Integrating low-temperature renewables in district energy systems

Guidelines for policy makers

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Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Bertelsen, N., Mathiesen, B. V., Djørup, S. R., Schneider, N. C. A., Paardekooper, S., Sánchez García, L., Thellufsen, J. Z., Kapetanakis, J., Angelino, L., & Kiruja, J. (2021). *Integrating low-temperature renewables in district energy systems: Guidelines for policy makers*. International Renewable Energy Agency.

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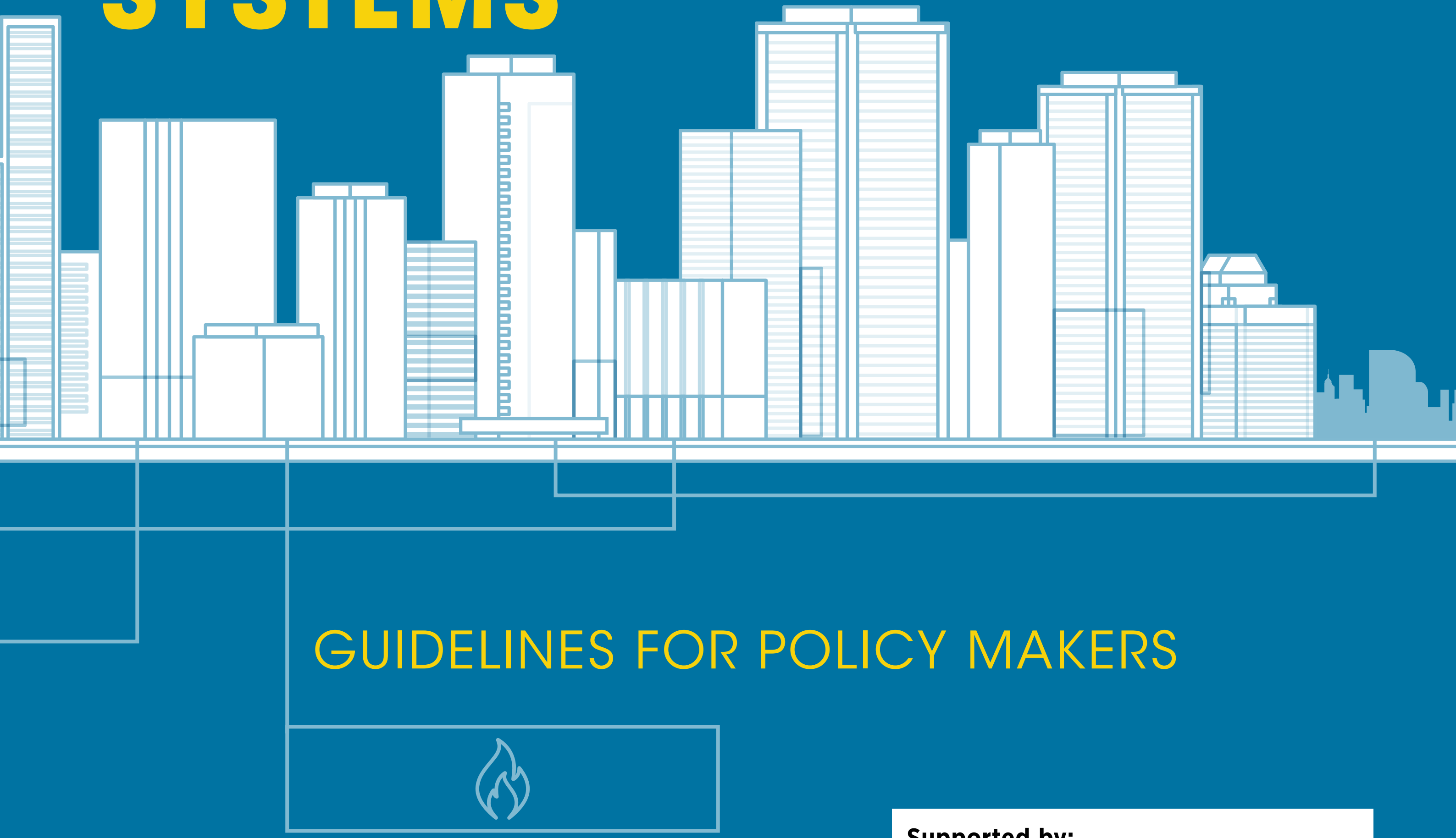
DENMARK

IRENA
International Renewable Energy Agency

INTEGRATING LOW-TEMPERATURE RENEWABLES IN DISTRICT ENERGY SYSTEMS



GUIDELINES FOR POLICY MAKERS

Supported by:

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

ISBN 978-92-9260-316-8

Citation: IRENA and Aalborg University (2021), *Integrating low-temperature renewables in district energy systems: Guidelines for policy makers*, International Renewable Energy Agency, Aalborg University, Abu Dhabi, Copenhagen.

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Aalborg University was created in 1974. The Department of Planning at Aalborg University conducts research in different fields including Energy Planning. The Sustainable Energy Planning (SEP) Research Group at Aalborg University's Department of Planning has more than 25 years of experience with an interdisciplinary approach to sustainable energy planning combining techno-economic, geographical and socio-political aspects. ***www.en.plan.aau.dk/research+groups/SEP/***

Acknowledgements

IRENA is grateful for the valuable contributions of the members of an ad hoc advisory group of experts constituted by IRENA and Aalborg University from the constituency of the Global Geothermal Alliance (GGA) and other institutions involved in the district heating and cooling sector. Inputs and feedback were received from the following experts: Eirikur Bragason (Arctic Green Energy), Leoni Paolo and Ralf-Roman Schmidt (Austrian Institute of Technology – Center for Energy), Wang Weiquan (Chinese Renewable Energy Industries Association – CREIA), Isabel Cabrita and Maria Carla Lourenco (Directorate-General of Energy and Geology – Portugal), Olivier Racle (Engie), Samra Arnaut (Enova – Bosnia), Eloi Piel (Euroheat & Power), Bojan Bogdanovic and Greg Gebrail (European Bank for Reconstruction and Development), Catherine Hickson (Geothermal Canada), Christiaan Gischler (Inter-American Development Bank – IDB), Marit Brommer (International Geothermal Association – IGA), Jure Cizman (Jozef Stefan Institute – Slovenia), Annamaria Nador (Mining and Geological Survey of Hungary), Paul Bonnetblanc (Ministère de la Transition Ecologique et Solidaire – France), Paul Ramsak (Netherlands Enterprise Agency – RVO), Jón Örn Jónsson (Reykjavik Geothermal), Christian Holter (SOLID solar thermal systems), Sebastien Danneels (Stoke-on-Trent City Council – UK), Celia Martinez and Zhuolun Chen (UNEP), Astu Sam Pratiwi and Marc Jaxa Rozen (University of Geneva), Elin Hallgrimsdottir and Joeri Frederik de Wit (World Bank ESMAP) and Emin Selahattin Umdu (Yasar University – Turkey). Valuable input was also provided by IRENA colleagues Fabian Barrera, Yong Chen, Jinlei Feng, Imen Gherboudj, Seungwoo Kang, Paul Komor and Toshimasa Masuyama. Participants in the "Integration of Low-Temperature Renewable Energy Sources into District Heating and Cooling Systems" event held in Serbia in December 2019 also provided valuable input which was used to enrich the content of this report.

Presentations from the workshop are available on the IRENA website:
https://irena.org/events/2019/Dec/Energy-Solutions-for-Cities-of-the-Future.

Contributors: This report was developed under the overall guidance of Gurbuz Gonul and Salvatore Vinci (IRENA) and technical guidance of Brian Vad Mathiesen (Aalborg University). It was authored by Luca Angelino and Jack Kiruja (IRENA), Nis Bertelsen, Brian Vad Mathiesen, Søren Roth Djørup, Noémi Schneider, Susana Paardekooper, Luis Sánchez-García, Jakob Zinck Thellufsen and John Kapetanakis (Aalborg University). Valuable advice was provided by Amjad Abdulla (IRENA).

IKI support:

This report forms part of the Energy Solutions for Cities of the Future project, which is supported by the International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag.

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Guidelines for policy makers

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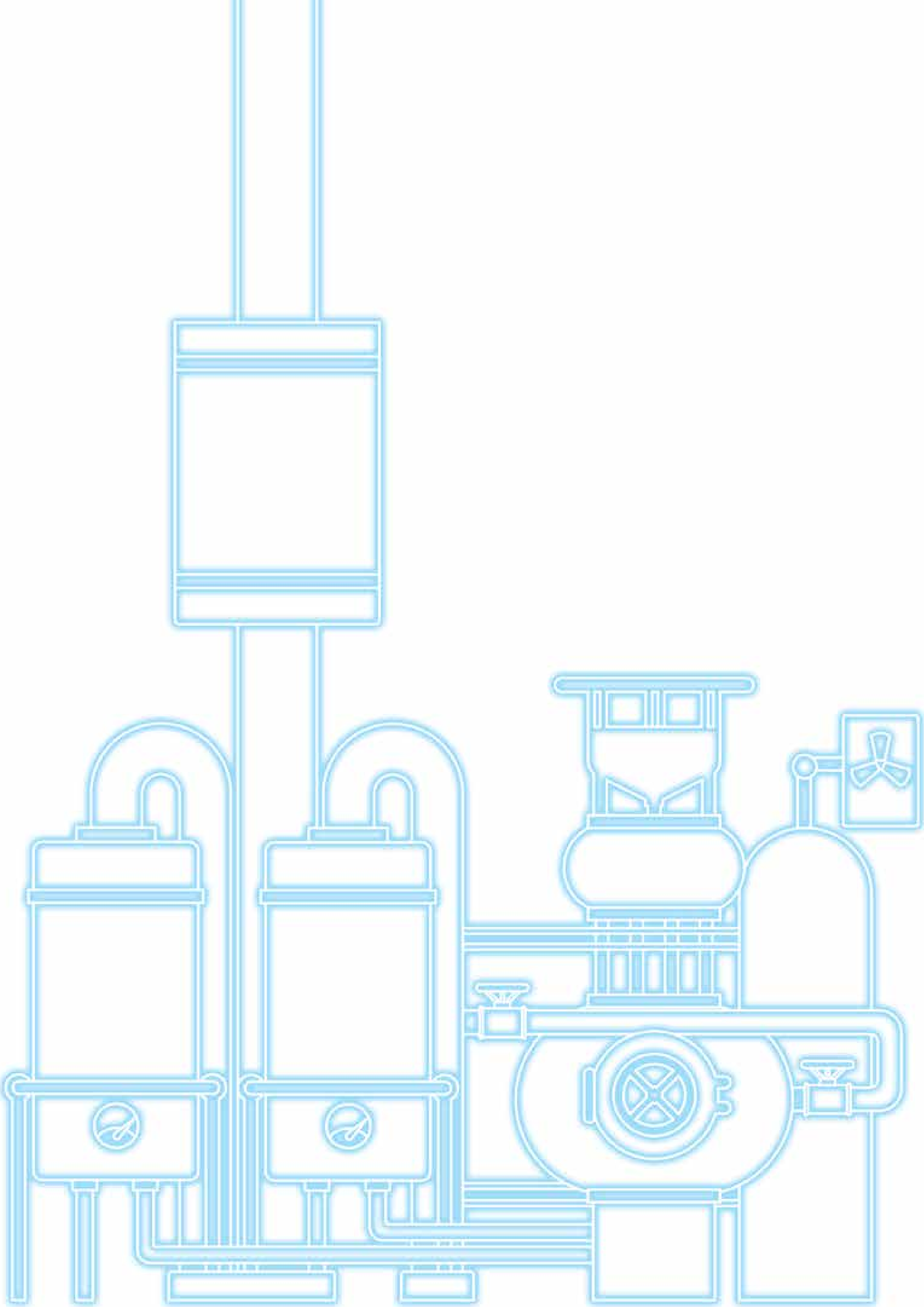
ABBREVIATIONS

AAU	Aalborg University
ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
CHP	Combined heat and power
CSP	Concentrated solar power
°C	Degree Celsius
CO$_2$	Carbon dioxide
CoP	Coefficient of performance
DHC	District heating and cooling
DHW	Domestic hot water
EBRD	European Bank for Reconstruction and Development
EJ	Exajoule
ESCO	Energy service company
EU	European Union
EUR	Euro
GHG	Greenhouse gas
GIS	Geographical information system
GJ	Gigajoule
GWh	Gigawatt-hour
HFC	Hydrofluorocarbon
hm^3	Cubic hectometre
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
km	Kilometre
km^2	Square kilometre
kW	Kilowatt
m^2	Square metre
m^3	Cubic metre
mm	Millimetre
MTES	Mine Thermal Energy Storage
MW	Megawatt
MWh	Megawatt-hour
O&M	Operation and maintenance
PETA	Pan European Thermal Atlas
PPP	Public-private partnership
PTES	Pit Thermal Energy Storage
ReDEWeB	Renewable District Energy in the Western Balkans
REN21	Renewable Energy Policy Network for the 21st Century
SEP	Strategic energy planning
SHCP	Strategic heating and cooling planning
SITG	Portal of the territorial information system (Geneva)
TES	Thermal energy storage
THERMOS	Thermal Energy Resource Modelling and Optimisation System
TRV	Thermostatic radiator valve
TWh	Terawatt-hour
USD	US dollar



EXECUTIVE SUMMARY

Reducing the heating and cooling sector's emissions is critical to mitigating against changes in climate and reducing air pollution. In this regard, district heating and cooling systems can assist in scaling up renewable energy use, increasing energy efficiency, decreasing the utilisation of fossil fuels in the heating and cooling sector, and improving urban area air quality.

Traditionally, district heating systems have been built to run at high temperatures to satisfy high heat demands from poorly insulated buildings. Achieving the high temperatures required in most cases necessitates the use of fossil fuels. However, technology innovation, digitalisation and current trends towards more energy-efficient buildings may enable the broader deployment of clean energy technologies such as low-temperature geothermal, solar thermal and energy from water bodies as well as low-temperature waste heat sources in the new generation of district energy systems. These sources are widely available at the local level in many regions. Still, they remain largely untapped because they are not immediately compatible with current district energy infrastructure and existing building stock.

The utilisation of low-temperature renewable energy sources and sustainable waste heat in district energy systems is often hampered by barriers, including the following:

- lack of data
- insufficient knowledge and awareness about the best available technologies
- disconnection with building renovation strategies
- unfair competition with individual fossil-based heating systems or electric cooling systems
- high upfront costs
- budgetary constraints at the municipal level
- inadequate regulation and lengthy authorisation procedures.

Given this background, this guidebook provides guidelines for policy makers and examples of available tools and solutions to facilitate the use of low-temperature renewable heat sources in new and existing district energy systems. An overview of applications for district heating and cooling and enabling technologies utilising low-temperature renewable energy is also presented. The guidebook focuses on energy systems utilising solar thermal, geothermal and energy in water bodies, which occur at low temperatures, as well as systems supported by heat pumps. Biomass, which represents the dominant renewable energy source in district heating, does not present major technical integration challenges with existing infrastructure running at high temperatures. Therefore, the integration of biomass into district heating will not be the focus of this report.

The key recommendations are the following:

Develop strategic heating and cooling plans based on clear political drivers and identify the main stakeholders to engage in the process. This process could be led by local authorities, but it requires key support from national governments to provide ambitious targets and an enabling framework.

- At the national level, provide proper governance and regulatory frameworks, and set the direction for the implementation of the entire energy system and the role of district energy in decarbonisation and sustainable development.
- Upgrade the required skills of the workforce, including those involved in individual renewable energy technologies and, in some markets, the modernisation of district energy infrastructure.
- Develop local strategic heating and cooling plans and determine which stakeholders will be involved and on what grounds, and how to engage them in the process.
- Facilitate the public acceptance of the transition to a low-carbon heating and cooling sector and the implementation of renewable-based district energy projects. This can be achieved by including citizens, practicing transparency and raising awareness about the merits of district energy systems and renewable technologies.

Elaborate technical scenarios based on the demand for heating and cooling and mapping of resources.

- Improve the collection of data on heating and cooling demand by making actual measurements at the building level or using existing tools to make demand estimates through top-down or bottom-up modelling.
- Assess the available heat resources for utilisation in the heating and cooling of buildings by using existing tools such as geographical information systems or by developing heat atlases. The information generated by the use of these tools could be used to support planning and investment in district energy systems.
- Ensure that the scenarios advanced for heating and cooling development are in line with long-term targets.

Integrate change of supply, modernisation of the network and building renovation plans to achieve an optimum performance level (both technical and socio economic) and avoid lock-in effects and disconnections.

- Align the development of district energy and energy efficiency in buildings and create synergies between them. For example, design neighbourhood schemes in which energy efficiency measures are implemented at the demand and supply sides simultaneously. Encourage more energy-efficient practices by moving to consumption-based billing for all consumers.
- Implement measures to decrease the operating temperatures both for systems already in operation and new district heating networks in existing neighbourhoods. This can be done i) at the building level by introducing control systems, redesigning heating equipment, retrofitting with energy efficient building envelopes, redesigning domestic hot water preparation systems and substations, etc.; and ii) at the network level by insulating pipes, incorporating temperature-boosting technologies, instituting measures to lower return temperatures, and avoiding higher flow rates that could damage the network, etc.

Promote the utilisation of locally available renewable energy sources for heating and cooling by addressing intrinsic challenges.

- Build capacity to develop sound renewable energy projects and address technical challenges for integrating and operating low-temperature sources in new or existing district energy systems.
- Ensure adherence to best practices for the operation of local renewable energy sources. These best practices result in the most cost-efficient and sustainable utilisation of resources, *e.g.*, reinjection for geothermal energy or seasonal thermal storage for solar thermal.

Ensure enabling regulatory conditions, supportive financing options and business models are put in place.

- Consider district energy grids as public infrastructure and ensure a level playing field through fiscal levers, legislation and price regulation, but also consider externalities such as greenhouse gas emissions or air pollutants.

- Overcome uncertainty associated with demand for heating and cooling to attract investment by first connecting high-demand consumers – while making sure the full potential can be exploited.
- In addition to public finance, including grants, explore the involvement of the private sector and innovative practices such as partnerships with energy service companies (ESCOs) or crowdfunding.
- Develop schemes to de-risk renewable-based applications. For example, promote support schemes for geothermal energy which are tailored to the market maturity and that reduce investors' risk of drilling unproductive wells and/or declining well productivity.
- Set up a comprehensive and transparent governance scheme through ownership, regulation and pricing that promotes district heating and cooling systems. The systems should be based on renewables and waste heat sources and align with societal goals.


Figure ES1. **Schematic framework for enabling the integration of low-temperature sources into district energy system**

INTRODUCTION

Air pollution, energy poverty, health risks, cost dependency on fluctuating hydrocarbon markets and climate change: these are just some of the challenges associated with the current fossil-based energy systems used in cities, and rapid urbanisation could cause further increases in all of them.

Heating is the largest form of energy utilisation globally, comprising over half of the final energy demand. Heating of buildings and generating hot water for domestic use account for about half of total heat produced (IEA, 2019a). The vast majority of this energy is produced from the combustion of fossil fuels, making the building sector an important contributor to greenhouse gas (GHG) emissions, air pollution and related health effects, which are major concerns to many cities around the world. On the cooling side, demand for cooling is growing rapidly worldwide. Demand for space cooling is generally high in warm climates in emerging countries *e.g.* in Southeast Asia, Africa, India and China. Heating and cooling are therefore sectors requiring urgent action. This is especially true for cities. About half (55%) of the people in the world today reside in urban areas, a trend that is forecast to rise to 68% by 2050 (UN, 2019).

The good news is that the sector can be decarbonised. The potential for additional energy efficiency in buildings and change to renewable and sustainable energy sources at the supply level is high. District energy systems can increase renewables usage, enhance energy efficiency, avert energy poverty, reduce the quantity of fossil fuel utilised and reduce CO_2 and hydrofluorocarbons (HFCs) emissions from the heating and cooling sector. By doing so, they contribute to making the heating and cooling sector compliant with emission reduction targets set by the Paris agreement (UN, 2015) and the Kigali Amendment to the Montreal Protocol (UN, 2016) in the heating and cooling sector in high density (urban) areas.

District heating systems have already enabled high energy efficiency in some regions. In Scandinavia, aggregating heat loads are allowed to progressively optimise the energy supply. This is achieved through combined heat and power (CHP) and/or the use of industrial waste heat (Galindo Fernández *et al.*, 2016). However, considerable effort is needed to lower district heating's carbon intensity. Despite bioenergy and (high and medium temperature) geothermal resources playing an important role in providing heating and cooling in some regions, renewable energy's overall share in district heating globally is marginal. In 2018, renewables' share of energy used in district heating was less than 8% (IEA, 2019b).

Expanding the use of renewable energy or sustainable waste heat sources through district heating and cooling (DHC) has the potential to make a substantial contribution to the Sustainable Development Goals[1] (UN, 2015) adopted by the United Nations (UN) in 2015, including through reduction of air pollution, increased access to cleaner and affordable energy technology, local job creation, and development of sustainable infrastructure as well as reduced GHG emissions (Figure 1).

Technology innovation and current trends towards more energy efficient buildings and the development of a new generation of district energy networks may enable the wider deployment of low-temperature renewable energy sources such as geothermal and solar thermal as well as waste heat from industrial (or commercial) sources. These sources are more widely available at the local level in many regions but remain largely untapped as they are not perceived as compatible with district energy infrastructure and most of the existing building stock.

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[1] The 2030 United Nations Sustainable Development Goals are 17 goals to achieve a better, more sustainable and inclusive future by addressing the global challenges related to poverty, inequality, climate change, environmental degradation, peace and justice.

Figure 1. **District energy systems using renewable energy sources contribute to the Sustainable Development Goals**

Reducing air pollution and related diseases	Increases access to cleaner technologies	Driving cities along a path of green growth	Acting as an evolutive backbone towards sustainable infrastructure	Contributing to resource-efficient and resilient cities	Contributing to decarbonisation of heating and cooling

The transition towards renewable-based district energy and smart energy systems that integrate smart electric, thermal and gas grids requires enabling frameworks, including innovative planning practices and support tools, to develop bankable projects compatible with a decarbonised energy system.

To this end, this guidebook aims to increase policy makers' knowledge about best practices and available options to address key challenges for incorporating renewable energy and sustainable waste heat resources occurring at low temperatures into DHC systems. This study is developed in the framework of the Energy Solutions for Cities of the Future project and implemented through a project collaboration between the International Renewable Energy Agency (IRENA) and Aalborg University (AAU) under the umbrella of the Global Geothermal Alliance.[2]

> "Energy efficient buildings and a new generation of district energy networks could use district heat from low-temperature renewable sources"

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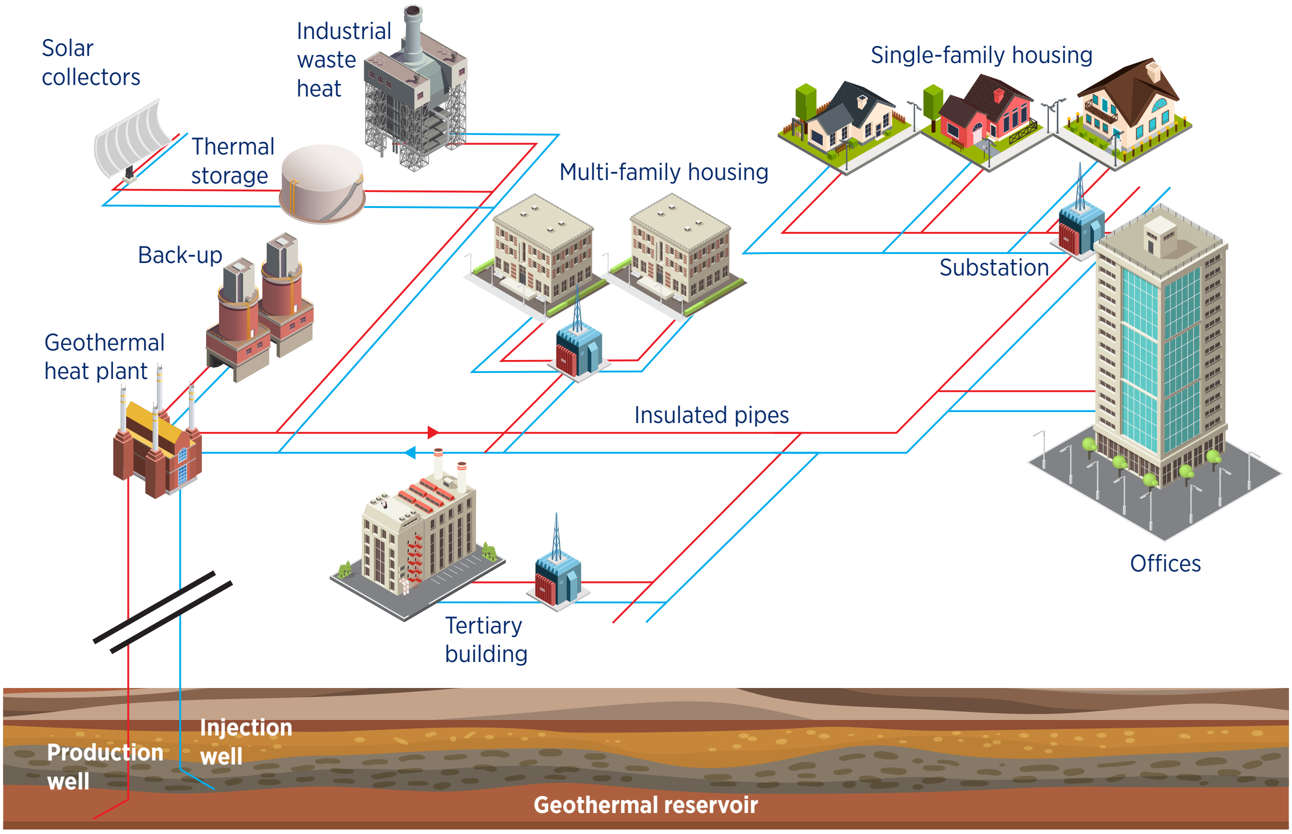
[2] www.globalgeothermalalliance.org/

Figure 2. **Schematic diagram of a district heating system using multiple energy sources**



Note: These are only examples of possible energy sources for a district heating network.

Scope and rationale

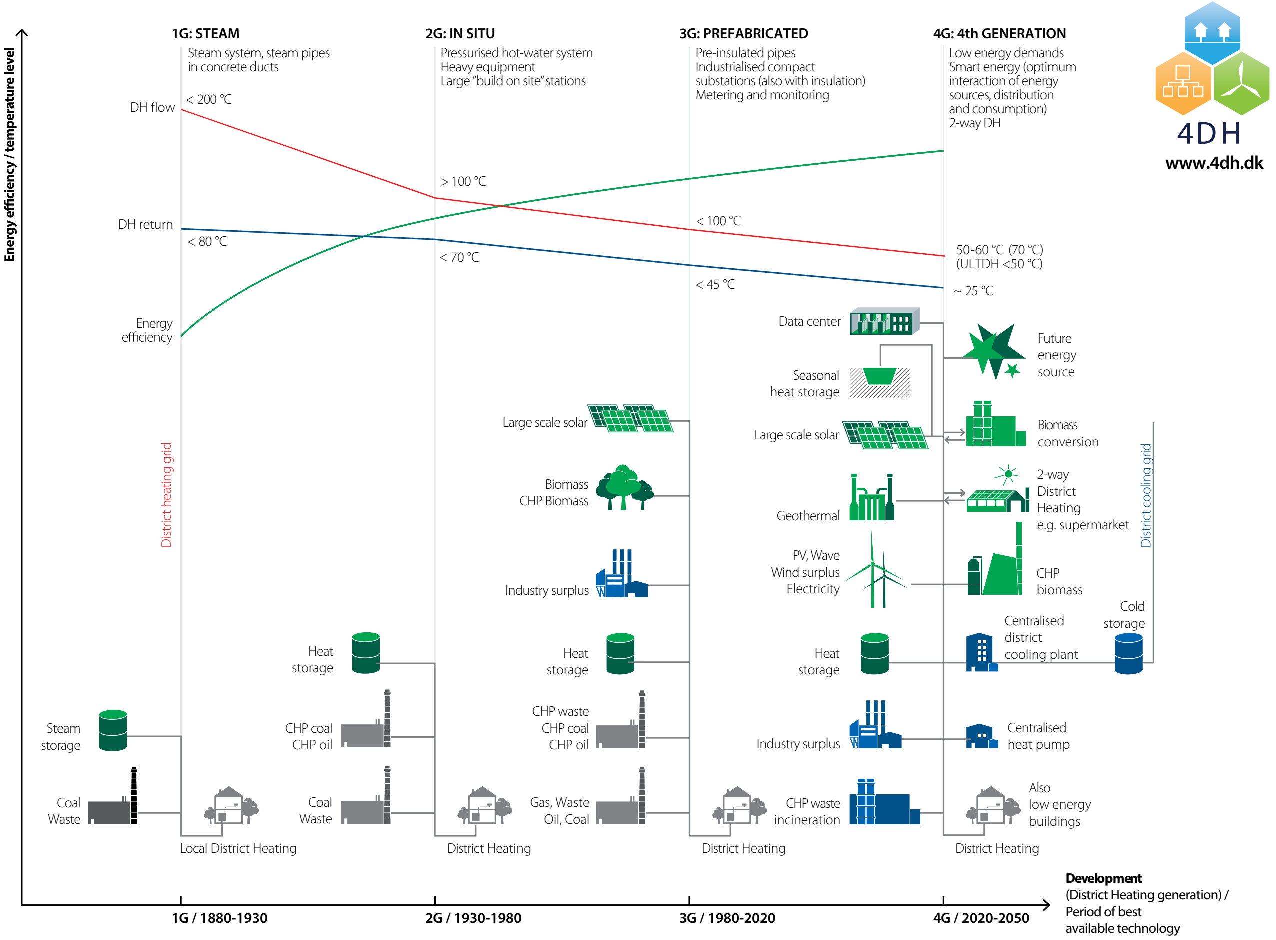
District heating, or heat networks, is a heat distributing system. Heat is generated in one (or several) central (or decentralised) location(s) and transported through a network of insulated transmission and distribution pipes and auxiliary equipment. This system meets the requirements of space heating and domestic hot water (DHW) for residential and tertiary buildings. Figure 2 illustrates an example of decentralised district heating system using multiple energy sources and technologies: solar thermal, moderate geothermal resources, industrial waste heat, back-up boiler and seasonal storage. Other technologies could be used such as cogeneration, heat pumps and waste heat from the service sector.

District cooling can be seen as a reverse heat network that functions on largely similar principles to those of district heating. District cooling distributes chilled water to residential and commercial buildings, offices, and factories.

A key advantage of district energy networks is that they make use of heat and cold sources that would be unsuitable for use in stand-alone heating systems. District energy networks can access energy for heating and cooling from boilers, CHP, heat pumps, seasonal storage or renewable sources such as geothermal or solar thermal energy. This results in improved generation efficiency of district energy and facilitates the utilisation of waste heat from industries or from the service sector.

Smart energy systems can enable the development of 100% renewable energy systems more efficiently. The main principle behind these systems is the integration of the electrical, thermal and gas grids to achieve co-benefits among the sectors and utilise cost-efficient storage solutions (H. Lund *et al.*, 2017). To achieve smart energy systems, all the energy-related sectors including electricity, heating, industry and transport are considered to be part of the energy system and are integrated to take advantage of existing synergies among them. District energy systems are an essential link in such smart energy systems (Mathiesen *et al.*, 2019).

Figure 3. **Evolution of district energy technologies, their operating temperatures and examples of energy sources**



Note: 1G: First generation district heating; 2G: Second generation district heating; 3G: Third generation district heating; 4G: Fourth generation district heating. CHP: Combined heat and power

Source: Lund *et. al* (2018)

As shown in Figure 3 the development of subsequent DHC technologies has resulted in improved efficiency and the use of lower supply temperature. First generation district heating systems were characterised by high temperature supply from steam, second generation systems utilised hot water under pressure, while third and fourth generation systems operate with lower and lower distribution temperatures. This trends pave the way for better utilisation of renewable and recycled low-temperature heat. For example, in second generation system, only high-temperature geothermal energy could be used, while in the third generation, low-temperature geothermal energy can be used, and ultra-low temperature geothermal energy in fourth generation district heating systems.

For district cooling systems, the technological development is as follows: the first generation used refrigerant as the distribution fluid, and from the second generation onward, water is used as distribution fluid, leading to potentially higher supply temperatures and more available energy sources (Lund *et al.*, 2018). This trend even makes it possible to share the distribution network of district heating and district cooling for those countries with separated heating/cooling supply seasons.

"Low-temperature" does not refer to a specific temperature range in absolute terms but depends on the energy source considered or the set of temperature in the district energy network.

In a given city or district, the different local heat sources available do not allow the same operating temperatures' regimes in district heating networks to be achieved.

Fuels – fossil (like gas) or renewable (like bioenergy) – can reach several hundred degrees and can therefore easily bring a heat carrier to a temperature of 100°C (degrees Celsius). Conversely, such temperatures are harder to achieve from sources such as shallow geothermal energy or unconventional waste heat recovery (from data centre cooling, for example). Solar thermal, industrial waste heat, large-scale heat pumps, etc., occupy many intermediate temperature ranges. The lower the operating temperature of the network, the wider the range of exploitable energy sources, and the more potential for including decarbonised and clean sources.

For the purpose of this guidebook, the term "low-temperature" will refer to the temperature range of the energy sources. Energy sources below 100°C will be considered low-temperature, because they can supply third or fourth generation district energy systems, which are the focus of this guidebook.

The utilisation of DHC systems varies greatly across countries, regions and cities. In some cities district energy systems are inherited from the 19th century, while others have been recently built with state-of-the-art technologies. High implementation rates of district heating can be found in most cities in some regions, such as some northern and eastern European countries, Russian Federation, as well as northern China. There are therefore various types of district heating markets worldwide: new and emerging markets (*e.g.*, the United Kingdom and the Netherlands), traditional district heating markets with older generations of systems (*e.g.*, Eastern Europe, China), and mature and expanding markets. When it comes to district cooling, the market is large and growing rapidly, especially in the region of the Cooperation Council for the Arab States of The Gulf.

However, globally only a small portion of the energy for space heating and cooling is supplied through district energy systems, with the majority being supplied by stand-alone systems at the building level (Werner, 2017). Moreover, existing district heating systems mainly utilise fossil fuels for heat and cold generation, resulting in high carbon emissions. These fossil fuels additionally have particulate-heavy combustion processes, generating air pollution and associated health issues.

DHC systems, in order to fulfil their role in future (renewable) sustainable energy systems, need to:

- utilise low-temperature resources to supply heat and cold in existing, new and renovated buildings
- have low thermal losses in the distribution grid
- integrate renewable heat sources such as solar thermal and geothermal energy as well as low-temperature waste heat
- be one of the components of a smart energy system that integrates variable renewable energy sources and promotes energy efficiency
- be developed taking into account local energy planning, policy schemes and system costs
- contribute to the development of sustainable energy systems of the future (Lund *et al.*, 2018).

The local and fragmented nature of heating and cooling makes the sector complex; hence, effective national policy making is challenging. In addition, this specificity of the heating and cooling sector gives a primary role to local authorities. They have different capacities at their disposal to develop district energy systems: through urban and energy planning, developing appropriate regulation, providing or guaranteeing finances, providing district energy infrastructure and services, and facilitating the connection of district energy to public buildings.

Despite the local nature of district energy planning, it should be co-ordinated starting from the regional and national levels to achieve wider societal goals. This guidebook will, therefore, present best practices and available tools and solutions that local and national governments can apply in different contexts to enable the integration of low-temperature renewable energy sources in new and existing DHC systems, taking into account various local contexts and national frameworks.

The guidebook aims to complement previous reports developed by partners such as the one from the District Energy in Cities Initiative co-ordinated by the United Nations Environment Programme (UNEP, 2015) and others that can be found in the references section. In addition, it aims to share insights and best practices between developed and emerging district heating and cooling markets.

> "District energy planning is local in nature but requires co-ordination with regional and national levels on wider societal goals"

Methodology

This study is based on:

- a literature review, including previous IRENA and AAU studies about district energy and future energy systems
- a selection of case studies of district energy projects and systems in medium-sized cities (population 30 000 to 1 million) that are the focus of the Energy Solutions for Cities of the Future project
- a consultation process with an advisory group of experts from governments, industry, academia, intergovernmental organisations and multilateral development banks.

These methods were used to identify in the most comprehensive and concrete way possible how to overcome the challenges and provide possible solutions for integrating low-temperature renewable energy in DHC.

The diversity of institutional layers in the energy sector and the varying distribution of competences among the national, regional and local levels from one country to another delimits the level of detail that can be reached in global guidelines developed within this guidebook. However, certain general challenges regarding the properties of low-temperature renewable sources and district energy technology can be derived. These have been grouped and addressed according to key topics.

The guidebook is structured as shown in Figure 4.

Part A of the guidebook "Overview of the heating and cooling sector" is divided into two sections. Part A, Section 1 aims to explain the challenges facing the heating and cooling sector worldwide and how modern DHC networks with low-temperature renewable and waste heat sources can play a key role in the transition towards renewable energy systems.

Part A, Section 2 provides an overview of renewable energy applications for DHC and enabling technologies.

Part B "Guidelines for policy makers on low-temperature district energy systems" is divided into six sections.
Part B, Section 1 proposes a model for a strategic heating and cooling planning approach as a first step to increase the share of renewable energy in DHC systems.

Part B, Section 2 details good practices to engage stakeholders in the strategic heating and cooling planning process and in the development of DHC projects.

Part B, Section 3 describes the challenges, options and tools available at the national, regional and local levels to assess heating and cooling demand, map and quantify energy resources and establish technical scenarios for a sustainable heat supply including low-temperature energy sources in DHC.

Part B, Section 4 describes the main technical challenges when integrating low-temperature supply into existing buildings and district networks.

Part B, Section 5 highlights options to overcome some of the main challenges to the integration and operation of geothermal, solar thermal and waste heat in DHC.

Lastly, Part B, Section 6 explores the different options for regulation and pricing, as well as financing and business models for DHC systems.

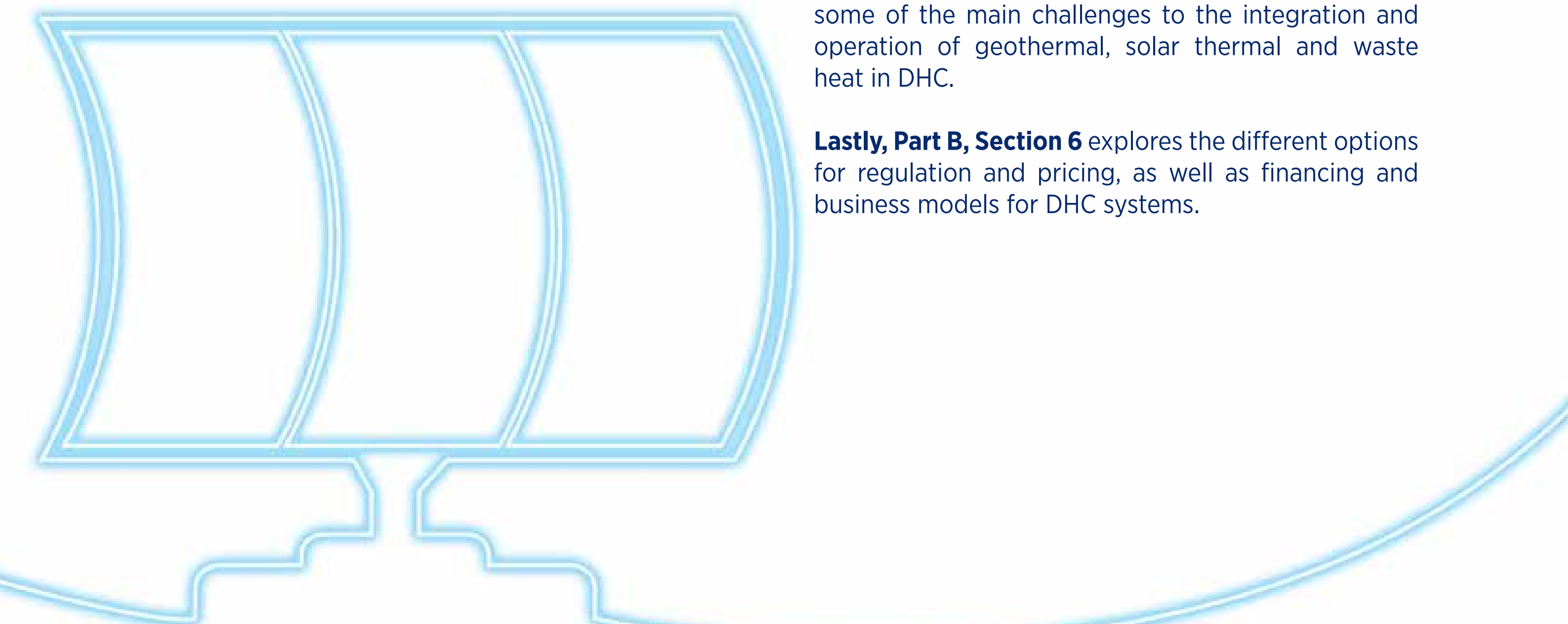
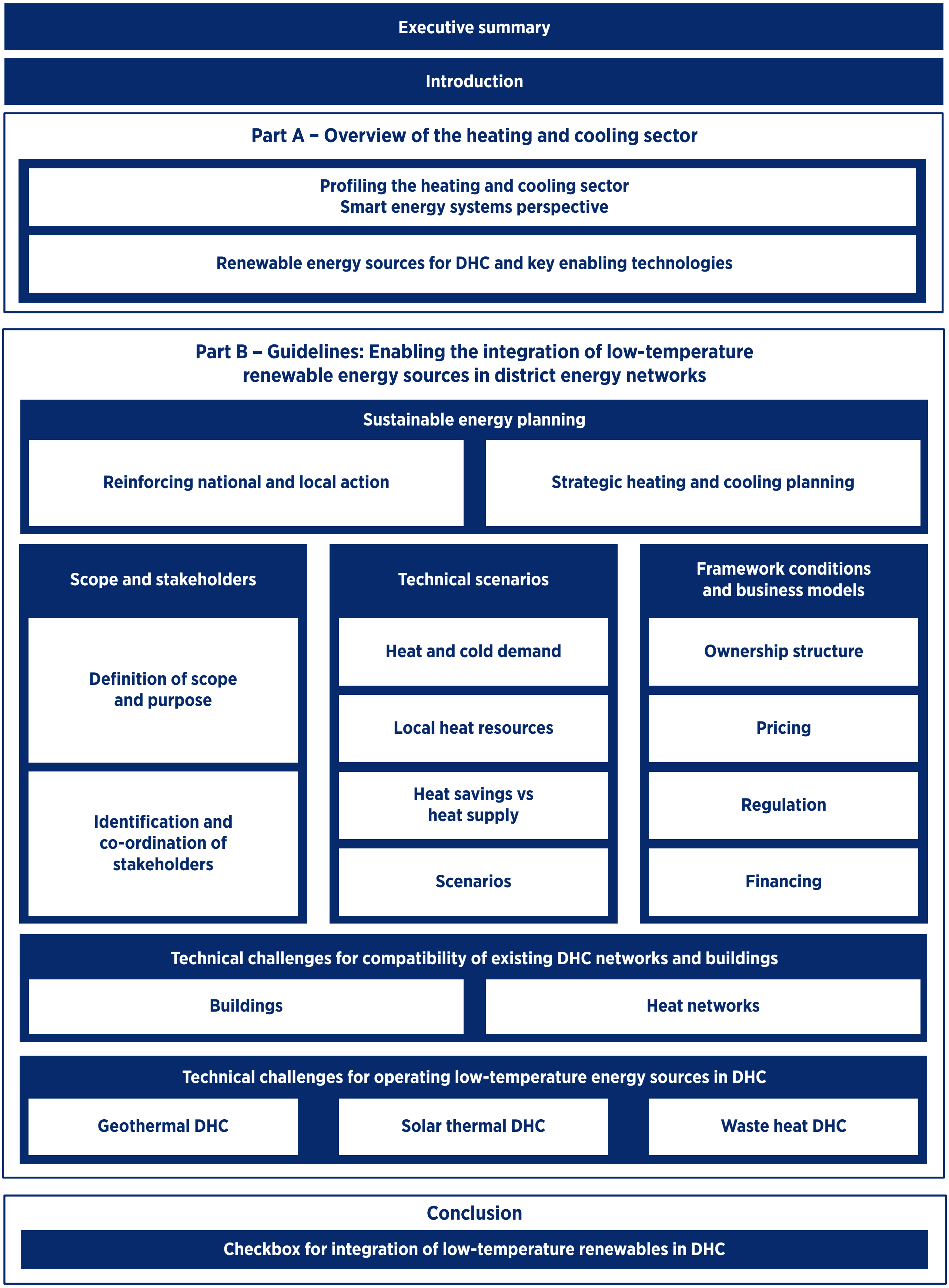


Figure 4. **The structure of the guidebook**



PART A:

OVERVIEW OF THE HEATING AND COOLING SECTOR

This part provides an overview of the status of the heating and cooling sector, which is predominantly fossil fuel-based, resulting in air pollution and emission of GHGs. The factors influencing the transformation of the current energy systems towards sustainability will be discussed and the vision for the energy systems of the future highlighted. The transformation of the energy systems will be supported by the utilisation of locally available renewable energy (and waste heat) sources in conjunction with existing technologies.

A.1 Towards a decarbonised heating and cooling sector: Unlocking the potential of energy efficiency, district energy systems and renewable energy

As presented in the introduction, the heating and cooling sector is both significant and reliant on fossil fuels. However, there is large potential to decarbonise the sector. Multiple avenues are possible to decarbonise the heating and cooling supply systems. This could be achieved by various routes and comprise a combination of applied measures, not only on the demand side (by reducing the demand in buildings through retrofitting and optimisation of technical building systems, for instance) but also on the supply side.

One way is by transitioning from stand-alone heat and cold supply systems based on fossil fuels or inefficient electric heaters and air conditioning units to DHC systems in urban areas. This increases energy efficiency and the use of renewables or waste heat while decreasing the use of fossil fuels in the heating and cooling sector.

The role of local authorities in steering the energy transition is growing over time. According to the UN, worldwide urbanisation levels are expected to reach about two-thirds of the population by 2050 (UN, 2019). This level of urbanisation is critical because cities were responsible for 60-80% of worldwide energy demand and 70% of anthropogenic carbon emissions in 2018 (UN Habitat, 2019). In addition, production of energy for supplies of DHW and space heating and cooling through both district energy systems and stand-alone energy systems using fossil fuels contributes to high localised pollution during periods of high heating demand, as is the case in cities such as Ulaanbaatar, Mongolia (see Photograph 1) (World Health Organisation, 2019).

Because so much energy use happens at the city or municipality level, local policy makers can exercise their authority to make an enormous impact. They may, for example, promote renewables uptake in built-up environments and adopt efficient, centralised district systems that can use renewable energy and store heat for later use (IRENA, 2019b).

To create better comprehension of the role of renewable DHC systems in the decarbonisation of the energy system, this part of the guidebook briefly describes the state-of-the-art knowledge about the heating and cooling sector worldwide. An overview of energy efficiency potential with improved energy performance on the customer side and a redesign of the supply system using the development potential of the new generation of DHC systems using low-temperature energy sources is then provided.

Photograph 1. **Air pollution in Mongolia**

Source: Shutterstock

A.1.1 The urgent need to address heating and cooling

The local and temporal nature of thermal demands and resources make analysis of the heat and cold supply complex. In addition, conventional energy balances and available statistics and data on final energy demand do not provide detailed information on end uses such as heating and cooling. The lack of data and methods for spatial and temporal analysis creates a disadvantage for the development of DHC technology compared to other systems. Consequently, these technologies remain largely untapped and overlooked in decarbonisation plans.

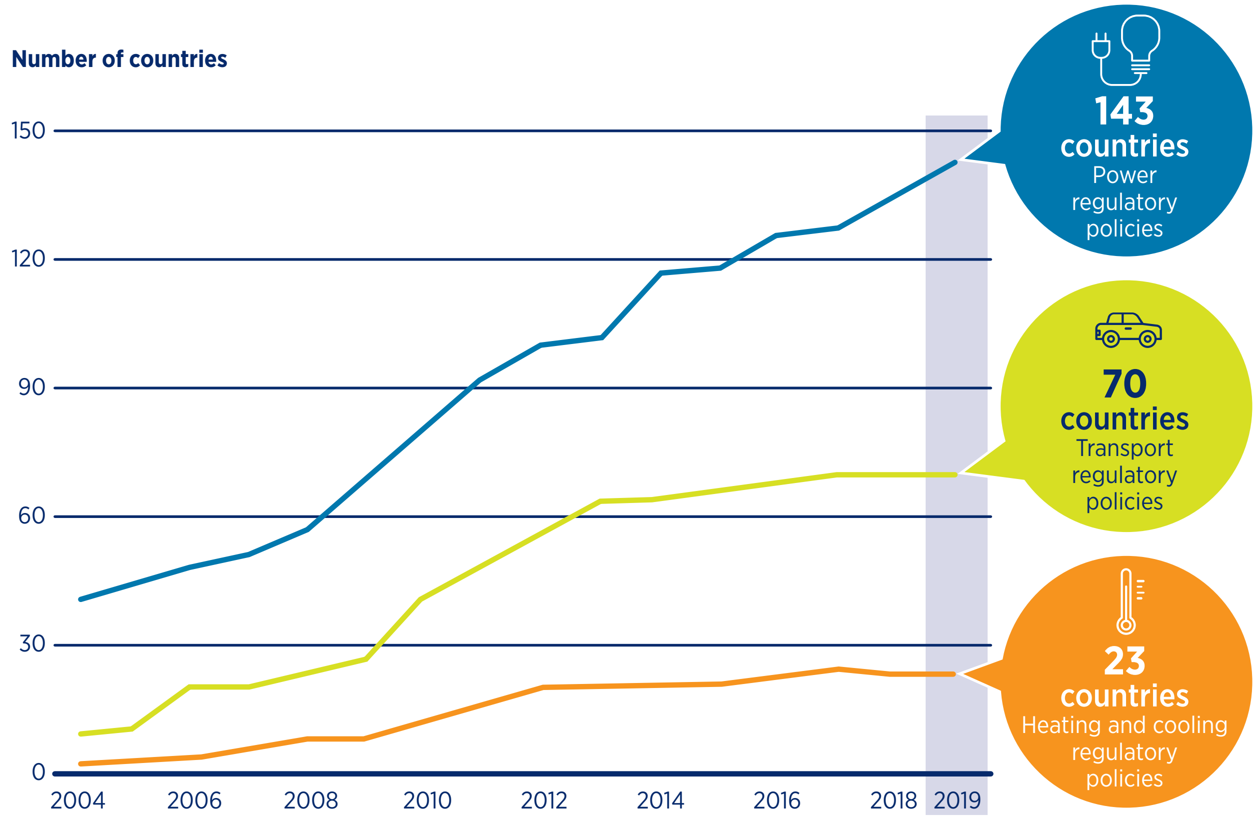
This is further illustrated by the fact that the majority of nationally determined contributions focus on renewable energy targets for power generation only, as shown in Figure 5. In recent years, a lack of supportive policies to encourage the uptake of renewable energy for heat and cold supply in both buildings and industries has resulted in fewer countries implementing regulatory incentives or mandating renewable heating and cooling in comparison to the countries with a power regulatory policy (REN21, 2020).

However, to reach the desired carbon emission reductions, substantial decreases in carbon dioxide (CO_2) emissions will be required in the heating and cooling of buildings and industry (IRENA, 2017c). IRENA (2017b) noted that a CO_2 reduction of -73% compared to a business-as-usual scenario will be required to align with the Paris Agreement.

Building on the 2018 report Renewable energy policies in a time of transition (IRENA, IEA and REN21, 2018), IRENA, the International Energy Agency (IEA) and Renewable Energy Policy Network for the 21st Century (REN21) have jointly developed the second edition of the publication *Renewable energy policies in a time of transition: Heating and cooling*. (IRENA, IEA and REN21, 2020. This study aims to support policy makers in the transition of heating and cooling towards renewables and maximise the socio-economic benefits.

This study highlights country experiences and best practices and provides a comprehensive policy framework to overcome the main challenges to the deployment of renewable heating and cooling to help countries advance the decarbonisation and sustainable development of this end use.

Figure 5. **Number of renewable energy regulatory incentives and mandates, by type, 2014-19**



Source: REN21 (2020)

It also highlights some key recommendations for policy makers to minimise the carbon intensity of the heating and cooling sector, including:

- Combining the electrification of heating and cooling with the deployment of renewable power generation to provide cost-competitive renewable sources of energy. Heat pumps and other efficient electrical appliances can improve system flexibility and facilitate integration of higher shares of variable renewable energy with the support of minimum performance standards and quality assurance policies. To this end, power market reforms, tariff redesign and infrastructure upgrades are necessary.

- Reducing the risk of geothermal exploration to accelerate the direct use of geothermal heat. Supporting policies include a geothermal resources data-sharing platform, exploration risk insurance and loan guarantees or grants for well-drilling.

- Improving the energy efficiency of distribution networks to enable the integration of low-temperature solar thermal, geothermal and other renewable-based heats into existing networks.

Previous studies – Connolly *et al.* (2012, 2015), Connolly *et al.* (2013a), Xiong *et al.* (2015), Paardekooper *et al.* (2018, 2020) – have shown that considering the energy efficiency potential of the heating and cooling sector through not only energy savings and efficient and renewable individual technologies, but also through the increased deployment of DHC systems, allows for faster and cost-effective decarbonisation of the energy system.

There is, therefore, a need to look in more detail at the "black box" of the heat and cold supply and demand for the building and industrial sector, and to develop the techniques that allow for modelling of thermal requirements for these sectors, to enable the quantification of the role district energy can play in the energy transition.

Thermal energy demand and energy efficiency in buildings

The energy used by buildings makes up a significant share of most countries' energy consumption. In the effort to transform national energy systems into sustainable energy systems for the future, as well as to reduce CO_2 emissions from fossil-based fuels, the development of energy-efficient building has a key role to play.

Improvements in the thermal energy performance – final energy demand per square metre (m^2) – within buildings since 2000 indicate that new buildings are becoming more efficient while old buildings are being refurbished. However, there has been no decrease in the total energy thermal energy usage since 2010. The lack of a downward trend has been attributed to an increase in developing countries' access to energy and an almost 3% per year growth in the floor area of global buildings (Global Alliance for Buildings and Construction, IEA and UNEP, 2018).

Cooling has on the contrary experienced robust growth in the last two decades. The demand for space cooling has doubled since 2000 and accounts for at least half of residential peak electricity demand. Beijing experienced this trend in the summer of 2017, when a heatwave caused daily peaks (IEA, 2018). Despite this significant growth, cooling still represents less than 6% of the energy use in buildings on average worldwide, even if it varies considerably from one region to another. However, there are factors that make cooling in general, and space cooling in particular, a noteworthy subject with respect to efficiency gains. The economic growth of countries with warmer climates can enable access to increased thermal comfort with space cooling. In addition, the warming climate and the heat island effect in urban areas increase the need for space cooling. The coming years will see an increased demand for cooling – forecast to more than double between 2015 and 2050 – due to these factors (IEA, 2018), making the energy efficiency of cooling a crucial topic. Moreover, efficient and clean cooling alternatives are key to phasing down HFC emissions as required by the Kigali Amendment to the Montreal Protocol (UN, 2016). District cooling options that incorporate refrigerants with low global warming potential have a crucial role to play for this purpose.

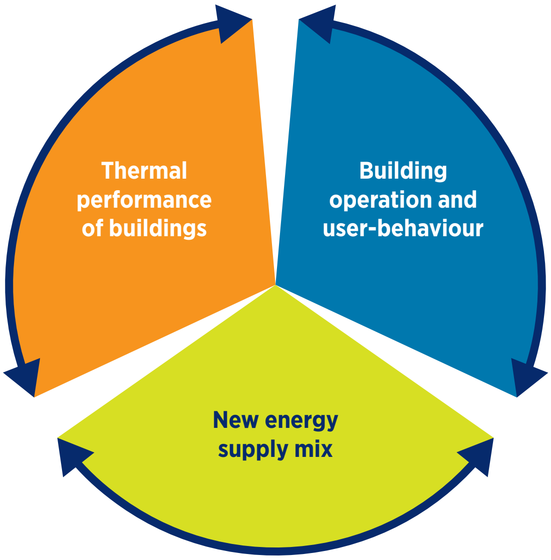
Globally, it is important that building stock is considered to be a long-term investment and infrastructure, since it is material-heavy and has the potential to define energy demand into the coming decades. Building performance and building quality assessment for new buildings are extremely important in rapidly emerging economies. As of 2018, 73 countries were setting energy performance levels for new buildings on either a voluntary or mandatory basis via the institution of building energy codes (Global Alliance for Buildings and Construction, IEA and UNEP, 2019). This, however, does not completely solve the building stock problem. Energy codes are lacking in two-thirds of the countries, and these are the places where the most sizeable future building growth is forecast.

Furthermore, energy demand cannot be reduced to a level sufficient for the energy system transformation by savings and low energy use in new buildings alone. This is because a focus on new buildings detracts from the importance of energy savings and a supply technology switch in existing buildings.

Achieving a sustainable energy system in the building sector requires three elements (Figure 6) (Mathiesen *et al.*, 2016). First, to enable a flexible renewable energy system, the whole stock must achieve greater energy efficiency – especially existing buildings. Second, to realise savings in heat and electricity demands over time, building operation and user behaviour must be optimised. The third is considering supply side options that open up possibilities for integrating renewable energy into the system. To unlock buildings' potential contribution to a renewable energy future, a holistic approach to these three closely intertwined elements is needed (Mathiesen *et al.*, 2016).

It is furthermore crucial to comprehend energy supply side technologies if effective decisions on energy use in buildings are to be taken. District energy has an important function in this area. Because these technological infrastructures are able to supply energy to both existing and new buildings, they can link the thermal and electricity sectors that underlie the Smart Energy System (see Part A, Section 1.2) and provide system flexibility.

Figure 6. **Three perspectives key to the role of buildings in future cost-effective sustainable energy systems**



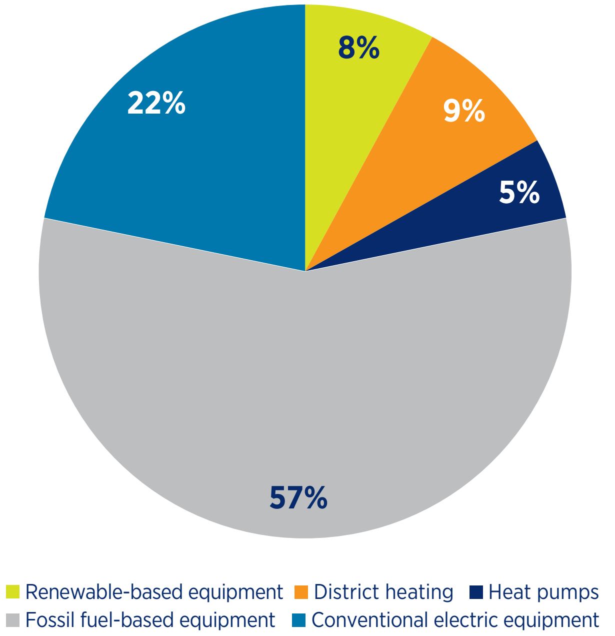
Source: Mathiesen *et al.* (2016)

A sector dominated by fossil-fuelled individual heating and cooling solutions at the building level

Recommendations to save energy and encourage behavioural changes in building operation go hand in hand with supply level recommendations. Technologies – such as large-scale heat pumps for district heating, seasonal heat storage units and ground source heat pumps – along with bioenergy can assist in integrating renewable energy into the energy system in a cost-effective manner.

The estimated share of heating technology sales for residential and service sector buildings during 2019 is presented in Figure 7. This excludes the traditional use of biomass, which still dominates global heat use, because it is used in many developing countries and rural areas. In terms of market share, fossil fuel-based equipment comprises 57% of buildings' total global heating equipment shares, while conventional electric heating equipment makes up 22%, individual heat pumps account for less than 5% and renewable heating equipment (such as solar hot water systems) represents 8%.

Figure 7. **Estimated shares of heating equipment in residential and service sector buildings in the world during 2019 by technology, excluding traditional use of biomass**



Note: Renewable-based equipment includes solar heating, hydrogen-based equipment and modern bioenergy heating.

Based on: IEA data (n.d.)

District heating networks supplied less than 6% of global heat consumption in 2018 (IEA, 2019b). However, there is a large variance from one country to another. North, Central and Eastern Europe, Russian Federation and northern China have a higher share of district heating systems for space heating, with the two latter countries each accounting for more than one-third of the DHC supply.

The variability of district heating shares from one region to another is, in some cases, due to particular climate and weather conditions and the availability of local energy sources. For example, regions with favourable geothermal resources or availability of waste heat from fuel or electricity production or waste incineration are more likely to have DHC systems. However, extensive heat mapping has shown that nearly all urban areas typically have some kind of heat resource available to them – be it renewable or sustainable reuse of heat (Moller *et al.*, 2018). In addition, technologies such as large-scale heat pumps allow for the development of DHC systems that use low-temperature local energy sources, which would otherwise not have been considered. Variances in the level of current district heating development are also driven by urban and energy policies. These policies have determined the heat planning traditions and typologies of urban fabrics conducive to taking advantage of the local conditions to facilitate the development of district heating (and cooling) (Paardekooper *et al.*, 2018). Fossil fuels are DHC's main energy source by a wide margin on a global basis while renewables accounted for less than 8% in 2018 (IEA, 2019b).

Demand for cooling is met mainly by individual solutions, such as air-conditioning split systems. Energy efficient cooling systems, *e.g.* electric-powered chillers, can be realised through district cooling systems (IEA, 2018). However, cold supply through district energy systems is significantly less than heat supply (Werner, 2017). As mentioned in the previous section, a huge increase in future demand for cooling has been estimated (IEA, 2018). The prevalence of district cooling is more strongly driven by climate globally but is in many cases still largely based on familiarity with district energy system planning practices. It is notable that Stockholm, Sweden has one of the largest district cooling systems in Europe, which demonstrates that this technology is viable even in cold climate countries.

A.1.2 Future energy systems and sustainable heating (and cooling) supply

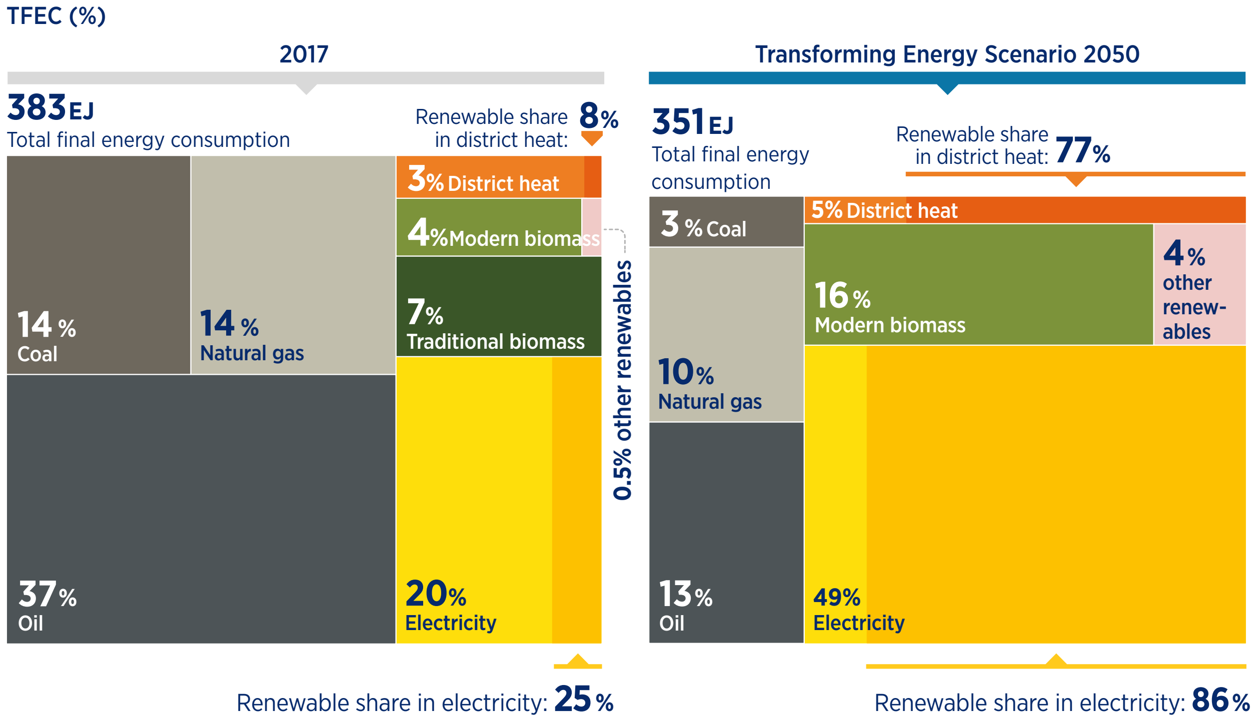
From a centralised energy system to smart energy systems

Despite the fact that most of the DHC systems are still operated on coal and natural gas, district energy networks can enable the integration of low-grade renewable heat sources, including geothermal, waste heat and solar thermal energy. According to IRENA's Transforming Energy Scenario described in the Global Renewables Outlook, the share of renewable energy in district heating could increase from 8% in 2017 to 77% in 2050, as shown in Figure 8. In addition, based on this scenario, 5% of the total final energy consumption could be delivered through DHC systems in 2050, up from 3% in 2017 (IRENA, 2020a). However, some studies at regional levels have shown that higher shares of district heating are cost-effective (see Figure 11).

District energy can be a key contributor to reducing the carbon intensity of the building sector and also help to transition to a smart energy system. Such a system integrates smart electric, thermal and gas grids. Additionally, smart energy systems offer flexibility for variable renewable electricity generation using thermal storage, electric boilers, power-to-gas (*i.e.*, technologies that convert and store electricity to a gas fuel such as hydrogen or methane) and large-scale heat pumps (David Connolly *et al.*, 2013b; Ridjan, 2015; Lund *et al.*, 2016; IRENA, IEA and REN21, 2018; Paardekooper, Lund and Lund, 2018).

Figure 9 depicts the interactions among the smart electric, thermal and gas grids through different conversion technologies and recovery systems. The multitude of connections means that different situations – *e.g.*, high (peak) demands, low wind power production, high solar energy production, and so forth – can activate different production and supply systems.

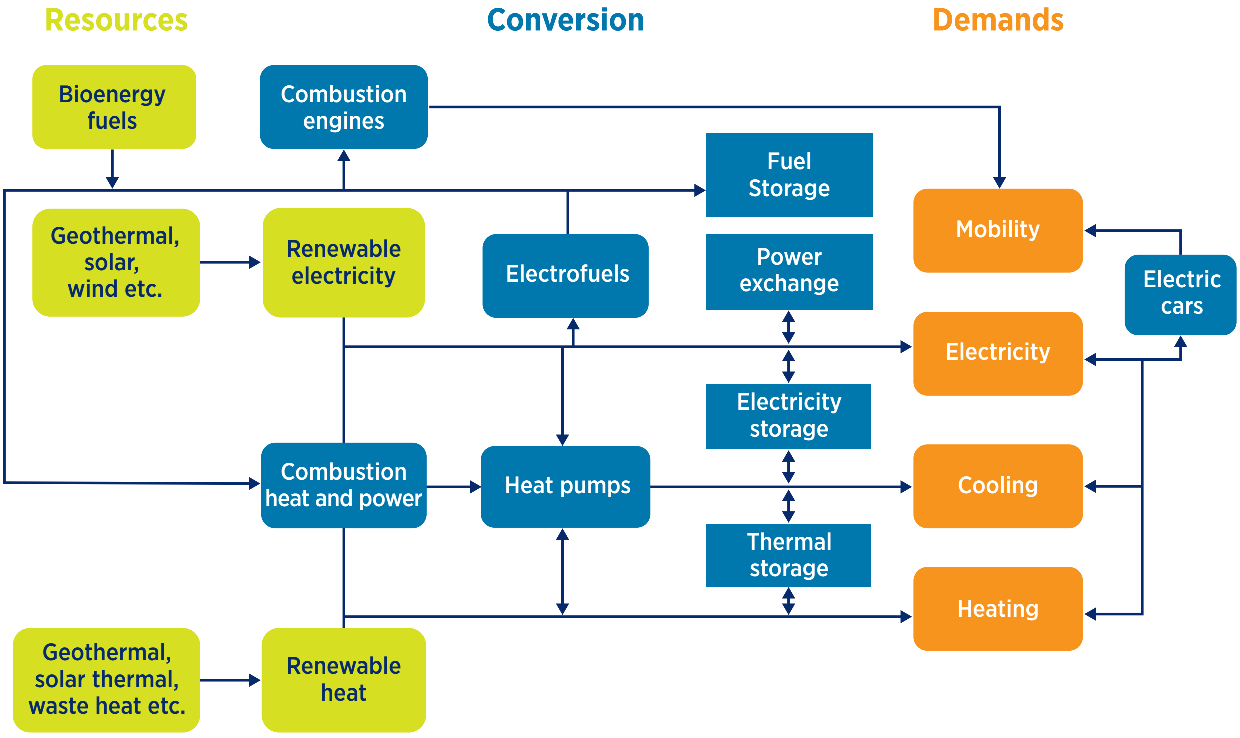
Figure 8. **Breakdown of total final energy consumption by energy carrier in 2017 and in the Transforming Energy Scenario 2050 (EJ)**



Note: EJ = exajoule.

Source: IRENA (2020)

Figure 9. **Interaction between sectors and technologies in a smart energy system**



Based on: Paardekooper *et al.* (2018)

Fourth generation district heating

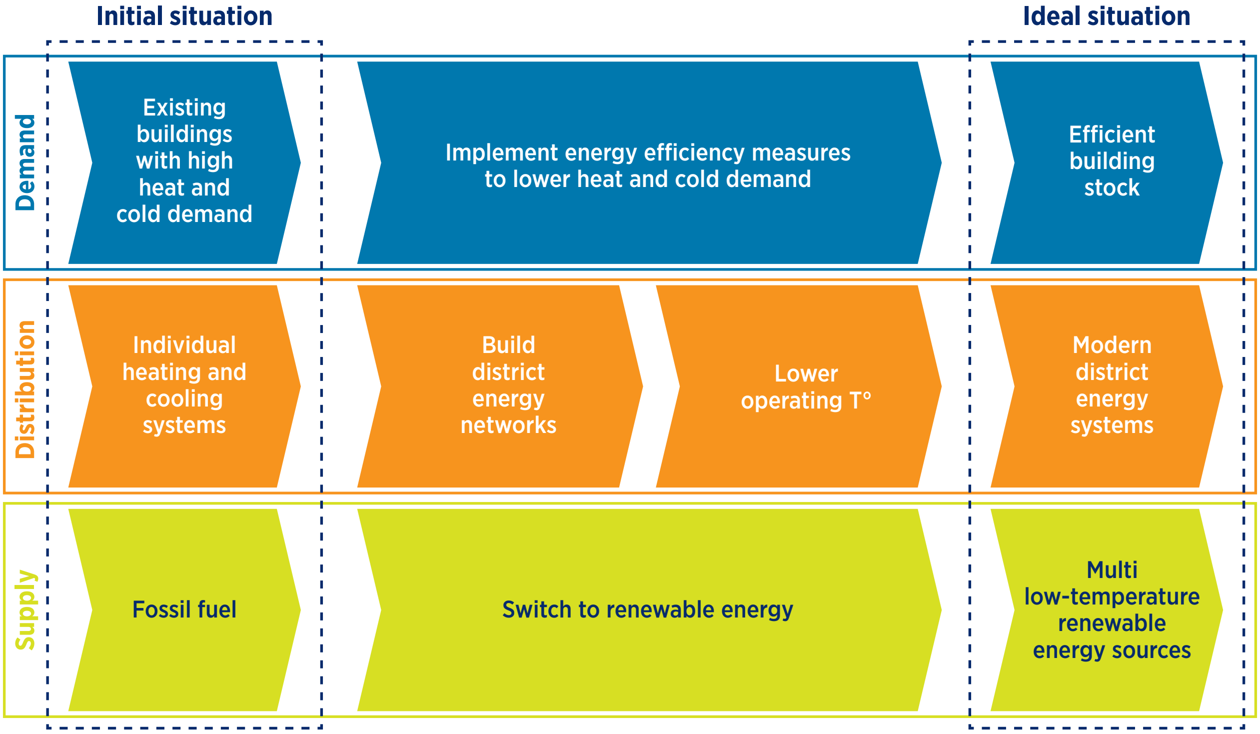
The design of future district energy infrastructures should take into consideration the envisaged smart energy system (described in the previous section). The fourth generation district heating concept describes these future district heating technologies and systems, referencing the three generations that came before (Figure 3) (Lund *et al.*, 2018). Supply temperatures have over time decreased in close association with the system's increasing energy efficiency. This increasing efficiency is in turn due to a decrease in heat loss from the distribution grid and the building stock, as well as the capacity to integrate assorted new heat sources (*e.g.*, renewable energy and waste heat), as shown in Figure 10. The integration of new heat sources indicates reduced CO_2 emissions and greater integration with other energy sectors to improve system flexibility. Energy savings and conservation measures in buildings form an important part in the development of fourth generation district heating systems.

It is to be noted that, even if the fourth-generation system is the ideal situation, low-temperature energy sources can be exploited with third generation systems, mainly through the use of large-scale heat pumps. The most important element is that networks are designed to be operated with hot water instead of steam. For cooling systems, the aim is to use natural refrigerants rather than conventional HFC refrigerants, which are to be phased out according to the Kigali Amendment to the Montreal Protocol (UN, 2016). Modern and medium-large DHC systems will rely on a variety of local and distributed sources, including low-temperature renewable energy and waste heat.

Vast potential to improve with energy savings (in buildings) and with a new sustainable supply system (DHC)

When considering how to decarbonise the heating sector, a central question is how to identify the optimal cost balance between investments in energy savings and investments in energy supply. Traditional methods take a simple marginal cost approach and are mostly focused on building level savings such as renovation and increasing insulation. However, energy savings can be realised along the entire energy system, from generation to transmission and consumption – whatever the scale of the energy system considered (national, regional, city or district level). Energy savings that have a lower marginal cost than that for developing new supply systems should be employed.

Figure 10. **Transition pathway from fossil-based individual heating to fourth generation district heating**



Note: District energy systems can replace most, but not all, individual heating and cooling systems in high density areas (see Part B, Section 6.4).

Hansen (2019) argues that "estimating ex ante (system) costs of the heat supply may be more complex than undertaking simple levelised cost of energy (LCOE) measures"[3] but, in the future energy system, external benefits and energy system synergies make this estimation necessary. It is difficult to estimate the energy savings from, for example, using waste heat from power plants with a simple marginal approach. This mechanism is further exemplified by a district heating system that uses geothermal energy rather than heat pumps at the building level, thereby reducing the need for peak electricity capacity, and the potential production of green gas, depending on weather systems.

These interactions are a result of the complexity and interdependence of the system, and cannot be properly captured in a simplified LCOE assessment without explicit energy system modelling at an appropriate timescale. Here, it is necessary to analyse energy flows across the entire energy system to include the savings across electricity and heating systems.

As an example, Figure 11 shows the viable share of heat savings and district energy systems in the heating market, taking into consideration energy system total costs for the 14 largest European Union (EU) member states, with a combined 90% share of heat requirement in the EU (Mathiesen *et al.*, 2019). It displays aggregated results for and differences among the 14 countries. For example, it is possible for the Czech Republic, Hungary, Poland and Romania all to achieve 25% more in heat savings in comparison to what current energy efficiency policies aim for, while other countries' policies for building performance are already well on track to minimise energy system costs by 2050. For a more detailed perspective, see Paardekooper *et al.* (2018).

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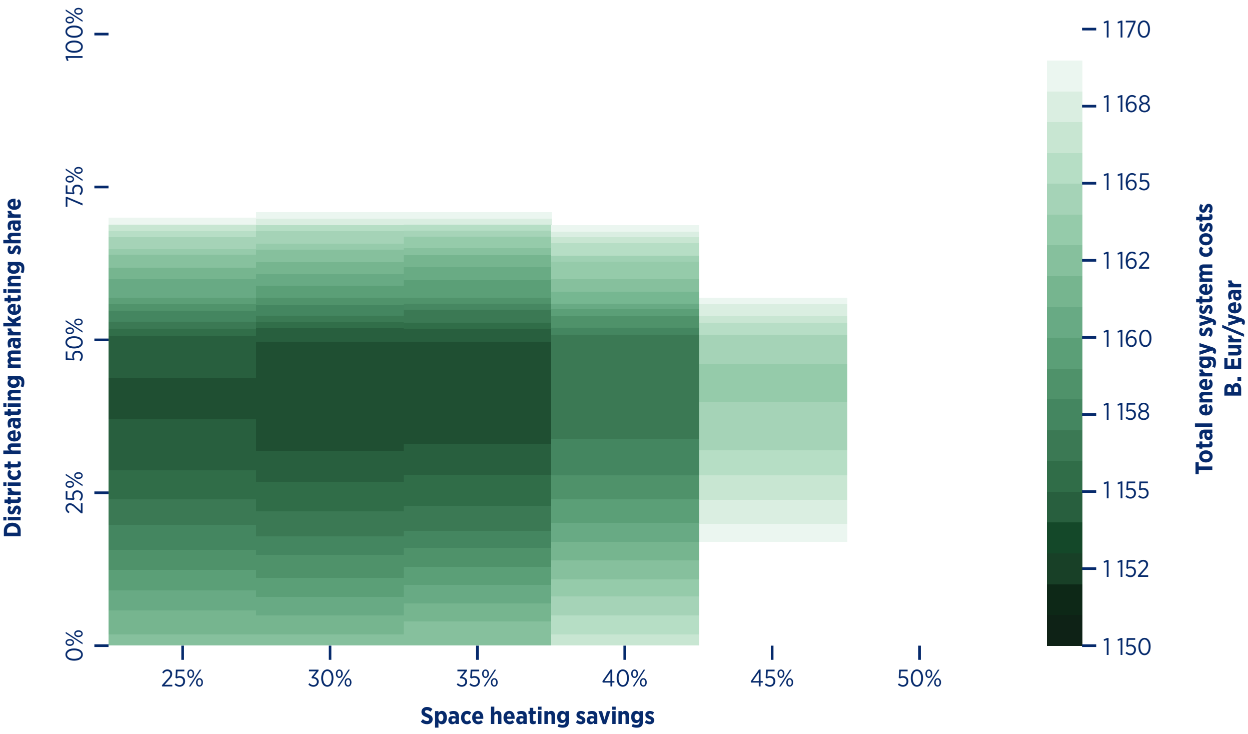
[3] Levelised cost measures lifetime costs of an energy project divided by its energy production.

Figure 11. **District heating and heat savings synergies for total energy system costs in the 14 European countries responsible for 90% of EU heat demand**



HRE14: The 14 largest EU member states in terms of heat demand, totalling 90% of the EU heat demand, studied in the Heat Roadmap Europe project.

Source: Mathiesen *et al.* (2019)

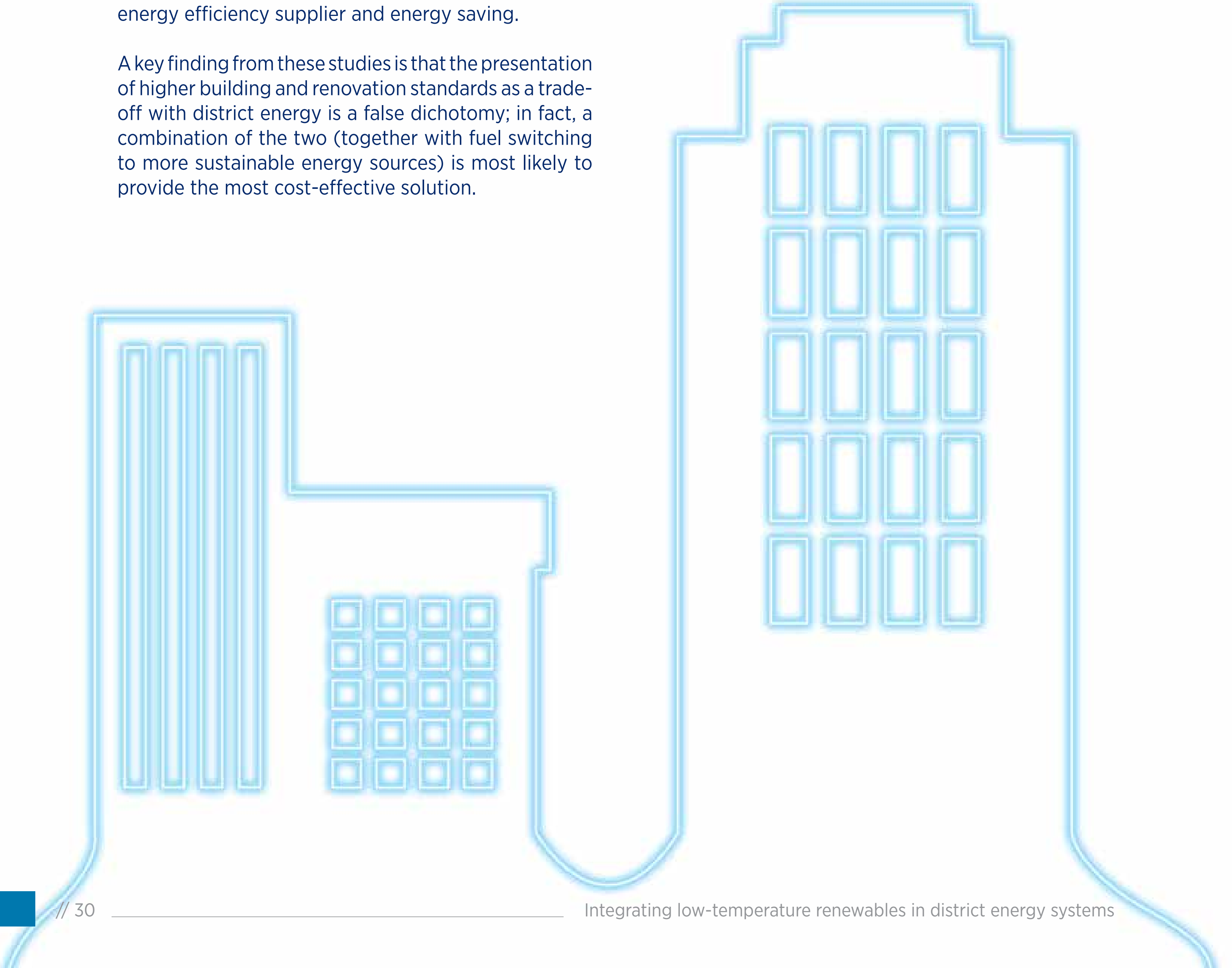
Figure 11 shows that investing in district heating supply and energy savings has the ability to produce lower total energy system costs. The figure shows the total energy system costs for 14 EU countries with the highest heat demand at different energy saving levels and district heating shares.

The lowest energy system costs are found around a 50% market share of district heating with 30% heat savings on a European level compared to 2015, represented by the darkest colour in the figure. It shows the importance of treating energy systems as complex interdependent systems where synergies exist across electricity, gas, and heating and cooling sectors. In this example, this synergy shows the potential of simultaneously investing in district heating supply and heat savings at the same time, to overall decrease the total energy system costs.

A study regarding China (Xiong *et al.*, 2015) also concluded that a more attractive solution for increasing cost-efficient and energy-saving heat demand is provided by a combination of energy recovery, a high energy efficiency supplier and energy saving.

A key finding from these studies is that the presentation of higher building and renovation standards as a trade-off with district energy is a false dichotomy; in fact, a combination of the two (together with fuel switching to more sustainable energy sources) is most likely to provide the most cost-effective solution.

> "Energy-efficient buildings connected to sustainable district energy supply could provide a cost-effective solution"



A.2 Overview of renewable energy sources for DHC and key enabling technologies

A.2.1 Renewable energy (and waste heat) sources and technologies for district heating

District heating is capable of utilising different energy sources and is not tied to a single type of supply. The evolution of Europe's district heating market provides a good illustration of this. In 1990, 50% of the continent's heat was generated from the burning of coal. Beginning in 1990, the share of natural gas – which replaced coal in CHP plants – grew to around one-third of total district heating production. From 1990 to 2017, biomass increased to 20% and other renewables to 6% of district heating production (Mathiesen *et al.*, 2019).

DHC can utilise a broad range of local energy sources, some of which would otherwise not be used. These include geothermal heat, solar thermal, waste heat from industrial processes or free cooling. Thus, these low-temperature energy sources are strategic for the development of DHC systems, and conversely, the development of DHC systems is strategic for the exploitation of low-temperature energy sources. The main strategic energy sources for DHC are described in the following sections.

Geothermal resources

Geothermal energy is a renewable energy source derived from naturally occurring heat beneath the Earth's surface. To generate electricity, geothermal resources at temperatures higher than 150°C are usually required. However, advanced technologies such as binary cycle power plants can exploit lower-temperature resources (IRENA, 2017a).

Geothermal energy can be accessed by drilling into the shallow subsurface or deeper subsurface. High temperature geothermal resources are usually found in the deep subsurface in areas that have high thermal gradient. Medium- and low-temperature resources are usually found in the shallow subsurface or the deep subsurface in areas that have low to moderate thermal gradient. On the other hand, low-temperature heat stored in the upper layers of the shallow subsurface is mainly derived from solar radiation. This heat is absorbed by the ground and distributed by groundwater systems (British Geological Survey, 2020).

Low- and medium-temperature geothermal resources suitable for direct use applications, including DHC, are more widely available than the higher-temperature geothermal resources needed for electricity generation (Limberger *et al.*, 2018).

Geothermal energy from hydrothermal systems exists over a range of temperatures depending on the geological setting. Several classifications have been adopted for geothermal resources depending on the characteristics of the geothermal system from which the energy is extracted. The main classifications are based on temperature, enthalpy, physical state of the fluids and geological setting. Temperature and enthalpy are mainly used for classifying geothermal resources for utilisation purposes. Classification of geothermal resources according to temperature is in three levels: low temperature, medium temperature and high temperature.

Since these temperature levels are ambiguous in themselves, different authors have used different temperature ranges for each level. In the context of DHC systems utilising low-temperature sources, geothermal resources below 90-100°C will be considered as low-temperature. At temperatures above 80°C, geothermal energy can be integrated into existing district heating networks without major modifications to the system. On the other hand, utilisation of geothermal resources at lower temperatures may necessitate modification of the existing district heating networks and buildings (see Part B, Section 4 of this guidebook).

High-temperature geothermal systems traditionally have been used primarily for electricity generation and in some instances cogeneration for direct use applications such as space heating through a cascaded approach.

These systems (that cascade heat from baseload power to district energy) are predominant in Iceland, *e.g.*, the Reykjavik Geothermal District Heating system, which supplies hot water to the city in Reykjavik at 75°C. A portion of this energy is co-generated from Nesjavellir and Hellisheiði geothermal power plants and piped to the city. The geothermal CHP plants account for about 50% of the peak heat demand in Reykjavik, while the lower temperature fields account for the rest. Over 90% of all the space heating needs in Iceland is met using geothermal energy (Tester *et al.*, 2015).

Unlike the high-temperature geothermal resources found in Iceland and a few other places with conducive geological conditions, most geothermal resources in the world are of low-medium temperatures, such as those found in sedimentary basins. Whereas the fluids produced from some of the wells in these sedimentary basin settings can be above 100°C (such as in the Pannonian Basin in southeast Hungary), others produce water in the range of 40-60°C (such as in the Chinese basins).

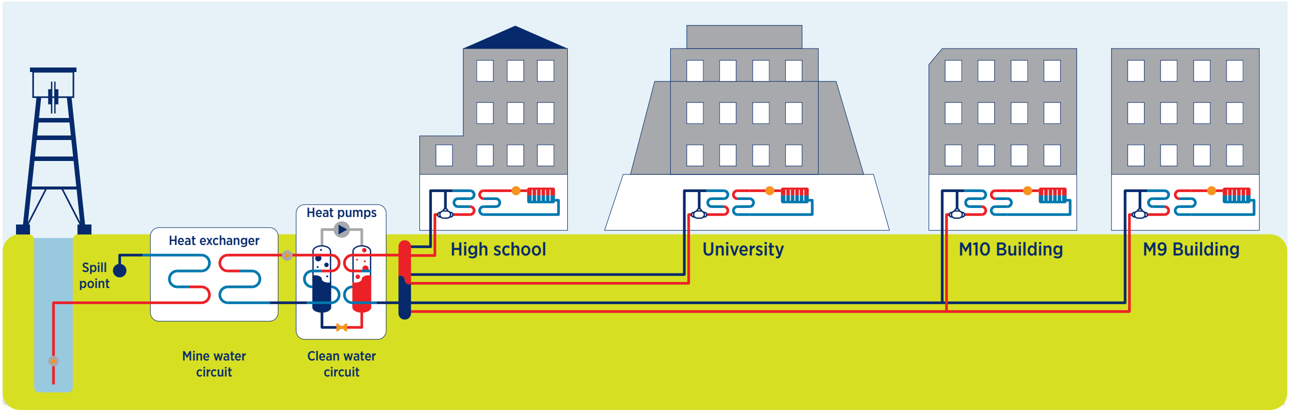
Geothermal energy for heating and cooling is in some cases being obtained from shallower reservoirs, typically less than 1000 metres, to obtain low-temperature fluids. A notable example is the Boise District heating system in Idaho, United States, which obtains hot water at 66-82°C from a number of wells drilled to a depth of 30-900 metres to heat several residential and commercial buildings (Tester *et al.*, 2015).

In more recent developments, cooler thermal waters which can be boosted using heat pumps for district heating are being obtained from shallow geothermal wells. This strategy of drilling shallow wells is being employed to lower the cost of drilling as well as to minimise the risks associated with deep geothermal drilling. The risks include uncertainty about the availability of the resource in terms of temperature and flow rates (Tester *et al.*, 2015). This strategy could also minimise the danger of scaling and corrosion from geothermal fluids as the cooler fluids in shallow aquifers are more conducive to utilisation. However, conversely these cooler shallow fluids may be linked to potable water supplies and thus create a danger of contamination and draw down of aquifers due to other uses (such as agriculture) and must be carefully monitored. The Paris Saclay District Heating system has geothermal wells drilled to a depth of 700 metres to access low-temperature geothermal water at around 30°C. Using heat pumps, the temperature of the geothermal water is raised to 45-63°C for heating buildings during winter. During summer, the heat pumps are used to generate cold water at 6-12°C for cooling buildings (Galindo Fernández *et al.*, 2016).

As developments in the district heating networks tend towards the use of low-temperature resources, new sources of geothermal energy are being deployed and hold promising potential for low-temperature systems, *e.g.*, from abandoned coal mines, as well as open and close loop ground source heat pumps.

After the end of mining operations, coal mines fill with water from underground over time. Due to the natural thermal gradient of the Earth, this water can maintain a constant temperature throughout the year, usually 18-35°C, depending on the depth. The Minewater (Mijnwater) Project in Heerlen (Mijnwater BV, 2014), the Netherlands, uses water at 28°C from an old mine to supply energy for heating city buildings and districts through the application of individual heat pumps to boost the temperature. The mine is also used as a heat sink for excess solar and waste heat from industries and cooling operations (Verhoeven *et al.*, 2014). This innovative project is continuously being enlarged, thus propelling the heat transformation (decarbonisation of the heating sector) in the agglomeration of Heerlen. Similarly, in Mieres, Spain, Barredo Colliery District heating project uses the pumped water from abandoned coal mines, which is known to have almost constant characteristics such as flow rate (3.96 cubic hectometres per year [hm^3/year]), temperature (23°C) and quality.

Figure 12. **Abandoned coal mines: Barredo Colliery district heating project (Mieres), Asturias, Spain**



Source: Decarb Europe (2020)

As shown in Figure 12, the design and operation of the district heating project, developed in 2018, is composed of submersible water pumps, a heat exchanger, two heat pumps and a series of underground pipelines connected to a high school, a university (through high-temperature networks) and 245 residential houses (through a low-temperature network).

The project replaces the previously used gas boilers for space heating. The electricity used in the operation of the heat pumps is supplied through an agreement that ensures it is obtained from renewable sources. This results in a reduction of 653 tonnes of CO_2 annually (Lettenbichler and Provaggi, 2019). With the extraction of heat from abandoned coal mines and in combination with heat pumps, geothermal energy can be accessed and utilised without the need for extensive exploration and drilling, particularly in areas where these mines are located close to heat or cold demand centres.

Similarly, low-medium temperature geothermal resources coexist with oil and gas and can be utilised to provide energy for space heating in areas where space heating load centres are located close to the oil and gas fields. As an example, Vermilion Energy supplies hot water co-produced from oil and gas wells to heat 15 hectares of greenhouse for growing tomatoes. The heat energy is also used to meet 80% of the heating needs of 550 apartments through its operations in France (Vermilion Energy, 2019). Additionally, oil and gas wells provide valuable information about the subsurface such as lithological formation, temperature and porosity. These datasets serve to substantially reduce the resource risk associated with geothermal projects, in addition to saving on the cost of exploration drilling.

The viability of co-production from functioning oil and gas wells should be reviewed prior to abandoning[4] a well. Major challenges of extracting geothermal energy from abandoned oil and gas wells include the cost of re-entering a well after abandonment and the high risk of poor well integrity that limits the long-term usefulness of the well. Since the flow rate (or "water cut") of a well is usually recorded in the production data, it can be used to determine if there is an economic advantage to re-entering a well. In addition, the narrow design of the oil and gas wells limit the use of downhole pumps to extract water for district heating (Hickson *et al*., 2020).

As an alternative to co-production, oil and gas wells may be suitable for low-temperature geothermal energy for space heating through the installation of borehole heat exchangers. In this way, temperatures of 20-70°C or higher can be extracted from the wells at a depth of 1 000-3 000 metres, depending on the thermal properties of the surrounding rock. However, heat exchange can only be performed at the surface, if the temperature and the flow rate of the extracted geothermal fluid are sufficiently high.

Solar thermal

Solar thermal consists of capturing solar radiation to produce heat. Small-scale solar systems are in wide use domestically for hot water preparation and for heating individual buildings in temperate climates, and for specific applications requiring temperatures of less than 100°C (Pauschinger, 2016). Large-scale systems are especially suited for integration with district heating networks due to the clear economies of scale.

Depending on the specific technology and the location of the plant, different classifications can be established.

Two main types of solar thermal technologies exist for harnessing solar energy: flat-plate collectors and concentrated solar power (CSP) (see Photograph 2).

- Flat-plate collectors consist of a panel containing a heat exchanger, which transfers the incoming radiation to a heat-transfer fluid. The front is usually glazed and the back is insulated to reduce the thermal losses (Duffie and Beckman, 2013; Danish Energy Agency, 2016a). The heat exchanger is usually a coil with absorber plates but new designs such as the multi-channel absorber are being developed. Flat-plate solar collectors produce thermal energy typically below 100°C.

- CSP uses mirrors to focus the incoming radiation onto a receiver. Depending on the shape of the mirrors and the receivers, it is possible to classify CSP into four categories: parabolic trough, Fresnel reflector, solar tower and solar dish. Unlike flat-plate solar collectors, CSP can reach very high temperatures, which range typically from 300°C to 500°C, although higher temperatures are possible. This means they can be used for the generation of both power and heat.

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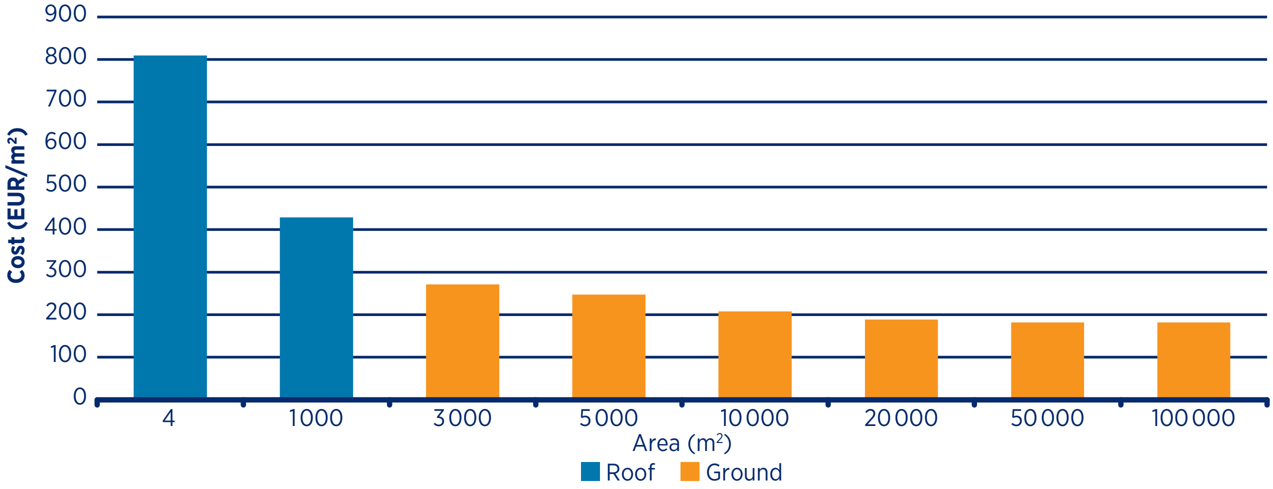
[4] Abandonment of a well involves the sealing or filling of the well (usually by setting of cement plugs to block any upward or downward flow in the well).

Photograph 2. **Solar plants with flat-plate collectors in Løgumkloster (Denmark) (left) and parabolic trough CSP in Brønderslev (Denmark) (right)**

Source: Solar Heat Europe

Image by Luis Sánchez-García

Figure 13. **Cost of roof-mounted and ground-based solar installations in Denmark**



Source: Dyrelund *et al.* (2010)

The efficiency of flat-plate solar collectors is rather sensitive to the district heating system temperatures and hence there is a big incentive to lower them. In this sense, Averfalk and Werner (2020) have determined a saving potential in the initial investment of EUR 100 (Euros) per terajoule (TJ) produced and per degree Celsius (°C) reduced in the return flow, which is among the highest of the studied technologies. In contrast to the efficiency of flat-plate solar collectors, the efficiency of CSP is not affected significantly by the heat carrier's temperatures, hence allowing for higher temperatures to be employed. Another difference between both technologies is the more complicated set-up necessary for CSP since this technology requires the mirrors to track the sun, whereas flat-plate collectors are typically fixed.

Regardless of the technology used, different types of integration are possible: centralised and decentralised.

- Centralised, where the collector field feeds the district energy system at a sole location. This is, for example, the case of the 15 megawatt (MW) solar district heating plant inaugurated in 2019 in the city of Salaspils, Latvia, which would meet about 20% of the annual heat demand on the system, with the rest of the demand being supplied by a 3 MW biomass boiler (Epp, 2019), or, at a smaller scale, the 600 m² roof-mounted solar collectors at Wits University Junction residence in Johannesburg, South Africa (Kganyapa, 2019). Centralised plants can, in turn, be located on the ground or above roofs or other constructions.

- Decentralised or distributed, where the solar collector fields, installed at suitable locations anywhere on the DHC network, are connected to the DHC primary circuit on site. An example is the Drake Landing Solar Community in Alberta, Canada, where 798 collectors have been mounted on the detached garages of 52 houses in a new neighbourhood and connected via an underground pipe to the community's Energy Centre (Drake Landing Solar Community, n.d.).

If land is available at a reasonable cost, the ground mounted option is the cheapest option as it becomes possible to reap the benefits of economies of scale: larger collectors, faster and more standardised installation. As shown in Figure 13, the specific cost of solar thermal district heating decreases with size, and ground installations are significantly cheaper than roof-mounted ones.

Since solar radiation reaches all the globe, in most countries the solar resource potential of solar thermal energy exceeds current demand for DHC. However, this theoretical potential may be substantially constrained due to the lack of ground or rooftop space. China is an example of the latter, where demand is high, but space for solar collectors in the urban setting may be limited (IRENA, 2017b).

The solar production follows two intertwined circles: daily and annual. In the daily cycle the production is null during the night and reaches its maximum output around the local solar noon (in a clear sky day). Moreover, and due to the tilt of Earth's axis, there exists a seasonal variation with the maximum output reached during the summer and minimum during the winter. This latter variability is highly dependent on the site's latitude, and production facilities located at lower latitudes will have a rather smooth pattern throughout the year, whereas plants located at higher latitudes, such as those of Scandinavia, present a much more marked summer peak.

This variability calls for thermal storage in order to accommodate the highly variable thermal production to consumption. Typically, solar district heating plants count on daily storages, which can smooth out the day and night cycle. These are typically in the range of a few thousand cubic meters. On the other hand, it is also possible to flatten the annual cycle by means of seasonal storage, but this requires much higher volumes.

Due to the cost of seasonal storage, most solar plants are used to meet the summer demand which, for instance, would lead in Denmark to a share of 15-20% from solar. This is possible, however, provided that there is district heating demand during the entire year, for instance for DHW or another similar base load. If, on the contrary, district heating consumption is non-existent during the summer, solar district heating may not be the best option. However, as seasonal storage continues to come down in cost, solar thermal is increasingly relevant. It is also possible for solar thermal plants to provide district cooling. In this instance, the advantage is that high output periods generally overlap with those of high cooling demand, resulting in a decreased requirement for storage as well as overcapacity.

Solar thermal plants can provide higher shares of renewable and emission-free energy for district heating systems when combined with thermal storage (Pauschinger, 2016).

The results from Mathiesen and Hansen (2017) show that, in Austria, Denmark, Germany and Italy, the overall solar thermal potential among countries and assorted kinds of energy systems is between 3% and 12% of total heat production. However, a larger share of district heating demands can be met by solar thermal potential than in the individual heating areas. The energy system flexibility is key to creating capacity for integration of solar thermal energy. This is in turn based on the share of baseload district heating production – which affects the system's ability to integrate solar thermal – and the share of variable renewable electricity sources. Additionally, the connection to the heating sector through heat pumps and CHP plants is crucial (Mathiesen and Hansen, 2017).

Solar thermal plants coupled with low-temperature geothermal resources may provide operational efficiencies that benefit both technologies. Combining the technologies may make them applicable to a wider range of situations that either technology alone.

Another solution for using solar radiation involves employing photovoltaic cells, which convert solar radiation into electricity. They can be used in district cooling systems with electricity-driven air conditioning systems.

Waste heat

Excess heat or waste heat includes all the heat flows resulting from any industrial process that cannot be recovered for the process itself but can be reutilised for other purposes such as DHC. This definition would include the excess heat resulting from electricity production in a power plant, but this source, due to its importance, is usually considered as a category on its own and the term "excess heat" is reserved for other industrial processes.

There is a myriad of industrial processes that release heat to the environment and can be utilised for DHC. Conventional sources include refineries such as that of Fredericia (Denmark) or Gothenburg (Sweden) (Frederiksen and Werner, 2013), cement production in Aalborg (Denmark) (Aalborg Varme A/S, 2020), and steel mills such as that of Ravne na Koroškem (Slovenia) (Konovšek *et al.*, 2017) or Dunkirk (France) (Belot and Juilhard, 2006).

The aforementioned sources provide temperatures that are high enough and can be used directly by a district heating network by means of a simple heat exchanger. Furthermore, they may also be employed for producing cooling thanks to sorption chillers, which convert heat to cooling with very limited electricity consumption (Calderoni *et al.*, 2019) (see Part A, Section 2.3).

The utilisation of heat pumps would enable the recovery of heat from a much broader range of heat sources whose temperatures are typically below 70°C. In this case, even though a heat pump is necessary, the employment of waste heat as a source brings the benefit of lower electricity consumption than if the air were used as a heat source. Examples of these new unconventional sources are data centres such as Facebook's in Odense, Denmark (Fjernvarme Fyn A/S, 2020) or Mäntsälä, Finland (CELSIUS Project, 2020a); crematories in Sweden (Petersen, 2017); wastewater treatment plants, such as that of Rødkærsbro, Denmark (Støchkel, Paaske and Clausen, 2017) or the city of Vancouver, Canada (City of Vancouver, n.d.); and metro stations such as Islington's in London (CELSIUS Project, 2020b). Heat recovery from the return flow from district cooling networks is also an option, as has been implemented in Høje Taastrup, Denmark (Schleiss, n. d.). Of these sources, data centres are perhaps the source with the highest future potential as Internet traffic is rapidly growing (Jones, 2018).

In Europe, it has been estimated that industrial waste heat sources could cover at least 25% of potential district heat production without the need for upgrading, considering the location, temperature and temporality (Paardekooper *et al.*, 2018). When considering other types of non-conventional lower-temperature waste heat sources, such as data centres, supermarkets, sewage treatment facilities or metro ventilation, the real potential could be even higher (Persson and Averfalk, 2018). In China, industrial waste heat has the potential to be a substantial resource for district heating systems because industrial energy consumption constitutes 70% of total national energy consumption (Xiong *et al.*, 2015).

Bioenergy

Biomass is the by far the single largest source of renewable heat. Some countries have large amounts of underused biomass feedstock that could be used by the energy sector, including district heating boilers or cogeneration plants (Paardekooper *et al.*, 2020). Biomass produced sustainably within existing farmland from agricultural residues and existing production forests is expected to play a more significant role in future energy systems. IRENA's Global Renewables Outlook shows that biomass can meet 23% of the total primary energy supply globally by 2050, mainly for power generation, but also for heating and transport (IRENA, 2020a).

Bioenergy for district heating includes fresh wood, energy waste, agricultural residue, food waste, industrial waste and co-products of manufacturing, and biogas (Wiltshire, 2016). Biogas is generated during the anaerobic decomposition of biomass and consists mainly of methane. Biomass on the other hand can further be used to produce various products such as wood pellets and wood chips.

Wood pellets are produced by compressing woody feedstocks, such as sawdust, to obtain cylindrical pieces measuring about 70 millimetres (mm) in diameter and 600 mm long. Pellets have a high energy density (10 GJ [gigajoules]/m^3 [cubic metre]), low moisture content (<8%) and homogeneous fuel characteristics in comparison to wood. They are also easy to transport. Wood chips are produced by breaking/cutting wood into smaller pieces measuring 5-50 mm. Wood chips have low energy density (3 GJ/m^3) and higher moisture content (20-25%) (IRENA, 2018).

Nevertheless, care must be taken to ensure biomass is used sustainably. It is likely that large portions of the available (sustainable) biomass in a fully renewable energy system will be necessary for the production of green gases and fuels, which are comparatively more difficult to produce than heating and cooling, so district energy systems should aim to limit their bioenergy consumption. From an energy system standpoint, district energy can also play an important role in integrating other kinds of renewables. Biomass dependence may be limited in district heating systems, according to many analyses of heating technologies, thus bioenergy may be left for other sectors while still facilitating a completely renewable energy system (Mathiesen, Lund and Connolly, 2012).

Biomass does not present major technical integration challenges with existing infrastructure running at high temperatures and will therefore not be the focus of this guidebook.

A.2.2 Renewable Energy sources for district cooling

A district cooling service can be provided with different technical solutions; in particular, two configurations are:

- Central cooling: cooling systems are centralised, and a cold water network is installed; this can be separate from the hot water network (dedicated to district heating) in systems providing heating and cooling, which connects the systems to the users.

- Cooling at the user level: there is no network dedicated to district cooling, but the district heating network is used; the systems are located near users, and are powered by thermal energy distributed by the network itself.

Centralised district cooling can be guaranteed by devices powered by electricity (compression refrigeration) or thermal (absorption refrigeration) units. District cooling at the user level can only take place with absorption refrigeration units because cooling at the user level through compression refrigeration units falls within the definition of individual heating (individual air conditioners that do not use the hot or cold water distribution network and therefore do not fall within the district cooling perimeter).

Heat sources such as excess heat from industries, geothermal and solar thermal can be used with absorption chillers. In regions with separated heating and cooling supply seasons, this allows for combined DHC systems, where the same low-temperature heat source is used in winter for heating and in summer for cooling. This is for example the case in Zhengzhou, China (see Box 2). Solar thermal for absorption refrigeration is an established, demonstrated technology (Hassan and Mohamad, 2012; Inayat and Raza, 2019). The number of installations across the globe has been growing, driven by the ease and capacity of cooling using solar thermal technology (Inayat and Raza, 2019). The water may be partially or fully chilled through heat exchange using natural resources in some locations, a method called “free cooling” (IEA, 2018).

Free cooling

Since most medium and large cities worldwide are close to large natural water bodies, the availability of natural water resources for DHC is substantial. Surface water heat pump systems – using water from the sea, lakes or rivers as their heat source/sink or both – are able to deliver heating and/or cooling for DHC systems. The usual way this system operates is by pumping cold water into the district cooling plant, where waste heat is extracted from the district cooling network through a heat exchanger. After this step is complete, water is discharged to the source. Another way to use free cooling is to store a large amount of snow or ice in a thermal storage system during the winter and to use it for cooling purposes during summer.

Gothenburg Energy (a DHC system in Sweden) primarily converts free cooling, that is, cold water from the Göta River, into district cooling. Alternatively, it supplements cooling by using waste heat from industries or waste incineration through so-called absorption technology. Gothenburg Energy supplies chilled water to businesses and organisations and has already set plans for expanding the district cooling network by 2050.

In Paris, the largest district cooling system in Europe, CLIMESPACE, supplies chilled water to high consumption clients, such as buildings of large companies and government, department stores, hotels, as well as cultural premises. Of the production plants, the three plants with the highest capacity use free cooling from the Seine River (Figure 14).

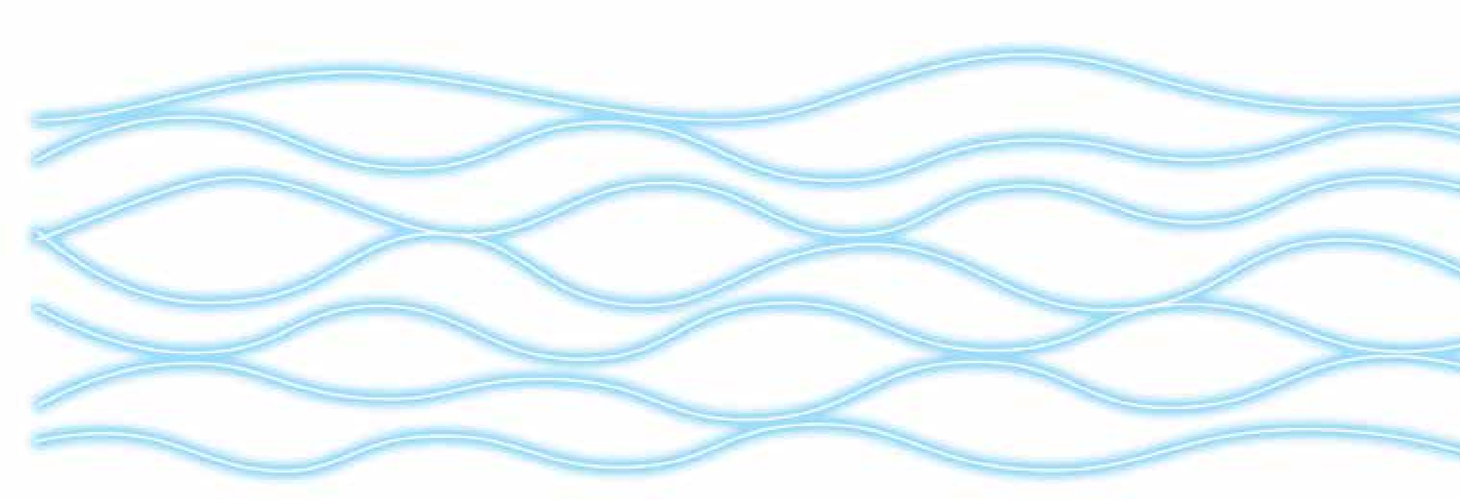


Figure 14. **Paris (France) district cooling networks**

Customer perspective

Description

- The largest district cooling system in Europe and the 11th in the word.
- A concession with the city of Paris since 1991, operated and developed by *CLIMESPACE*

Main Customers

High system performance requirements (temperatures, resiliency…) by the following clients

- Louvre Museum, Paris
- Opéra Garnier, Paris
- Elysée (Presidential residence)
- Paris Town Hall
- Data centers…

Client needs

- Connected customers : nearly 700 customers
- Over 6 million m^2

Project benefits

People

- 35% less electricity consumption

Planet

- 50% reduction in CO_2 emissions
- 50% increase in energy efficiency
- Peak Demand Management
- Phasing out of refrigerants
- 100% power supplied from Hydro entity (Green PPA)

Profit

- 50% less energy consumption
- 65% decrease in water consumption

Technical perspectives

Technical aspects

- 10 cooling plants
- Cooling capacity : 269 MWt
- Distribution : 79 km of underground network
- 3 energy storage facilities : 140 MWh
- Free cooling from the nearby Seine river
- Largest European cooling network by distance of network (km) and in installed power (MWt)

Ownership model

- Public Service Delegation : Design, build, finance, operate & maintain contract

Based on: Engie (2020)

A.2.3 Key enabling technologies

In a future renewable energy system, power-to-heat may shape a significant portion of the heating sector. Firstly, electrification is a straightforward way of using renewable energy and replacing solid fuels in the heating sector. Secondly, flexible use of power-to-heat makes it possible to utilise more renewable electricity (for example, during high wind hours) outside of the heating sector only, thus increasing the capacity factor of renewable electricity technologies and using more renewables in the heating sector. This flexible interconnection is a key mechanism through which district energy can support the decarbonisation and decontamination (particle reduction) of the energy system. Three elements are essential to interconnect the electricity and the heating and cooling sectors: heat pumps, thermal storage and waste heat from electricity production. In addition, the utilisation of renewables for heating and cooling would also require district energy networks as well as buildings that require heating and cooling.

Heat pumps

Heat pumps use electricity (compression heat pumps) or thermal energy (absorption heat pumps) as their primary energy source. Heat pumps can upgrade low-temperature heat sources to higher temperature levels or to produce cold. Figure 15 and Figure 16 explain the underlying functioning of these apparatuses.

Compression heat pumps use electricity to upgrade a low-temperature heat source, using a mechanical compressor working on a refrigerant (see Figure 15 and Photograph 3). These refrigerants can be natural, such as CO_2 or ammonia, or synthetic, such as hydrofluorocarbons (Danish Energy Agency, 2016b). There is a tendency towards the utilisation of natural refrigerants as they are ozone friendly and do not have significant global-warming potential (Danish Energy Agency, 2016b). In fact, some countries such as Denmark forbid the operation of heat pumps with more than 10 kilogrammes of a synthetic refrigerant (Danish Energy Agency, 2016b).

Electric heat pumps in a district energy system provide a crucial conversion technology between the electricity and the heating sectors. Heat pumps provide flexibility for the integration of variable renewable-based electricity sources when combined with adequate heat storage (Henrik Lund *et al.*, 2016), which individual heat pumps cannot deliver. Further on, the use of heat pumps connected to the electricity transmission network (high voltage) can counteract limitations of the distribution network (low voltage) capacity and thus avoid investments into grid reinforcement or alternative costlier storage systems, *e.g.*, electro-chemical batteries (Andrews *et al.*, 2012). The installation of large heat pumps connected to DHC systems can also prevent the high losses in the distribution grid that would occur if heat pumps were deployed individually as stand-alone installations at a large scale in urban areas (Andrews *et al.*, 2012).

An electric heat pump's efficiency is primarily determined by the source temperature and the required network temperature, although variations across manufacturers or working fluids do exist. It is measured by a ratio called the coefficient of performance (CoP). The CoP is simply the ratio between the thermal output and the electricity input for the heat pump. A higher CoP denotes lower electricity consumption for the same heat output. A higher-temperature heat source denotes a higher CoP with less electricity required to increase the heat source to the desired temperature by the district heating network. This is the main driver for using waste heat or any other low-temperature heat source instead of air or water, which frequently are more readily available. For example, a low-temperature waste heat industrial facility, a low-temperature geothermal resource or a heat storage facility connected to a solar thermal facility will provide heat at a lower cost than ambient heat since the electricity expense for the heat pump will be considerably reduced.

In addition, regardless of the heat source, heat pumps perform at a higher efficiency (higher CoP) when they are used to deliver heat at a lower temperature instead of at a higher temperature. This is a key motivation for moving away from first to thirds generations of DHC and transitioning towards fourth generation DHCs. Apart from the efficiency, lower operating temperatures open up a broader range of heat pump technologies to be used since many refrigerants have an upper bound of working temperatures.

Absorption heat pumps, on the other hand, are driven by thermal energy. Their electricity consumption is minimal and, in some cases, null (Klein and Nellis, 2012). These machines take advantage of the phenomenon in which heat is released when one substance is absorbed into another (*e.g.*, water and ammonia or water and lithium-bromide) (Frederiksen and Werner, 2013). Their efficiency is, as can be appreciated when comparing the CoPs of the heat pumps presented in Figure 15 and Figure 16, not as high as the efficiency of compression heat pumps. It is usually around 1.7 (Danish Energy Agency, 2016a).

A variation of absorption heat pumps are absorption chillers, which can produce cold using heat at high temperatures. In this sense, there is a lower bound for the temperature of the heat source, which lies around 80°C (Klein and Nellis, 2012). The CoP, or fraction between the cold output and the heat input, is limited to 0.5-0.7[5] for the most common types (Herold, Radermacher and Klein, 2016).

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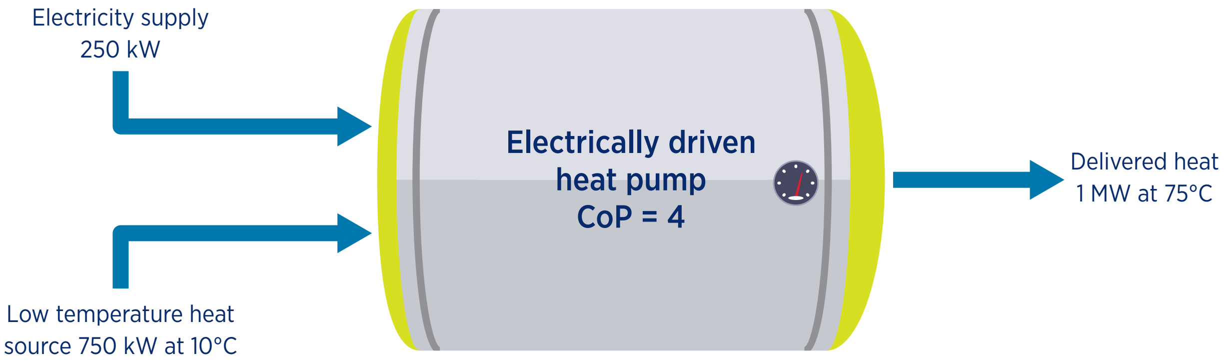
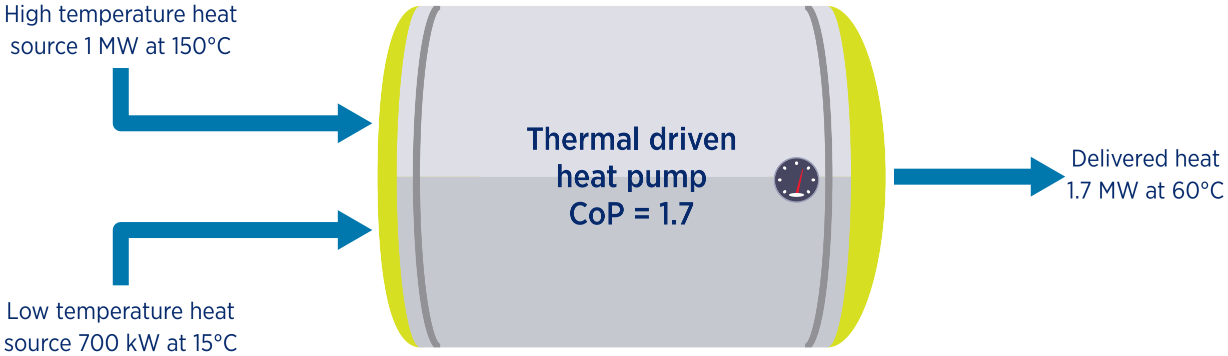
[5] The CoP of either electric chillers or absorption chillers is one unit lower than their heat pump counterparts working at the same temperatures.

Figure 15. **Working principle of a compression heat pump**



kW: Kilowatt

Figure 16. **Working principle of an absorption heat pump**



Photograph 3. **Compression heat pump supplying a district heating system in Denmark**

Source: Luis Sánchez-García

Absorption machines offer the possibility of taking advantage of an inexpensive source of thermal energy either to upgrade a low-temperature heat source, and hence increase the total thermal output, or to produce cooling. Potential heat sources for absorption machines include bioenergy (biogas or biomass boilers), solar thermal (in concentrating arrays and in flat-plate collectors), direct geothermal heat, waste heat from industrial processes or power generation through thermal cycles or waste incineration. Although the heat source may not be renewable, because the heat is generated as a by-product of the process and it would otherwise be "wasted" by dissipation into the environment, it can be considered that the environmental impact is minimal and its employment eliminates the need to exploit other energy resources (Sanner *et al.*, 2011).

Thermal storage

To accelerate the decarbonisation of heating and cooling, thermal energy storage (TES) has an important role to play, particularly in cities where the population density is high enough to adopt district systems. TES enables the decoupling of heat/cold generation from consumption, facilitating more flexibility in energy systems. These technologies can accommodate a range of timescales from short (hourly) to seasonal storage, link better supply with demand, reduce curtailment and avoid the need for costly electricity network reinforcement.

The IRENA report *Innovation outlook: Thermal energy storage* discusses the different thermal energy storage technologies and user cases for heating and cooling systems, and projects the development and innovation needs for the next decades IRENA (2020).

Thermal storage consists of a system able to accumulate thermal energy and put it aside for later use. TES usually makes use of water as storing fluid, due to its large heat capacity and low price, but the ground can also be used. There exist other materials such as phase changing materials, but they have not found widespread use in DHC networks. In the case of cold storage, chilled water, ice or brine have been employed (Frederiksen and Werner, 2013).

TES can be utilised not only for storing the heat produced in thermal renewables such as solar or geothermal, but also for capturing excess wind or photovoltaic electricity production once it is converted to heat thanks to a heat pump or an electric boiler. This latter option has the benefit of coupling the electricity and heat sectors, thus collaborating to bring about the Smart Energy Systems concept (Mathiesen *et al.*, 2015) (see Part A, Section 1.2) and hence, a cheaper decarbonisation of the entire energy system.

Furthermore, thermal energy storage is considerably cheaper than electricity storage such as batteries or pumped hydro (Lund *et al.*, 2016; Paardekooper, Lund and Lund, 2018).

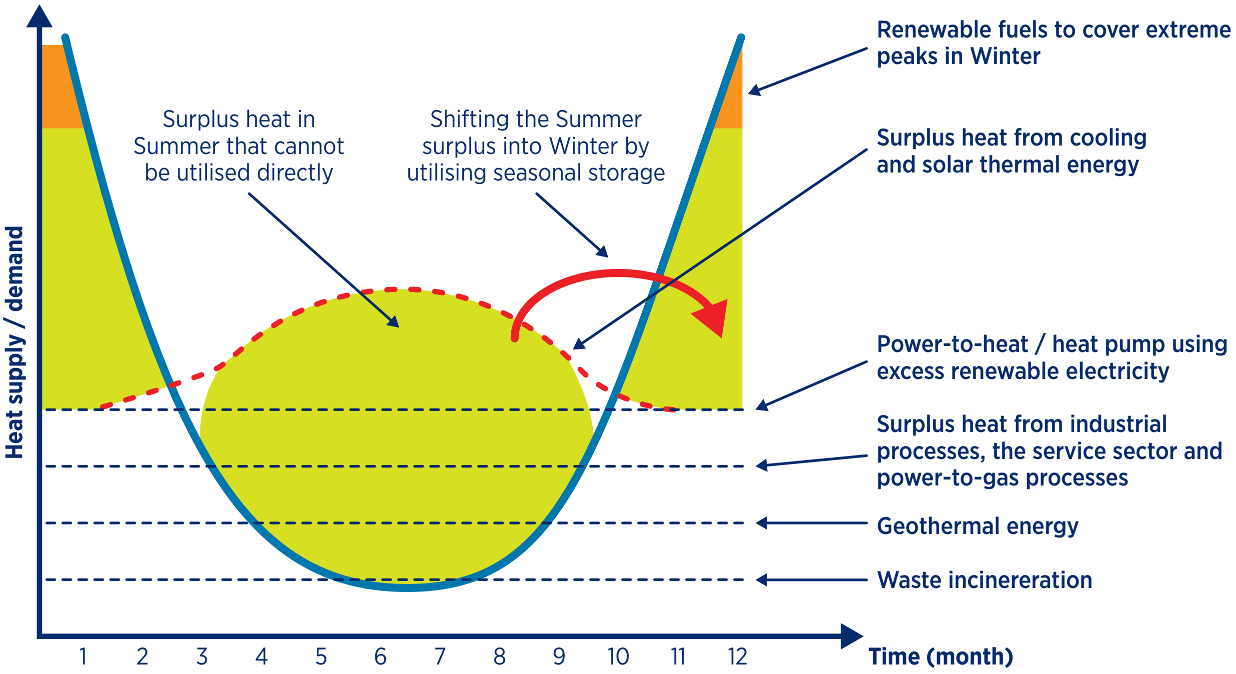
The size of thermal storage has a wide range, spanning from a few hundreds of cubic meters to hundreds of thousands of cubic meters. In the lower end, the most typical types consist of water tanks such as those shown in photograph 4. These have been used traditionally for load shifting in cogeneration plants or daily load matching in solar thermal plants.

Larger storage sizes would make it possible to remove a key barrier to integrating significant shares of different renewables heat sources (excluding biomass) in district heating networks. This barrier is the seasonal discrepancy between the demand and supply profiles, and the competition between each other in summer. The surplus heat in summer can be stored for transition or winter, substituting fossil units (Köfinger *et al.*, 2018) (Figure 17).

Photograph 4. **Thermal heat storage (44 000 m^3) at Avedøre Kraftværket in Copenhagen (Denmark)**

Source: Luis Sánchez-García

Figure 17. **Supply competition between various renewable and low-carbon heat sources and the potential of seasonal storage to overcome the competition**



Source: AIT (2020) (Schmidt, Geyer and Lucas, 2020)

The typologies of large-scale or seasonal storage are more varied and include aquifer, borehole, or pit storage (Xu, Wang and Li, 2014), some of which are illustrated in Figure 18.

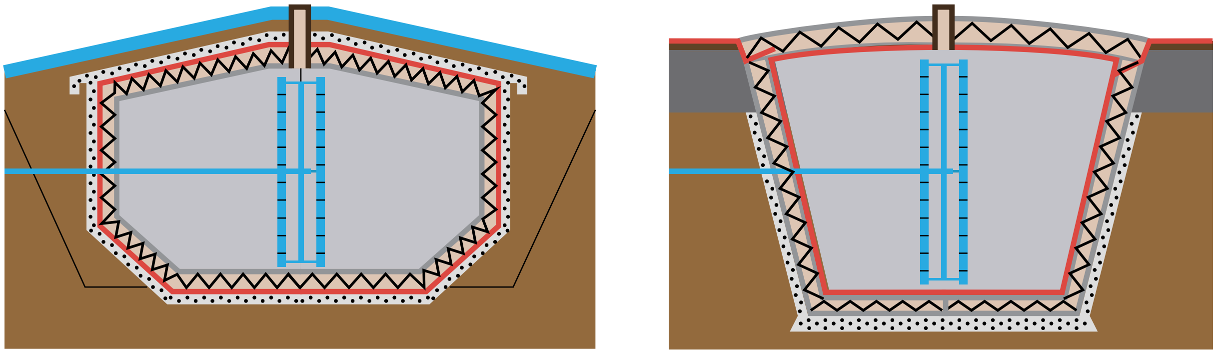
1. Aquifer Thermal Energy Storage (ATES): Heat is stored in an underground water reservoir at a low temperature (<30°C), a medium temperature (30- 60°C) and a high temperature (>60°C).

2. Borehole Thermal Energy Storage (BTES): Heat (up to 90°C) is stored in the upper 20-200 metre layer of the ground. For example, the Drake Landing Solar Community project in Canada is made up of 144 boreholes drilled to a depth of 35 metres. Solar energy stemming from 2 300 m^2 of solar collectors located on rooftops is stored in the boreholes and used during winter to meet 90% of the heating needs of 52 high-energy-efficient buildings. Another example is the seasonal storage located in the Danish town of Brædstrup, where 48 boreholes are used to store the heat from a nearby 18 600 m^2 solar field (PlanEnergi, 2017).

3. Pit Thermal Energy Storage (PTES): Large excavated basins with insulated lids store hot water of up to 90°C. Several pit storages have been built in Denmark, including Marstal (75 000 m^3), Dronninglund (60 000 m^3) and Vojens (200 000 m^3) (PlanEnergi, 2017).

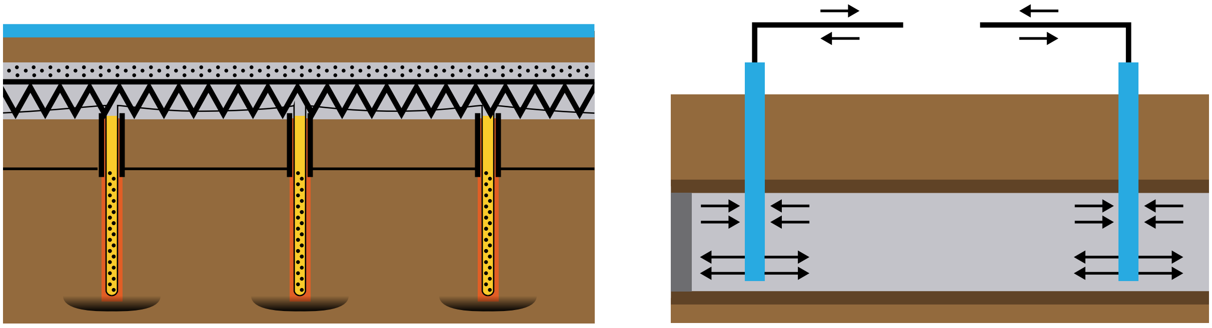
4. Mine Thermal Energy Storage (MTES): Water in abandoned or flooded coal mines is used as a source of low-temperature heat for space heating. The abandoned mines in Springfield, Canada and the Mijnwater project in Heerlen, The Netherlands are used as heat storage during summer to store waste heat from building and industries. A variant of mine thermal storage is cavern thermal storage, where a cavern is excavated for the sole purpose of storing thermal energy. This is the case of Lyckebo in Sweden, which stores energy in a cavern of 100 000 m^3 in bedrock (Duffie and Beckman, 2013).

Figure 18. **Seasonal thermal storage concepts**



Tank thermal energy storage (TTES)

Pit thermal energy storage (PTES)



Borehole thermal energy storage (BTES)

Aquifer thermal energy storage (ATES)

Source: Schmidt and Miedaner (2012)

TES is not only considerably cheaper than electricity storage, as mentioned before, but it also presents important economies of scale. Therefore, the specific cost of large pit storage systems is nearly 20 times lower than the cost of water tanks in the range of 1000 m³. This cost reduction is shown in Figure 19.

Large thermal storage systems have not been implemented so far in large systems. The examples presented above usually serve small towns of a few thousand inhabitants. Nonetheless, there are projects under consideration and development in larger towns. One prominent example is the Austrian city of Graz, where the current district heating network is supplied with heat from a fossil fuel-based CHP. In Graz, one option being considered is the provision of solar thermal energy in combination with a seasonal storage of about 1800 000 m³, to meet about 20% of the heat demand by utilising 450 000 m³ of solar collectors (Reiter, Poier and Holter, 2016). In urban district heating networks, high investment costs constitute one of the main challenges to the development of seasonal storage systems, along with the associated investment risk caused by extended payback periods. In this situation, an allowance for production dispatching for multiple supply units leads to better storage utilisation and minimisation of investment and operational costs (Köfinger *et al.*, 2018).

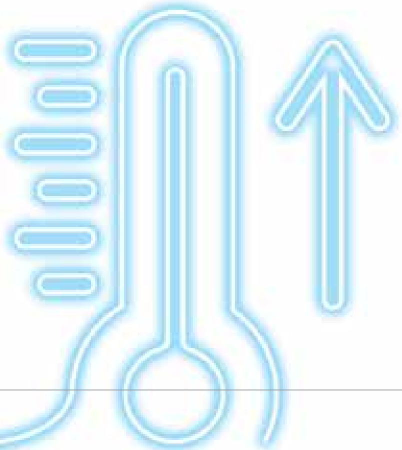
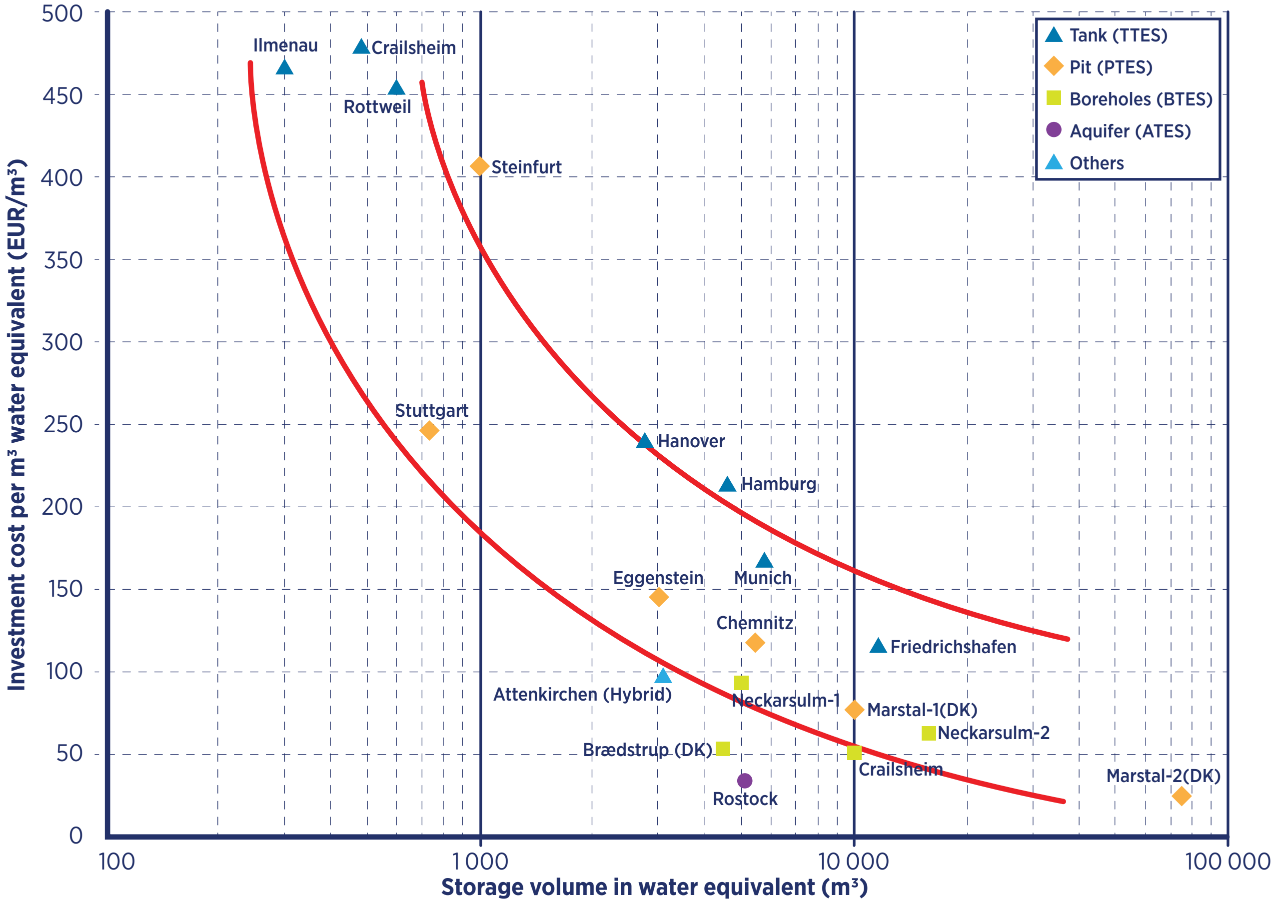


Figure 19. **Cost of seasonal storage**



Source: Schmidt and Miedaner (2012)

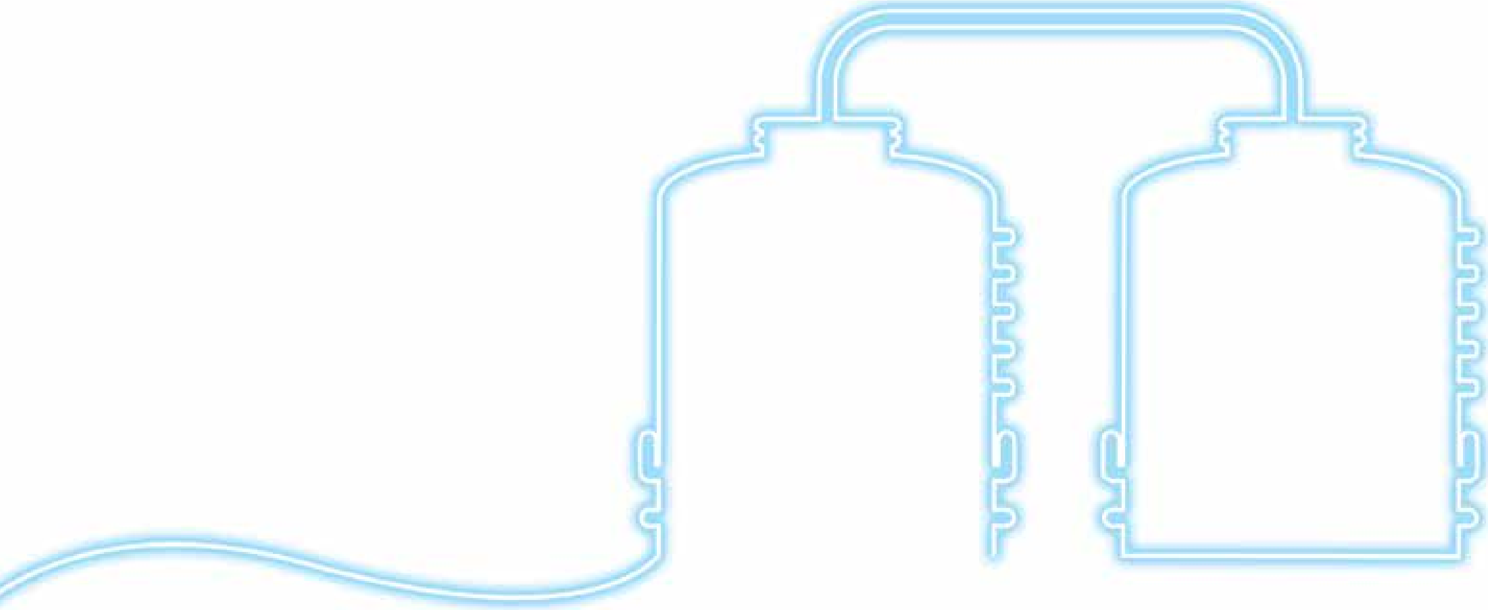
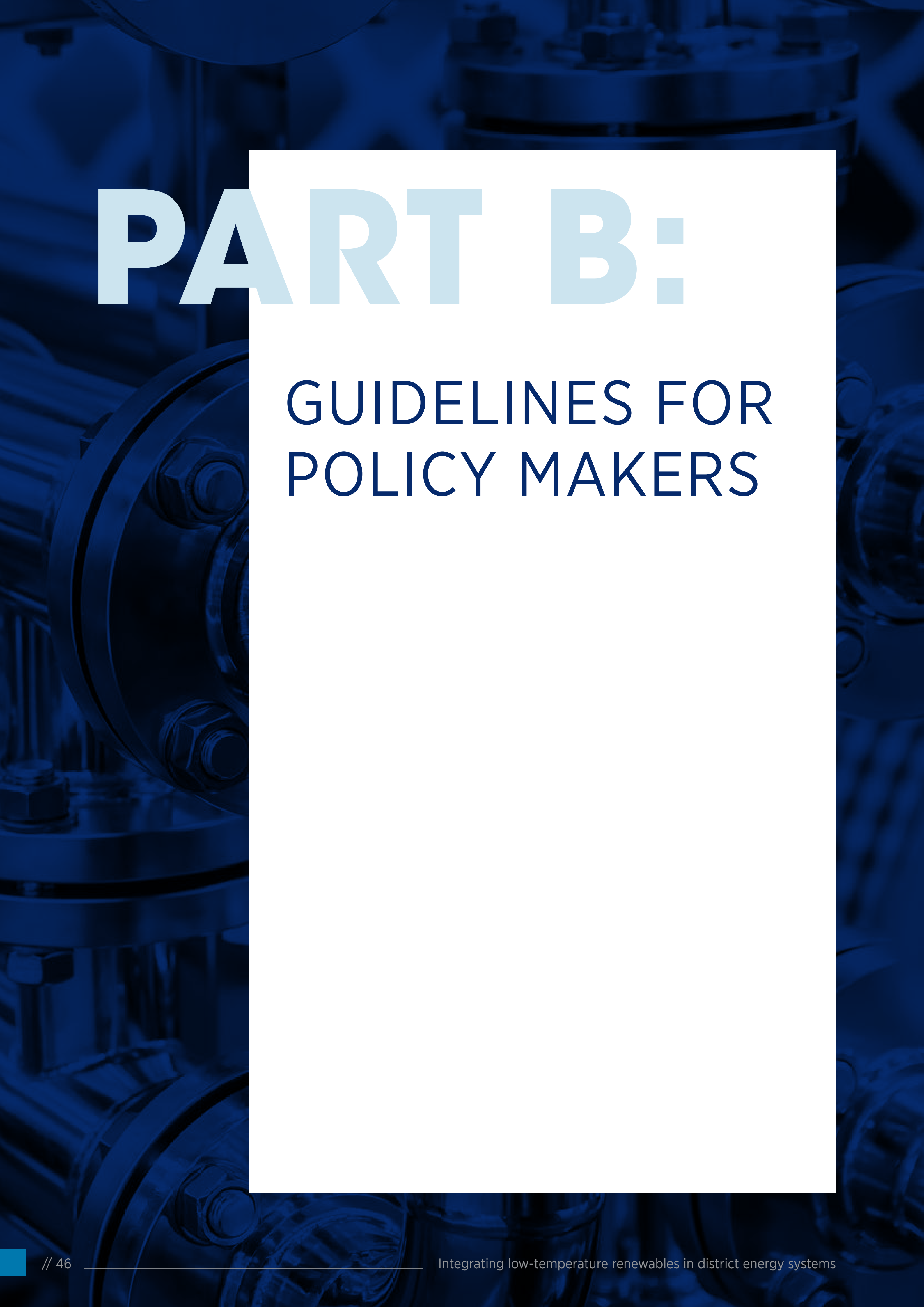


Table 1 summarises the advantages and roles of the main low-carbon heat sources and enabling technologies in a smart energy system.

Table 1. **Main advantages and role of renewable energy, waste heat sources and enabling technologies in the energy system**

		ADVANTAGES	POTENTIALS	ROLE IN THE ENERGY SYSTEM
SOURCES	**Geothermal**	Continuously available and not dependent on weather conditions Very low operation and maintenance (O&M) costs	Large, especially for shallow and low-temperature geothermal resources (Resource available at different temperatures and depths)	Can be used for centralised exploitation in large-scale district heating or cooling systems
	Solar thermal	Sustainable resource Very low O&M Very long lifespan	Almost everywhere	Can cover summer load in district heating systems Can provide cooling in summer Can be combined with seasonal storage
	Bioenergy	Abundant and sustainable source in some areas	Almost everywhere	Can be combined with solar thermal for district heating Can compete with uses in other sectors (transport or other purposes)
	Free cooling	Abundant Very low O&M costs	Large	Can reduce electricity consumption and allow the chilled water to bypass chillers
	Waste heat	Use of a resource that would otherwise be lost Advantageous cost	Industrial and commercial areas	Can reduce energy consumption for the alternative sources of heating or cooling
ENABLING TECHNOLOGIES	**Heat pumps**	Capacity to use renewable energy from air, water or ground and waste heat from buildings and processes to deliver heating and cooling	Everywhere	Can act as the conversion technology between electricity and heating sector Can upgrade low-temperature heat sources to higher-temperature levels or to produce cold
	Thermal storage	Costs 100 times less in investment terms per unit of storage capacity compared to electricity storage Economy of scale	Everywhere where room is available and geological conditions are favourable	Integration of variable renewable energy production



PART B:

GUIDELINES FOR POLICY MAKERS

B.1 **Developing strategic heating and cooling plans**

B.1.1 Need for mutually reinforced national, regional and local action

To address energy-related challenges in a co-ordinated and informed manner and with a long-term perspective, strategic energy planning (SEP) should be deployed. The main purpose of SEP is to address issues with current energy supply and to formulate long-term strategies and plans for transitions. It is necessary to include technical, economic, environmental and societal contexts in the assessment (Krog and Sperling, 2019).

SEP can be carried out at different governmental levels and different geographical areas or with different technological foci. Nevertheless, SEP should include considerations across these diverse fields to avoid sub-optimising certain areas.

Strategic heating and cooling planning (SHCP) differs from planning for other energy carriers due to the local nature of heating and cooling supply resource. Therefore, this guidebook will examine this issue in detail and discuss the involvement of local actors in participating in SHCP activities.

Supranational, national or regional energy and climate targets can be met only if they are locally adapted and adopted. Conversely, local ambitions must take into account national perspectives and need a favourable legislative framework to succeed.

Furthermore, SHCP must be conducted from a system perspective, and this is even more important in a renewable energy system. The technical synergies that flow from a system perspective in the electrical, heating and cooling sector must ideally also be reflected in policy and regulation, as highlighted by the project Hotmaps (Hotmaps Project, 2020), which considered how to carry out SHCP activities within the EU member states.

In that perspective, before initiating a SHCP process, a mapping of the public policy and regulation framework is essential to make sure it is embedded and co-ordinated at all levels of governance and across all energy-related policy areas (Djørup *et al.*, 2019a). Table 2 proposes a model of the matrix on which such mapping could be based.

On the other hand, local authorities in jurisdictions with existing DHC systems have formidable leverage for action. SHCP allows the assessment of the implementation of a project within the perspective of a long-term, holistic energy perspective.

The role of local authorities in developing DHC is multidimensional and concerns all levels of civil society: energy and urban planning, setting up financial and technical support mechanisms through the provision of infrastructure and services, provision of legal permits for the deployment of district energy systems, and even the connection of public buildings to DHC networks. All public authorities have a role to play. For example, as the regulator, city government can release local zoning policies that mandate the connection of DHC (IRENA, 2016). In some countries, local authorities do not perceive themselves as able to carry out energy planning or set up support mechanisms, etc.; thus, they do not feel it is within their remit to directly affect implementation of DHC. However, even if regulatory power is centralised, their role as convenors, facilitators and a knowledge base for DHC development in the region can be key to developing DHC.

> "Local energy and climate plans must align with national goals and consider integration of all the energy systems in a city"

Table 2. **Model of matrix for mapping the public regulatory framework for heat planning**

	PROJECT REGULATION	HEAT AND BUILDING REGULATION	ENERGY SYSTEM REGULATION
LOCAL REGULATION	☑	☑	
REGIONAL REGULATION	☑	☑	
NATIONAL REGULATION	☑	☑	☑
SUPRANATIONAL REGULATION	☑	☑	☑


Source: Solar Heat Europe

B.1.2 Building a sustainable energy supply with strategic heating and cooling planning

SHCP is not merely an engineering, economic or political activity but is interdisciplinary in its nature. The very first step is a (political) assessment of what the strategic objectives are that the heating and cooling system need to achieve; what is the problem that needs to be solved? In many cases the catalyst for starting SHCP will be the need for targets on decarbonisation of the energy system or the reduction of particulate matter. However, underlying this will also often be the desire to have affordable heating and cooling, and further prevent energy poverty through price resilience; to align and facilitate with other sectors in the energy system; and to support local economies through the development of local markets. The establishment of these strategic energy objectives before beginning the SHCP process on a political and social level allows for the development of a plan that functions for long-term needs and desires, and enables each (renewable) heat project to better align with the process.

Subsequently, to formulate a plan, consideration of available resources, energy demands, technical potentials, current legislation, the organisation of the energy sector and the related actors and political drivers, among others, is necessary. All these influence the possible solutions and allow the identification of barriers. Challenges regarding low-carbon energy supply can equally be of a technical, economic, political or social nature, and will often be distributed among these factors. It is important that the energy planner doing SHCP remains open and considers the importance of all these diverse contexts (Mirakyan and De Guio, 2013).

SHCP is a best practice model to develop cost-effective district energy. It identifies opportunities and synergies and applies tailored policies or financial incentives within an urban area's various districts (UNEP, 2015). This guidebook addresses these aspects and presents a model for how to carry out a SHCP process. Given this background, it is important for readers to consider local contexts that can alter the necessary steps, focus or methods.

As SHCP includes many different areas of expertise, it is a challenge to harness the right knowledge and skills for such assessments. The planning includes knowledge of building sectors, available resources, the energy sector, the law and business. This will typically span several different areas of expertise in a local municipality and across offices that might not be used to working together in a cross-sectoral manner. This is an organisational challenge that should be considered from the beginning. In addition, depending on the level of change needed, the time frame for such projects can be long and can be affected not only by exhaustive construction but also by policy changes or public acceptance.

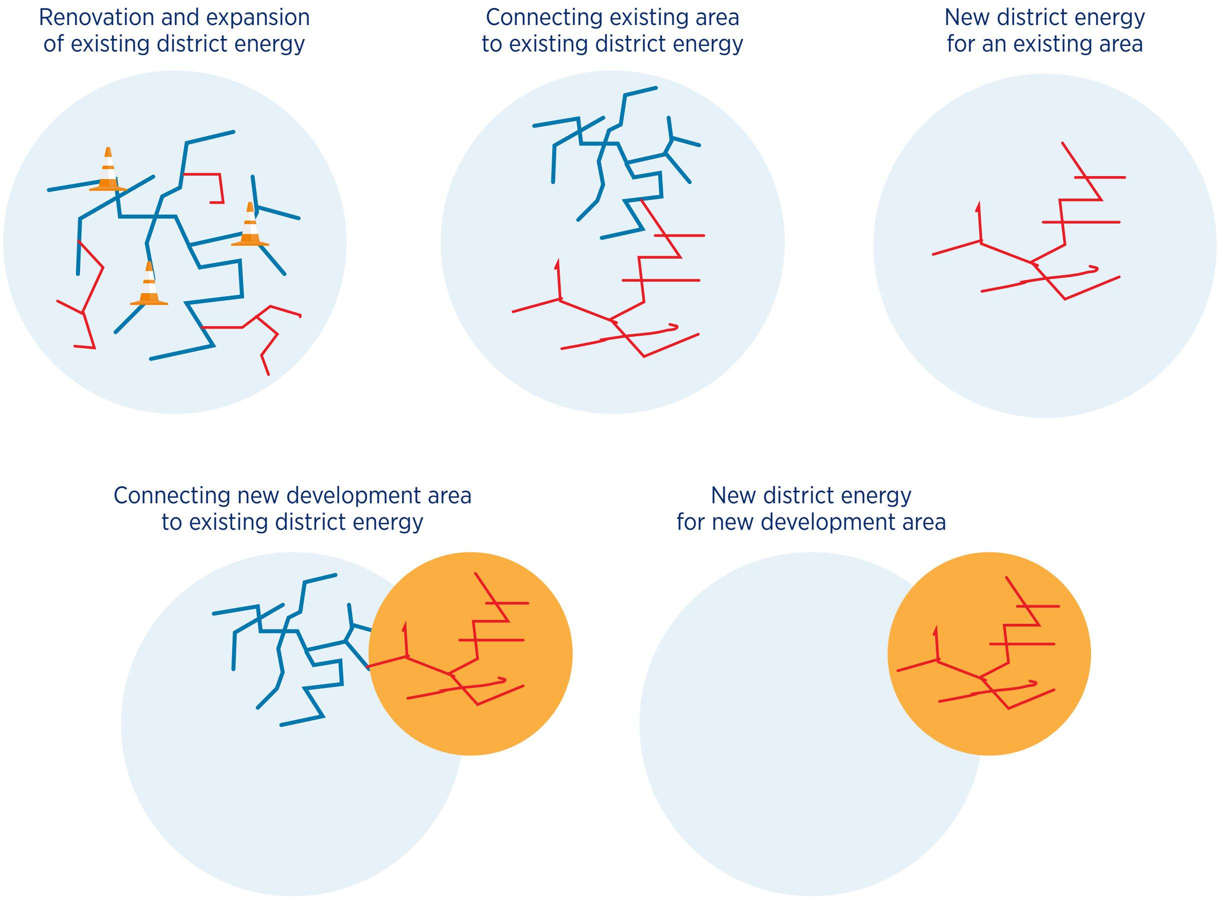
When assessing the role of district energy systems in SHCP at the local level, the main questions to answer pertain to the feasible size of the system and its organisation and regulation. This report addresses three main stages in a SHCP process:

- the scoping of the strategic objectives the plan is addressing, development of the purpose of the plan, and identification and mapping of stakeholders
- the technical analysis that can be applied in the search for a system suitable to strategic aims
- the assessment of the key institutional, financial and organisational elements and development of policies to facilitate the transition.

The whole process, as well as each of its steps, must be conducted in an iterative way, each stage influencing the others. Each iteration will specify the details of the implementation plan. The construction of the technical scenarios for strategic heat supply, in particular, requires a number of iterations. This is necessary to identify the long-term balance between investments in heat supply and heat savings and to make sure the objectives are aligned with national or international targets. The first steps of the SHCP process will help identify the potential and role of district energy project(s), which ones should be prioritised, and the potential for fuel switching in existing systems.

These stages can both be applied to the national level or to the planning of new areas to expand current systems or refurbishment and reconfiguration of existing systems. At the local level, different cases can be contemplated, as district energy can be supplied to both new and existing buildings, and thus its establishment can be considered in new and existing neighbourhoods. Some examples of applications are illustrated in Figure 20.

Figure 20. **District energy network applications in a range of urban environments**



Renovation and expansion of existing district energy

Connecting existing area to existing district energy

New district energy for an existing area

Connecting new development area to existing district energy

New district energy for new development area

Based on: IRENA (2017b) and Olsen (2014)

> “Strategic heating and cooling planning is a best practice model to develop cost-effective district energy systems. It identifies opportunities and synergies and applies tailored policies or financial incentives within an urban area”

Considering the different possible applications, the SHCP process will have differing focuses depending on the local context. In the case of existing DHC systems, the SHCP should include a diagnosis of the current system and an evaluation of the quality of service provided. "Quality" is subjective, but should include an accounting of the GHG reduction realised with the system, customer satisfaction with the service and cost offsets for alternative fuels (hydrocarbon or coal).

In urban areas that do not have an established DHC system in place, principles for the organisation, ownership and regulation of the heat/cold network typically do not exist or are based on other types of infrastructure that do not specifically facilitate the development of DHC. In these cases particularly, the establishment of these principles must be considered and developed after having investigated the technical potential of the different heating and cooling technologies in the early planning phase through a city-wide assessment and district energy strategy (see Part B, Section 6). This way, the governance principles are adapted to the city-wide strategic objectives and resulting potential of DHC, and specific projects can be implemented within that frame, rather than the governance barriers adapting to project challenges.

B.1.3 Defining scope and purpose for strategic heating and cooling planning

The first part of a SHCP process will focus on identifying the purposes for changing the thinking about heating and/or cooling supply and establishing the strategic objectives. This first step is important as it will influence the rest of the SHCP process. The purpose identified in this step will influence the groups seen as relevant stakeholders, the technologies that can be used and the governance models that should be deployed. This is also why the feedback loop of the SHCP is important, as new knowledge might surface later in the process.

Possible reasons to develop a new heating and cooling plan can include the need to reduce carbon emissions, establish security of supply, improve energy efficiency, reduce local air pollution, capitalise on available resources as well as simply conform to regulatory tasks such as mandatory assessments of DHC potentials or others. Many of these reasons might be in alignment while at the same time addressing the agendas of different actors. While a national government might set out goals to decarbonise heat supply to limit climate change, local governments can promote changes to decrease local pollution or enhance other "green" initiatives that might be adopted at a local level. Increasingly, cities are taking over responsibilities related to decarbonising their energy consumption and/or supply and are requesting governance and regulatory tools to implement their solutions. Once there is an identified purpose, these goals should focus on which problems the heating and cooling plan aims to resolve, rather than set out to support any particular technology. The purpose can thus relate to changes that are not easy to implement or that require wide organisational and regulatory changes.

Local governments, including cities, can participate in propelling the energy transition and planning community-based energy solutions to assist in meeting specific objectives and targets (IRENA, 2016). In view of the various conflicting objectives, an energy strategy should set an official target for renewable energy that overtly addresses the heating/cooling sector. An official target is critical for achieving a successful energy transition. The target should delineate the main strength of different technologies – including district energy – in meeting the wider social, economic and environmental objectives.

Consideration of district energy's role in the transition to an integrated energy system composed of low-carbon sources is important. In this context, heating and cooling can be the focus, but a DHC system's relationship with other energy sectors – such as electricity, gas and transport – should also be considered (sector coupling) (see Part A, Section 1.2).

Concrete heating and cooling plans are often shaped as local projects at the city level; however, proper SHCP must be embedded and co-ordinated in terms of the long-term potential of the city-wide energy system, and not only the DHC project at hand. For example, it is important to avoid the establishment of a DHC project that 5 years later turns out not to allow for easy expansion or be able to interconnect to the rest of the system. In addition, it must establish congruence with all levels of governance, across all energy-related policy areas due to the potential synergies between the sectors. In local planning processes, there is the risk of sub-optimising by not co-ordinating efforts on wider scales, *e.g.*, across projects, regions or at national and international levels.

An example of planning with an integrated energy system approach for an existing district heating system is the SHCP work carried out in Aalborg, Denmark. The main objective of Aalborg Energy Vision 2050 (see Box 1) is to propose how Aalborg's energy supply can be designed to contribute to the realisation of Denmark's long-term vision to become 100% fossil fuel-free in 2050. The Zhengzhou case illustrates the SHCP process for a new development area (Box 2).

BOX 1 AALBORG (DENMARK): AALBORG ENERGY VISION 2050

Aalborg's case is characteristic of integrated energy system planning. The Aalborg Energy Vision constitutes a study of the overall energy system, including an analysis of district heating's role and aspects, and takes into account the national long-term goal to become 100% fossil fuel-free by 2050.

Several options were taken into account during the development process of the Aalborg Energy Vision 2050. This was done in part to demonstrate the need for heat savings and low-temperature district heating, and in part to show the extent to which Aalborg would be dependent on industrial excess heat in its heating system. In addition, an alternative was considered in which district heating was replaced with individual heat pumps.

The results indicated that the least-cost option is the flexible utilisation of power to generate heat for district energy systems through heat pumps, and in combination with thermal storage. Under these circumstances, individual heating amounts to about 0.2 terawatt-hours (TWh) in comparison to a heating requirement of about 1.9 TWh. Industrial waste heat contributes about 0.9 TWh towards the district heating's 1.65 TWh demand. The rest of the demand is to be met with heat from geothermal sources, heat pumps and gas-based CHP plants.

The SEP process was regularly discussed with representatives of Aalborg Municipality, the Environment and Energy Administration, the Urban and Landscape Administration, and Aalborg District Heating (utility). In addition, there has been a dialogue with local industrial and business interests. This flow of information among stakeholders constitutes a guiding principle of the SEP process. It is, in addition, a methodology that authorities can apply in the planning of energy systems for the future that enables stakeholder participation and buy-in as co-ordinated parts of the national and global efforts (Thellufsen *et al.*, 2019).

Source: Shutterstock

View of central Aalborg and waterfront from Nørre Sundby

BOX 2 ZHENGZHOU (CHINA): STRATEGIC HEAT PLANNING IN NEW AREA

Longhu Financial Center in Zhengzhou City, China, is an extension project of the Zhengdong New Area's Central Business District. It is intended to house high-rise office buildings and residences with a total built-up area of approximately 3 100 000 m².

Zhengzhou is an interesting case in which SHCP has been applied to a newly built district energy system, where heating and cooling are considered integral parts of the city infrastructure from the outset. During the urban planning stage, several public services and utilities (wastewater and heating/cooling, water and electricity supply, internet cable, transportation) were coupled together in the overall urban planning documentation.

In this way, the thermal grid reaches every area of the new district, making the district energy system available to all buildings in a cost-effective manner. Furthermore, the combined planning of the district heating grid and the utilities facilitates the use of waste heat from wastewater as a heat source for the thermal grid.

During urban planning and after it was completed, the local government assisted in co-ordinating the necessary regulations, policies and design guidelines to support the development of the project. As part of the strategic approach, the regulations included the obligatory connection of all new buildings to the district energy grid (Riahi *et al.*, 2017).


Source: Shutterstock

City view Zhengdong New District, Zhengzhou City, China.

As can be seen from these two examples, both local and national levels of government play an important role in strategic planning and ultimately the implementation of the development plan. Local levels of government should be responsible for the co-ordination of stakeholders and implementation of heating and cooling infrastructures. National or regional governments must ensure proper regulation that guide local authorities to act and set proper boundary conditions that direct the local actions in a co-ordinated manner (see Part B, Section 6.3). Without a clear direction – for example, decarbonisation targets, pollution targets, customer protection regulation and energy availability – there is a risk that local governments will address the issues in different ways that sometimes differ among neighbouring jurisdictions. Heating and cooling plans that include the utilisation of low-temperature resources, including geothermal resources, with clearly outlined targets can thus be developed.

Lastly, the timeframe of the SHCP should consider as much as possible long-term societal goals, not just short investment horizons of, for example, 10 years. By keeping a long timeframe, it is possible to analyse how different societal goals can be reached. If this is not considered, then there is the risk that investments that look beneficial today do not fit into the future energy supply and become stranded assets.

> "Local and national levels of government play an important role in strategic heating and cooling planning and ultimately the implementation of the development plan"

Summary of recommendations for developing SHCP

SHCP is the first step to develop and use renewable energy sources occurring at low temperatures in both new and existing DHC systems. The key success factors of a SHCP process are summarised below.

Identify the scope and purpose of the SHCP.

- ➡ Decide on the strategic objectives of the SHCP. The SHCP process could be carried out for various reasons (e.g., decarbonisation, minimising pollution, provision of affordable heating and cooling, etc.). This strategic objective should be what guides the rest of the process.
- ➡ Align local heating and cooling objectives with the national decarbonisation strategies, if any. Heat planning takes place at the city or municipal level due to the local nature of heat utilisation. However, the local plans need to be aligned and be guided at national and regional level.

Address issues with the current energy supply with long-term strategies and plans for transition.

- ➡ Involve local authorities in SHCP. Local authorities play a crucial role in the SHCP process, including energy and urban planning, provision of infrastructure for heating and cooling, regulation and financing, etc.
- ➡ Make sure to embed and co-ordinate the SHCP at all levels of governance and across all energy-related policy areas. In particular, integrate SHCP with the planning of energy-efficient building stock, which may include some technologies that can only be feasibly implemented in a level of building clusters (district) instead of single buildings.

Take into account the iterative, multidisciplinary and continuous dimension of the SHCP process, which is adaptable to different levels and contexts.

- ➡ Optimise the process through a multidimensional, iterative approach. To reap maximum benefits, the SHCP process should take a long-term perspective, consider synergies with other energy systems (*e.g.*, electric grids) and take a multidisciplinary approach including economic, environmental and technical aspects.
- ➡ Adapt the focus of the SHCP process to the local context. However, keep in mind that the governance principles should be adapted to the strategic objectives rather than to the project challenges. Address the three main stages in the SHCP process: i) define the scope, objective and stakeholder engagement plan; ii) establish the technical scenarios for a sustainable energy supply iteratively; and iii) define the DHC governance scheme.

B.2 **Stakeholder engagement**

B.2.1 Identification and co-ordination of stakeholders

Many stakeholders are involved in the heating and cooling sector, all with their own agendas. Stakeholders can be consumers with high energy demands such as industry, hospitals, wastewater treatment plants or greenhouses. All of these have high energy consumption and are also potential waste heat sources. Key stakeholders can also be directly related to the energy sector such as power plants, energy transmission companies such as existing district energy providers, or extraction industries. However, some stakeholders may not necessarily consider themselves so if it is not their primary activity.

As heating and cooling is local, it is important to identify and work with local stakeholders in transitions towards low-carbon heating and cooling supply. Local governments will be key actors in organising the process and identifying and involving stakeholders.

It is vital to be clear on who the main actor in leading the process is and therefore who is responsible for identifying and involving actors, as it also must be possible to exclude stakeholders who do not fit in within the established scope. Not all heat sources will fit within the purpose, and national and local plans might be in clear opposition to certain established actors.

This leads to the need for:

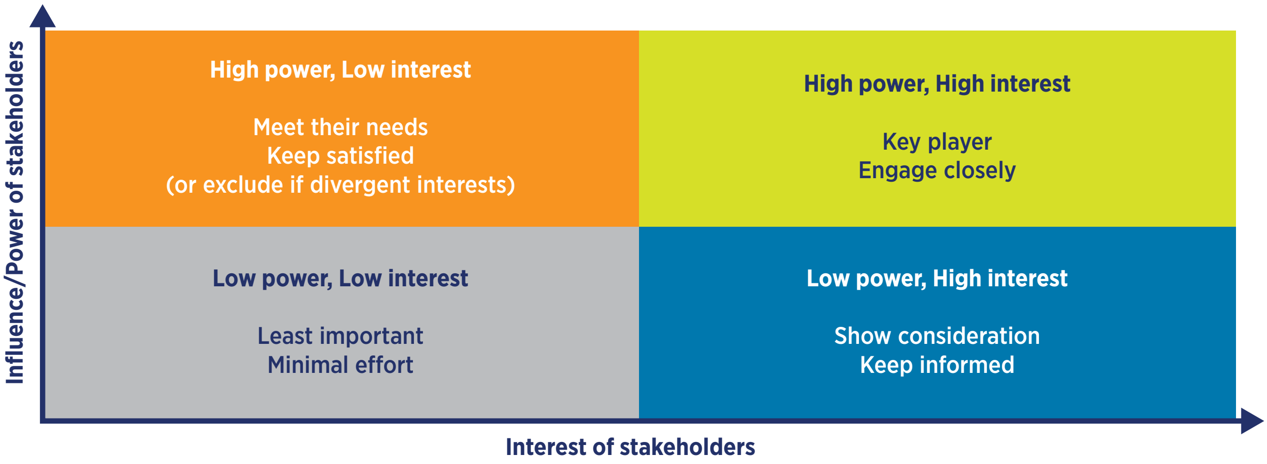
- identifying opportunities to involve stakeholders that can play a constructive role in realising heating and cooling plans

- identifying synergies and opportunities for cost-effective district energy systems.

Stakeholder engagement and management at the earliest possible opportunity is recommended, especially to facilitate public acceptance. It is also key to be clear on who is a key stakeholder for which part of the plan; some may be stakeholders to the long-term planning, some may be stakeholders to specific parts (*e.g.*, the development of particular renewable sources) and others may be stakeholders to, for example, the development of the network in already established areas. This means that while some stakeholders may be key for certain parts of the DHC system development, they may also not be relevant for other areas.

Co-ordination of stakeholders with differing agendas can create difficulties for governance, especially where there are stakeholders whose functions and objectives are sometimes divergent. Many potential stakeholders must likely be actively engaged, in order to increase their interest and engagement, or be excluded. For example, a hospital may not consider themselves a key player – because their activity is providing health care services, and heating and cooling is only a small part of all these activities, their interest may not initially be very high. It is, therefore, necessary to classify the stakeholders based on the level of influence and interest in the project to develop a strategy for engagement, as shown in Figure 21.

Figure 21. **Classification of stakeholders based on level of influence and interest**



High power, Low interest Meet their needs Keep satisfied (or exclude if divergent interests)	**High power, High interest** Key player Engage closely
Low power, Low interest Least important Minimal effort	**Low power, High interest** Show consideration Keep informed

Source: UNIGE; based on Mendelow (1981)

Stakeholders' role in the development of a SHCP or in a project can be assessed in terms of their influence and the level of interest they hold. Stakeholders of high influence and high interest are critical to the success of the strategy or the project and should be identified and engaged closely at the earliest possible opportunity, whereas those of low influence and low interest may require minimal engagement.

The scope and purpose of the heating and cooling planning activity is important in dealing with the question of which actors and stakeholders should be included in the process. The stakeholders likely to be involved in a project should be identified and a strategy for engagement developed to ensure the success of the project, as shown in Table 3. The extensive list of key stakeholders and their roles in the processes related to retrofitting of district heating systems in Central and Eastern Europe can be found in Čižman and Buganova (2019).

Table 3. **Possible stakeholders, their role in SHCP and strategy for engagement**

STAKEHOLDERS	ROLES / INFLUENCE / INTEREST	ENGAGEMENT STRATEGY
National, state or provincial authorities[6]	Provide framework conditions in terms of regulations, tools and mandate. Generally provide the permits and licenses to allow the project to proceed. Can provide the finance for the project.	Should be engaged based on national energy policy. This can be in terms of energy security, health, decarbonisation, etc.
Local (municipal/civic) authority[6]	Generally monitor the implementation of legislation. Project owner and main driver. Possess important local knowledge about project-specific conditions. Can provide the permits to allow the project to proceed. Protect consumer interests. Major consumer (public buildings).	Engaged based on drivers for the SHCP. These can be local demands such as energy poverty, air pollution and lack of access to energy. They can also be provided from national (or state/provincial) authorities in terms of mandatory assessment of DHC potentials or regulation.
Utility/development company	Depends upon ownership. Interests should be to operate DHC systems in line with strategic objectives. Benefits from identifying synergies with other developers.	Development of business case.
Investors and financial institutions	Provide the finance and investment for the project, recover investments.	Understand the evaluation criteria and priorities that govern the investment decisions.
Researchers/academia	Provide (independent) knowledge about new emerging technologies, challenges and phenomena. Can provide independent assessments of potential pathways of development.	Research-action projects.

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[6] The mentioned national government roles and relevant policies may performed by state, provincial or local government in another context (and vice versa) due to the variety of government systems

Table 3. **Possible stakeholders, their role in SHCP and strategy for engagement - CONT.**

STAKEHOLDERS	ROLES / INFLUENCE / INTEREST	ENGAGEMENT STRATEGY
Building developers	Develop new buildings that allow for utilisation of low-temperature sources for heating and cooling.	Implementation of building codes or standards. Make provisions for connecting the buildings to the district energy supply.
Building owners	Provide information on the building-side plants. Allow inspections to detect/correct system faults. Take the decision about whether to optimise the systems.	Implementation of building codes or standards. Make provisions for connecting the buildings to the district energy supply.
Customers	Provide information about heat demand. Affect system efficiency through behaviour. Pay the bills. Act as prosumers.	Align interests with that of the customers. Protect interests through contractual agreements.
Citizens	Provide public acceptance. Act as heat customer and engage in employment. Become investors.	Should be included in the process. The wishes and drivers of this group should be understood.
Geological surveys	Provide critical information about geological conditions and available geothermal resources.	Assessment of resource potential.
Geothermal and solar developers	Initiate projects and provide more detailed indications on heat sources.	Need certainty for investments and risk management. Need proper tenders for exploration, testing and operation.
Waste heat suppliers	May provide cheap heat to the network.	Need understanding of technical issues around recovering heat and potential commercial implications. Participation in contractual “heat off-take” agreements.
Technology suppliers	Generate local added value and jobs. Support the increase of DHC systems flexibility.	Need certainty for investments and risk management. Funding for research and development in sustainable technologies for heating and cooling supply.

After stakeholders are identified, they must see themselves in the process and be willing to be engaged. Stakeholders should be able to see a benefit from engaging in a process to exploit waste heat, switch to renewables, and install new or refurbish older district energy systems. This can take the form of a profitable business case, increased environmental profile, stable energy supply or others. Box 3 highlights the role of the main stakeholder in two different cases in Denmark.

BOX 3 THE ROLE OF THE MAIN STAKEHOLDER

Two different cases from Denmark highlight the importance of the main stakeholder and its influence in the development and implementation of future strategies.

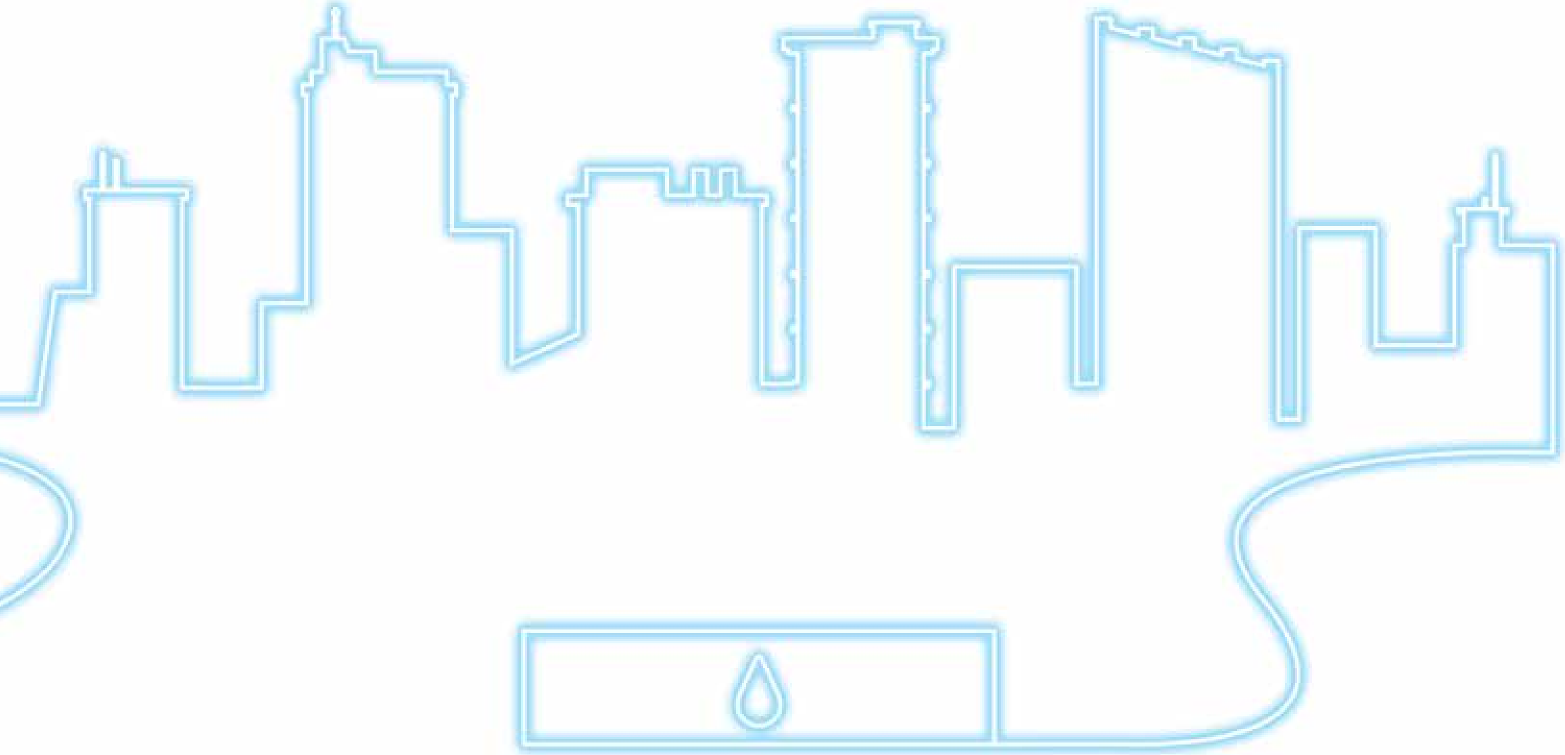
- In Aalborg, the city council has adopted ambitious targets in the heat plan, which does not include coal-based heat production by the year 2050. As the main stakeholder, Aalborg City Council is determined to implement its strategic heat plan for green energy and thus decided to exclude a private energy vendor who is the main supplier of heat and whose interests did not fit with the city's desired purpose. Therefore, the city council bought back from the private energy company the local CHP DHC plant, in order to avoid potential conflicts of interest when introducing changes in heat production and eventually replacing the coal-fired CHP as a heat source.
- In Viborg, the district heating utility is co-operative company owned by the consumers and is the main stakeholder. The company has developed a strategy taking into account its customers' wishes. These wishes include stable pricing, independence from fossil fuels and their fluctuating costs, energy efficiency on the demand side, and a transition to low-temperature district heating. The implementation of this strategy would be on contrary terms with the interests of the municipal CHP plant that supplies heat to the system from natural gas. Therefore, the utility decided to buy out the heat production unit from the municipality, and as such removed a stakeholder from the planning process.

In both cities the heating utility is identified as the main stakeholder, which aims for sustainable heat production and implementation of a green strategy for heat. Both cases are examples of conflicting interests between important DHC stakeholders that can hinder the transition of the system to a more sustainable operation. In particular, the control of heat production is vital in case technologies need to be replaced or fossil fuels are to be abandoned.

Environmental concerns regarding the development of some renewables in cities should be addressed to foster social acceptance. In an effort to demystify geothermal energy and address the environmental concerns which could result in social resistance, the GEOENVI Project (GEOENVI, 2019) developed a database on environmental aspects related to geothermal projects in terms of both impacts and risks as well as mitigation measures. In addition, as of April 2020, the project was developing a harmonised methodology for assessing the environmental impact of geothermal projects as well as harmonising life cycle analysis methodologies. The objective is to increase awareness of policy makers and the general public about geothermal energy by making information on geothermal projects available through a publicly accessible database.

Engaging the stakeholders who will be directly or indirectly affected by the implementation of an energy project should be structured and detailed to ensure that their concerns and expectations are addressed through the project. For example, the utilisation of geothermal resources entails accessing the subsurface to extract the energy. This will involve drilling and testing of geothermal wells in or close to residential properties and built-up areas. This may result in social resistance to the project as it involves mobilisation of heavy equipment, noise during drilling and the possibility of induced micro-seismicity (Popovski, 2003). In this regard, sharing information about the project and engaging the stakeholders, including citizens, at the very beginning of a project is of crucial importance as demonstrated in the case of Groß-Gerau, Germany (Box 4). While this stakeholder engagement strategy has been implemented at a project level, similar principles can be applied at the strategic level (national or local authority level) when developing the SHCP.

> “Stakeholder engagement must start early to address concerns and ensure broad public acceptance”



BOX 4 GROß-GERAU (GERMANY): A SUCCESSFUL STAKEHOLDER ENGAGEMENT STRATEGY

As demonstrated by Überlandwerk Groß-Gerau GmbH (ÜWG), a public utility company in Groß-Gerau, Germany, stakeholder engagement ensured there was transparency as well as mutual trust between the local community and the geothermal developer, which in turn led to public acceptance of the project. The engagement process was structured to create a politically robust project.

The first phase of the engagement, social site characterisation, entailed gathering the views of the public regarding the project such as hopes, expectations, fears and perceptions. This was done through interviews and continuous media analysis.

In the second phase, stakeholder dialogue, the issues identified during the social site characterisation were discussed by an advisory group, drawing membership from a diverse range of stakeholders. The advisory group then formulated requests to the project developer covering environmental aspects, cost and benefits, project risks, and communication. The final phase, civil engagement, included the general public, for which information was provided and questions answered while controversial issues were discussed in detail. This was done in the form of meetings.

At the end of this process, a survey indicated that most of the residents in the affected area supported the project and preferred the development of geothermal to other sources of energy (Wallquist and Holenstein, 2015; Allansdottir, Pellizzone and Sciullo, 2019).


Source: Shutterstock

Aerial view of the town Groß-Gerau near Frankfurt in Hessen, Germany.

This level of transparency, coupled with strong local engagement, is expected to increase understanding and acceptance of district energy and renewable energy projects.

Summary of challenges and recommendations for stakeholder mapping and engagement

Identify and engage stakeholders.

- Identify the relevant stakeholders in the SHCP, their interest and level of influence in a heating and cooling project. The leader of the SHCP, usually the local authorities, need to be clear about their political drivers and targets: if some stakeholders do not align with the overall purpose, then they do not have to be part of the process.

- Raise awareness and promote public acceptance for DHC as a way of meeting specific social and environmental goals. To facilitate the public acceptance of the heat planning process and district energy, the engagement of policy makers and the general public should be promoted as early as possible.

With regard to promoting specific energy sources for DHC as well as developing specific projects, the project operator could engage the stakeholders as follows.

- Develop tools and methodologies for assessing the environmental impact of heating and cooling and lobby policy makers to harmonise environmental legislation for different energy sources. The environmental impacts of energy projects should be assessed using simplified tools that promote comparison with other, similar projects, and mitigation measures should be well articulated. This is especially true regarding geothermal, so as to enhance transparency in geothermal development and create awareness about the risks and associated mitigation measures of geothermal projects.

- Promote transparency by engaging stakeholders in the development process so that they can understand the benefits as well as the drawbacks of the project. The general public and policy makers may not have adequate information about some renewable energy technologies and may generate resistance due to perceived environmental and social risks.

B.3 Assessing and mapping heating (and cooling) demand and energy resources

In many countries, regions and cities, heating (and cooling) have not traditionally been an object of governance. Energy policies are most often found in sectorial policies focussing on electricity and gas on the supply side and buildings efficiency on the demand side. Therefore, knowledge of the fundamental state of play of the heating and cooling sectors is often lacking. Perhaps, electricity and gas supply are measured, but only as aggregated energy supply figures that mix cooking, lighting, heating and other end-use demands together. Established district energy systems without control systems and energy metering also often lack knowledge about the actual energy demands at the consumer level. Heating and cooling demands can thus be unknown and therefore hard to use for strategic planning purposes.

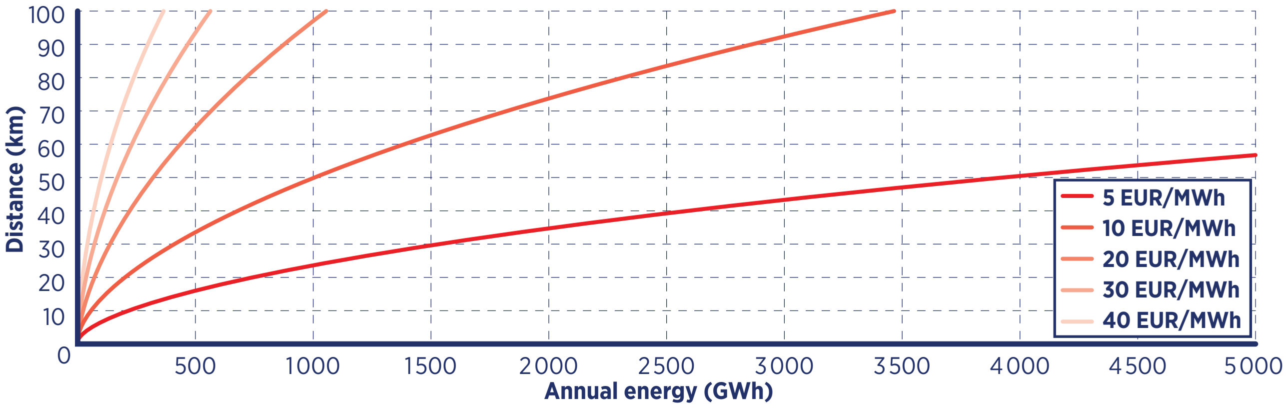
To carry out a SHCP process or a feasibility study, it is necessary to collect and utilise knowledge and data about the location and amount of heating and cooling that is actually required, the potential supply options, and the state of the building stock. It is also vital to include other energy sectors in the analyses to capture wider changes such as increasing amounts of variable renewable electricity, increasing energy demands, etc. Significant cross-sectoral synergies exist that should be exploited, and sub-optimisations within energy domains should be avoided. The collected data are necessary to develop technical scenarios that play a critical role in strategic planning. The steps of technical mapping will entail a quantification of the heat demand, identification and quantification of potential heat resources, and an assessment of the potentials for heat savings in buildings and identification.

A significant difference between heat planning and other types of energy planning is the critical importance of the location of the demand and supply. Thus, having knowledge about the location of heating resources and the existing heating and cooling demand enables connecting these two together and assessing their viability. Mapping the location and quantification of heating and cooling demand is therefore a crucial part of SHCP and vital to get investors to support district energy projects with renewable energy and waste heat sources.

In particular for DHC planners, this knowledge is important to estimate the size of the networks and installed capacities. For investors, as district energy grids are capital intensive investments, it is important to know the potential market size, the supply quantities and potential customers.

The distance over which heat can be transmitted cost-effectively depends on the amount of energy to be delivered. Figure 22 depicts the longest distance heat can be transmitted at a unit cost. For example, 2 500 gigawatt-hours (GWh) can be sent up to 40 kilometres (km) with a cost of merely USD 5.50 (US dollars)/megawatt-hour (MWh). But if the distance between production and consumption were 50 km, it would be necessary to deliver 4 000 GWh to obtain the same unit cost.

Figure 22. **Cost of heat transmission**



Note: The cost of transmission includes the construction cost and the cost of pumping. Construction costs for district heating pipes have been taken from Svensk Fjärrvärme AB (2007), updated following Sánchez-García (2017) and amortised at 30 years with an interest rate of 5%. Pumping cost have been calculated assuming an electricity price of USD 11/MWh. Furthermore, it has been assumed that the energy transported through the pipeline varies sinusoidally through the year (Phetteplace, 1995).

Moreover, it is technically relevant to avoid excessively long pipe distances. Indeed, even if pipes are well insulated at present, heat losses still occur (which can be decreased by using lower operating temperatures).

B.3.1 Mapping heating and cooling demand

The main approaches to begin developing information about heating demand are presented here: measuring actual demand, modelling demand at the building level and aggregating it, and disaggregating through spatial modelling.

i. **Measurements of actual demand allow for actual knowledge of consumption.** This obviously forms the most accurate basis for an assessment for heating. A high time resolution should be adopted where possible, for example 1-hour intervals. This gives valuable knowledge to the distribution and production companies about the variability of the expected demand load. It allows for better operation of production units by optimising the production to the demand and increased co operation between the heating system and variable sources for electricity production. Metering (and proper control systems) also allows for individual consumption-based billing, enabling incentives for decreasing energy consumption.

ii. **Bottom-up modelling of buildings' energy performance and consumption allows for estimations of expected heat demand.** Modelling or estimating demands for buildings, and subsequently aggregating them, can be a way forward to provide inputs for decision making. Some cities, such as Geneva in Switzerland, have made it mandatory for house owners to report their heat demand. They are provided with the tools and guidelines, and also have the opportunity to hire accredited persons to do the calculation for them. Modelling or estimating requires datasets on the building stock (location, surface area, age, main energy source, etc.). These datasets can be made available to cities by national authorities, as has been done in Switzerland (see Box 5). Such initiatives could be replicated in other countries. Where these types of datasets do not exist, surveys and field work may be necessary to establish sufficiently granular data to model heat demands, which can be costly.

iii. **Top-down modelling the spatial distribution of heat demands to identify priority areas.** Projects such as PETA 4 or the Hotmaps toolbox provide examples of modelled European heat demand atlases (see Box 6). Those tools have to take into account not only local policies (thermic regulation for public buildings) but also the local behaviours of the final users from hot or cold and the temperature need of the end-user. (For recent buildings with radiant floor heating, the need for heating will be around 30°C; for iron radiators, it will be around 80°C to 90°C.) These models use energy statistics, which provide the heat demand for a country, region or city, and then disaggregate these demands spatially to enable the estimation of heat distribution costs and to identify high-potential areas for district heating development, based on density and proximity to heat sources. This gives the least accurate result of the three methods, but allows for SHCP in data- or resource-scarce contexts.

In the case of a new development area, the modelling of future heat demands will also be necessary to design the future DHC system.

Caution should be exercised to ensure demands are calculated very conservatively. Sensitivity analyses should be run.

This understanding and quantification of heating demand should also include data on cooling and the local electricity consumption for it. This enables cities to identify and deal with electricity demand challenges locally instead of relying solely on improvements to and the development of the national electricity grid (UNEP, 2015).

> "Heating and cooling demand for buildings in a city can be deduced through measurements of actual demand, bottom-up modelling of building consumption and top-down modelling of heat demand"

BOX 5 OPEN DATA FOR PRELIMINARY STUDIES: THE CASE OF SWITZERLAND

- Open data sources can significantly contribute to the preliminary assessment of energy demand for SHP of DHC. In Switzerland, the opendata.swiss portal synthesises a wide variety of freely accessible datasets across the confederation, cantons and communes. This includes data from the Swiss national building register, GWR, which describes the basic properties of approximately 2 million buildings on the national territory – such as their location, surface area and main energy source. Local datasets can provide complementary, site-specific information: in the canton of Geneva, the portal of the territorial information system (SITG), for instance, details the heating energy consumption of multifamily and utility buildings.

https://opendata.swiss/en/

https://ge.ch/sitg/

- Such datasets can support the development of preliminary scenarios for the planning and development of DHC systems integrating low-temperature renewable energy sources by estimating spatial patterns for energy demand and their evolution under future conditions. Chambers *et al.* (2019) thus used open data to map the local potential for future district heating systems in Switzerland, noting that highly energy-efficient scenarios could significantly increase the relative potential of DHC systems operating with lower temperatures compared to conventional DHC – but also that these scenarios would shift the spatial distribution of energy demand from buildings. For planners and policy makers, this highlights the importance of co-ordinating the planning of heat supply and demand to avoid a mismatch between the capacity of local infrastructures and the actual density of energy demand under different policy goals.

- The spatial assessment of heat demand should therefore be accompanied by a similar evaluation of possible sources of renewable or waste heat – such as geothermal energy or waste heat from industry. Within the territory of Geneva, such activities are carried out under the umbrella of the Geothermie 2020 project, which is directed by the canton of Geneva with funding and implementation by the utility, Services industriels de Genève. This project builds upon existing knowledge of the subsurface to better understand the local potential for geothermal energy and to co ordinate the development of this potential along with complementary infrastructures such as DHC. Early results from the project have been promising: for instance, exploratory drillings in the commune of Versoix have evidenced potential from shallow aquifers. These aquifers could eventually contribute to the supply of renewable heat to the local DHC network. These results will supplement existing knowledge on subsurface conditions in Geneva, such as spatially explicit datasets on thermal conductivity and heat capacity, which are already available through the Services industriels de Genève portal.

www.geothermie2020.ch/

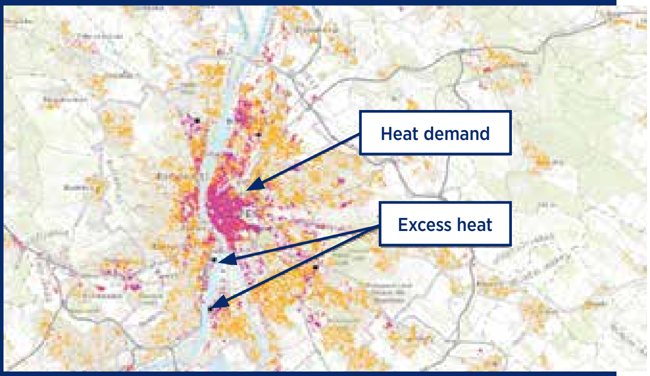

Source: Freepik

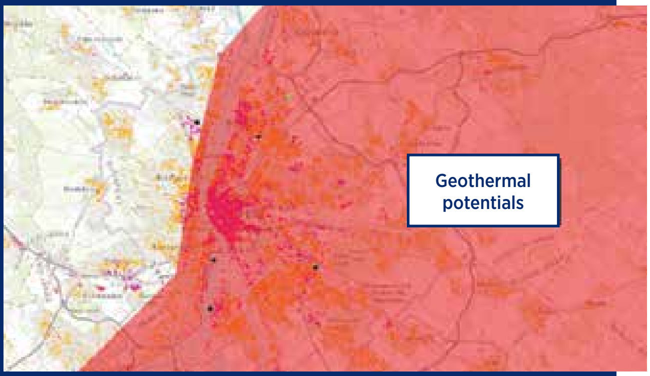
BOX 6 HEATING AND COOLING DEMANDS MAPPING TOOLS

PETA 4

PETA 4 is the latest version of the Pan European Thermal Atlas (Peta), an interactive map useful for district energy planning. PETA 4 can model heat demand to the hectare level. It also can identify areas with heating and cooling demand that have district energy potential. The map includes industries or installations with excess (waste) heat potential, prospective district heating networks, and renewable energy source availability including solar irradiation, geothermal and biomass. The Heat Roadmap Europe project series has used PETA 4 to map and quantify the spatial distribution of the significant elements that constitute the European heating and cooling market.

Examples to the right show heat demands and excess heat potential (top) and geothermal potential for the city of Budapest, Hungary (bottom).
https://heatroadmap.eu/peta4/





Hotmaps toolbox

The data and tool developed within the Hotmaps project, funded by the EU's Horizon 2020 programme, allow European public authorities to identify, analyse, model and map resources and solutions. This resource offers a cost-efficient way to supply the energy needs of their territories of jurisdiction.

Examples opposite show the modelled heating (top) and cooling (bottom) demands for the city of Budapest, Hungary.
www.hotmaps.hevs.ch/map

Thermos

Thermos (Thermal Energy Resource Modelling and Optimisation System) is an open-source, web-based software package designed to optimise local district energy network planning processes and to support sustainable energy master planning. It provides mapping and built-in energy demand estimations for European cities.
www.thermos-project.eu/resources/thermos-tool/

B.3.2 Identifying local heat resources

Just as it is important to understand heat demand, so is it important to have data on available heat sources. As explained in Part A, Section 2, strategic heat sources are typically either waste heat or renewable sources. These sources are often distributed over large areas, but require infrastructure such as district energy distribution grids to be utilised. These resources are often also low-temperature, which sets certain requirements to the grid. Modern district energy systems are better outfitted to exploit a larger selection of heat source options – with or without applying heat pumps – and to take advantage of thermal storage options (see Part A, Section 2.3, "Key enabling technologies") and Figure 23.

Strategic heat sources can thus include low-temperature decentralised renewables such as:

- geothermal heat
- solar thermal
- waste heat: both conventional and recovered from industrial processes or space cooling, such as in supermarkets and data centres, etc.

Bioenergy resources should also be assessed, as combined or hybrid systems may be a relevant solution. Considering a specific profile of heat demand, usually one or more main sources will be used continuously, and a backup source will be mobilised when the demand for heating is higher, which in most systems represents only a few days per year. In hybrid district energy systems using thermal storage, it is not even necessary to use one source continuously: the most suitable source will be used given its availability and cost of production at all times (see Figure 24). The most suitable solution depends on the local context. For large-scale systems, multiple energy sources will be required, and that thermal storage enables the exploitation of variable renewable energy sources.

Figure 23. **Diagram of a multi-energy district energy system**

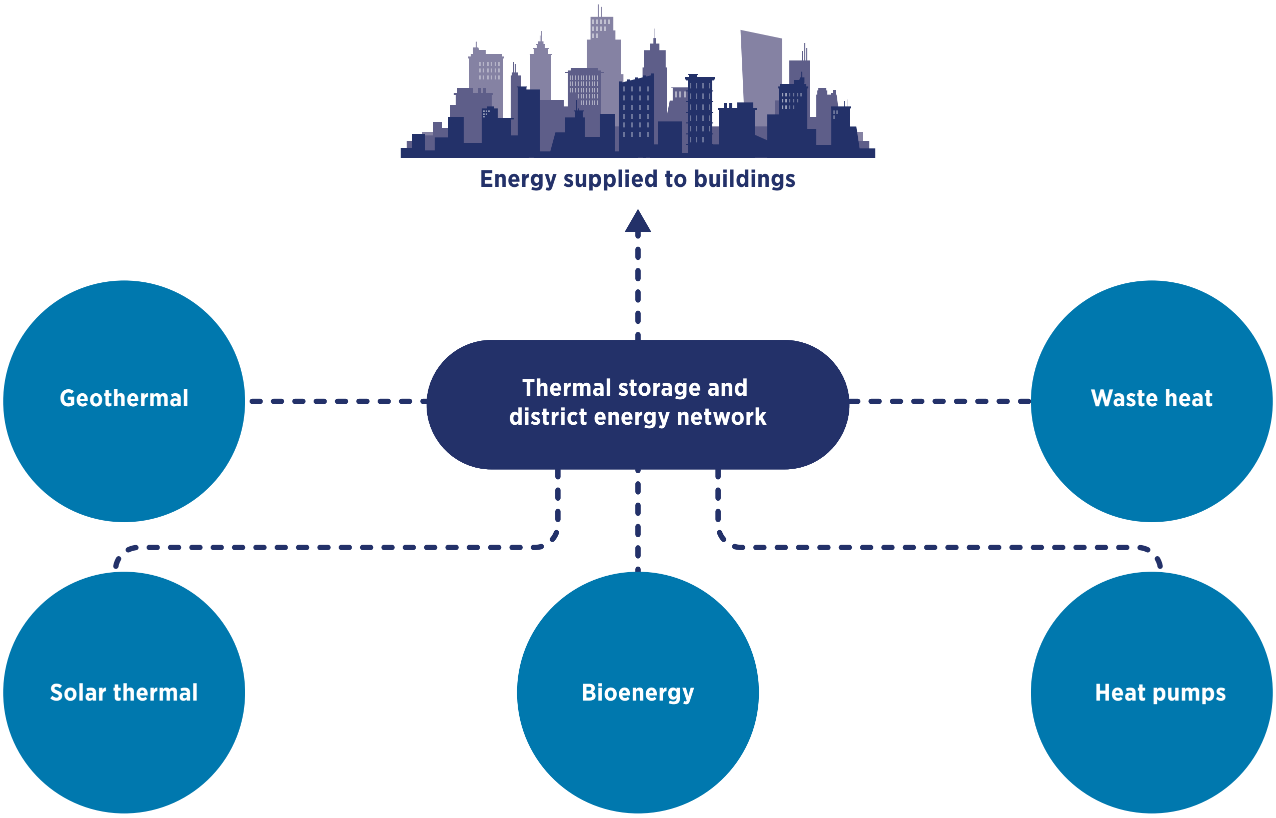
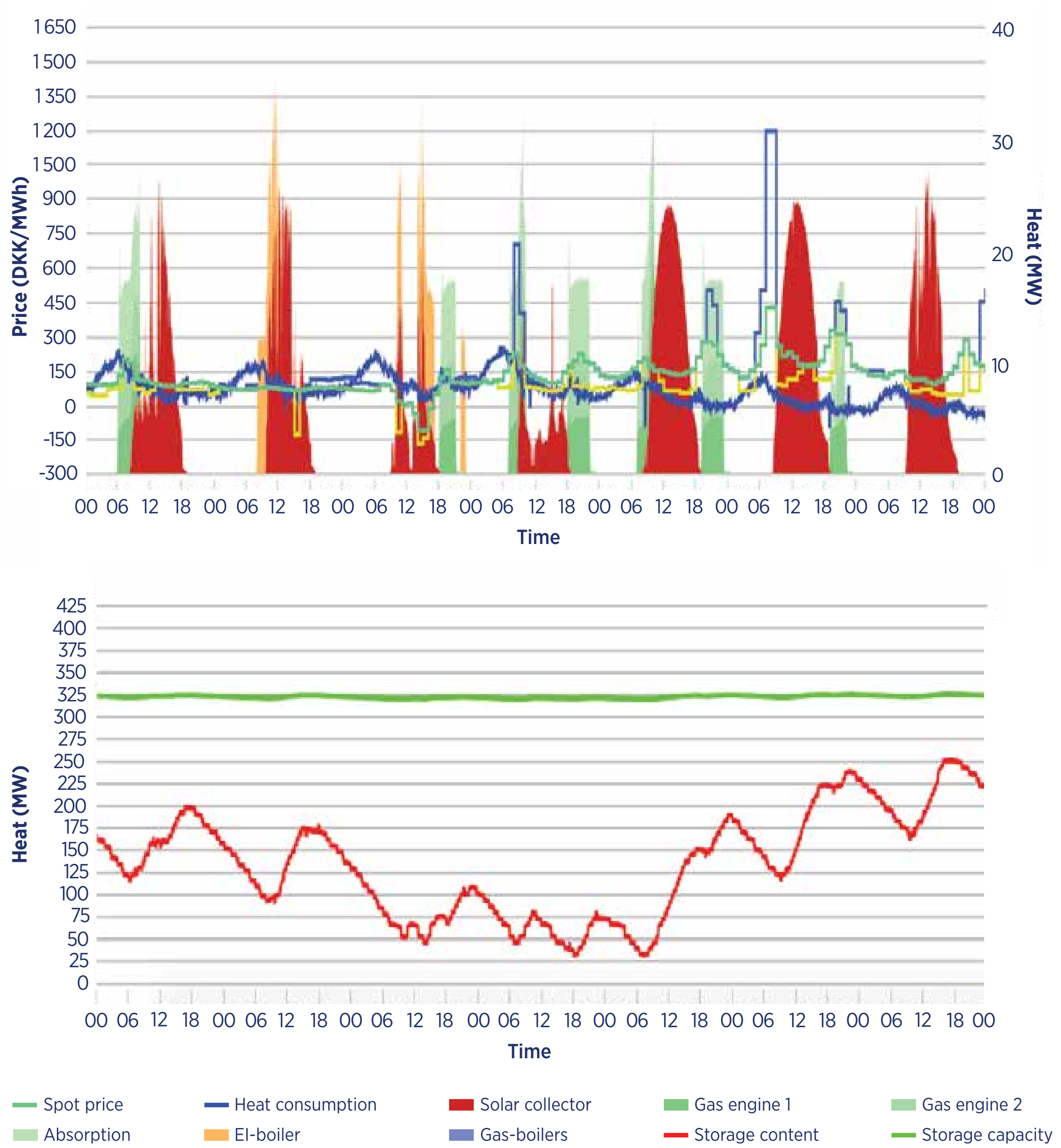


Figure 24. **Example of daily heat production of a hybrid district heating system using thermal storage**



DKK: Danish krone

Source: EMD International (www.energyweb.dk/saeby/?english&history)

The proximity of a potential heat source to the demand centre should be estimated and represented on a map. The availability of land for project development, information about access to land and potential conflict about its use should also be investigated. In addition, based on readily available literature and data, the level of certainty to which the resource can meet the demand for heating can be approximated before more detailed resource assessment can be carried out (Lund and Lienau, 2009).

The possibility of exploiting heat sources for heating and cooling is determined by location, temperature and temporality resource characteristics:

- Resource accessibility may be constrained by the limited geographical scope of urban areas (thus heat demand), given that it is often not economically viable to transport small quantities of heat over large distances. Therefore, the location (distance of the heat source to the heating/cooling grid and land accessibility) is critical. If the heat source is not in close proximity to the district energy network, the need for investments in new pipelines to make the required connections can reduce the solution's cost-effectiveness and become a reason not to use the heat source in the district energy system (Køhler Pedersen and Holm Christiansen, 2019). In addition, the longer the pipeline, the greater the heat losses. Any regulatory requirements such as permitting for land-use change or exploration of the energy source, in the case of geothermal, need to be established.

- Low-temperature resource characteristics, which vary based on the nature of the different heat sources and could be categorised as separate parameters (Køhler Pedersen and Holm Christiansen, 2019):

    - Temperature level: depending on heat sources' temperature levels and the district energy system operating temperature – and whether the heat is injected into the return or the supply line of a district energy system – it may be necessary to increase the temperature level using a heat pump to harmonise with the temperature of the actual system.

    - Temperature fluctuations: waste heat from industrial applications with a fluctuating temperature output can be viable. This can be achieved through combined connections, such as delivering to the supply line at high-temperature levels or to the return line when the waste heat temperature level is low.

    - Temporal fluctuation of the heat output and annual operation: waste heat from applications with a constant heat output and baseload renewable sources will be easier to integrate into a DHC system than those such as waste heat from air conditioning systems, which mainly generate excess heat in the summer.

    - Sustainability of the resource: Some sources may decline or even disappear over time. This issue concerns geothermal but mainly waste heat. How long will the heat potential be available? Some data centres may be established for only a couple of years, for example. In such a case, it is important to discuss the contractual duration of the heat supply with the operator.

> "Distributed renewable and waste heat resources require district energy grids, often with low-temperature specifications"

Geothermal

Geothermal energy for DHC purposes can be obtained from deep wells drilled to tap the heat contained in hydrothermal reservoirs as well as from shallow wells that tap the heat contained in ground water or shallow soil/rock. In regions that have known geothermal resources, the cost of exploration can be significantly minimised by using pre-existing data. This is true even in regions where hydrocarbon extraction has been carried out, but geothermal development may be limited. The data available from hydrocarbon exploration and exploitation can reduce conventional geothermal exploration costs. This is the case in the Île-de-France region (France), close to Paris: due to old oil drilling tests, a precise public map of the geologic layers was created and temperature gradient measurements made by the public french agency for geothermal. Additionally, options for co-production (or the possibility of using heat exchangers in idle wells) should be investigated (Hickson *et al.*, 2020b) as possible lower-cost options in areas where idle wells are located close to possible heat demand. Furthermore, the utilisation of waste heat from existing geothermal power plants for DHC through cogeneration could also be investigated.

Several tools have been developed to help decision makers at the local and national levels plan for the utilisation of geothermal potential. Some of these tools, such as online geographical information system (GIS) systems, are used to estimate the potential of the geothermal resource based on the available data. They are also used to estimate the potential of the resource for utilisation by defining other relevant parameters such as the most appropriate technologies, existing population centres, economic viability and existing enabling infrastructure such as district heating networks. Box 7 presents some examples of the available tools for facilitating decision making to utilise geothermal resources.

At the project level, exploring and proving the existence of a geothermal resource can be a highly technical and capital-intensive activity. Geothermal exploration involves detecting the presence of a suitable geothermal resource in the subsurface, determining its physical extent, quantifying its energy content and establishing its chemical properties. This can be done at a national, regional, reservoir or project level. The standard techniques for establishing the existence of a geothermal resource include geological mapping, geophysical measurements (*e.g.*, resistivity, gravity and seismic measurements), geochemical analysis and heat flow measurements.

Data obtained from these techniques are used to infer the subsurface geothermal conditions, develop a geothermal conceptual model and estimate the resource potential, followed by drilling. Municipalities may lack the technical capacity to undertake these tasks, so care should be taken to engage with capable and effective partners in both establishing technical potential and communicating clearly the risks and potentials to decision makers, civil society and citizens. Sometimes, the expertise to carry out exploration can be found within provincial/state or national geological surveys.

Geothermal data can, however, be obtained and analysed by making use of technical assistance programmes offered by states/provinces, national and international agencies, which could provide expertise to analyse the geothermal data for resource estimation purposes and facilitate technology transfer. In addition, a *Geothermal Exploration Best Practice Guide* developed by the International Geothermal Association proposes the most appropriate tools and techniques to be used by geothermal developers to locate, estimate the potential and predict the productivity characteristics of geothermal resources (IGA and IFC, 2014).

BOX 7 TOOLS FOR ASSESSING UTILISATION POTENTIAL OF GEOTHERMAL RESOURCES

www.darlinge.eu/#:~:text=Welcome%20to%20the%20Danube%20Region%20Geothermal%20Information%20Platform%20(DRGIP)&text=DRGIP%20has%20two%20main%20parts,information%20on%20some%20selected%20topics.

- **Danube Region Geothermal Information Platform (DRGIP).** The DARLINGe project developed a methodology for studying the geothermal resource in six countries of the Danube region (Bosnia and Herzegovina, Croatia, Hungary, Romania, Serbia and Slovenia). The partner countries provided the geothermal data for the project, which was diverse in terms of content, format, density and level of knowledge. The data were used to determine a generalised regional geology of the Pannonian Basin, which formed as a result of crustal extension and was later filled with sedimentary material. The hydrothermal system which consists of fractures in the basement rock as well as in the sedimentary layers, and the geothermal conditions are characterised by a positive temperature gradient averaging 45°C/km. A conceptual model of the Pannonian Basin defining the lithology and porosity of the upper sedimentary layers as well as the basement rock, subsurface temperature distribution and the extent of the reservoir was also developed. On the basis of this information, the geothermal resource in this region covering an area of approximately 100 000 km^2 was assessed at a regional level (Nador, A. *et. al*, 2019).

- **Database of wells drilled in Geneva.** It is the responsibility of the company that drills the well to register the characteristics of the underground to the relevant authority.
  www.etat.ge.ch/geoportail/pro/?mapresources=GEOTHERMIE%2CGEOLOGIEGEOMOL%2CGEOLOGIE&hidden=GEOTHERMIE%2CGEOLOGIE_GEOMOL

- **District Heating Development Action Plan.** In Hungary, the potential for geothermal district heating has been assessed in the District Heating Development Action Plan, under the framework of the National Energy Strategy. As emphasis was on the exploitation of geothermal resources, the Action Plan includes two lists with potential development sites: the first contains the settlements with existing district heating systems, where the current heat source can be replaced with geothermal energy. The second includes a list of locations where geothermal energy meets the heat demand, making them hotspots for developing district heating systems based on geothermal resources. Although these lists are a product of preliminary research, they can be used as a guide for further assessing the potential of the region.

- **Coal Authority's Interactive Viewer and web services** - a web map by the British Geological Survey and the Coal Authority showing the location of abandoned mines and their temperature gradients.
  https://mapapps2.bgs.ac.uk/coalauthority/home.html

BOX 8 TOOLS FOR ASSESSING UTILISATION POTENTIAL OF SOLAR THERMAL RESOURCES

- Solar radiation data can be derived from **Meteonorm software.** https://meteonorm.com/en/

- The **Photovoltaic Geographical Information System (PV GIS)** online platform provides solar radiation data that can be used to assess solar thermal plants. Though created for photovoltaic, the platform permits the calculation of solar radiation on tilted surfaces. https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

- **National solar maps,** for example those developed by national meteorological institutes, can be used as assessment tools. A good example is the data available from the Australian Bureau of Meteorology. www.bom.gov.au/climate/data-services/solar/index.shtml

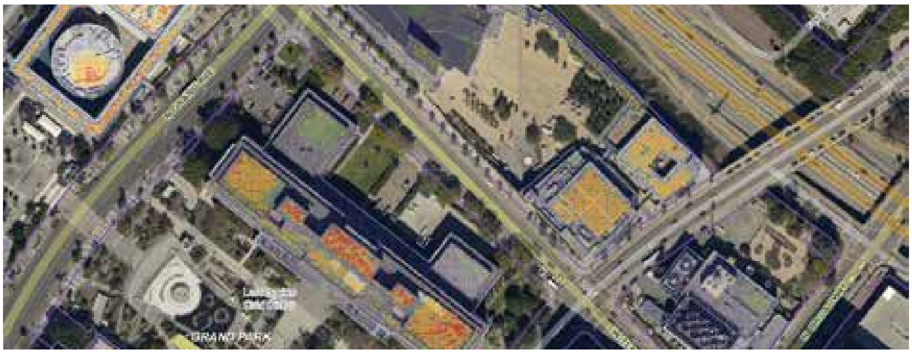
- **IRENA's Global Atlas for Renewable Energy** displays maps for different energy resources on a web-based platform, allowing users to view the resource maps for different locations, including maps for solar radiation. https://irena.masdar.ac.ae/gallery/#gallery

- **Power Data Access Viewer** is a web-based mapping application that provides tools for visualisation, data subsetting and charting available from the Langley Research Center of the United States' National Aeronautics and Space Administration (NASA). https://power.larc.nasa.gov/data-access-viewer/

Solar thermal

To assess the feasibility of solar district heating (and/or cooling) plants, the first parameter to consider into account is the available solar resource. Different tools and software are available to provide these data. Some of them are presented in Box 8. The system designer and installer can estimate the energy available to be harnessed in those areas and decide which technology is suitable for installation.The available locations for collectors (and storage) need to be defined. Two types of collector installation can be considered: roof-mounted collectors and ground-mounted collectors. The least expensive solution is usually ground-mounted collectors unless land prices are high. In addition, the length of the pipeline to the heat offtaker(s) should be within an economical distance to keep the costs low (Schmidt and Miedaner, 2012). Regarding roof-mounted collectors, solar cadastres could be developed at national, regional or local levels. These are online portals that represent the solar energy potential of the roofs of cities and municipalities. They enable conclusions to be drawn about the suitability of individual buildings for the installation of solar systems. For example, the Los Angeles County Solar Map shows the potential solar capacity of buildings' rooftops in Los Angeles County (California), as well as existing solar installations and solar provider locations (Figure 25).

Figure 25. **Rooftop solar map application for Los Angeles County (United States)**



🟥 Excellent (>4.9 kWh/day)
🟧 Good (4.0 to 4.9 kWh/day)
🟩 Poor (3.3 to 4.0 kWh/day)
🟦 Not advisable (<3.3 kWh/day)

Source: Los Angeles County (n.d.); https://apps.gis.lacounty.gov/solar/m/?viewer=solarmap

Waste heat

DHC's waste heat potential depends on heat demand and where waste heat sources are located. A study for Danish cases showed that, with the assessment of waste heat per production unit – combined with industry-specific temperature profiles and building spatial analysis – the potential is inconsistent. Specifically, it scores high in industrial regions close to medium size cities (Bühler *et al.*, 2017). This is anticipated to be the case in other countries where waste heat is more readily available close to industrial complexes, large buildings or other infrastructure.

Among the methods used to assess the potential are surveys that include questionnaires, reports and databases, and estimations of top-down, bottom-up or combined approaches. Some available studies and tools are presented in Box 9.

BOX 9 TOOLS FOR ASSESSING UTILISATION POTENTIAL OF WASTE HEAT RESOURCES

- Different studies carried out to collect data on industrial waste (or excess) heat and estimation of its potential on a country level and per sector are useful for supporting the need for further exploiting the excess heat and adapting strategic policies on a national or regional level. However, they lack local data, which are vital for identifying realistic/feasible cases for excess heat use in the DHC (Brückner *et al.*, 2014; Miró, Brückner and Cabeza, 2015; Papapetrou *et al.*, 2018).

- The EU-funded project ***Waste heat*** provides a manual for assessing waste heat potential and a toolbox involving investment, funding and permits.
  www.waste-heat.eu/

- The EU-funded project ***ReUseHeat*** assessed the potential of the accessible excess heating in Europe from four sources: data centres, metro stations, service sector buildings and wastewater plants.
  www.reuseheat.eu/

- ***Pan-European Thermal Atlas*** (Peta 4.3) developed under the EU-funded *Heat Roadmap Europe* provides spatial data on excess heat sources and heat synergy regions.
  https://heatroadmap.eu/peta4/

- Tools and software suggested by the Office of Energy Efficiency and Renewable Energy, US Department of Energy.
  www.energy.gov/eere/amo/articles/waste-heat-recovery-resource-page

- ***Project Memphis*** provides a tool to map and evaluate waste heat potential from various sources by using open source data. This is especially helpful for identification of smaller and low-grade waste heat sources.
  http://blogs.hawk-hhg.de/memphis/
  and
  http://cities.ait.ac.at/uilab/udb/home/memphis/

- ***Project HotCity*** identifies waste heat potential using a gamification approach in which citizens collect data for mapping waste heat sources by photographing, for instance, chimneys and recooling systems, and by conducting Internet research, completing on-site surveys, and by using online maps, etc.
  https://cities.ait.ac.at/projects/hotcity/
  (in German)

B.3.3 Quantifying and assessing heat-saving potentials vs. sustainable supply

Energy savings are important to consider when completing a SHCP analysis. Saving 1 kWh of energy might very well be cheaper than supplying one. One approach is to assess the marginal costs of different energy-saving measures and implement the ones that are cheaper than the cost of sustainable energy supply. Such an approach is depicted in Figure 26. This approach can be applied at national, regional or local level.

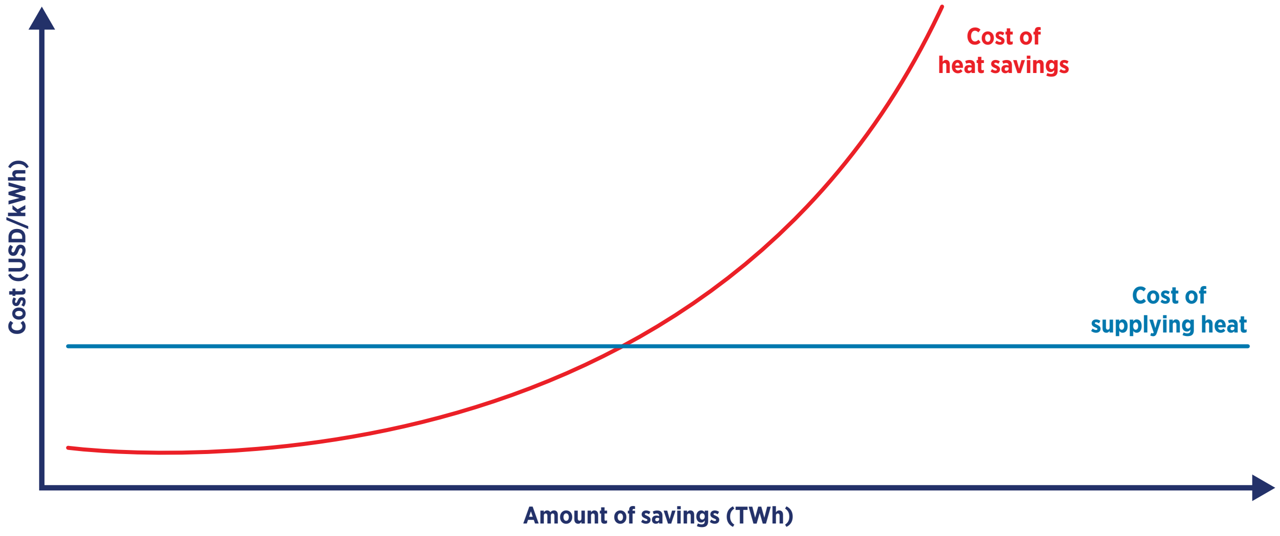
Energy efficiency measures have a supply chain effect (see Figure 27). A decreased energy demand can also translate into less capacity needed in the distribution and generation side of the energy system. For new district energy systems to be planned or in refurbishment projects, this is a very important concept to include as new infrastructure can be adjusted to new demand levels. Lower energy demand can also translate in higher shares of renewable energy and enable the transition from third to fourth generation district energy.

Building renovation measures are usually implemented with very long timeframes due to their high upfront investment costs, and it is not always feasible to postpone the realisation of a district energy project until certain energy efficiency potentials have been realised. Certain future-proof measures exist for realising energy savings (such as heating control systems and heat measurement), enabling consumption-based billing. This is an effective tool for involving customers.

DHC is still achievable even with the introduction of energy efficiency measures. For both existing and new networks, energy-efficient buildings can effectively flatten peaks and boost the performance and feasibility of the district energy network as a whole. A new low-temperature network can be designed for new or renovated energy-efficient buildings, enabling the connection of additional consumers to the grid and the lowering of the existing network's peak demand. The relatively small number of hours per year with peak demand are often the most expensive in district heating with regard to operating expenditure and/or capital expenditure. This is because required capacity may have few full-load hours per year (Trier *et al.*, 2018).

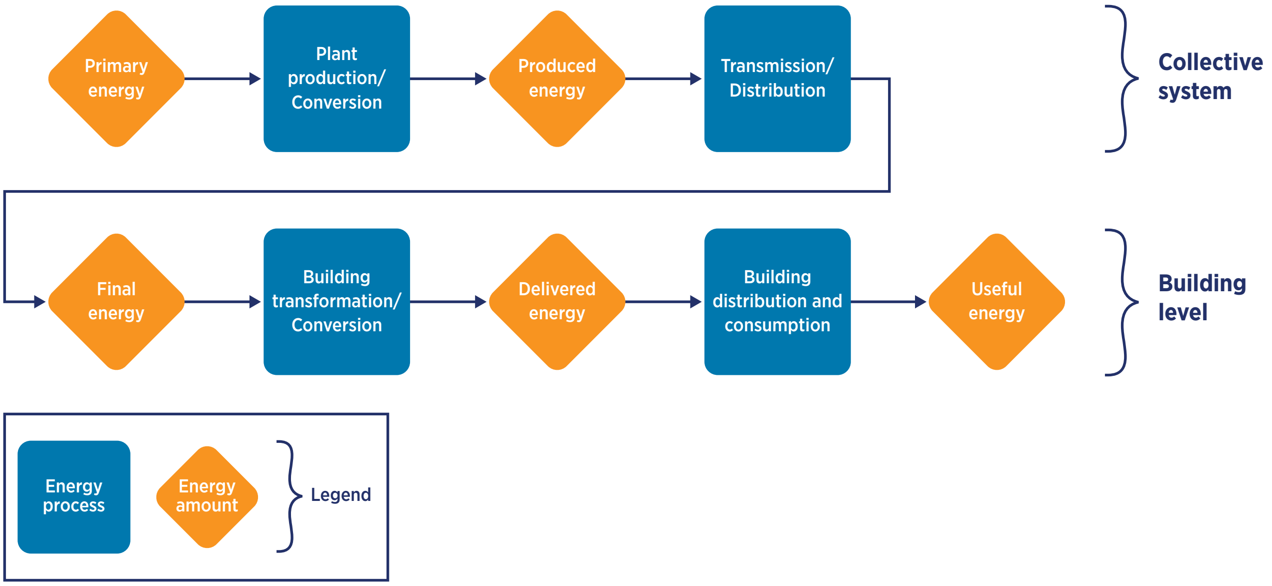
An efficient and well-functioning heating system will facilitate the integration of low-temperature energy sources. These kinds of heating systems need well-designed and operated district heating networks as well as good consumer connections and functional in-house installations for DHW preparation and space heating (Olsen, 2014).

Figure 26. **Approach to assess feasible level of energy savings**



Based on: Paardekooper *et al.* (2018)

Figure 27. **Energy efficiency value chain from primary energy to useful energy**



Source: Mathiesen *et al.* (2019)

Transitioning to a new generation district heating system does require "right sizing" in terms of compatibility with the existing building stock and proper design of networks and consumer connections. In new development areas with low-energy consumption buildings the development of fourth generation district heating systems can be especially suitable. However, in cities with an existing district energy system, this may mean the need for adapting installations and potential retrofitting of buildings.

Three main situations can be anticipated: retrofitting an existing district energy system, development of a new district energy system in an existing area, and a new district energy system in a new development area that nevertheless has some common characteristics (illustrated in Table 4).

As shown in Table 4, the retrofitting of an existing district heating system is the situation that will pose the most significant challenges because the premises and the network were designed for rather different conditions. Schemes for new urban areas will actually be the easiest to realise because both the network and the internal systems of the consumers can be planned to operate with low temperatures. A new network in an existing area will be an intermediate case because it is possible to design the network for low temperatures, but it will be more problematic to alter consumers' installations in existing buildings.

Part B, Section 4 presents the main elements that should be considered to assess and facilitate the compatibility of existing buildings and networks of low-temperature supply.

Table 4. **Development scenarios for new generation of district heating and potential modifications needed to the system elements**

	EXISTING DISTRICT HEATING SYSTEM	NEW DISTRICT HEATING SYSTEM
Existing area	**Adaptation** of consumers' connections, substations, and in-house installations for space heating and DHW supply. Potential need for **retrofitting** the network, if the network is not oversized.	**Adaptation** of consumers' connections, substations and equipment for space heating and DHW supply.
New development area	Low supply temperature is particularly **suitable** to new low-energy buildings with low-temperature heating installations, *e.g.* floor heating or low supply temperature radiators.	

B.3.4 Establishing scenarios for heat supply

The purpose of estimating demands, supply and potentials for energy savings is to establish a scenario that fulfils these boundaries and harnesses locally available resources. When establishing these scenarios, several elements are important to keep in mind:

- the scope of energy systems analysis
- the perspective of energy systems analysis
- the timeframe of energy systems analysis.

The scope is important to consider, as heating and cooling are not separate parts of the system, but should be seen in connection with other energy domains, as electricity or gas supply and transport demands. Supply potentials should be considered, taking all energy demands into account, as there will be competition for scarce resources. Box 10 presents some planning tools evaluated within the IEA DHC Annex TS1, including the simplified planning tool for DHC that has been developed.

Considering the perspective of the analyst is vital, as different approaches can yield very different results. Differentiating between analyses from the perspective of society and that from a business perspective is important because a business perspective solely based on market prices does not take into account all relevant aspects for a society.

A societal perspective should consider aspects such as climate change, air pollution and job creation (Djørup *et al.*, 2019b). Such aspects can be labelled as externalities. Externalities can prove difficult to assess and quantify (especially to assign a monetary value) and are, per definition, not included in market prices, which are often not sufficient for a thorough analysis of socio-economic potential.

Including all externalities is only possible in theory, not in practice. These assessments will likely be influenced by local matters, ways of accounting, the urgency of impacts and more. Two ways of dealing with this issue are the following:

- Make the assumptions used in assessments clear and available. This will allow transparency and democratic debate about whether they are reasonable or not. This will not be possible if they are not clearly stated.

- Carry out technical and economic assessments in several steps. This also highlights the importance of externalities and will show where, in the analysis, they have an impact.

The socio-economic assessment should assess potential supply options from the perspective of society and provide guidance for local and national authorities on which technical scenarios align with the goals and scope set for the SHCP (see Part B, Section 1). When a socio-economic assessment of potential scenarios for heat supply has been made, this can then be compared to a business-economic evaluation. If the two assessments align and yield similar results, then investors can go ahead and invest in the scenarios that are most feasible to society as well. If the two do not align and provide different results (as often will be the case), then it is up to the policy makers to assess where conflicts arise and why the two analyses do not reach the same conclusion. This will potentially point towards externalities that are important to internalise in market prices or other barriers hindering the deployment of new sustainable technologies.

> "Heat supply scenarios reflect their underlying analytical scope and time frame"

BOX 10 PLANNING TOOLS FOR DISTRICT HEATING AND COOLING

- Energy system models simulate the movement of energy from its primary source to its transformation into useful energy and transmission to final utilisation.

  EnergyPLAN: A widely used model to simulate the operation of various sectors in national energy systems.
  https://energyplan.eu

  EnergyPRO: A tool to analyse energy projects environmentally and financially and can facilitate decision-making when it comes to the development of new energy plants.
  www.emd.dk/energypro/

  KOPTI: A model for estimating the production of energy in a location where district heating is to be implemented.

  TIMES Local: A model that provides solutions for the preparation of long-term energy projects. It supports cost-efficient the planning of sustainable energy systems.
  https://iea-etsap.org/

- Thermodynamic modelling of heat grids, their hydraulic and thermodynamic characteristics, and the different temperature levels of renewable energies needed to feed into the heat grid are complementary to energy system modelling.

  Termis: a tool for modelling the operation of a district heating system by simulating operating conditions based on realtime network data.
  https://it.kelvin.pl/en/termis-district-heating-network-management-system

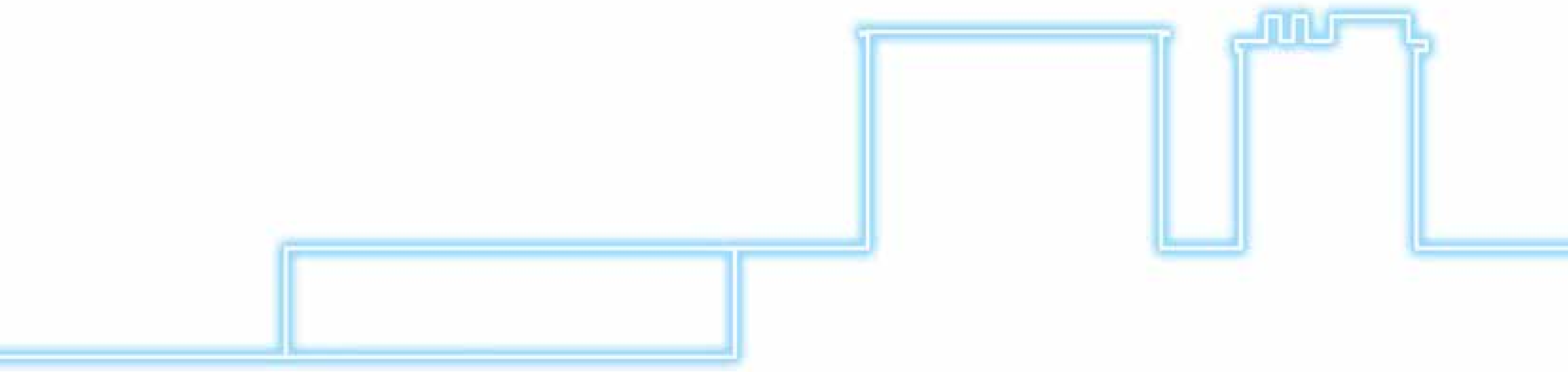
- Other useful tools include the ***District Energy Concept Adviser***, which compares different energy concepts (*e.g.*, local district heating and gas condensing boilers); ***EME Forecast***, a time series model that forecasts heat and electricity loads; and ***Exergy Pass Online***, an analytical tool for the exergy of buildings' resource consumption.

- The **IEA DHC Annex TS1** developed ***Easy District Analysis (EDA-Tool)***. Based on an assessment of 12 tools, EDA-Tool is intended for use by urban planners and utilities. It can be used to analyse the energetic, economic and ecologic aspects of low-temperature energy systems for comparison with other heat supply systems. EDA-Tool can also be used to evaluate whole districts.

- ***Thermos*** is a tool under development combining state-of-the-art energy system data and models in an easy-to-use, map-driven open-source web-based application.
  www.thermos-project.eu/

  The EU-funded project ***INDIGO*** developed an open-source stand-alone planning tool for evaluating the performance, benefits and potential of a district cooling system. The tool enables analysis of a cooling system for a defined area consisting of a group of buildings.
  www.indigo-project.eu/

- ***INDIGO Planning tool – IndPT***: A model to assess the financing and environmental impact of district cooling systems.
  https://zenodo.org/record/3891384



Summary of challenges and recommendations for assessing and mapping heating (and cooling) demand and energy resources

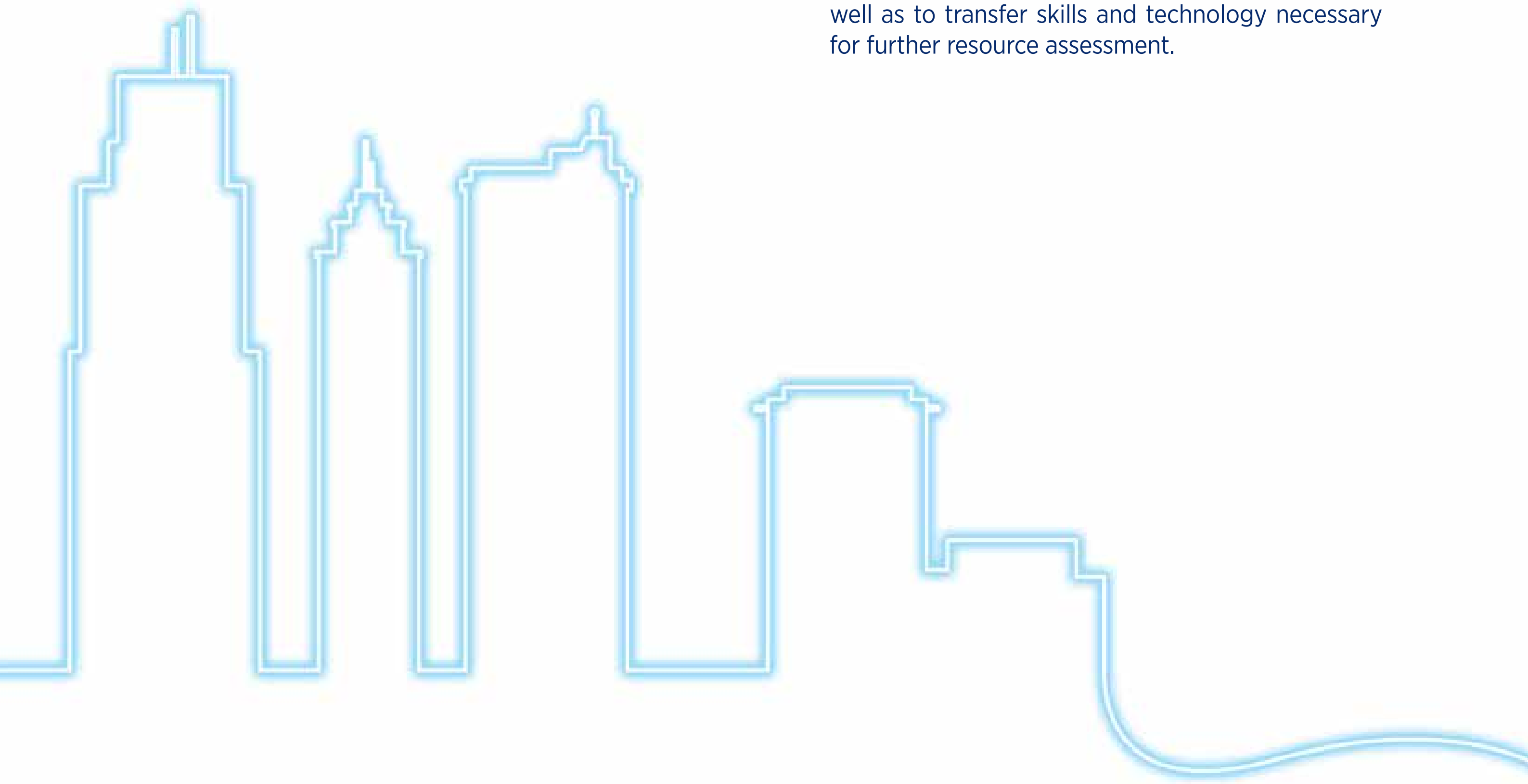
This step has outlined a methodology for how to make a technical assessment of heating and cooling supply. Gaining knowledge about demands, supply and potential savings – and estimating a balance between these elements – is important. These activities can be undertaken by the authorities to facilitate the development of district energy systems.

- ➡ Measure the actual demand for heating and cooling to generate knowledge of the spatial and temporal distribution of consumption. This will create certainty to support investment in high capital cost district energy projects and allow for individual metering and billing, which are incentives for decreasing energy consumption (especially during peak hours or seasons) and consumer involvement. If actual measurements are not available, model or estimate demand to provide inputs for decision making. Existing tools such as GIS developed to help assess the interplay between heat demands (including temperature levels), available infrastructure and heat resources are available and should be promoted, or created if they are lacking.

- ➡ Identify and quantify renewable energy resources that are available locally for heating and cooling. Several tools are available that have been developed to quantify local energy resources and support decision making by matching resources with demand.

- ➡ Consider the energy saving potential of the existing energy system before developing new supply infrastructure. If the implementation of energy efficiency measures has a lower marginal cost than the development of new supply capacity, then this option should be implemented. Energy efficiency measures are however not a substitute for DHC systems, but they complement each other in the long term.

- ➡ Make decisions on which technical scenarios for heating and cooling are to be implemented based not only on business-economic considerations but also more importantly on socio-economic considerations. This will ensure that projects address wider societal goals such as decarbonisation, job creation and air pollution mitigation. For energy sources such as geothermal, which are highly specialised and for which the assessment and quantification expertise might be lacking within the local authorities' workforce, make use of industry best practices and technical assistance services from specialised companies or institutions to analyse data and estimate the resource potential as well as to transfer skills and technology necessary for further resource assessment.



B.4 Integrating low-temperature supply into existing buildings and district heating networks

From a technical perspective, the integration of new heat sources into existing district energy systems is influenced to a large extent by the difference in temperature between the operating system design temperature and the heat source. For example, medium- and high-temperature geothermal resources present no impediment to their integration in existing systems and buildings. Adjustments may be necessary, however, if the heat source temperature is lower than the network's operating temperature.

The technical challenges which arise when deploying a fourth generation district heating system (see Part A, Section 1.2) that operates with lower distribution temperatures than previous generations (over 70°C in first to third generations) can stem from either the pipe network or the building stock, and they will depend on what application it is intended to cover (Volkova, Mašatin and Siirde, 2018).

Transitioning to a new generation of district heating requires first and foremost an analysis of the compatibility with the consumer connections. Furthermore, a consideration of building stock, proper network design and a building renovation strategy aligned with a strategy for the transition to a low-temperature and sustainable supply are all needed. All of this will work to ensure cost-efficient decarbonisation and avoid lock-in effects to solutions that are not compatible with long-term objectives (*e.g.*, condensing gas boilers). This assessment is also an opportunity to consider how to integrate cooling in the existing district heating system.

The technical challenges to take into account to assess these compatibilities as well as the possible solutions are detailed in the following sections.

B.4.1 Assess compatibility with existing building stock

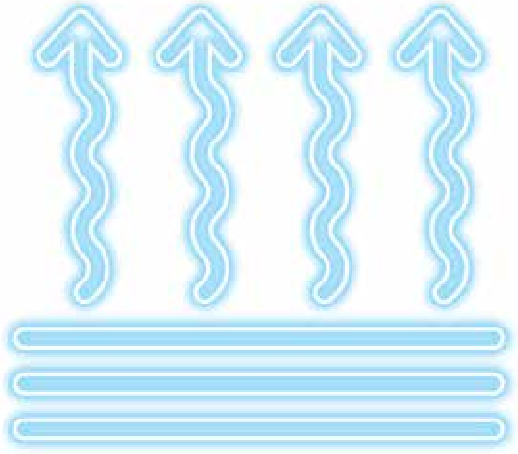
District heating substations

District heating substations (or energy transfer stations) link the district heating network to the consumers' installations. Their function is to transfer the thermal energy between them, by supplying the building's heating system and DHW preparation.

Adequate substation performance is crucial for attaining low system temperatures, but they frequently malfunction. The faults oblige district heating operators to maintain supply temperatures at higher than needed levels and cause higher return temperatures than necessary. Fixing these errors must be a priority if temperatures are to be lowered. For quick detection of temperature faults, automatic metering systems allowing continuous monitoring of substations should be installed (Frederiksen and Werner, 2013; Gadd and Werner, 2014). Another advantage of substation monitoring is enabling consumption-based billing (The World Bank, 2012; European Bank for Reconstruction and Development, 2018).

In comparison to central fossil-fuel boilers, a major advantage for district heating substations is that they require much less space in buildings, as illustrated in Photograph 5.

There are multiple variants of district heating substations (see, for example, Frederiksen and Werner, 2013). However, this report will address only the two most common categories: direct connections and indirect connections, as illustrated in Figure 28. Their respective advantages and disadvantages are presented in Table 5. Obviously, direct systems can only be applied provided that the consumer counts on a hydronic heating system. In the case of air heating systems, such as in the Canadian Drake Landing Community (Dalla Rosa *et al.*, 2014), only indirect connections can be applied.

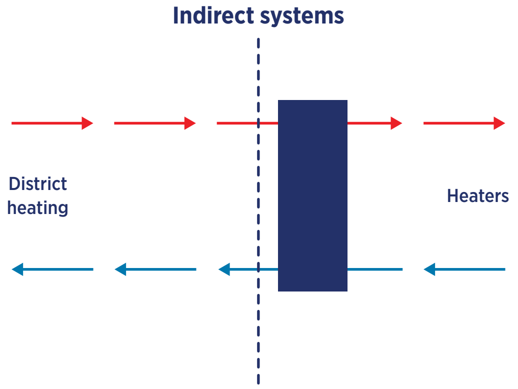


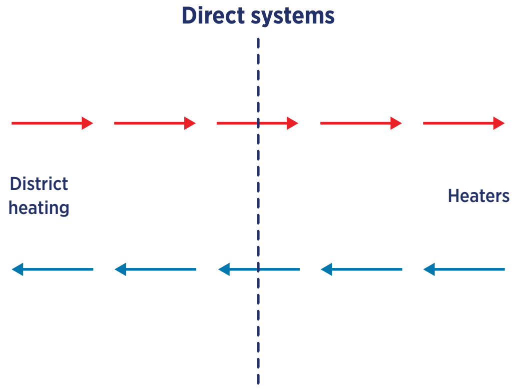
Photograph 5. **Gas boilers in a gas boiler room (left) and a substation in a building in Belgium (right)**


Source: Shutterstock


Source: Luis Sánchez-García

Figure 28. **A schematic of direct and indirect space heating systems**





Source: Frederiksen and Werner (2013)

Table 5. **Advantages and disadvantages of direct and indirect substations**

SUBSTATION TYPE	ADVANTAGES	DISADVANTAGES
Direct	• They can function with lower temperatures since there is no heat exchanger and hence, no temperature penalisation. • They are rather simple and therefore less prone to errors. • They are less expensive due to their simpler architecture.	• The pressures in the district heating network are limited to the maximum pressure withstood by consumers' heating systems. • Leakages can be more damaging since there is a nearly endless supply of water coming from the network.
Indirect	• A clear boundary exists between the district heating installations and consumers' heating installations. • They allow higher pressures in the network. • Leakage from the network into consumers' premises is less likely.	• They are more expensive due to their more complex architecture: they require a pump, expansion tank and control system. • They are more prone to errors.

Source: Frederiksen and Werner (2013)

Space heating

The temperatures required to provide space heating to a dwelling or premise from the tertiary sector (commercial and service sector) depend on a series of parameters: the building's thermal envelope, the heating equipment, the control system and the consumers' behaviour. In the case of hydronic systems, hydraulic balancing is also an important parameter. Hence, a reduction of the supply temperatures to a building's heating system will need to address all these elements.

Firstly, poorly insulated buildings not only consume more energy for heating and cooling but also lead to higher peak loads as their thermal inertia is rather low (Frederiksen and Werner, 2013). The thermal inertia plays an important role on the instantaneous load of a system since poorly insulated buildings increase their energy demand soon after a drop of the outdoor temperatures, whereas well-insulated buildings take a longer time to react.

Refurbishment of the building stock can bring about a decrease in the energy requirement and a significant drop of the peak loads. It can also enable further decreases of the peak loads thanks to demand response management (Pedersen, Hedegaard and Petersen, 2017; Johra, Heiselberg and Dréau, 2019). In the latter case, the building can be pre-heated to avoid peaks, which allows lower temperatures all year. In this context, policy makers should prioritise poorly insulated buildings and the largest consumers when implementing building renovation policies. A district-level approach to building renovation that prioritises large consumers, like social housing and public buildings, may also represent an opportunity to secure the bulk of the demand for a new district heating and/or cooling system.

Another benefit of heating load reduction following a building's renovation would be the reduction of the temperatures needed in the heating equipment, as higher heat loads require higher temperatures for the same emitters.

Secondly, the heating equipment may have been designed for the high temperatures enabled by fossil fuels, since higher temperatures render smaller sizes of the heating equipment and hence, lower investment costs. This problem can arise regardless of the specific heating equipment utilised to warm a building up, be it a hydronic system or air. In either case, a type of heat exchanger will be needed between the district heating network and the indoor air, for example, radiators in a hydronic system. For instance, radiators in Sweden were designed until the 1980s for temperatures between 60°C and 80°C (Frederiksen and Werner, 2013).

The consequence of insufficient sizing of the heating equipment is that low-temperatures fluids can only be of use during the milder parts of the heating season (Østergaard and Svendsen, 2016a; Tunzi *et al.*, 2016; Østergaard and Svendsen, 2016b). Regulations for new buildings and renovations ought to promote more generous sizing of the heating equipment so lower temperature fluids can be employed. For example, the new Spanish regulation for heating installations, which is still under discussion, would require a maximum supply temperature of 60°C (Spain, 2020).

A number of actions can be taken to tackle the issue of insufficient sizing of heating equipment. These include renovations such as the aforementioned building renovation that would lead to lower heat loads and therefore would directly enable lower temperatures to be used. Furthermore, changes in the heating equipment may also be implemented whether the building is refurbished or not. Finally, alterations may be made to the apparatuses themselves as well as the control equipment or the consumers' patterns, which is addressed below.

Floor heating is well suited for a low supply temperature (Averfalk and Werner, 2017; Schmidt *et al.*, 2017). However, it requires extensive refurbishment that may prove to be excessively costly and if the control equipment is inadequate, the return temperatures could be higher than expected. The installation of larger radiators could bring about the same benefits of lower operating temperatures at a lower cost. These devices can operate with arbitrarily low temperatures and are also capable of returning district heating water at temperatures slightly above room temperature. However, caveats must be made with regard to radiators: convectors ought to be avoided and high panel radiators need to be employed to enable enough cooling in the water (Svendsen, Østergaard and Yang, 2017).

Another option could be to use air heating as this is usually supplied at temperatures slightly above the set-point temperature. Yet air heating cannot achieve the same comfort levels as radiators or floor heating due to the different temperature profile inside a room (Nilsson, 2003).

The control equipment is crucial for the correct functioning of a heating system. Thermostatic valves and automatic balancing valves fulfil this function adequately. They adjust the flow through a radiator, providing the needed heating power and thus maintaining the set indoor temperature, but also minimising the return temperature to the district heating system (Tunzi *et al.*, 2016; Zhang.*et al.*, 2017).

Their absence can give rise to discomfort as the indoor temperature may be insufficient or excessive, and poor cooling of the return water may occur. The latter may have dire consequences for the performance of the district heating system, as the network may not be able to cope with the increased flow.

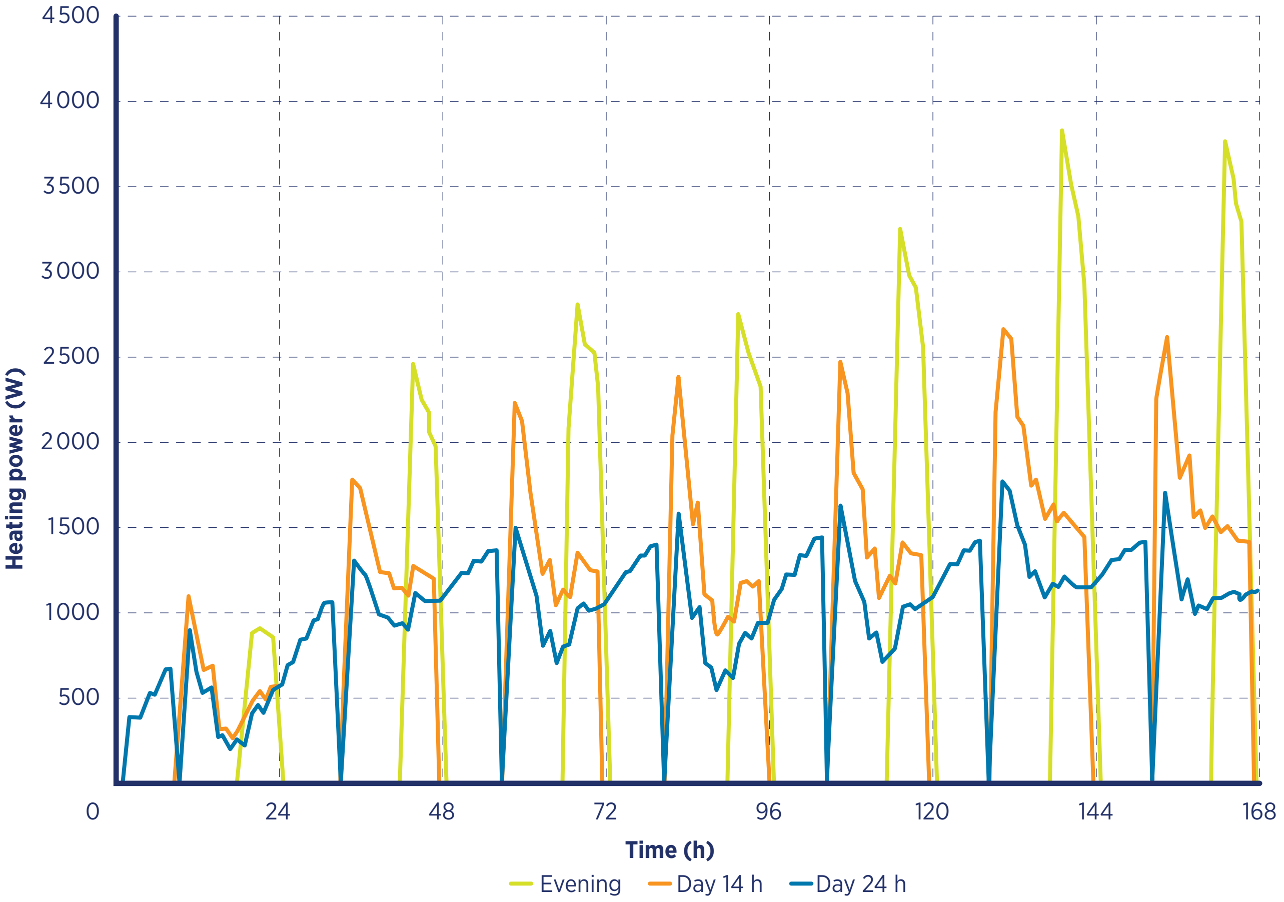
Consumer behaviour can also hinder the deployment of low-temperature systems. A frequent problem is the utilisation of periods with set-backs. These provide a reduction of energy consumption whose magnitude will be highly influenced by the thermal envelope, but the heating system will experience a higher load once they are reconnected (Frederiksen and Werner, 2013). Examples of this type of behaviour can be observed in Italian district heating networks (Noussan, Jarre and Poggio, 2017; Manente *et al.*, 2019) or in Belgian households (Jebamalai, Marlein and Laverge, 2020). In this case, radiators will necessitate higher temperatures than otherwise necessary, with consequently lower network efficiency and flexibility (or with higher infrastructure costs to guarantee the desired flexibility).

Figure 29 depicts the heating power required by a dwelling with different heating schedules and shows how the heating power (and thus the temperature) is rather higher when set-backs are applied. For example, in the Evening schedule, the heating system is on for a few hours a day (5 hours).

When it is turned on, not only does the system need to overcome the heat losses, it also it needs to warm the building up. If the heating system is functioning for longer periods as in the 14 hour and 24 hour schedules, the heating equipment solely provides heat to compensate for the heat losses.

The city of Ravne na Koroškem in Slovenia is an example in which a modification of utilisation times has led to a reduction in the supply temperatures. The city has reduced the supply temperature from 130°C to 80°C by increasing the number of hours the heating systems were working.

Figure 29. **Heating power required by a poorly insulated flat with different heating schedules**



Based on: Frederiksen and Werner (2013)

In addition, the district heating system uses excess heat generated during the cooling of the electric arc furnace in the nearby steel plant (which was earlier discharged into the environment through cooling towers). This amount represents about 40% of all the heat distributed to customers in the city, and this share is anticipated to increase to more than half of total heat demand (also using heat-pipe technology to recover heat from industrial process). In the city of Antwerp (Belgium), the district heating operator wished to supply the buildings at 70°C. The typical supply temperature provided by gas boilers before connecting to the district heating network is 90°C. This has been achieved by eliminating set-back periods.

Another issue highlighted by research has been the misuse of thermostatic radiator valves (TRVs). Most consumers ignore the way they should be employed (Liao, Swainson and Dexter, 2005). Users tend to modify the set-point temperature constantly, which leads to poor cooling (and/or heating) and discomfort. Two solutions for this problem are available: electronic TRVs, in which the consumer indicates the desired room temperature, and temperature control limiters installed at the outflow of the radiator.

The different technical challenges detailed above have been mostly analysed separately. Nonetheless, there exist important synergies between them, as an improvement of the thermal envelope allows a reduction in a radiator's temperatures, without further measures being required.

> "Policy makers should integrate plans for building renovation, change of supply and modernisation of the network so as to achieve an optimum performance level"

Domestic hot water preparation

There are multiple forms of producing DHW as, for example, some substations incorporate several heat exchangers in cascade to take advantage of the return flow from the heating system (Frederiksen and Werner, 2013). For the sake of simplicity, this report shall focus on the most common ones.

Regardless of the specific DHW preparation form, they can be categorised as follows: instantaneous preparation and preparation with storage. In the first case, hot water is produced and consumed almost simultaneously, whereas in the second option, production and consumption are decoupled. Two rather common options are plate heat exchangers for instantaneous production and water tanks for preparation with storage (Photograph 6).

In water tanks, district heating water normally circulates along an internal coil to heat the stored water, although it is also possible to employ an external plate heat exchanger for such a purpose (Christiansen *et al.*, 2012). Photograph 6 illustrates two substations with a hot water tank and a plate heat exchanger for DHW preparation.

Water tanks present two challenges in low-temperature systems. First, they need high temperatures (above 60°C) to prevent the proliferation of bacteria (such as legionella), provided that no other treatment is employed (Yang, 2016). This requirement hinders the utilisation of temperatures below 65-70°C. At the same time, the return water exiting from water tanks is seldom below 30°C (Thorsen and Kristjansson, 2006).

In a district energy system, the energy delivered in a given moment is the product of the flow circulating through the network and the temperature difference between the supply and return water. For a certain amount of energy, the more the temperature difference, the lower the flow and vice versa. It is therefore essential to maintain a low return temperature to enable a reduction of the supply temperature without causing flows that are too high.

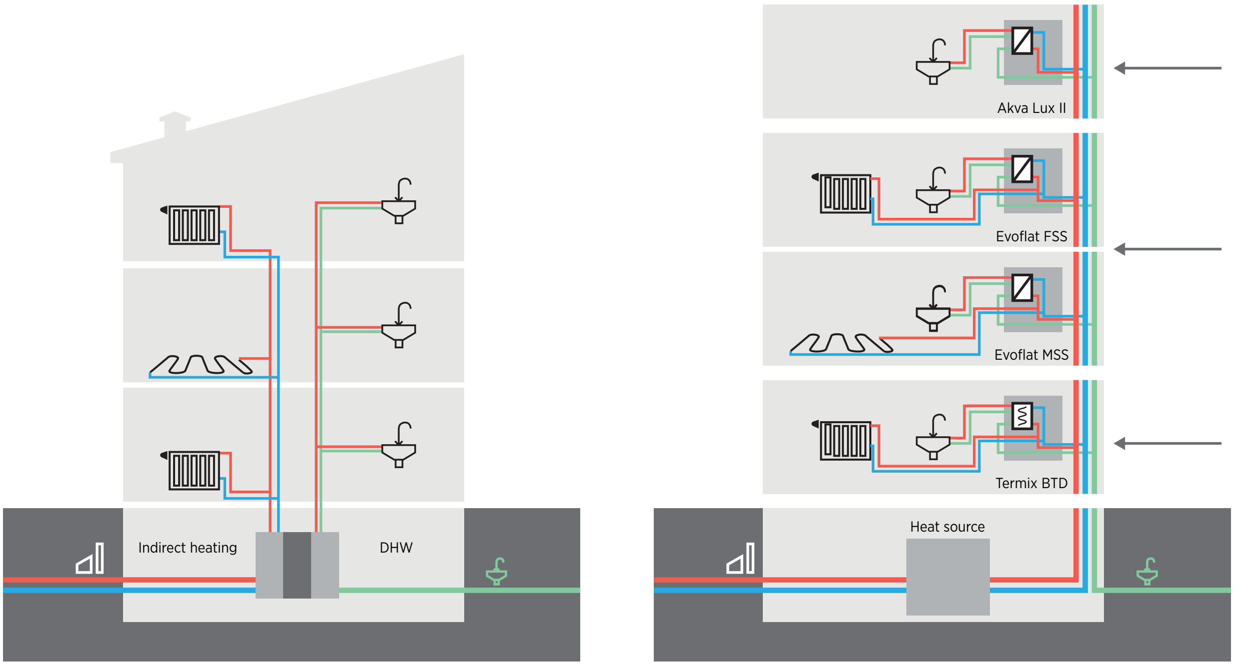
A relatively high return temperature from water tanks causes a small temperature change in the district heating network. Hence, it would require higher flows and bigger pumps and a higher consumption of electricity for pumping (Thorsen and Kristjansson, 2006), which may jeopardise the ability of the network to supply the consumers' demands during the winter peaks.

Photograph 6. **Examples of water tank (left) and plate heat exchanger (right) for DHW preparation**


Source: Shutterstock

Source: Luis Sánchez-García

Figure 30. **Preparation of DHW at the building level (left) and the flat level (right)**



Source: Danfoss (www.danfoss.com/)

Instantaneous DHW preparation is, on the contrary, well suited for low-temperature networks, as plate heat exchangers can be operated with supply temperatures as low as 50°C, provided that the volume between the substation unit and the tap is lower than three litres (Brand, 2014) and simultaneously return the district heating system water at temperatures extremely close to the incoming potable water temperature (Thorsen and Kristjansson, 2006).

However, instantaneous production requires higher flows in the connection pipes[7] between the distribution network and the consumer and hence, larger diameters.

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[7] These connection pipes are usually denominated service pipes.

Concerning the point of preparation, DHW may be produced and stored centrally, at a building level, or in each flat/premise, as illustrated in Figure 30. In the first case, a circulation system is necessary to maintain an adequate temperature at the furthermost point of consumption. Unfortunately, these systems present drawbacks similar to those of water tanks: high temperatures are necessary to prevent the growth of bacteria in the large volume of the circulation pipes and hence, the potential benefit of utilising plate heat exchangers for DHW preparation is partially lost. Furthermore, they are much less efficient as a considerable part of the energy is lost in the circulation system (Bøhm, 2013). Circulation systems are not needed in decentralised preparation with flat substations.

Therefore, the preferred method to realise the maximum advantages of low temperature supply in district energy systems is a decentralised preparation with plate heat exchanger (Lund *et al.*, 2017).

The solutions proposed above entail a renovation of the DHW system, which may prove to be unfeasible. Other technical alternatives are available. One possibility consists of the employment of chemical (such as chlorination) or physical (ultraviolet radiation) treatments that avoid the growth of bacteria (Yang, 2016). Another option utilises temperature boosting by means of electric boilers or heat pumps so the district heating does not need to supply such high temperatures (Elmegaard *et al.*, 2016).

B.4.2 Assess compatibility with existing heat network

If no measures are applied to the consumers' equipment, lowering the supply water temperature will be followed by a simultaneous increase in the return water temperature (Averfalk *et al.*, 2017) and thus, a smaller temperature drop between the supply and return water flows. This small temperature change will, in turn, result in higher flow rates in the network. If the pipes are not oversized, the pressure losses could be excessive and become higher than the maximum pressure withstood by the pipes and/or higher than the maximum pressures the pumps are able to deliver.

Therefore, it is critical to attain a lower return water temperature, which will facilitate the desired decrease of the supply temperature. Even if the return temperatures are lowered to 20-30°C, and the supply temperatures maintained in the 50-60°C range, the temperature difference will be slightly smaller than in a conventional district heating system (40-80°C). Hence, in a system supplied with low-temperature resources for space heating, the supply temperature may require boosting during the coldest days (Tol and Svendsen, 2015).

An example where lowering the return temperature enabled a drop of the supply temperature is provided by the district heating of Viborg (Denmark). This network has managed to lower the return temperature from 50°C to 40°C in 14 years (2002-2016) (Diget, 2019).

On some occasions, it becomes possible to reduce the system's temperatures in a given area while the rest of the network continues to operate with higher temperatures. This will occur, for example, when a new district is erected, and its building have been designed to operate with low temperatures or when the buildings of a given area have been refurbished. In these cases, the temperature of the supply flow can be lowered in that specific area by means of a mixing shunt (Figure 31). This is what was realised in the Danish towns of Lystrup, Sønderby and Tilst (Olsen, 2014).

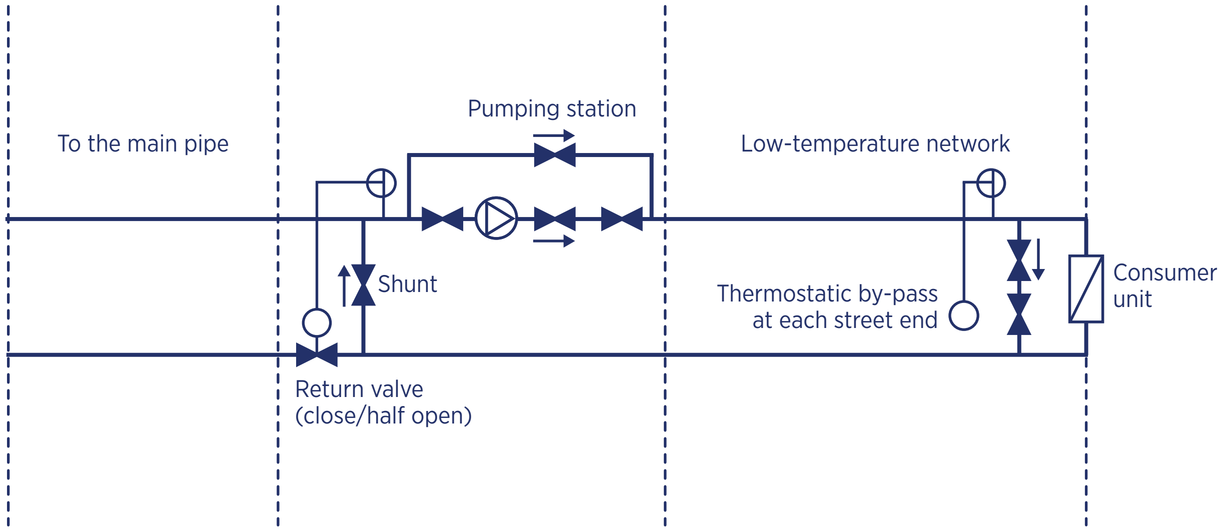
This strategy permits a reduction of the heat losses in that concrete zone, but it does not allow the maximum advantages of low-temperature district heating to be realised because the production temperature remains unaltered. A solution for this problem would be to operate parallel networks with different temperature levels, each supplying different consumers depending on their needs.

This is for example the strategy followed in a French network on the outskirts of Paris (Box 11) and in the Spanish town of Mieres (HUNOSA, 2019). This solution would enable the economic fruit of low temperatures to be enjoyed in part of the production.

A common problem district heating systems experience is the rise of the return temperature during the summer. This undesired phenomenon would also occur in new networks supplying buildings designed for operating with low supply temperatures year-round. This happens due to the by-pass of hot water from the supply pipes to the return pipes, which becomes necessary in periods of low consumption. If it were not carried out, the supply temperature would eventually drop so much as to cause unacceptable waiting times when the consumer demanded heat again.

This rise, although stemming from different causes, has similar negative consequences to the ones enumerated before: higher heat losses, lower efficiencies in production and reduced storage capacity.

Figure 31. **Sketch of the mixing shunt for integrating a low-temperature network into a conventional network**



Source: Olsen (2014)

Several proposals have been put forward to address this issue, including the comfort bathroom, advocated by Yang and Svendsen (Yang, 2016), and the three-pipe system suggested by Averfalk and Werner (Averfalk and Werner, 2018).

The comfort bathroom proposal intends to cool the by-passed flow in the bathroom's floor heating system. Once cooled, the by-passed flow is returned to the production facility by the same return pipe as the non-by-passed return flow. A problem with this solution is that it may heat the bathroom up to uncomfortable temperatures, especially in warmer countries. Furthermore, it obliges the consumer to use the bathroom's floor heating throughout the year, which they may not be willing to do.

The three-pipe system does not cool down the by-passed flow, but instead returns it to the production plant along a different pipe, which enables a separation between the cooled flow (return pipe) and the by-passed flow (recirculation pipe). This way, the cooled water stemming from the DHW production is not warmed up by the by-passed flow and it is possible to obtain a low-return temperature throughout the year. However, this is a novel concept which hitherto has not been demonstrated. Furthermore, the inclusion of a third pipe is bound to increase the construction costs of the district heating network.

The thermal properties of the pipes could also impede a reduction of the supply temperatures. Heat losses will drop if lower temperatures are utilised. Nonetheless, if the pipe insulation is not adequate and the temperature drop between the production plant and the consumer is high, the temperature at the consumer's point could drop below the minimum necessary to provide adequate heating when the supply temperature at the production plant is lowered. In this case, upgrading of the pipe network becomes necessary.

In addition, new waste heat sources may require new network concepts because the usable temperatures cannot be adapted to an existing system. Temperature boosting technology such as heat pumps may become relevant to increase temperature from a supply source and/or to increase the temperature along certain places in the grid during cold seasons.

Summary of technical challenges for compatibility of existing heat networks and buildings

A new generation of district heating systems promises to utilise more of the energy generated and enable the use of low-temperature renewable sources. However, transitioning from existing DHC systems to modern ones requires the proper design of networks and compatibility with consumer connections and the heating systems in the building stock. Recommendations to national and local authorities to assess where and to what extent retrofitting would be most beneficial, and to ensure it is strategically planned, are summarised below.

Integrate building renovation and change of supply and modernisation of the network plans so as to achieve an optimum performance level and avoid lock-in effects and disconnections.

- Establish cooperation between strategies to achieve district energy and energy efficiency in buildings. Consider, for example, a neighbourhood approach to simultaneously implement energy efficiency measures on the supply and demand sides.

- Prioritise poorly insulated buildings and the largest consumers that require more energy for implementing renovation policies.

- Move towards consumption-based billing for all consumers to encourage more energy-efficient practices.

Furthermore, district energy operators can take the following measures, which ensure the compatibility of district energy networks with low-temperature supply.

For both existing and new district heating systems in existing neighbourhoods, assess and enable compatibility with existing building stock.

- Renovate the building envelope of existing buildings to improve energy performance at the building level and reduce peak load at the energy system level. This would enable the integration of low-temperature local energy sources, including renewables.

- Currently installed heating equipment (radiators) might not be scalable for low-temperature usage. Therefore, redesign and change the equipment together with the renovation of the building stock.

- Install control equipment such as thermostatic valves to regulate flow rate and control comfort levels.

- Low temperatures in hot water systems can lead to proliferation of bacteria (for example, legionella) in the water tank. Install instantaneous DHW preparation options such as plate heat exchangers as a solution. However, for much lower temperatures, apply alternative technical solutions such as sterilisation using chemical/physical treatment methods or integration of heat pumps or electric heaters to boost the temperature.

- Adapt user behaviour to best practices for the management of heating operations in a building to enable the switch to low-temperature supply. This could include avoiding the utilisation of periods with set-back.

- Promote new substation concepts.

Assess and enable compatibility with the existing heat network.

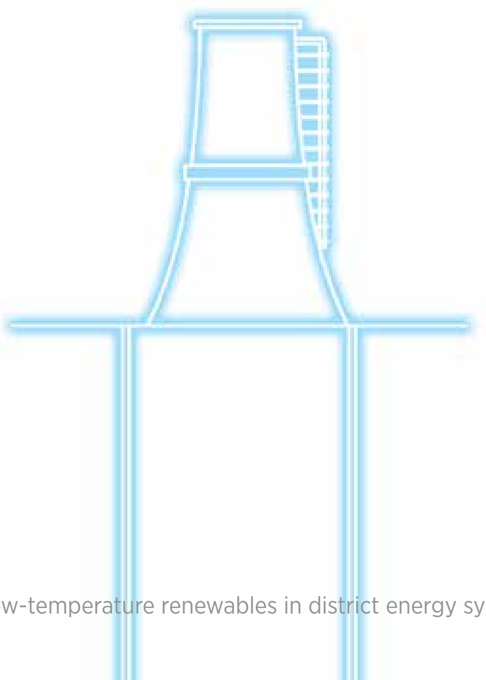
- Switching to lower supply temperature can lead to higher flow rates, which can damage the network. To avoid this outcome, ensure the return temperature from the building into the network is lowered too (*e.g.*, by the adoption of the comfort bathroom).

- In case the supply temperature is too low to meet the demand for heating, incorporate boosting technology (heat pumps) to either increase temperature from a supply source or to increase temperature in certain places in the grid during cold seasons or to meet peak demand requirements.

- Reduce excessive heat loss in the network to prevent insufficient heating of buildings. This can be achieved through adequate insulation of pipes.

Build local capacity to address technical challenges for integrating low-temperature heat sources into existing networks and building stock.

- Because district energy and energy efficiency in buildings are technical in nature, authorities need to invest in improving local expertise.



B.5 Addressing technical challenges in the exploitation of low-temperature energy sources

Each low-temperature heat source supplied to district energy networks can present specific challenges. Therefore, it may be useful to investigate specific challenges dependent on the local context. These challenges can influence the results of technical scenarios, and recommended actions to tackle them are discussed below for each heat source.

A key factor in addressing the technical challenges related to the use of low-temperature energy sources is local workforce capacity development. As discussed in Part B, Section 3.2, both the national and local authorities could leverage available technical assistance programmes for knowledge transfer. In addition, authorities could provide research and development support to the developers of district energy systems, who would in turn invest in innovation. Further capacity could be built by adopting industry best practices and engaging in forums for sharing experiences.

B.5.1 Geothermal energy

When local-level decision makers consider using geothermal energy for DHC, it is critical that they understand geothermal energy's' benefits and potential. The assessed geothermal energy potential should be adequate to meet the desired level of heating and cooling demand. However, the extraction of geothermal fluids from the reservoir over time can result in a decline in productivity due to pressure and volume changes in the reservoir. This decline in reservoir productivity can be managed through reinjection of the fluids back into the reservoir to ensure sustainability after the energy has been utilised through district heating or other applications.

Reinjection strategies are critical to ensure sustainability of the resource. Some projects have total reinjection, others no reinjection while others have varying degrees of reinjection where a portion of the fluid is reinjected. Through time, experience at operating fields has shown that near total reinjection is an important determinant in the longevity of the resource. As a result, most modern geothermal developments have total or near total reinjection.

The most common design of geothermal district heating systems that allow for reinjection is the doublet system, where two wells are drilled: one as a production well and the other as a reinjection well. As noted above, most modern geothermal developments incorporate total injection not just for resource sustainability by also for environmental considerations, *i.e.*, to avoid thermal load and chemical pollution deriving from the surface discharge of used thermal water. There are few places in the world where environmental considerations permit the disposal of large quantities of non-potable water on the surface. A modification of the doublet system is the triplet system, in which a third well is drilled when the productivity of the existing one decreases substantially. The existing two wells are then modified and converted into reinjection wells, while the newly drilled one becomes the production well. With a triplet system, the economic life of the geothermal project can be extended (Sigfusson and Uihlein, 2015).

The majority of the world's geothermal systems are of the low- to medium-temperature type, such as in sedimentary basins. The rock formations within these basins is usually hard (consolidated) in the deeper sections, but, in some cases, *e.g.*, the Pannonian Basin in Central Europe, the upper section of the reservoir is composed of unconsolidated or semi-consolidated sand or sandstone. Reinjection into this kind of reservoir creates unique challenges. These challenges include the possibility of causing damage to the semi-consolidated formation, collapse of the formations into the well bore or liberation of particles that are carried into the production or injection fluid. As the reinjected water flows through the reservoir, it carries the loose sand particles, leading to clogging of the pore spaces, thus reducing permeability and hence reducing the productivity of the wells. In addition, significant cooling of the reservoir fluids could occur due to the high rates at which the fluid can move through the reservoir. Close monitoring of the reservoir temperatures is necessary to detect thermal breakthrough if the movement of the reinjected water towards the production well is too fast.

Geothermal reservoir management and reinjection require an understanding of the hydrology and geology of such systems. Proper reservoir management will facilitate the determination of the correct pressure to be used in the reinjection of fluids into the reservoir to minimise damage to the formation. At the same time, the selected reinjection pressure and proper filters placed into the screened intervals of the wells should ensure that the mobility of the sand particles in the reservoir is kept to a minimum to avoid clogging of the permeable zones.

In addition, the spacing between the production wells and reinjection wells should be selected carefully to ensure that the reinjected fluids have adequate time to heat up before reaching the production well, to avoid a quick progression of thermal breakthrough, which could result in significant cooling of the reservoir (GeoCom, 2013). Project development and long-term production often require adjustments in the injection strategy to prevent cooling of the system. Monitoring the resource is part of the long-term management of the system for sustainability.

When the dissolved substances in geothermal fluids precipitate due to thermodynamic changes in the fluid (pressure and temperatures), chemical properties of the fluid change and minerals can be deposited on the surfaces of equipment and wells, resulting in "scaling". Unchecked deposition and scaling could result in a significant reduction in the efficiency of equipment such as the heat exchanger, or narrowing of the diameter of pipes constricting flow rate.

Deposition in geothermal wells or rock formation could also result in reduced productivity of geothermal wells. Similarly, due to the interaction of the geothermal fluids with chemical elements in the underground, their pH could vary significantly. Acidic geothermal fluids react with the metallic material used in the construction of equipment, resulting in corrosion (IRENA, 2019a). The consequence of the challenges associated with geothermal fluids is an increase in the operation and maintenance (O&M) costs of the projects.

One of the ways to minimise scaling is to strictly control the temperature and pressure of the fluid. If the geothermal fluid is cooled to a temperature below the saturation temperature (or pressure) of the dissolved substances, deposition will occur. With few exceptions, the greater the temperature drop, the greater the rate of deposition. It is advisable to ensure that geothermal fluids are pressurised at all times to avoid flashing of gases.

Pressure drops result in changes in pH, a situation that could trigger precipitation of the dissolved substances. In addition, mixing of specific geothermal reservoir fluids with fluids from other reservoirs is not recommended as it is known to cause a high rate of precipitation.

This is more likely in fluid extraction and injection in systems within sedimentary basins. Geological formations above and below the producing formation are chemically distinct, and mixing may result in mineral precipitation.

Any deposition occurring on the surface of the heat exchanger can be removed mechanically at scheduled intervals or by using chemicals to dissolve the scales so that the efficiency of the equipment is not compromised. Additionally, chemical methods such as adjusting the pH of the geothermal fluid and dosing with anti-scalants can reduce the rate of precipitation and scaling, including in the geothermal wells and the formation (Brown, 2013). In cases of highly corrosive geothermal fluids, equipment made from materials that are known to resist corrosion, such as titanium, should be selected for the heat exchanger and potentially the well casing and wellhead.

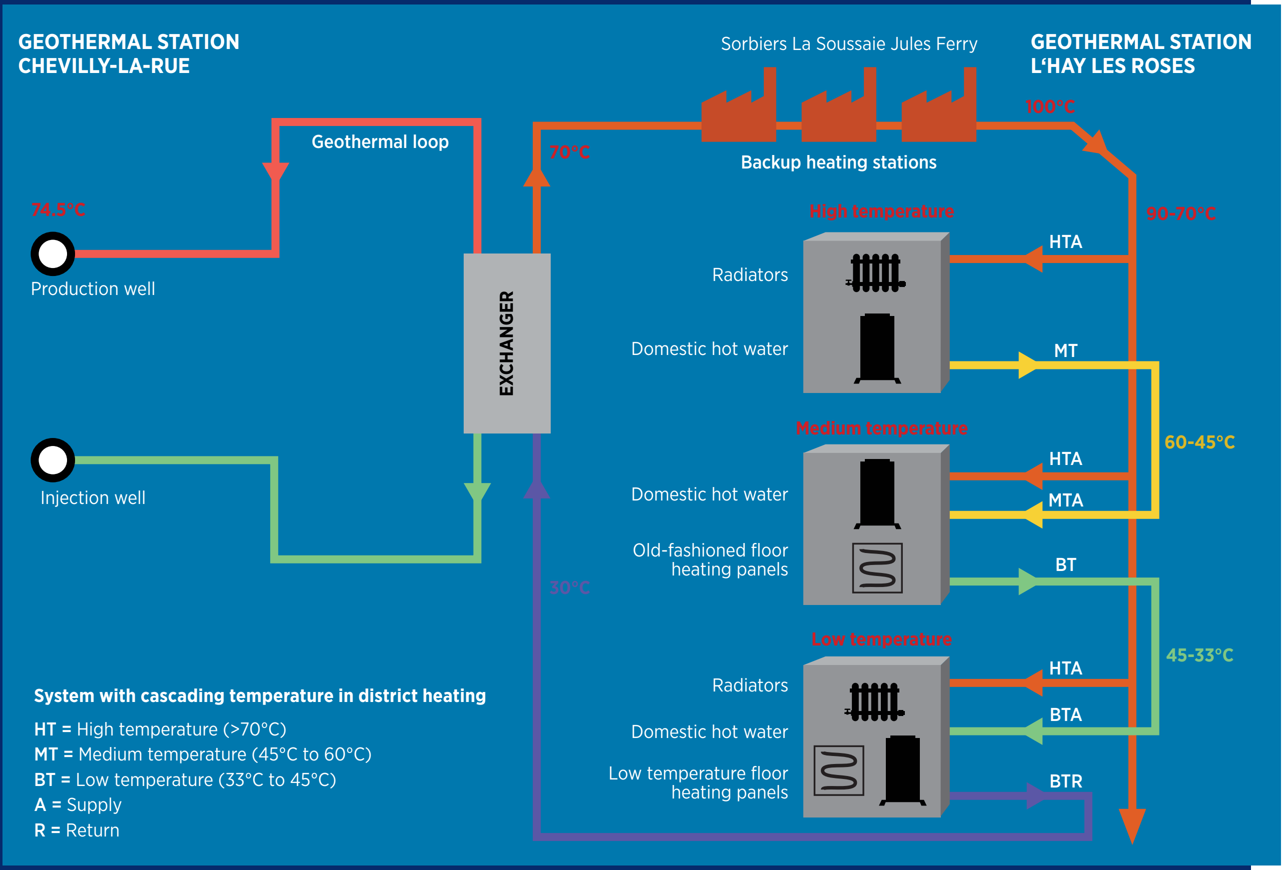
Development and utilisation of geothermal energy can result in micro seismicity, which is a huge concern, especially for projects located close to built-up areas. Among the causes of micro seismicity are extraction and reinjection of fluids, stimulation of the reservoir as well as drilling. A better understanding of the geological properties of the reservoir, *i.e.*, both the rock and fluid, could contribute to minimising and managing micro seismicity (GEOENVI, 2020).

To increase efficiency and recover as much heat as possible from the geothermal source, a geothermal district heating network can be structured in cascades of two or even three levels. The cascades work on a priority basis in which the hot water first feeds industrial processes or buildings requiring "higher-temperature" levels, then those requiring "medium-temperature" level, and lastly the newest buildings requiring the lowest temperature levels. An example from the Paris area is described in Box 11.

International cooperation and multilateral partnerships such as the Global Geothermal Alliance can be crucial to transfer knowledge, address barriers and sustain emerging markets. An example of such cooperation is the Geothermal Serbian Pilot projects for Heat and Electricity (GOSPEL), which is financed using French public funds and leverages French industrial expertise and Serbian local knowledge to identify at least three feasible geothermal energy projects (Mouchot *et al.*, 2019). Alternatively, countries can utilise technical assistance facilities offered by development institutions. An example is the Geothermal Energy Development Program (GeoFund) which was provided by the World Bank in 2006 to Europe and Central Asia. The programme consisted of a fund of USD 25 million, out of which USD 1.5 million was used for technical assistance for the Armenia geothermal project and a further USD 810 000 was used to provide regional technical assistance through the International Geothermal Association (IGA) (Wang *et al.*, 2013).

BOX 11

CASCADING: MULTI-TEMPERATURE GEOTHERMAL DISTRICT HEATING SYSTEM IN PARIS (FRANCE)



The Île-de-France subsurface is rich in geothermal energy. The utility SEMHACH operates in the Paris suburban municipalities of Chevilly-Larue, L'Haÿ-les-Roses and Villejuif and implements a cascading multi-temperature district heating system, where five different temperature levels exist, including the transmission pipe temperature.

The thermal water in the district heating grid starts from the power plants, collects the heat from the boilers, and with high temperature supplies first the heat exchangers of the oldest buildings, which have a higher temperature requirement. The return flow with medium temperature is high enough to supply heat to other old buildings with lower heating demand than the first ones and which thus require a lower temperature. Finally, the second and lower return temperature water serves the most efficient buildings, as well as greenhouses and swimming pools, which are low-temperature installations.

Thus, the final return water back at the plant has a very low temperature of 30°C. With regard to DHW, it is supplied in all cases at high temperature and returns to the grid in low or very low temperature.

This cascading system enhances the use of geothermal energy, as the final return temperature (second return) is low enough to extract larger amount of geothermal heat from the power plant. The temperature variety gives customers the option to choose the most suitable temperature necessary for their needs (radiators, heated floors, panels, etc.). Most importantly, through this network structure, the utilisation efficiency of the produced energy is maximised.

B.5.2 Solar thermal

Solar thermal is by nature seasonal and variable. This can lead to a situation in which there is a low supply of solar and a high demand for space heating in buildings during winter. In summer – when the district heating load is typically low – solar plants deliver their highest output. This however can make solar thermal plants suitable for district cooling. If large solar fractions are desired, large thermal storage can be incorporated. In Denmark, several pit storages have been built for this purpose such as that of Dronninglund or Marstal. Another example is the Drake Landing Solar Community in Alberta, Canada, where excess solar energy is stored in the near subsurface rocks and soil during summer and utilised during winter to heat homes and businesses (Drake Landing Solar Community, n.d.). Solar thermal could in combination with other energy sources be used to supply part of the heating demand in hybrid systems. This is for example the case in Salaspils, Latvia, where a 5 MW solar thermal district heating plant is combined with a 3 MW biomass-based boiler to provide district heating to 85% of the town.

Another challenge facing solar thermal is the need for large open spaces in the cities for the installation of ground-based large-scale solar heating plants. One alternative would be to locate them in areas adjacent to the cities and couple them to the district heating system (Lund *et al.*, 2018). When land must be purchased to establish solar district heating systems, supply and demand issues, such as the local landowners' plans for the land, will affect its cost. Land costs may be higher closer to urban areas, so an estimation of the optimal distance at which to locate the collectors must be performed. This distance will require further study and will likely make more sense for larger scale projects (Trier *et al.*, 2018). Alternative sites for solar thermal collectors and thermal storage facilities in cities could be on large roofs of shopping centres and parking garages (although this solution is very difficult for integration in district heating systems and should concern only pioneer installations), polluted or contaminated land, patches along traffic routes and sewage treatment basins, among others (Battisti, 2018) (Photograph 7).

When starting a solar district heating project in cities with existing district heating, there are two main problems. The first is that the summer load is normally already "occupied" because the DHC utility uses heat from power production or other sources of waste heat, resulting in surplus solar thermal energy. The second is that it is difficult and expensive to find areas to place the solar panels (Sørensen, 2017). To overcome these difficulties, thermal storage often has to be a part of the DHC system. In that case, large solar thermal can be a cost-effective solution, as it is one of the cheapest heating technologies.

There can be a large night and day difference in the temperature of the components of a solar thermal system. Use of a higher operating temperature may make this difference even larger. It is essential that all components and each connection in the system have the ability to cope with the expansion and contraction associated with variations in temperature (Schmidt and Miedaner, 2012). Furthermore, the solar thermal system must be able to deal with the worst case scenario, where strong solar irradiation can last for long periods. To avoid overheating (with resulting damage), the collector loop can be run during the night, cooling down a part of the tank volume. This example shows that the design guidelines can be reconsidered by including night-time cooling. However, this recommendation can only be applied for plants with a certain volume of thermal storage (Heller, 2001).

Photograph 7. **Solar district cooling plant, Scottsdale, Arizona (United States) (left) and part of the Fernheizwerk collector field, Graz (Austria) (right)**

Source: SOLID Solar Energy Systems GmbH

B.5.3 Waste heat

According to a recent study (Schmidt, Geyer and Lucas, 2020), the following technical barriers can be distinguished: i) a temporal mismatch of the waste heat availability and heat demand, including the supply competition to most of the renewable heat sources in summer times; ii) a quality mismatch. The latter concerns some waste heat sources, which have a combination of one or all of the following aspects: a low temperature level, a relatively small volume and/or a discontinuous occurrence. The use of thermal storage and heat pumps technologies can generally solve those technical challenges; however, these necessitate additional investment costs, which can result in financial challenges.

Increased operational complexity can be caused by the necessity of installing backup capacities to manage the risk of inadvertent disruptions in the supply of waste heat, including low-temperature waste heat, which depends on the use of a heat pump. Other complications may arise from limited standardisations (both contractual and technical) and the involvement of more stakeholders.

B.5.4 Free cooling

Technical challenges to be addressed when using water from lakes, rivers or the sea for free cooling mostly concern the safety of aquatic life, water quality, fouling and corrosion (CELSIUS Project, 2019). A good filtration system protects marine life and decreases fouling effects. Other antifouling solutions are: i) the use of chemicals, such as chlorine; ii) advanced oxidation processes; and iii) non-chemical treatments such as thermal shocks. Studies have also shown that increasing the flow rate of cooling water may hinder the buildup of deposits inside the heat exchanger.

Evaluation of the most suitable antifouling system needs to be based on environmental considerations and existing regulations concerning allowable amounts of chemical discharge. The antifouling system should be optimised over different seasons since the amount of organic matter in the water is dependent on the season, thus minimising the discharge to the environment (CELSIUS Project, 2019).

Summary of technical challenges and recommendations for exploiting low-temperature energy sources

The main recommendations to national and local authorities and operators of DHC systems to address the technical challenges in the exploitation of low-temperature energy sources are summarised below.

Build capacity to address technical challenges for operating low-temperature renewable or waste heat sources.

- Develop a critical mass of experts, including public authorities, in renewable energy technologies, *e.g.* geothermal energy and solar thermal.

- Invest in improving the local expertise of the workforce to ensure the smooth operation of district energy networks. This not only contributes to optimised operation of the networks but also ensures that technical issues are addressed with minimal disruption to the energy supply.

For the smooth operation of district energy systems, operators need to implement the following measures in their projects.

Adhere to best practices for the operation of geothermal-based energy systems.

- Adhere to industry best practices regarding reservoir management as well as O&M of equipment in geothermal-based district energy systems. These best practices include reinjection of spent geothermal fluids for the sustainability of the reservoir and engineering strategies to manage scaling and corrosion.

Deploy solutions to manage fluctuations in the supply of solar thermal and waste heat to avoid instability in the grid.

- Integrate large-scale thermal energy storage in the DHC networks to enable capturing of surplus heat such as solar thermal and waste heat produced during times of low demand and store them for future utilisation when demand increases.

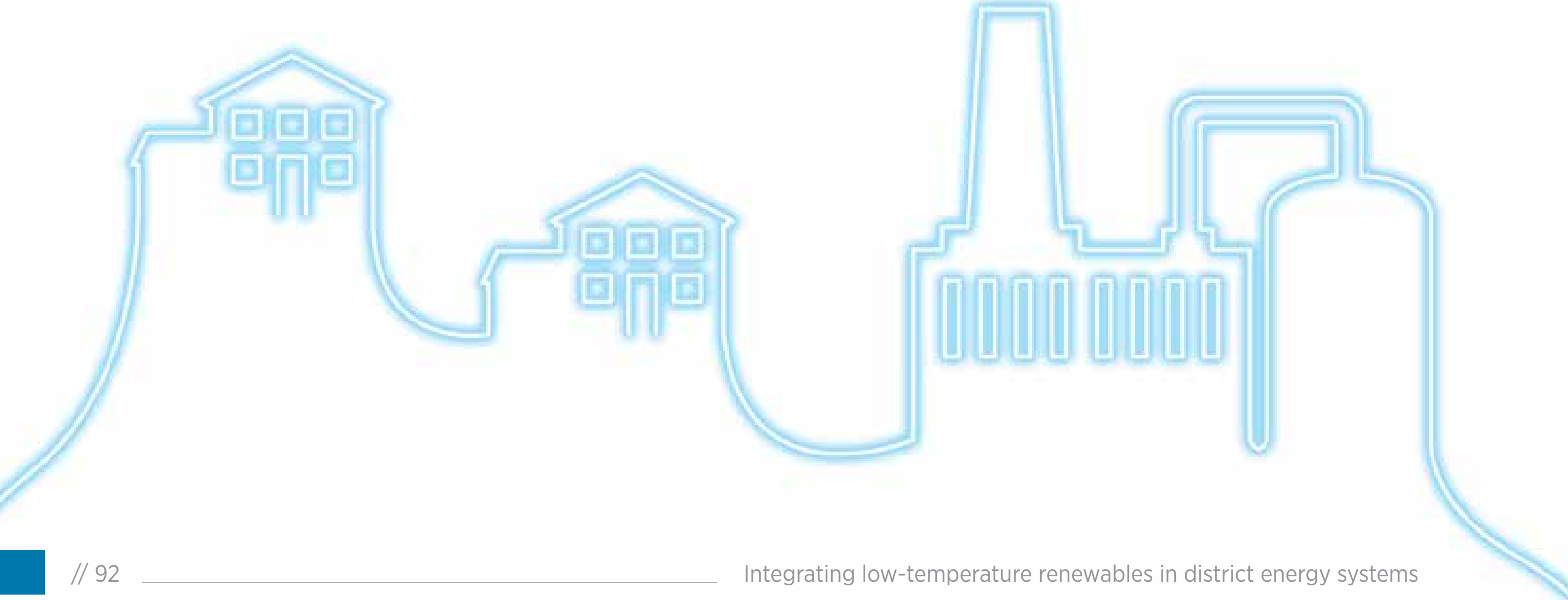
- Develop strategies to ensure that the supply of district energy is not disrupted such as implementing long-term contracts for providing waste heat to the district energy network.

- Fluctuating output and temperature on the supply side is a very likely scenario of low-temperature local energy sources. If this is the case, utilise heat pumps to raise the temperature, thus ensuring that customers' heating demand is still met.

Table 6 summarises the main technical challenges and options for geothermal and solar thermal and waste heat.

Table 6. **Main challenges and possible solutions to exploit low-temperature renewable or waste heat sources in DHC**

SOURCE	MAIN CHALLENGES	POSSIBLE SOLUTIONS
Geothermal	High investment cost Risk of drilling failure Risk of decreasing productivity over time Risk of scaling and corrosion	Establishing geothermal resource risk and well-productivity guarantee schemes Conducting extensive geo-scientific studies Monitoring reservoirs and managing resources (especially of injection) Maintaining temperature of geothermal fluid above the saturation temperature of the dissolved substances during heat exchange, regularly maintaining heat exchangers and other equipment, treating of geothermal fluids using chemical methods (*e.g.*, anti-scalants) to reduce the rate of precipitation and scaling
Solar thermal	Offset between seasonal availability and demands High investment costs Constraint temperature Space constraint	Ensuring use in systems that have a DHW demand Using solar thermal to provide cooling when the supply and demand for heating are mismatched Incorporating thermal storage to take care of surplus solar thermal Using alternative spaces, *e.g.*, rooftops, sewage basins, former landfill sites, etc.
Waste heat	Sustainability of the resource Fluctuating conditions of supply	Developing contractual agreements to assure of supply Incorporating thermal storage in the network Combining connections to deliver high-temperature to the supply line and lower temperature to the return line
Free cooling	Preservation of water quality and aquatic life Risk of fouling and corrosion	Filtering Antifouling processes



B.6 Enabling regulatory conditions, financing and business models

A DHC project is subject to regulation originated and/or implemented at a local, national or sub-national level (provincial/state). Further, the particular project is also affected by general heating and building regulations as well as legislation governing underground water resource extraction (in the case of geothermal projects), land use (especially for solar thermal projects) and energy systems. District heating and cooling projects often overlap several different areas of expertise, such as building type and renovation, zoning, energy supply, road maintenance for implementing pipes, etc. All these policies are also shaped by legislation at all governmental levels, as shown in Figure 32.

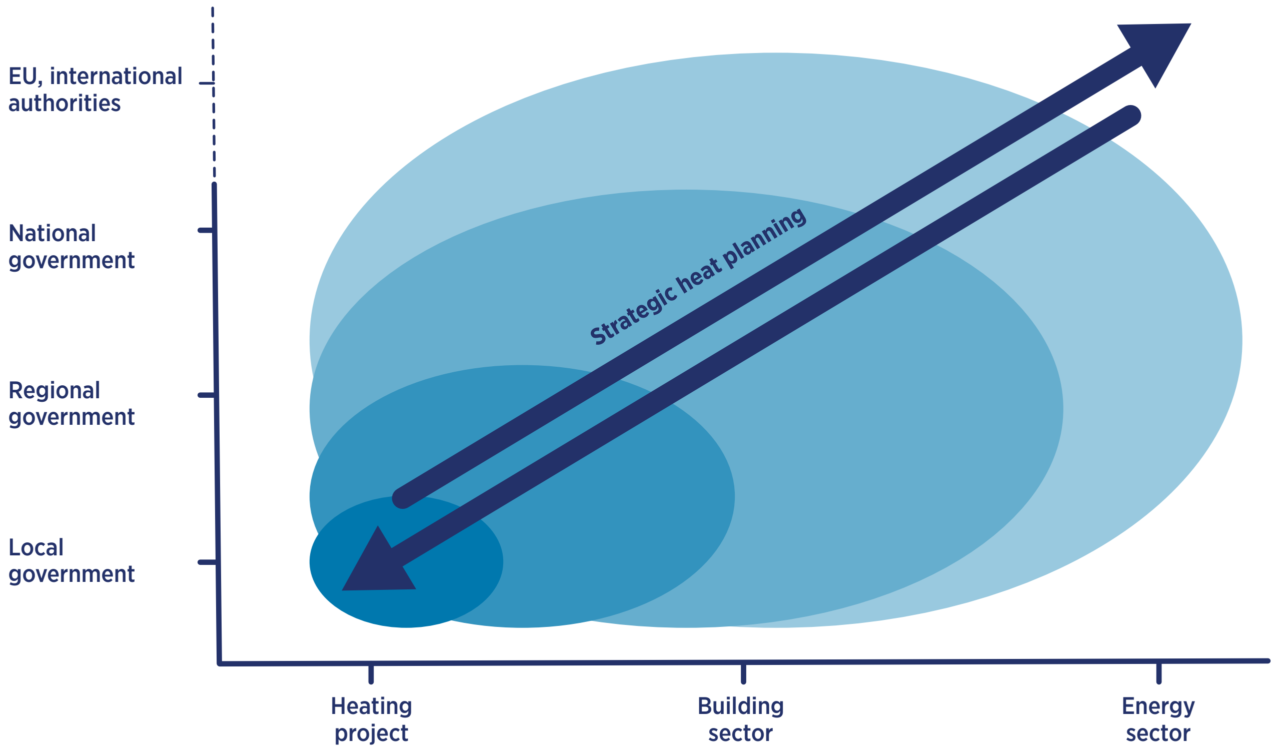
National and local authorities need to establish both financial and regulatory measures to ensure that the benefits of DHC systems are captured by the established pricing regimes. At the same time, the existing regimes must ensure they do not disadvantage DHC systems because of subsidies (direct or indirect) for other energy sources.

The implementation of a new district energy project (or fuel switch from fossil fuels) typically requires significant investments that have to be carried out by one investor, as opposed to spending on individual equipment that is spread across a large group of consumers/investors. Relative to other options, district energy systems based on waste heat sources and renewable energy can be disadvantaged by energy pricing regimes, market structures and high upfront capital costs. Therefore, it is important to evaluate the district energy project with a long-term perspective, as it can be difficult to break even within a short timeframe.

District energy systems based on low-temperature solar thermal, geothermal or a hybrid system demand business models customised for each particular project. Such a model should guarantee financial returns for all stakeholders as well as achieve any larger socio-economic gains that are being sought.

With this in mind, the choice of ownership structure and price regulation models influences the options that may be applied to integrate low-temperature energy sources in district energy systems.

Figure 32. **Local/strategic heat planning in the context of national and international regulation and alignment with multiple interests and needs**



B.6.1 Ownership structures

There are four main ownership models for district energy systems: consumer, public, private (commercial) and public-private partnerships (PPPs) (Djørup *et al.*, 2019a). In practice, hybrids of these four forms can be encountered, especially in the structure of public-private hybrids. These ownership structures can exist in a competitive market or as monopolies. The question of ownership applies to the two main components of a district energy system: the transmission and distribution network and the production units.

Ownership of transmission and distribution networks

Figure 33 illustrates the role of the district energy grid as a vital infrastructure that enables DHC producers to deliver the produced heat and cold for distribution to consumers. The grids are the infrastructure that allow the system to function.

A central question for district energy systems relates to the ownership of the distribution and transmission grids. This is primarily what constitutes the monopoly situation, as this controls the access to delivering energy. Two important factors are worth considering: first, who has the majority stake, and second, the anticipated return on investment. A key factor to note is whether the district energy distribution networks are publicly or privately owned and who has the majority share. Public ownership will typically ensure that the networks are used as public infrastructure, while private companies see the networks as an investment and require a return. This leads to the second aspect: the return on investment required. Because district energy networks are capital-intensive and have long lifetimes, a requirement to have a high internal rate of return (IRR)[8] might be a barrier to establishing city-wide district energy networks. This is expanded further in Part B, Section 6.4. While private companies will use an IRR of around 10-15%, public investments could consider an IRR around 3-5%, taking a socio-economic perspective. This will dramatically shift the possibilities and business cases for expanding district energy networks.

The governance of the operations of the distribution network is a central aspect to consider to mitigate against monopolistic tendencies when a single entity owns the supply network, which is often the case. Infrastructure monopolies are common and often governed with high success rates. Examples are electricity grids, gas grids, water supply and highways. What is important is that they are governed with the common good in mind, and not managed for profit maximisation.

Ownership of production units

In large networks with several producers, competition can be ensured under certain conditions that allow the whole system to function in the most efficient way, but this is difficult in smaller networks with one single producer. Therefore, the production part of DHC will also often be a monopoly, which on most markets will face competition from individual sources (*e.g.*, heat pumps or/and individual boilers). In DHC networks supplied with low-temperature energy, this situation will potentially change. With the introduction of new geothermal resources, heat pumps, solar thermal and waste heat, many more producers can potentially feed into a DHC network, thereby limiting the monopoly situation on the supply side.

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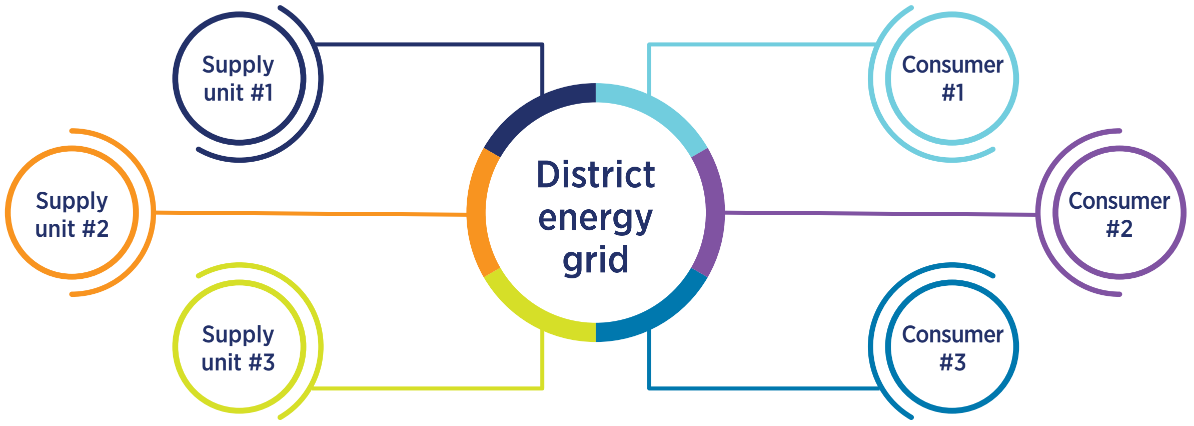
[8] The IRR is a value calculated to evaluate the profitability of potential investments. It can be compared to a hurdle rate or discount rate and needs to be at least at a similar level as the weighted average cost of capital to indicate a potentially profitable investment.

Figure 33. **The district energy grid: A vital infrastructure connecting supply units and consumers**



The right type of ownership

The ownership model can significantly impact the attainment of a project, in particular consumers' off-take motivation. The motives of publicly and privately owned DHC projects are often fundamentally different in terms of initiation, development and financing. For example, a publicly owned DHC project is more likely to pursue lower heat prices and environmental and socio-economic benefits than a privately-owned project, which will largely focus on maximising company profits. Consumer-owned DHC projects often seek the lowest heat prices.

Monopoly structures do not necessarily pose a problem with the public or consumer ownership if an alignment of interests is assured. Public or consumer ownership should be interested in supplying heat as economically as possible. Increasing the heating price for profit would only result in returning profits back to the heat consumers (if combined with a true cost price regulation).

For public ownership, profits might be used in other public areas such as schools, transport or health care. If this is allowed, heat consumers essentially subsidise other public areas through their heat bills. This is in the end a political question which, if adopted, can result in a negative perception of district heating systems if prices increase due to other public spending.

Regardless of which model and type is chosen, transparency of funding, pricing and financing is very important. To establish and maintain public trust in monopoly infrastructures, how funding is used must be publicly known. National price statistics comparing utilities on different parameters are also useful, as this enables consumers to see how their utility compares with other utility companies.

Private ownership will usually have the primary objective of managing prices to maximise profits. This introduces a conflict with consumers, who are interested in the lowest possible prices, and is a typical monopoly issue. Both the issue of public developer spending for other public areas and the private developers desire of profit maximisation can be controlled through price regulation.

Public ownership

- **Benefits:** Interest is often aligned with the interests of the local population but can also include wider concerns such as energy poverty, decarbonisation or clean air. Public ownership gives the potential advantage of an easier alignment of public interests and investment and planning decisions. While private companies will seek profit maximisation, public companies can base decisions on public benefits.

- **Challenges:** There might be profit-maximisation incentives for local governments where heat sales contribute to other public expenses such as education, health care or roadworks. There can also be trust issues if the local government is perceived as not being able to manage a district heating project. In case of low trust in government or inefficient government structures, public ownership will obviously suffer. In any publicly owned utility, transparency, democratic governance and accountability will be central factors in efficient DHC operation.

Consumer ownership

- **Benefits:** As consumers are the owners, their interests are aligned and there is no reason to include a profit margin in the heat sales as this would directly return to the consumers themselves.

- **Challenges:** It can be difficult to engage enough local consumers to actually reach a critical mass of engaged local consumers. Consumer-owned district heating systems also need professional expertise to ensure optimal operation and development of the system.

Private ownership

- **Benefits:** If sufficient competition is ensured, private companies will have an incentive for optimal operation, development and investment into the system. Often, private companies come with access to capital, which might not be available to public or consumer ownership. But this is also related to the regulatory regime, and in some countries (*e.g.*, Denmark) publicly owned utilities have access to publicly guaranteed loans.

- **Challenges:** Sufficient competition and market-like structures can be difficult to ensure in district heating systems. Therefore, private ownership will most likely have to be controlled by consumer protection regulation. These price regulations can be difficult to monitor and enforce as the public authorities may not have access to all the operational information in the custody of the private company.

PPPs

- **Benefits:** The public sector can take the risks that the private sector might not be willing to take while the private sector brings in development innovation. The project could also attract sources of financing, such as grants and concession loans, that the private sector might not have access to.

- **Challenges:** Complexity of funding, pricing, financing and governance arrangements can lead to a lack of trust in this type of ownership structure.

Box 12 presents some cases that illustrate the different categories of ownership.

BOX 12

SOME EXAMPLES OF OWNERSHIP MODELS

- In **Aalborg (Denmark)**, the district heating utility belongs to the municipality, which also owns the thermal grid and is responsible for delivering heat. Having purchased the main heat production unit from a private energy company, the municipality-owned utility has embarked on implementing a green energy strategy by 2050. Its intermediate target for 2028 is to have fossil-free heat production, which effectively means replacing the coal-fired cogeneration unit.

- The city of **Hamburg (Germany)** decided to take back control of the district heating system after selling it to a private energy company. The local government, prompted by public support as a matter of city politics, initiated discussions with the private vendor, which ended in buying back the energy production plants and the distribution network. The principal reason for this was decarbonising the city's heating sector and contributing to the German Energy Transition Policy (Energiewende). Since September 2019, the newly founded municipal company has been in charge of the district heating system and controls approximately 80% of the heating sector within the city's limits. The aim for transition includes the replacement of coal and the introduction of waste heat and renewable heat sources.

- The city of **Viborg (Denmark)** stands out as an interesting case for the consumer-owned heat distributor, which actively promotes the use of new, energy-efficient technologies to supply heat to its customers as a part of transitioning to low-temperature district heating. This was on the grounds that merging heat production and distribution would allow for investments in decentralised renewable heat sources, which would otherwise have led to conflict with a separate entity's interests. The utility company, persuaded the city council to sell its stake in the municipality-owned CHP DHC plant.

- In **Lendava (Slovenia)**, the DHC system is managed by a private company (Petrol), which owns the network (pipelines) and geothermal energy production (geothermal production well, reinjection well), as well as the boilers for peak load coverage. The district heating system is managed under a PPP (under a concession contract). With regard to pricing, the Slovenian Energy Agency has set the regulation of district heating prices. Regulation is carried out in accordance with the act on the methodology for district heating pricing, which sets the criteria and grounds for the starting price of heat and its changes due to modification of eligible costs.

B.6.2 Pricing of DHC supply

Most district energy supply systems require some form of price regulation to protect consumers from the monopoly situation. It is vital that the pricing reflect the utility received and that there is transparency in the pricing structure and levels. Without transparency and trust in the correct pricing, consumers will lose trust in the district energy supply, which will then suffer from poor operation and potentially enter a negative spiral with disconnections, increasing pricing and lack of satisfaction.

The price paid by the consumer should cover all necessary costs related to supplying heating and/or cooling. Heating tariffs should therefore include fixed and variable costs.

Fixed costs:

- production facility investment
- DHC network investment
- cost of financing
- depreciation of equipment
- administrative costs.

Variable costs:

- production facility O&M cost
- DHC network O&M
- fuel costs.

The efficiency of the production facilities, heat losses in the network, fuel and electricity prices, taxes, financing support and grants can affect heating costs. In general, fuel costs including taxes make up the largest proportion of the costs. Pricing should therefore also be structured based on the level of consumption in addition to capacity or fixed costs. To incentivise energy efficiency and meet energy demand, consumers should pay per energy amount consumed (consumption-based billing), not only according to a flat rate (Djørup et al., 2020). It is, for example, a central element of the EU’s Energy Efficiency Directive (Articles 9-11) (European Parliament, 2018b), to roll out energy meters where it is financially viable.

Generally, there are three main models of price regulation: true costs, price cap and no price regulation (Djørup et al., 2019a).

> "Pricing mechanisms must ensure transparency to maintain customer trust"

True cost pricing

This is for example used in the Danish district heating sector. It stipulates that only costs related to the production and distribution of heat to the customers can be included in the heating price. This includes depreciation of assets and financing costs to ensure that district heating companies are able to sustain and develop in the short and long term.

- **Benefits:** This model works well when interests are aligned in keeping prices down. It is a benefit in that it discourages public authorities from using profits generated from district energy supply in other areas of public spending.

- **Challenges:** This model does not control increasing spending in, for example, O&M, increasing depreciation time or increasing salaries. These aspects are areas where profit maximisation could be introduced. The success of true cost pricing relies on equal access to information about how prices are set, as issues can arise in situations where public regulatory authorities do not have access to all the necessary information about the pricing structure.

Price cap

The price cap principle is used in Dutch district heating systems. It sets a maximum allowed price for heat sales, usually set against another benchmark of heat supply types. In the Netherlands, the price cap is set against the cost of heat supply based on natural gas. It stipulates that the heating price from a district heating supplier cannot exceed the cost of the benchmark heat supply. A variation of price cap is to allow a certain percentage return to owners.

- **Benefits:** This is a simple model that ensures prices remain below the political set threshold. It also promotes cost-efficiency in DHC companies as investments or spending that will increase heat prices above the threshold cannot be covered.

- **Challenges:** It is a fairly rigid model that often does not include room for local conditions. It also does not incorporate the influence of global natural gas prices and how falling prices can negatively impact the cost of the heat supply where a project's capital expense and operational expense were based on higher prices. This could be managed by specific legislation. The model also entails the question of what a feasible benchmark price is. Is natural gas a useful benchmark in a global market, and is there a mechanism for including a carbon price? Could the price be set as the cost of individual renewable heating installations or heat pumps? It also includes the incentive to set DHC prices just below the benchmark price to maximise revenue. Price cap pricing relies on equal access to information about how prices are set, and issues can arise in situations where companies have better information than public authorities.

No price regulation

A model with no price regulation is usually combined with no mandatory connection regulation. Therefore, customers paying high tariffs in one DHC network are free to choose other supply options, including individual systems. Here, DHC companies will have to convince consumers of the quality and low price of their product before customers connect. This is the case in Gothenburg, Sweden.

- **Benefits:** This is a simple method that does not require detailed regulation and can potentially realise efficient prices if proper (competition) mechanisms are in place.

- **Challenges:** This model does not sufficiently account for sunk-costs of developers or those made by customers who connect to DHC systems. It is usually not easy to switch heating systems and will only be profitable over long timeframes. It also introduces a significant amount of risk for DHC companies because they do not know their market size with certainty. It also entails a risk of not effectively dealing with the monopoly situation in DHC systems.

In countries without a tradition of district energy supply systems, it may be challenging to define heat tariffs and heat purchase agreements. It is crucial that these prices and tariffs are set in a transparent manner so everything that is being paid for is available to the consumer. This includes specifying costs for fuel, investments, O&M, profit, salaries, etc. It is also important to have an independent benchmarking authority that can compare prices across utilities and point out or penalise excessive prices or price irregularities.

A central issue in determining price regulation is the ability to enforce these prices and the availability of information. The true cost principle is limited by uneven access to information about production, financing and O&M costs, and it can be difficult for an independent price regulator to correctly assess prices. Therefore, the ownership issue is important to consider together with the price regulation. In addition, access to price statistics is also very important, as this allows comparison between utilities.

In the end, the pricing of DHC supply will depend upon local conditions, regulation and practice. What is generally important is that policy makers choose price mechanisms that reflect production and capacity costs, remain competitive and allow transparency so trust can be built for district supply options.

B.6.3 Regulation

DHC regulation

DHC legislation and regulation is a broad topic which is impossible to cover fully in this report. A general account of different approaches will instead be provided here.

Broadly speaking, three types of district heating (and cooling) governance exist (Werner, 2004):

- specific district heating (and/or cooling) legislation
- no specific district heating legislation, but some fiscal levers
- neither specific district heating legislation nor fiscal levers.

Some countries with a long history of district heating, such as Poland, Hungary or Estonia, have developed specific district heating legislation (Werner, 2004). Other countries regulate the district heating (and/or cooling) sector either through general heating (and/or cooling) legislation or through other legislation, such as energy efficiency, energy supply or environmental legislation. Some countries lack heating regulation altogether.

Regulation should ensure a level playing field, provide long-term stability, ensure least-cost system design and energy supply and manage environmental benefits and harm. A level playing field should, for example, deal with energy price distortion from different supply types, such as subsidised residential gas prices. As mentioned previously, DHC networks should be considered to be an infrastructure alongside electricity, gas or water networks.

In some countries, there are complex requirements for applications and lengthy evaluation and approval processes, including for the refurbishment of existing systems. This increases uncertainty for investors, which may translate in higher costs. Policy makers at a national and local level should therefore guarantee streamlined and swift authorisation procedures.

Policy makers could also consider how regulation can improve transparency and promote presentation of correct information to consumers. For example, the revised version of the EU's Renewable Energy Directive (Article 24.1 Directive 2018/2001/EU) requires the EU's national authorities to ensure that final energy consumers are kept informed about the efficiency and proportion of renewables in the DHC systems that supply them. This information should be easily accessible, such as on energy bills, at the suppliers' websites or upon request. This measure can inspire policy makers beyond the EU to increase awareness of the consumers on the deployment of renewables and improvements in energy efficiency.

Furthermore, regulation should ensure a market design that promotes the least-cost socio-economic energy system design. This is a difficult task and must be revisited continuously. But the market design should promote the technologies identified as feasible for society in the establishment of the technical scenarios as outlined in previous sections. Lastly, regulation and market design should manage and deal with major externalities. It is crucial that policy makers develop market design that reflects important societal goals such as clean air, decarbonisation or access to energy.

Geothermal energy regulation

The development of geothermal resources to provide heat (and cold) as well as electricity is regulated in most countries under mining laws, water laws, environmental protection laws, geological laws, renewable resources laws or land use regulations. In some instances, separate geothermal laws have been enacted (Rupprecht et al., 2017).

A key element of geothermal regulations is the definition of geothermal energy. In the EU (Article 2, Directive 2009/28/EC), geothermal energy is defined as "the energy stored in the form of heat beneath the surface of the Earth." At a national level, however, there is no standard legal definition, as the resource is defined differently by different authorities.

The ownership of geothermal resources in most of the jurisdictions is vested with the national or regional governments.

The most common geothermal licenses issued by authorities to regulate geothermal activities include exploration licenses, exploitation licenses, drilling licenses and generation licenses. The regulated aspects of geothermal energy include the right to access the resource, the rights and obligations for the use of the geothermal water (extraction and reinjection), drilling and environmental protection.

For the purposes of regulations, geothermal resources are classified differently to ensure that the appropriate level of regulation is applied. The classification takes into account different aspects of the resource as follows:

- thermodynamic properties of geothermal water (temperature, pressure, etc.)
- depth of drilling and extraction
- end-use (electricity generation, heating and/or cooling)
- installed capacity of the heat and/or power plant.

To facilitate the fuel switch to geothermal energy, the laws and regulations governing the licensing of geothermal (or mineral or water) resource extraction play a key role. However, these are sometimes considered too weak or too complex and burdensome to attract investment.

Many countries lack policies that are specific for geothermal utilisation for heating (and/or cooling), such as roadmaps or dedicated licencing rules. A first step is to clearly define and classify geothermal resources.

In this regard, a good example is represented by Italy, where three classes of geothermal energy systems have been differentiated. These are high-temperature systems (>150°C), medium-temperature systems (150-90°C) and low-temperature systems (<90°C). Furthermore, all geothermal heat pump systems with a capacity <2 MWt and with wells drilled down to 400 m are considered as "water resources" and do not require an exploration and a production license (Angelino et al., 2016).

Such a classification can be a prerequisite to ensure that small-scale projects and shallower wells (*e.g.*, down to 400 m depth) benefit from simplified authorisation procedures compared to larger projects for high enthalpy resources.

Developing a dedicated and streamlined geothermal licensing regime could attract more investment and development of projects. In this context, the EU-funded GeoDH project has proposed an ideal regulatory framework for geothermal district heating which may be adapted to specific contexts (see Box 13).

BOX 13

REGULATORY FRAMEWORK FOR GEOTHERMAL DISTRICT HEATING: KEY RECOMMENDATIONS FROM GEODH PROJECT

- **National and local rules must include a definition of geothermal energy resources and related terms.**
- **Ownership rights should be guaranteed.**
- **Administrative procedures for geothermal licensing have to be fit to purpose - they should be streamlined wherever possible and the burden on the applicant should reflect the complexity, cost and potential impacts of the proposed geothermal energy development.**
- **The rules concerning the authorisation and licensing procedures must be proportionate and simplified, and transferred to regional (or local) administration level if appropriate.**
- **The administrative process must be reduced.**
- **Rules for district heating should be as decentralised as possible in order to be adaptable to the local context, and stipulate a mandatory minimum level of energy from renewable sources.**
- **A unique geothermal licensing authority should be set up.**
- **Information on geothermal resources suitable for geothermal district heating systems should be available and easily accessible.**
- **Geothermal district heating should be included in national, regional and local energy planning and strategies.**
- **Policy makers and civil servants should be well informed about geothermal energy.**
- **Technicians and Energy Service Companies (ESCO) should be trained in geothermal technologies.**
- **The public should be informed and consulted about geothermal district heating project development in order to support public acceptance.**
- **Legislation should aim to protect the environment and set priorities for the use of underground.**

http://geodh.eu/wp-content/uploads/2012/07/D-3.5-GEODH-Regulatory-Framework-17-02-2014.pdf

Source: GeoDH (2014)

Solar thermal energy regulation

The installation of solar collectors typically requires permission from local authorities. In the case of roof-mounted solar collectors, building restrictions may apply to roofs (especially those of old buildings and in historic areas). Usually, the only permission needed is building permission (Sørensen *et al.*, 2012).

Regarding ground-mounted solar plants, the visual impact can be a sensitive issue due to landscape peculiarities and consequent restrictive laws on visual impact and visual protection. A policy measure would be a standardisation, at the regional level, of the authorisation procedures needed for developing a solar district heating project. Of course, the achievement of such a strong result depends on the political will and commitment as well as on the competencies of the region and its municipalities. Quite often, lower levels of government cannot draft pieces of legislation which are against the national law on visual impact and landscape protection (Trier, 2018).

Various strategies can be used to avoid or minimise the impact on land from solar systems. These include utilising degraded land and co-locating solar systems with agricultural land (Fritsche *et al.*, 2017).

An environmental permit is necessary for a solar district heating system plant because these plants usually contain glycol. Identifying special conditions in which the national authority has a veto is important. Drinking water interests are an example of this kind of condition. If the system necessitates long-term storage – such as pit heat storage or boreholes – special permission that assures drinking water protection will also be needed (Sørensen *et al.*, 2012).

Waste heat regulation

There are no regulations that restrict the integration of waste heat into DHC networks. However, DHC's market situation differs across the world, which leads to different policy recommendations depending on the local situation.

In the EU, for example, legislation that provides incentives to member states to accelerate decarbonisation of the heating and cooling sector and recognises waste heat's role has been enacted. However, in the new Renewable Energy Directive (European Parliament, 2018a), heat sources, *e.g.*, waste heat from tunnels and subways, power-to-gas processes, etc., cannot be counted towards national renewable targets, which could have the effect of an unbalanced treatment. Moreover, in the waste heat definition, the term "unavoidable" is difficult to define because it could relate to either economic or technical feasibility. The Energy Performance of Buildings Directive (European Parliament, 2010) forecasts minimum requirements for new and renovated buildings' primary energy factor. However, the member states set this factor, and sometimes it is unfavourable for waste heat.

Long payback periods give rise to economic and financial obstructions. This is due to possibly increased costs of investment and somewhat low revenues from heat sales, particularly in summer. A lack of long-term guarantees concerning future waste heat availability is thus imposing a risk of stranded investments. Furthermore, industrial companies' maximum amortisation periods range between 2 and 3 years, whereas DHC companies have a long-term orientation; *i.e.*, amortisation periods of up to 20 years are often acceptable. There is also a diverging view on the value of the waste heat, *i.e.*, private companies tend to maximise profits. To ensure the availability of the waste heat source over time, it is recommended that contracts be made for the long term. Calling for tenders for heat supply could also be a means of ensuring heat will remain supplied to the network in all circumstances.

Building regulations

In many countries, heating and cooling regulations are covered in building and energy efficiency regulations. Typically, this type of regulation focuses on a single building and its energy consumption, and not on the building's role in the broader energy system, as is also the case for green building certifications like Leadership in Energy and Environmental Design (LEED) or Building Research Establishment Environmental Assessment Method (BREEAM).

To make sure that building regulations also promote district energy supply, it is important that policy makers and regulators at the national and local levels take an energy system perspective and not just focus on a single building. The Smart Energy Systems perspective is presented in Part A, Section 1.2, and an approach to energy efficiency from a system perspective is presented in Part B, Section 3.3.

A central element is whether regulations and standards related to minimum energy performance requirements of buildings measures final or primary energy. Final energy consumption measured at the building level does not take wider efficiency gains on an energy system level into account.

Using primary energy (as an assessment thereof) also considers efficiency improvements found, for example, in the production part, where DHC plants improve energy system efficiency.

Additionally, decision makers could ensure that minimum energy performance requirements and energy performance certificates do not only valorise on-site renewable energy generation, but also take into account the positive impact of renewable heat and cold generated off-site and supplied by a DHC. Energy performance certificates should also valorise buildings with DHC supplied with sustainable sources, *i.e.*, this should be clearly indicated.

Concerning the building itself, regulations should require building equipment to be designed for operating at low temperatures regardless of the current existence of a district energy system in the area. This would ease an ulterior connection of the building to a district energy network.

Furthermore, in mature markets where there is enough trust towards DHC, a connection obligation could be imposed. This is the case in Italy, where new buildings need to be prepared for district heating and are obliged to connect if there is a system within 1 km from the building (Ministry of Economic Development, 2015; Costanzo *et al.*, 2018).

B.6.4 Financing

New renewable energy-based district energy systems, retrofitting and fuel switch to low-temperature renewable sources in existing systems

The upfront capital costs involved in the construction and refurbishment of a DHC network, as well as of some renewable heat projects, are substantial. Although DHC networks should ultimately pay for themselves, it can take a decade or longer before the initial expense (*e.g.*, the design and build) is recouped and any profits realised. These projects therefore are good matches for investors seeking a comparatively secure long-term revenue stream, rather than a quick return on their investment.

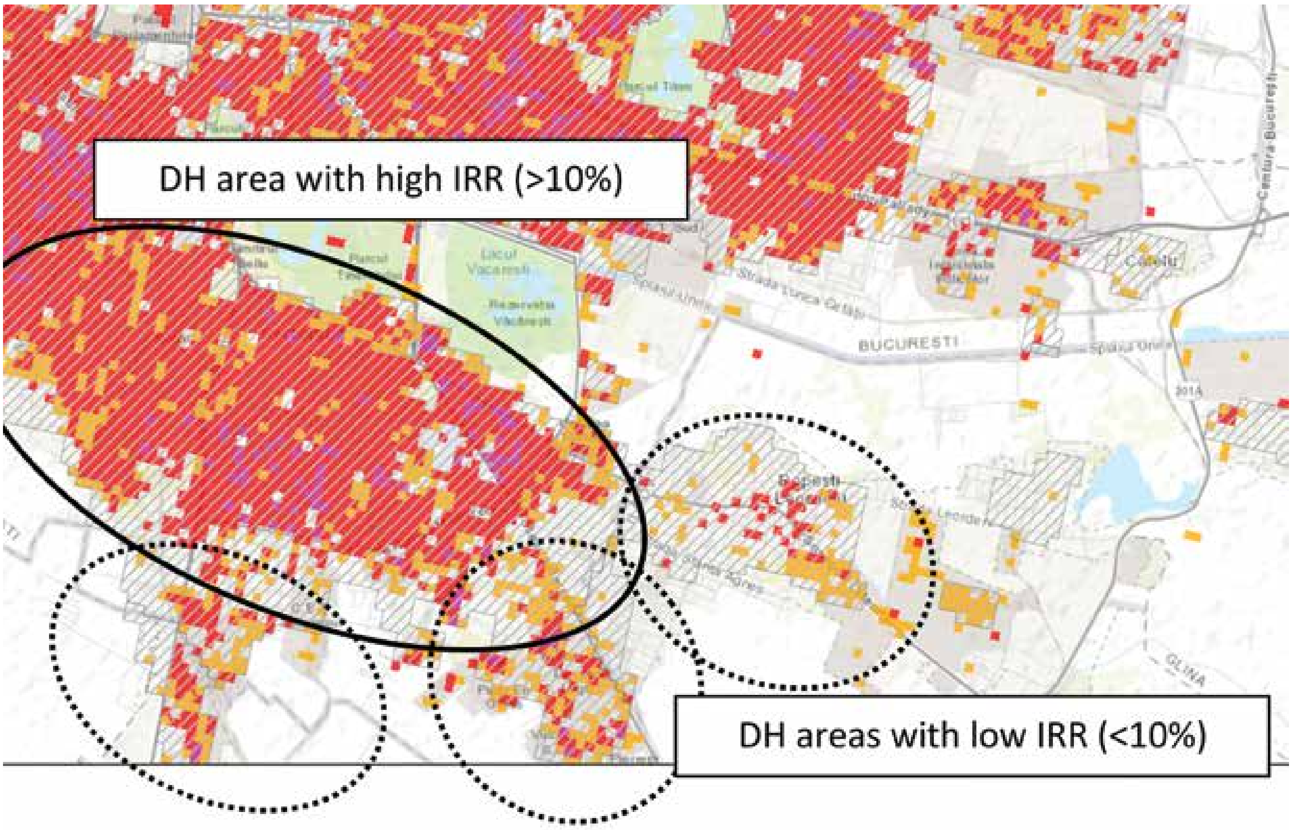
> “District energy projects are good matches for investors seeking a comparatively secure long-term revenue stream, rather than a quick return on their investment”

A significant barrier to investments in DHC systems can be uncertainty associated with heat demand, the potential for renewable or waste heat resources, potential customers or connection rates. As investments in district heating networks have a long timeframe, long-term stability must be ensured. This can, for example, be done through concession contracts, zoning and mandatory connections, or connection of public consumers as well as customers with high demand.

One approach to managing risk in new development projects is to start with known high-demand customers, such as hospitals, industry, swimming pools or other areas where the heat demand density is known to be stable and high. Single high-consumption customers increase the certainty of the investment if they agree to long-term contracts. This strategy can also be called “picking the low-hanging fruit.”

The benefit of these strategies is that starting with the high-value areas will enable putting pipes in the ground. New district heating companies will be able to climb the learning curve with these cases and be able to expand their coverage afterwards. There is often more room for learning in cases with a high IRR instead of cases with a lower IRR. Therefore, starting with the most profitable areas for new developments can be an important way to establish new systems.

Figure 34. **Example of developing district heating for areas with high and low IRRs**



Note: Areas are only examples and do not represent a real case. DH: district heating.

Source: AAU, based on PETA 4 data (n.d.)

A challenge associated with starting with the most profitable areas is that developers might exclude less profitable areas and never connect these to the district heating grids. An example is provided in Figure 34. It shows an area with high heat demand and three connected areas with lower heat demands. All four areas are prospective supply districts, according to the PETA 4 map, and could be supplied with district heating (Flensbourg University, Halmstad University and Aalborg University, 2018). If the high-demand area is developed first without an obligation to develop the remaining three districts, this would potentially leave these areas unprofitable after district heating has been implemented in the most profitable area.

DHC planners and decision makers should consider this dilemma when, for example, planning new areas, making new tenders, implementing new DHC zoning, etc. They should ensure that areas deemed profitable from a socio-economic perspective (see Part B.3.4 Establishing scenarios for heat supply") and not only those from a business economic perspective be developed with DHC supply.

Development of low-temperature resources such as geothermal is also considered financially risky, particularly in the early phase of development when limited information about the subsurface is available. The geological risk involved in the early phase of geothermal development includes drilling of unsuccessful wells due to low or no permeability.

Geothermal project can face challenges in attracting finance until the resource is proven through successful confirmatory drilling. In addition, the upfront investment required to develop a geothermal district heating system is usually much higher than for other sources. This is due to the generally capital-intensive drilling phase. Furthermore, geothermal projects have a longer lead time for development.

Traditional financing sources for district heating are municipal resources, supported by grants and concessional loans. Grants and concessional loans typically come from international, subnational or national funds, or from city-level initiatives (Leoni, Geyer and Schmidt, 2020).

Government actions to increase the attractiveness of renewable energy in DHC systems can be justified. Economic and financial instruments may include direct investment (government procurements, grants) such as those from which the city of Jinan, China, has benefited (see Box 14); fiscal or financial incentives (feed-in tariffs, taxes or taxes exemption); or market-based instruments (green or white certificates, green bonds).

Additionally, development banks' programmes can contribute to support financing (as well as feasibility analyses). The Renewable District Energy in the Western Balkans (ReDEWeB) Programme fund from the European Bank for Reconstruction and Development (EBRD; no date), which aims to enable renewable district energy investment in the Western Balkans (see Box 15).

BOX 14 JINAN (CHINA)

District heating has been the main technology devised by the government of Jinan for securing adequate heating for residents since the 1980s. Until recently, policies and state investments aimed to satisfy increasing heat demand by grid extension and capacity expansion in a system based on coal-fired production.

In 2015, district heating policy making entered a new stage in which the acceleration of ultra-low emissions from coal-fired boilers was targeted. Soon after, the regulatory framework became more concrete and comprehensive, specifying actions aimed at the replacement of coal-fired heat production with "clean heating". Financing increased accordingly.

In recent years, China in general has attached great importance to clean heating and has introduced a series of policies to promote, support and accelerate the implementation of clean heating. Jinan, as one of the national pilot cities of "winter clean heating", has received USD 100 million of special financial support from the central government annually, or USD 300 million for 3 years in total.

Under the impetus of the national clean heating policy, Jinan has formulated a plan for a pollution-free heating system by 2020. The plan includes, apart from the demolition or replacement of coal boilers, the use of alternative heat sources such as long-distance waste heat and geothermal. It also addresses demand-side management by utilising smart meters and implementing energy efficiency measures in building stock.

This case demonstrates the leverage of national energy policies and subsidies on local renewable district energy projects.


Source: Shutterstock

Jinan City, Capital of Shandong Province (China).

BOX 15 EBRD'S RENEWABLE DISTRICT ENERGY IN THE WESTERN BALKANS PROGRAMME

The ReDEWeB Programme was established by the EBRD to support the development of a renewables-based district energy market in the Western Balkans. The countries benefiting from the programme include Albania, Bosnia and Herzegovina, *Kosovo, North Macedonia, Montenegro and Serbia.

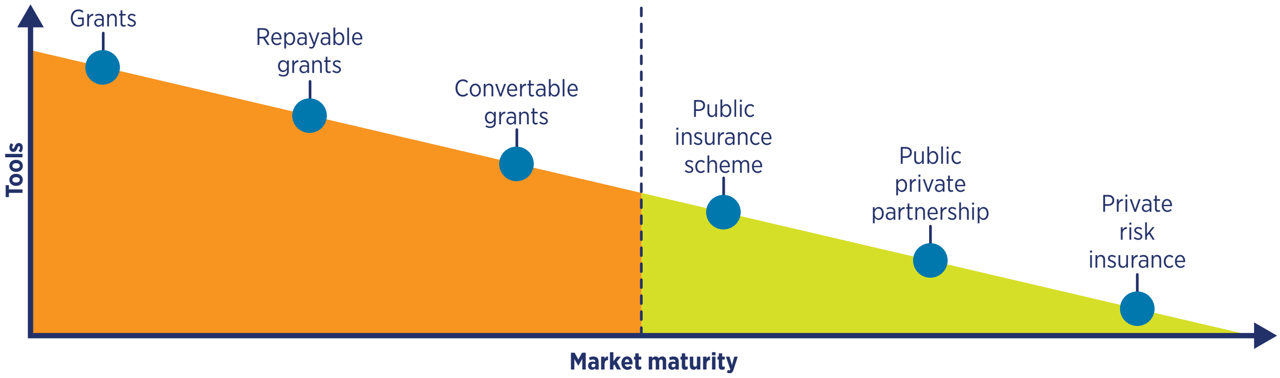
The programme focuses on developing sustainable urban energy systems in specific local contexts in the Western Balkans by:

- supporting the Western Balkan countries to develop action plans for renewables-based DHCs and achieving their renewable energy and energy efficiency contractual obligations
- supporting the establishment of city policy measures that encourage the generation, storage and utilisation of renewable energy in district energy systems
- supporting municipalities and the private sector to prepare district energy investment proposals, feasibility studies and preliminary designs
- organising events to promote the exchange of experiences and best practices in the development and operation of district energy systems
- financing or co-financing eligible district energy projects in the Western Balkans (Lukic, 2018).

Through the ReDEWeB programme, EBRD provides financial support for district energy projects as follows: sovereign-backed loans to national governments, municipal or utility loans guaranteed by the municipality to the local government, quasi-corporate utility loans to utility companies, and loans to PPP or to the private sector.

* The designation of Kosovo is without prejudice to positions on status and the United Nations Security Council Resolution 1244 (1999).

Figure 35. **Relationship between risk mitigation scheme and geothermal market maturity**



Source: Seyidov and Weimann (2020)

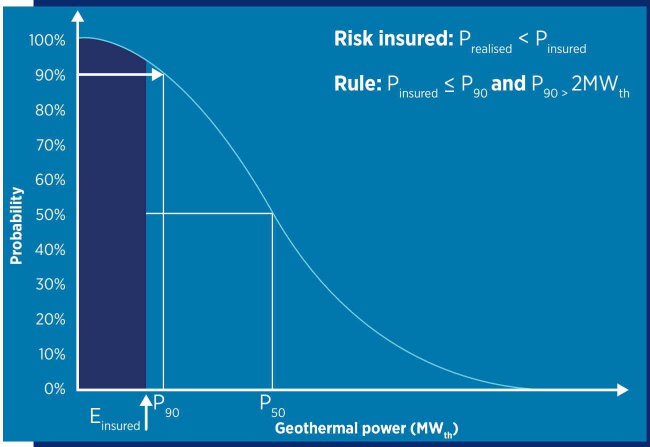
The private sector can also provide the financing required to develop district energy projects. However, legal and regulatory frameworks should be designed to allow for private sector participation in addition to being transparent and predictable. In addition, the structure of the heat tariff should allow investors to cover all their operating costs, make a profit and incentivise the more efficient heat suppliers. Finally, policy measures such as feed-in tariffs and fiscal incentives (*e.g.*, tax exemptions, heat zoning and preferential grid access) could encourage the private sector to invest in DHC (IFC, 2014).

Regarding geothermal energy specifically, public support and public-private well-productivity schemes have contributed to significant growth of geothermal heat in countries such as France and the Netherlands (see Box 16). As demonstrated in the EU-funded GeoRisk project, the type of support mechanisms used to de-risk geothermal projects may depend on the market maturity of the country/region, as shown in Figure 35.

For juvenile markets, project-based mechanisms may be preferred, *e.g.*, grants and convertible grants. This is because attracting private capital could be difficult without the intervention of the public sector, especially for project de-risking purposes. The more developed markets, which have a larger portfolio of projects, could adopt public insurance schemes, public-private schemes and private risk insurance (Seyidov and Weimann, 2020).

> "The choice of support mechanisms to de-risk geothermal projects depends on market maturity"

BOX 16 GEOTHERMAL RISK MITIGATION SCHEMES



Source: (Boissavy, 2019)

The Netherlands

An insurance-based geothermal risk mitigation scheme compensates developers for realising less than the expected output from drilled geothermal wells and by doing so, covers the geological risk of geothermal projects. According to the scheme, the insured is compensated when the realised geothermal power output from a drilled well is less than the 90% probability (P90) expected geothermal power output, as shown in the figure above.

For the eligible projects, the developer pays a premium equivalent to 7% of the total drilling costs to the scheme. In case the project is completely unsuccessful, the developer is compensated 85% of the total cost, capped at EUR 11.05 (Euros) million (USD 13.26 million) for shallow geothermal and EUR 18.7 million for deep geothermal projects.

Since 2009, when the scheme was inaugurated, 11 projects have been successfully realised (as of May 2020) and four claims made. The total amount of grants issued during the nine application rounds for the scheme to date cumulatively total EUR 146 million (Ramsak, 2020).

France

In France, a renewable heat fund was established in 2009 after the risk mitigation scheme in existence since the 1980s came to an end. The heat fund is composed of two components. One covers the geological risk through a short-term fund that compensates developers for unsuccessful drilling. The other is a long-term fund that covers repairs (*e.g.*, re-drilling injection wells in different locations) to the geothermal system to ensure continued operation. This fund will cover projects developed in the Dogger Aquifer in Paris as well as in other regions such as Alsace, Rhone River Corridor, Mediterranean areas and the Aquitaine Basin.

Since the establishment of the renewable heat fund, ten new projects had been developed as of 2019. In addition, geothermal projects developed in the 1980s would also be eligible for further drilling through the fund to extend their operational lives (Boissavy, 2019).

Another example of financing option can be found in Canada. Significant areas of the country are underlain by sedimentary basins known to host low-temperature geothermal resources, yet they have no electrical geothermal power production and no conventional deep geothermal direct-use. Canada's national government is investing over USD 75 million in several geothermal projects (conventional, co-production and unconventional) to prove geothermal development can assist the country in reducing carbon emissions and help in the transition to less dependence on hydrocarbons and coal (Hickson *et al.*, 2020a)

At the project level, innovative ways to finance the development and expansion of a district energy system have emerged.

For example, district energy companies may partner with an energy service company (ESCO) to offer consumers energy-saving programmes directly (Leoni, Geyer and Schmidt, 2020). An example was implemented by Toplana-Šabac, the district heating operator in the city of Šabac, Serbia (Jovanović, 2019). Such programmes typically include an energy audit of the housing or building and offers financing to the customers, repayable through utility bills. After the payback period has ended, customers reap the savings from reduced energy bills, which allows the utility to retain customers. Furthermore, with a high level of efficiency improvements, pursuit of sustainable energy supply options such renewable or waste heat-based DHC can become a more cost-effective way to satisfy the outstanding energy demand. This means there is an opportunity to expand the district energy network without increasing installed heat capacity, but with switching to low-temperature energy sources.

The proposed ideas for innovative business models aimed at optimising DHC systems through building-side measures are intended to act in concert to solve the key economic, social, technological and regulatory obstacles to decrease the supply temperatures (Leoni, Geyer and Schmidt, 2020). Those solutions act on three points:

- Engaging customers to achieve operational efficiency at the building level. This can be achieved through forging better relationships and communication, adding new tariff structures, and offering services with personalised promotions.

- Financing of optimisation measures and fault detection. This can be realised through strategic partnerships and crowdfunding platforms.

- Contracting energy savings. This is central to solving concerns related to rental homes' split incentives. Energy savings in a building result in lower energy bills to the occupier. However, if the occupier is a tenant, the building owner might not be willing to invest in energy performance improvement measures if no benefits accrue to him or her, resulting in a situation referred to as split incentive.

Furthermore, concerning financing, it is possible that strategic partnerships with stakeholders may provide economic benefits from a lower operating temperature. According to Leoni, Geyer and Schmidt (2020), these include:

- Industries and commercial activities such as data centres that can supply low temperature energy to the DHC system, *e.g.* waste heat.

- Proprietors of technologies that are suitable for DHC operating with low return temperature, *e.g.* solar thermal systems and heat pumps.

- Proprietors of information and communication systems for providing operational support in DHC systems.

- Proprietors of technologies and equipment for enabling low-temperature supply in buildings.

- Business schemes that generate vouchers that the DHC utility may purchase and award to "virtuous" customers, if such a motivator is desired (Leoni, Geyer and Schmidt, 2020).

These stakeholders may provide funds to implement temperature reduction in DHC. Returns on such investments can take various forms: the sale of waste heat for those who invest in waste heat supply the provision of technologies to the utility or to customers for technology developers and providers; and voucher sales for investors in business schemes that deliver vouchers. Other potential collaborations may entail joint ventures.

DHC projects generally appeal to investors whose goals are not simply to maximise returns but also to promote activities with ethical, social and environmental objectives. Related to this, a potentially viable business model option for district energy funding is providing citizens with the opportunity to engage with the DHC business through crowdfunding platforms and retirement funds (Candelise, 2018; Leoni, Geyer and Schmidt, 2020).

Crowdfunding is a form of alternative finance in which several people provide relatively small amounts of money to a project via web-based platforms. This solution was chosen, in addition to public subsidies, to finance the geothermal district heating project, GeoMarne, in the municipalities, in the municipalities of Champs-de-Marne and Noisiel in the greater Paris area of France (Richter, 2020). EUR 1 million was collected in this way from the inhabitants of the Île-de-France Region, for a total investment of EUR 40 million.

Access to financing could further be hindered by a low level of institutional and technical expertise, especially in developing countries. Such expertise is required to establish the bankability of renewable energy projects. Among the tools that have been developed to address this challenge is IRENA's Project Navigator (IRENA, n.d.), an online platform that provides a step-by-step practical guide for developing bankable renewable energy projects, including projects for district energy, as shown in Box 17.

BOX 17

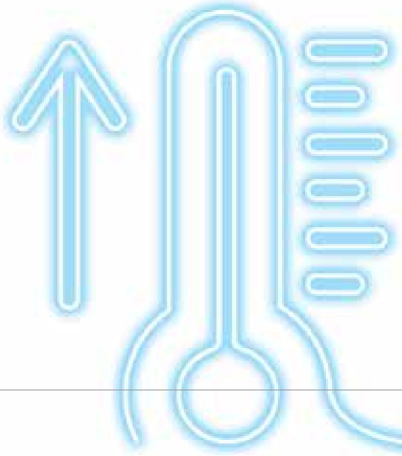
DEVELOPING BANKABLE RENEWABLE ENERGY PROJECTS: IRENA PROJECT NAVIGATOR

The IRENA Project Navigator guidelines provide crucial information to assist project developers in building bankable proposals for renewable energy projects. The navigator guides project developers through the typical stages of project development. At each stage, distinct steps are described, including what needs to be accomplished at the end of that stage of development.

The major stages in the entire lifecycle of project development, beginning at the project idea through to construction, O&M and decommissioning, are described in Project Navigator, including the actions and deliverables.

Project Navigator also provides real-life case studies, industry best practices and the relevant financing instruments for each technology. Furthermore, developers are provided with a workspace and tools to prepare projects, keep track of their progress and identify gaps. The results can be exported for further processing using tools such as financial models or checklists.

https://navigator.irena.org/index.html



Summary of challenges and recommendations for enabling regulatory conditions, financing and business models

This section has presented different models and challenges related to the ownership, pricing, financing and regulation of DHC systems. These different factors are closely related and usually affect each other. Therefore, a public or private developer or DHC company should take all these factors into account at the same time to create trust in the district energy system.

With this interconnection, it follows that a comprehensive DHC governance scheme should comprise a combination of measures. Many more aspects than those presented in Figure 36 will impact the operation and functioning of DHC systems adhering to the governance schemes. These include local knowledge, perception and acceptance of DHC, operation of systems, engineering knowledge and practice, and access to resources. The governance scheme of choice should ensure that investments are profitable, consumers benefit through competitive prices and transparency in pricing is promoted.

Set up a comprehensive district energy governance scheme.

National and local authorities could employ various governance measures in the district energy sector to achieve specific economic and social goals.

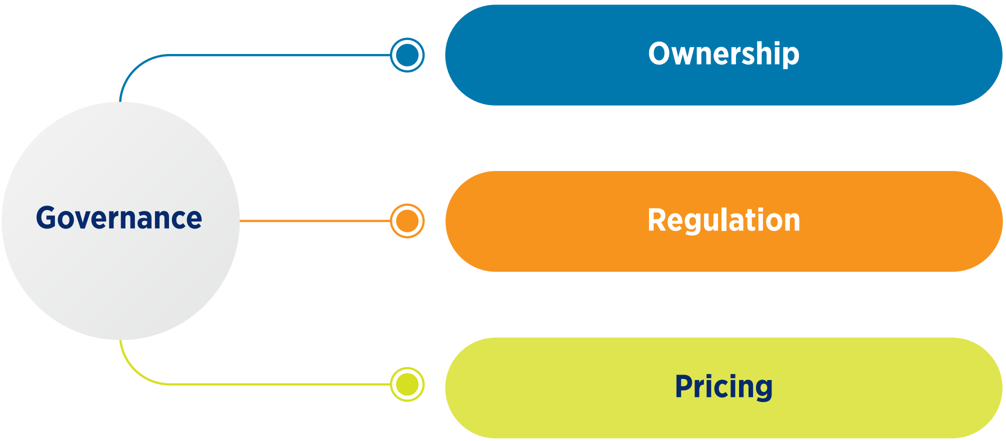
- ➡ Identify and implement a governance scheme that ensures that a district energy system produces the greatest societal benefits. This scheme could entail a combination of various aspects such as price regulation, ownership and legislation. For example, the true costs principle has produced low prices combined with public or community ownership in Danish district heating systems.

Ensure a level playing field.

To make district energy projects based on renewable energy competitive with other existing options for heating and cooling, national and local authorities have a pivotal role to play.

- ➡ Consider district energy grids as public infrastructure. Infrastructure that is at least partially publicly owned is often recommended

Figure 36. **Factors forming a district heating governance scheme**



because significant investment is often required to successfully establish a district energy company and its related infrastructure. This ensures that the projects can attract low-cost and long-term financing options, which contributes to bringing down the cost of energy.

- Promote competition in the local heat markets, for example in the production of heat through tenders. Multiple heat generators competing on price of supply eliminates the danger of natural monopoly and encourages innovation and efficiency in production, which result in cheaper energy.

- Introduce different instruments at the national and local levels to ensure a level playing field: heat tariffs, fiscal levers, streamlined DHC legislation, price regulation and monitoring, as well as instruments addressing externalities – for instance, CO_2 pricing. All options to develop sustainable systems should be considered in a holistic perspective: for example, those regarding building regulation.

- Develop a conducive environment for renewable energy resources such as geothermal and solar thermal through the removal of regulatory barriers as well as by optimising and simplifying regulations at the local and national levels. This can entail regulations on accessing, exploring and exploiting geothermal resources as well as licensing of solar thermal projects.

Overcome the barriers to investment to enable a capital-intensive transition.
National and local authorities can support district energy operators by minimising certain risks associated with energy resources to attract further financing.

- Support the development of insurance schemes to de-risk renewable sources such as geothermal by compensating investors for drilling of unproductive wells and/or for declining well productivity.

- Provide direct funding from the public sector or develop technical assistance programmes. These funds could be utilised to assess the viability of projects, develop district energy infrastructure in new markets or to assess renewable energy supply options.

At the project level, the following measures can be undertaken to attract financing.

- Assess the low-hanging fruit. Start with high-demand consumers or public buildings – while ensuring the full potential can be exploited. This strategy ensures the uncertainty associated with demand in new developments is addressed in order to unlock financing.

- Explore innovative financing practices that entail partnerships. Energy efficiency measures at the building level could be financed through partnerships with ESCOs or technology providers, while crowdfunding could be explored to reap the benefits of low-cost capital, *e.g.*, from pension funds.

CHECKLIST

Enabling the integration of low-temperature renewable energy in DHC

SCOPING AND STAKEHOLDER MAPPING AND ENGAGEMENT

- ☑ Clarify the main drivers and targets
- ☑ Map the stakeholders and identify their interests
- ☑ Elaborate a stakeholder engagement strategy that includes citizens
- ☑ Carry out the engagement process

DEMAND AND RESOURCE MAPPING FOR TECHNICAL SCENARIOS AND PROJECT IDENTIFICATION

- ☑ Map heat and cold demand using data from measurements and/or modelled/ estimated demand through spatial analysis tools
- ☑ Map energy sources and analyse their potential for district energy, taking into account the best available technologies to exploit the available low-temperature energy sources
- ☑ Balance heat savings and redesign of the supply to avoid overcapacity
- ☑ Establish scenarios with the right level of detail necessary to make decisions, taking into account the societal goals that motivated the strategic energy planning (SEP) process
- ☑ Adopt an iterative approach to move toward an increasingly detailed project

ADDRESSING TECHNICAL CHALLENGES WITH BUILDING STOCK, NETWORKS AND ENERGY RESOURCES

- ☑ For areas with existing district heating systems, assess the compatibility of the existing building stock and network
- ☑ Integrate DHC modernisation and building renovation plansif needed, including improvement of control systems, metering and consumption-based billing and advice to households
- ☑ Address DHW preparation and other secondary measures to reduce system operating temperature
- ☑ Evaluate whether pipes are oversized or if a substitution is needed in existing DHC systems
- ☑ Address the technical challenges in the exploitation of low-temperature energy sources
- ☑ Geothermal: Assess drilling, scaling and injection risks, temperature and flow
- ☑ Solar: Evaluate land or roof availability and storage
- ☑ Waste heat: Determine temperature and flow, availability over time, location and temporal mismatch

ENABLING REGULATORY CONDITIONS, FINANCING AND BUSINESS MODELS

- ☑ Choose an ownership model that will deal effectively with the different interests of the stakeholders
- ☑ Choose the right option for pricing regulation to ensure competitive prices in the heat market
- ☑ Mitigate risk with innovative financing/ insurance schemes and picking low-hanging fruit first
- ☑ Ensure a level playing field through fiscal levers and legislation, considering externalities

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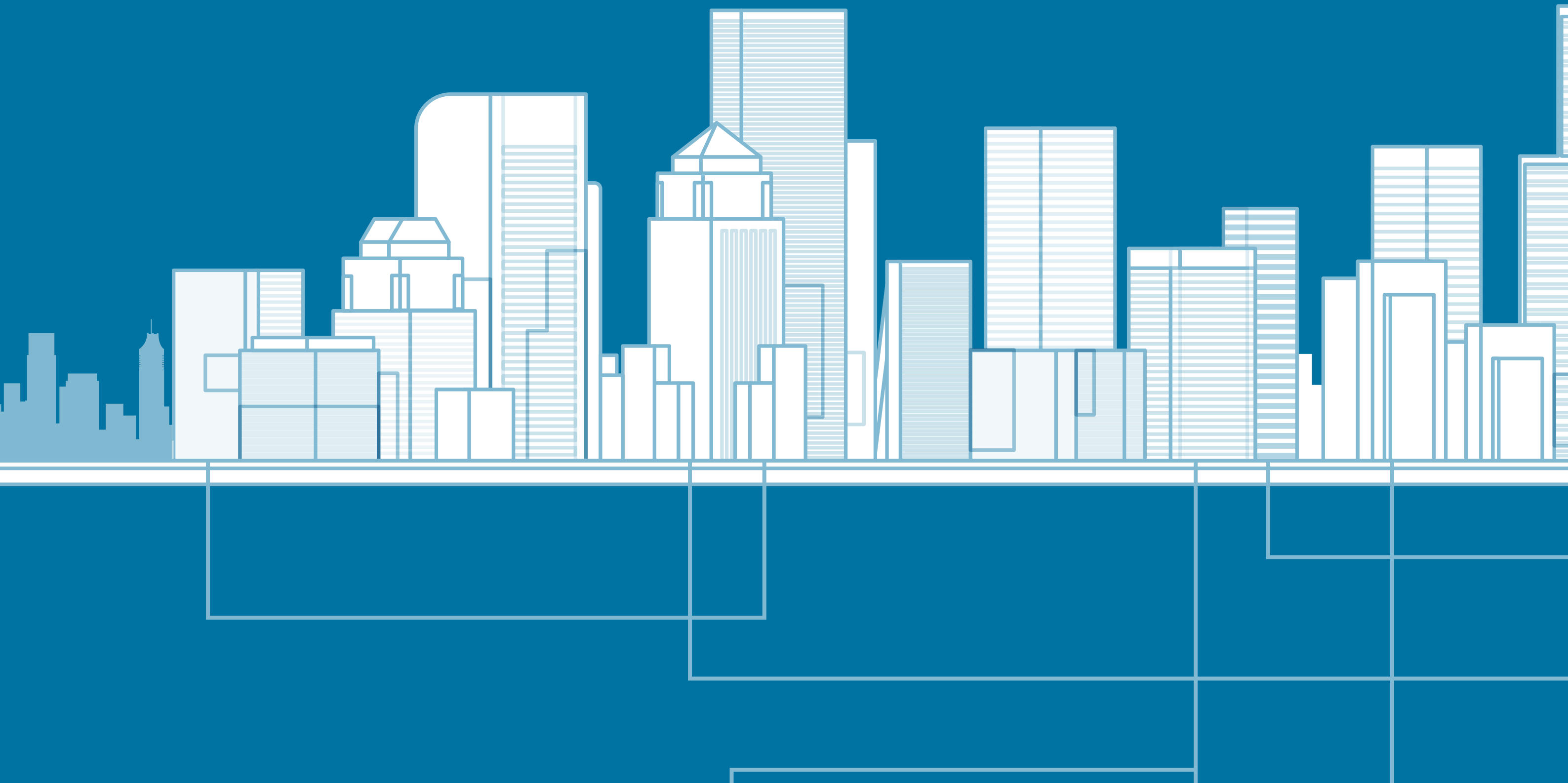

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