERS SHOULD:

Provide a clear development plan that helps define the role of renewable gases in a future low-carbon energy system. The plan can take the form of national strategies and roadmaps that establish key areas for the use of green gases in hard-to-abate sectors (*e.g.*, industrial processes). Including quantitative targets for the production and consumption of renewable gases based on a prospective assessment of needs is instrumental to providing the visibility required to unlock private sector investment.

Harness the potential of existing gas network infrastructure to accommodate renewable gases. This requires a clear long-term vision; the removal of unnecessary regulatory barriers; certification to identify, track and balance renewable gases that flow through the networks; and regulatory frameworks that enable network modifications and upgrades to facilitate blending or full repurposing of infrastructure. For hydrogen, in particular, demonstration projects also have a key role to play in probing the limits and long-term effects of using hydrogen in existing gas network infrastructure.

Take concerted action to lower the production cost of renewable gases. This requires both supply-side support for technology development and production scale-up, as well as demand-side measures that lower investment risks by identifying key consumption zones and setting targets for consumption in those zones.

Recognise that biogas and biomethane offer broad benefits, such as improved waste management, avoided methane emissions and economic diversification in rural development. These need to be considered and leveraged when establishing policies to support the production and use of these fuels.

In the off-grid context, policy makers should take actions to **support the adoption of household biogas digesters** in a way that improves livelihoods and supports socio-economic development. To this end, they should:

Mitigate the upfront cost of household biogas digesters, thereby allowing these devices to expand access to low cost heating and cooking fuel.

- **Ensure the longevity of biogas digesters** through training programmes and service-related regulations that build capacity, raise quality standards and assure after-sale services.
- **Leverage existing clean cooking policy frameworks to level the playing field for biogas,** allowing it to compete against charcoal, kerosene, and pellets in the access context. The policies to be leveraged include tax incentives and the elimination (or reduction) of fossil fuel subsidies.
- **Incentivise and facilitate farmers' access to micro-finance, awareness-raising and capacity building** to induce them to take advantage of the benefits of biogas and the synergies at the nexus of agriculture, waste and energy.

TO SUPPORT THE SUSTAINABLE USE OF BIOENERGY, POLICY MAKERS SHOULD:

Recognise the benefits of forms of biomass combustion that can lower emissions in residential, commercial and public buildings and in industry. The sustainable use of biomass can complement other approaches, including district heating.

Support the development and scale-up of existing and new biomass applications and technologies through policies on innovation, research and development. Many such applications are available commercially and ready for use in high-temperature industrial applications.

Encourage the use of biomass including for co-generation, using residues and waste with a cost-effective and stable feedstock supply, such as bagasse produced in the sugar industry and wood residues from forestry and timber operations. Modern small- and medium-scale biomass heating devices can efficiently provide heat not only for the residential sector, but also for commercial and public buildings, where the larger scale makes applications more cost-competitive.

In the context of the inefficient use of biomass, policy makers should **take actions to support its sustainable use** in a way that improves livelihoods and supports socio-economic development. To this end, they should:

- **Devote more resources to tackling the clean cooking problem** and the unsustainable use of biomass and charcoal. Despite increased attention to the Sustainable Development Goal (SDG) on clean cooking, efforts to promote sustainable solutions aligned with long-term decarbonisation objectives have not been adequate. Without more emphasis, the SDG of universal access to clean cooking solutions by 2030 is unlikely to be attained.
- **Ensure that supported clean cooking solutions meet air quality standards and satisfy user needs.** Solutions include a combination of improved systems and fuels such as pellets or briquettes or alcohol fuels, or a move to anaerobic digestion. Standards, certification and testing play key roles in ensuring the deployment of systems of good quality.
- **Stimulate a wider adoption of schemes to certify sustainable fuel supply chains** as well as improved combustion devices for clean cooking programmes.
- **Offer the public information and training,** both vital components of clean cooking programmes.
- **Develop clear and specialised regulatory guidelines for the use of bioethanol for cooking,** with tailored legal processes, quality standards, and financial incentives, all clearly distinguished from the use of bioethanol in the beverage industry or as a transport fuel.
- **Incentivise the deployment of ethanol micro-distilleries** to complement medium-scale ethanol distilleries and to enable decentralised production. The presence of such micro-distilleries is necessary to improve competition with other industries and meet the challenge of distributing bioethanol as a cooking fuel to last-mile consumers.

TO SUPPORT THE DIRECT USE OF SOLAR THERMAL HEAT, POLICY MAKERS SHOULD:

Introduce mandates and financial incentives to create a market for technologies such as solar water heaters. Such policies can also be implemented at the subnational level, taking into consideration context-specific factors. Fiscal and financial incentives, including low-interest loans, concessional funding, and tax exemptions, are key to reducing the high upfront costs of solar thermal technologies.

In the off-grid context, policy makers should take actions to support the **adoption of decentralised solutions for solar thermal energy,** in a way that improves livelihoods and supports socio-economic development. To this end, they should:

- **Encourage financing mechanisms** like pay-as-you-go and lease-to-own models to make solar thermal technologies for productive uses more affordable to smallholder farmers.
- **Provide information and training to end users** to drive behavioural change and ensure the proper use of solar thermal technologies.

TO SUPPORT THE DIRECT USE OF GEOTHERMAL HEAT, POLICY MAKERS SHOULD:

Reduce the risk of geothermal exploration. Government support policies and measures include collecting and sharing geothermal data on public platforms, providing insurance against exploration risks, and offering loan guarantees and grants to reduce the risk represented by the sunk cost of well drilling.

Increase support for RD&D to improve the integration of cost-effective geothermal heat into large-scale industrial systems and district heating and cooling networks.

Integrate policies and planning for energy, rural development, and agriculture to build a cross-sectoral nexus in developing markets. To take one example, farmers can benefit from geothermal energy to raise their yields, dry their agricultural outputs and enjoy clean heat.

ANNEX I. RENEWABLE ENERGY OPTIONS AND APPLICATION SUITABILITY

The uses of energy for heating and cooling span a wide range of end-use applications and technologies, all necessary for basic human needs, economic development and comfort. Those uses have traditionally been supplied by biomass or fossil fuels.

In buildings, activities related to heating and cooling include cooking, water heating, ambient heating and cooling and refrigeration. The agri-food chain also comprises a wide range of heating and cooling activities (IRENA, 2019k), including greenhouse heating, soil heating, crop drying and refrigeration.

In industry, energy needs for industrial processes range from temperatures below 0°C (*e.g.* in the food industry, where refrigeration permits storage and transport of products) to high-temperature applications (*e.g.* 800-1 400°C in the cement, iron and steel industries).

As such, heating and cooling uses include activities with very different needs in terms of temperatures. Fossil fuels, thanks to their high heating values and energy density, have been able to provide all the heating services, and, paired with electricity-driven chillers and refrigerators, they can cover the full spectrum of heating and cooling services.

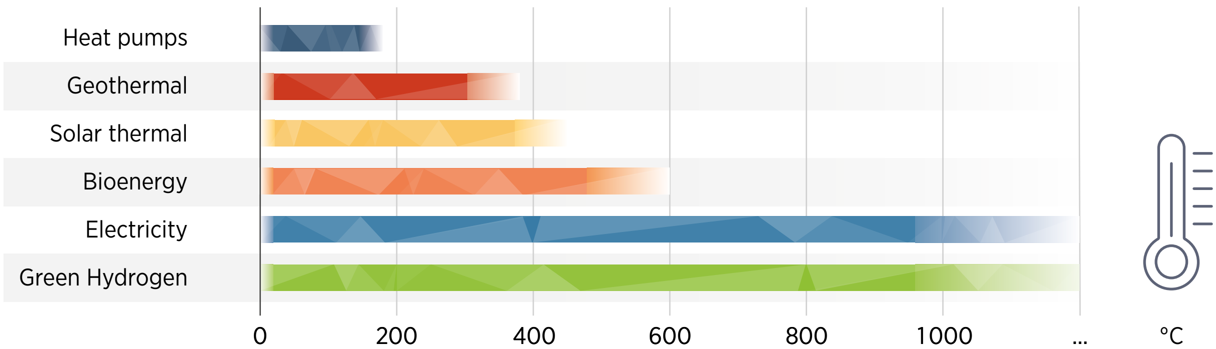
Renewable energy sources, such as geothermal energy, solar energy and bioenergy are good alternatives to electricity and fossil fuels for low-temperature heating services. Solar thermal technology includes a variety of collector types, from unglazed to concentrating collectors. Temperature ranges between 20 and 200°C (IEA-ETSAP and IRENA, 2015b). Geothermal fluids can provide heat above 300°C (IRENA, 2017a). Biomass, biogas and biomethane, can provide heat at 600°C (Figure AI.1). The working temperature that a specific renewable technology can supply depends on multiple factors. For example, the amount of heat that a flat-plate solar system can supply will depend on how much sunlight it receives, and at what angle. The amount of heat from bioenergy depends on the treatment and nature of the biomass (presence of moisture, density), as well as the technologies used.

Bioenergy can provide high-temperature heat. However, costs, sustainability issues and availability are barriers to its larger use. Renewable fuelled absorption cycles can provide cooling services, but the requisite technology is still more expensive than electric alternatives.

To cover both high-temperature services and cooling demand, renewable electricity and green hydrogen can help close the gap, allowing renewable energy sources to provide the full array of services for heating and cooling needs.

The exact working temperature requirements for a particular building's heating or cooling or for a certain industrial process depend on factors such as system type, size, and location and efficiency. Energy efficiency, in particular, plays an important role in accelerating the deployment of renewable energy for heating and cooling, since it can reduce the working temperatures needed (for example, a thermally insulated house needs lower temperatures from radiators to be comfortable in winter), rendering more feasible the use of cost-effective technologies that provide low working temperatures.

Figure AI.1. Working temperatures for various renewable heat technologies



Source: Adapted from IEA (2019a).

ANNEX II. CLASSIFICATION OF POLICIES TO SUPPORT THE ENERGY TRANSITION IN HEATING AND COOLING

Renewable Energy Policies in a Time of Transition (IRENA, IEA and REN21, 2018) classified policies in accordance with a new approach to renewable energy policy making, highlighting policies beyond those driving the deployment of renewable energy technologies. Also analysed were policies to support the integration of renewables into the broader energy system, policies to create an enabling environment for development of the sector, and economy-wide policies that affect the sustainability and pace of the energy transition.

This report, following the first one, classifies renewable heating and cooling policies into three categories.

- **Direct policies** and instruments are used to support the deployment of renewable energy heating and cooling fuels, appliances, and products.
- **Integrating policies** for renewable heating and cooling include policies designed to improve the energy efficiency of buildings and appliances, as well as to develop necessary infrastructure.
- **Enabling policies** for heating and cooling include carbon pricing policies, climate policies, technology standards, labour policies and industrial policies.

Table AII.1 presents an updated classification of renewable energy policies based on these three categories for use generally and in the specific context of expanding access to energy.[1] This classification provides a harmonised framework to track policies and link them to broader growth and development objectives, including socio-economic dimensions.

Table AII.1. Policies to support the transition to sustainable heating and cooling

Policy category		General context	Access context	Maximisation of socio-economic benefits
Direct policies	Push	• Binding targets for the use of renewable energy, including net zero energy targets • Building codes and appliance efficiency standards • Mandates (*e.g.* solar water heaters, renewables in district heating) • Planned replacement of equipment • Blending mandates • Procurement by municipal governments	• Rural electrification targets, strategies, programmes • Clean cooking strategies, programmes • Biogas digester programmes	Deployment policies designed to maximise benefits and ensure a sustainable transition (*e.g.* communities, gender) including requirements, preferential treatment and financial incentives for installations and projects that help meet socio-economic objectives Policies to support productive uses in rural areas, including in the agri-food chain
	Pull	• Regulatory and pricing policies (*e.g.* feed-in policies) • Tradable certificates • Instruments for self-consumption • Measures to support voluntary programmes	• Regulatory and pricing policies (*e.g.* legal provisions, price/tariff regulation)	
	Fiscal and financial	• Tax incentives (*e.g.* tax credits, accelerated depreciation, tax reductions) • Subsidies • Grants • Loans	• Tax incentives (*e.g.* reductions) • Subsidies • Grants • Concessional financing • Support for financial intermediaries	

1 The table presents examples of policies and measures in each category of policies. It is not exhaustive.

Table AII.1. Policies to support the transition to sustainable heating and cooling (continued)

<table>
<tr><th>Policy category</th><th>General context</th><th>Access context</th><th>Maximisation of socio-economic benefits</th></tr>
<tr><td rowspan="3">Integrating policies</td><td>• Measures to enhance system flexibility (e.g. promotion of flexible resources such as thermal and electrical storage, dispatchable supply, load shaping)</td><td>• Policies for the integration of off-grid systems with main grid
• Policies for mini-grids and smart distributed energy systems
• Coupling of renewable energy policies with efficient appliances and energy services; use of thermal energy storage as an enabler for sector coupling</td><td rowspan="2">Adoption of credible certification entities and schemes (e.g. certification for sustainable use of biomass)</td></tr>
<tr><td colspan="2">• Policies to ensure the presence of needed infrastructure (e.g. transmission and distribution networks, district heating infrastructure, road access)
• Policies for sector coupling</td></tr>
<tr><td colspan="3">• Better alignment of energy efficiency and renewable energy policies
• Incorporation of decarbonisation objectives into national energy plans
• Measures to adapt socio-economic structure to the energy transition</td></tr>
<tr><td rowspan="2">Enabling policies</td><td colspan="2">• Policies to level the playing field (e.g. fossil fuel subsidy reform, carbon pricing policies)
• Measures to adapt the design of energy markets (e.g. flexible short-term trading, long-term price signals)
• Policies to ensure the reliability of technology (e.g. quality and technical standards, certificates)</td><td>• Industrial policy (e.g. leveraging local capacity)
• Trade policies (e.g. trade agreements, export promotion)
• Environmental and climate policies (e.g. environmental regulations)</td></tr>
<tr><td colspan="3">• General and sector-specific national renewable energy policy (e.g. objectives, targets)
• Policies to facilitate access to affordable financing for all stakeholders
• Education policies (e.g. inclusion of renewable energy in curricula, coordination of education and training with assessments of actual and needed skills
• Labour policies (e.g. labour market policies, training and retraining programmes)
• Land-use policies
• RD&D and innovation policies (e.g. grants and funds, partnerships, facilitation of entrepreneurship, formation of industry clusters)
• Urban policies (e.g. urban planning, zoning policies)
• Public health policies (e.g. relative to levels of air pollutants)</td></tr>
<tr><td>Enabling and integrating policies</td><td colspan="3">• Supportive governance and institutional architecture (e.g. streamlined permitting procedures, dedicated institutions for renewables)
• Participative programs and schemes actively involving lay citizens in decision making
• Programmes to raise awareness of the importance and urgency of the energy transition geared towards awareness and behavioural change
• Social protection policies to address disruptions
• Measures for integrated resource management (e.g. the nexus of energy, food and water)</td></tr>
</table>

Source: Adapted from IRENA, IEA and REN21, 2018.

Note: RD&D = research, development and demonstration.

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