AALBORG UNIVERSITY
DENMARK

IRENA
International Renewable Energy Agency

INTEGRATING LOW-TEMPERATURE RENEWABLES IN DISTRICT ENERGY SYSTEMS

GUIDELINES FOR POLICY MAKERS

SUMMARY

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About IRENA

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

About Aalborg University

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/***

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

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Integrating low-temperature renewables in district energy systems

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.

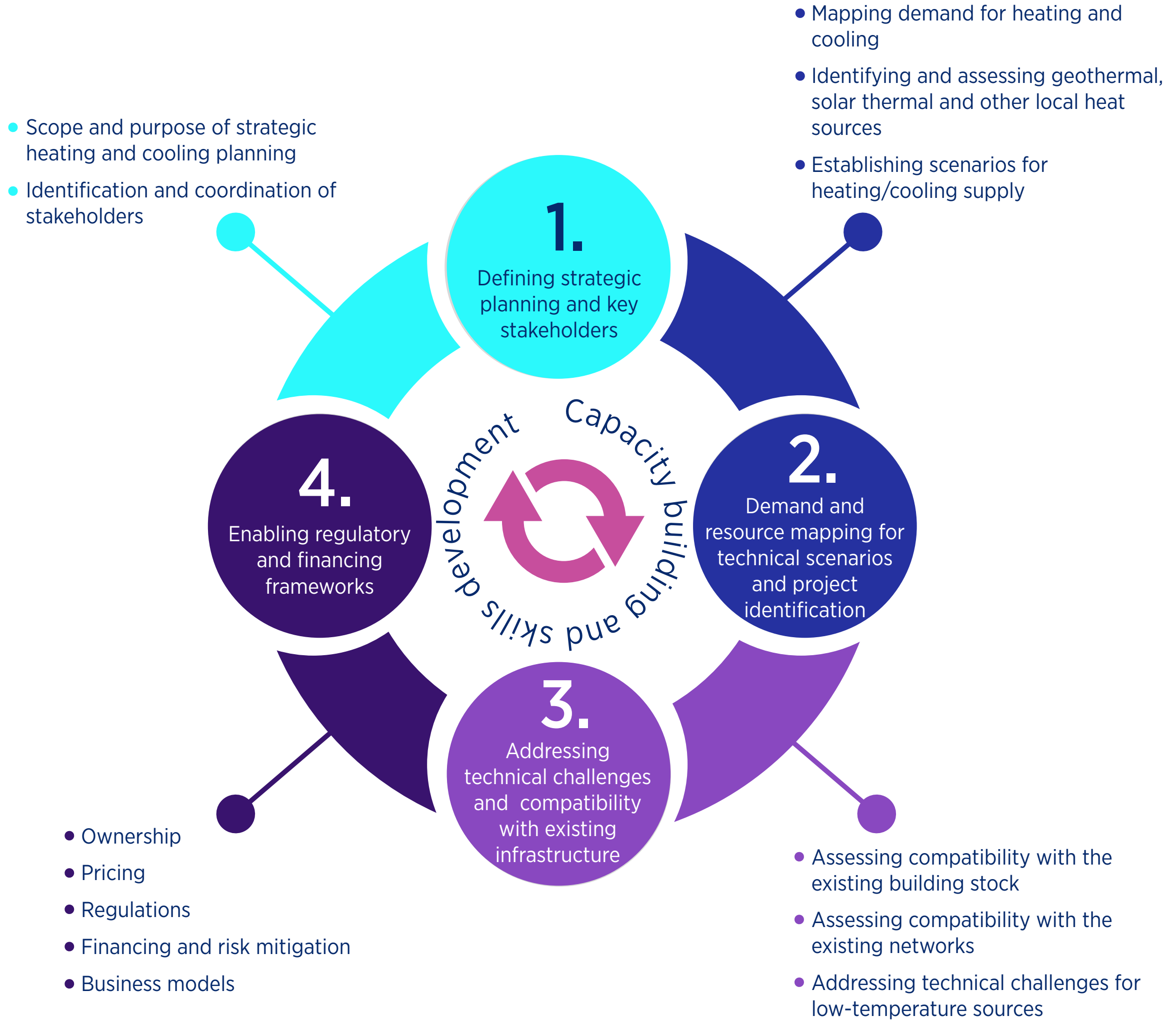
- Ensure adherence to best practices for the operation of local renewable energy sources. These best practices result in the most cost-efficient and sustainable utilisation of resources, *e.g.*, reinjection for geothermal energy or seasonal thermal storage for solar thermal.

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.

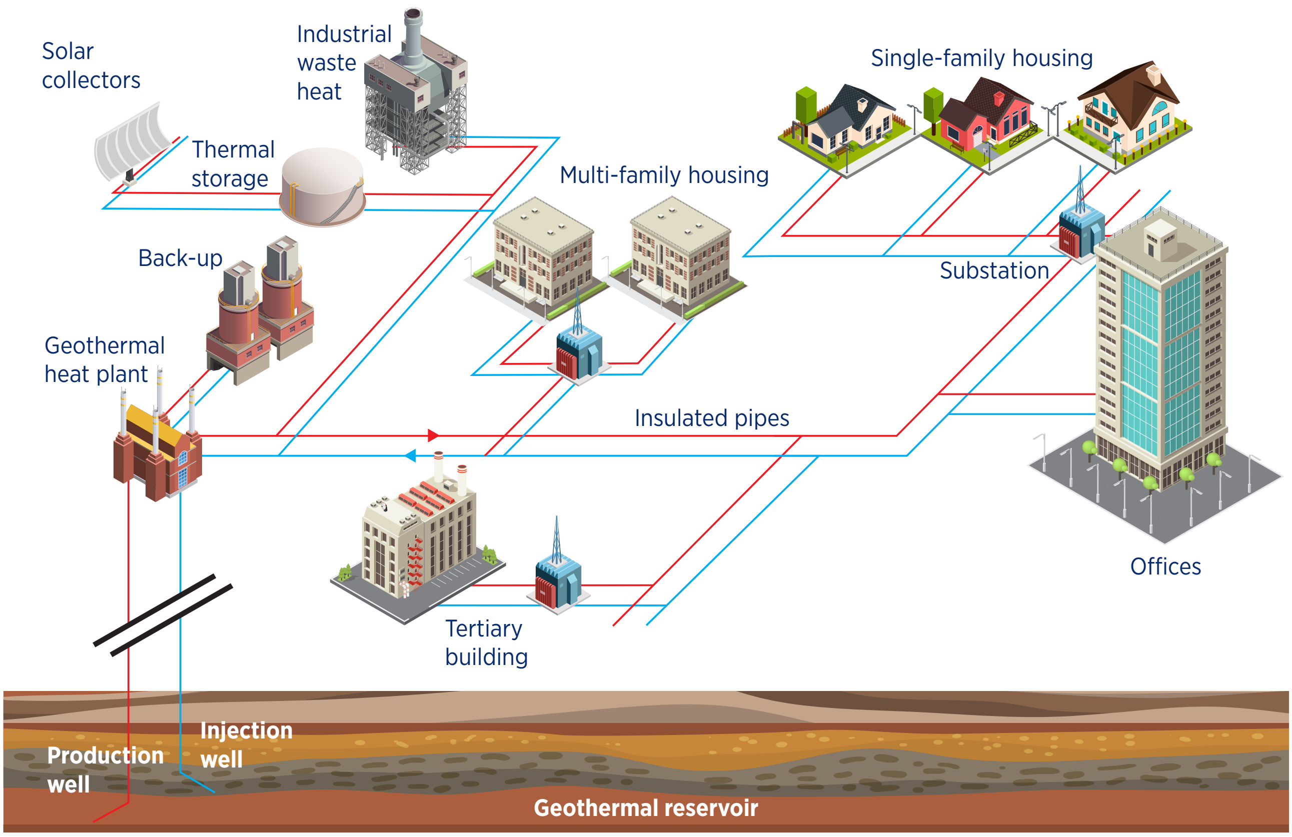
- Overcome uncertainty associated with demand for heating and cooling to attract investment by first connecting high-demand consumers – while making sure the full potential can be exploited.
- In addition to public finance, including grants, explore the involvement of the private sector and innovative 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.

Schematic framework for enabling the integration of low-temperature renewables into district energy systems



District heating and cooling systems

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

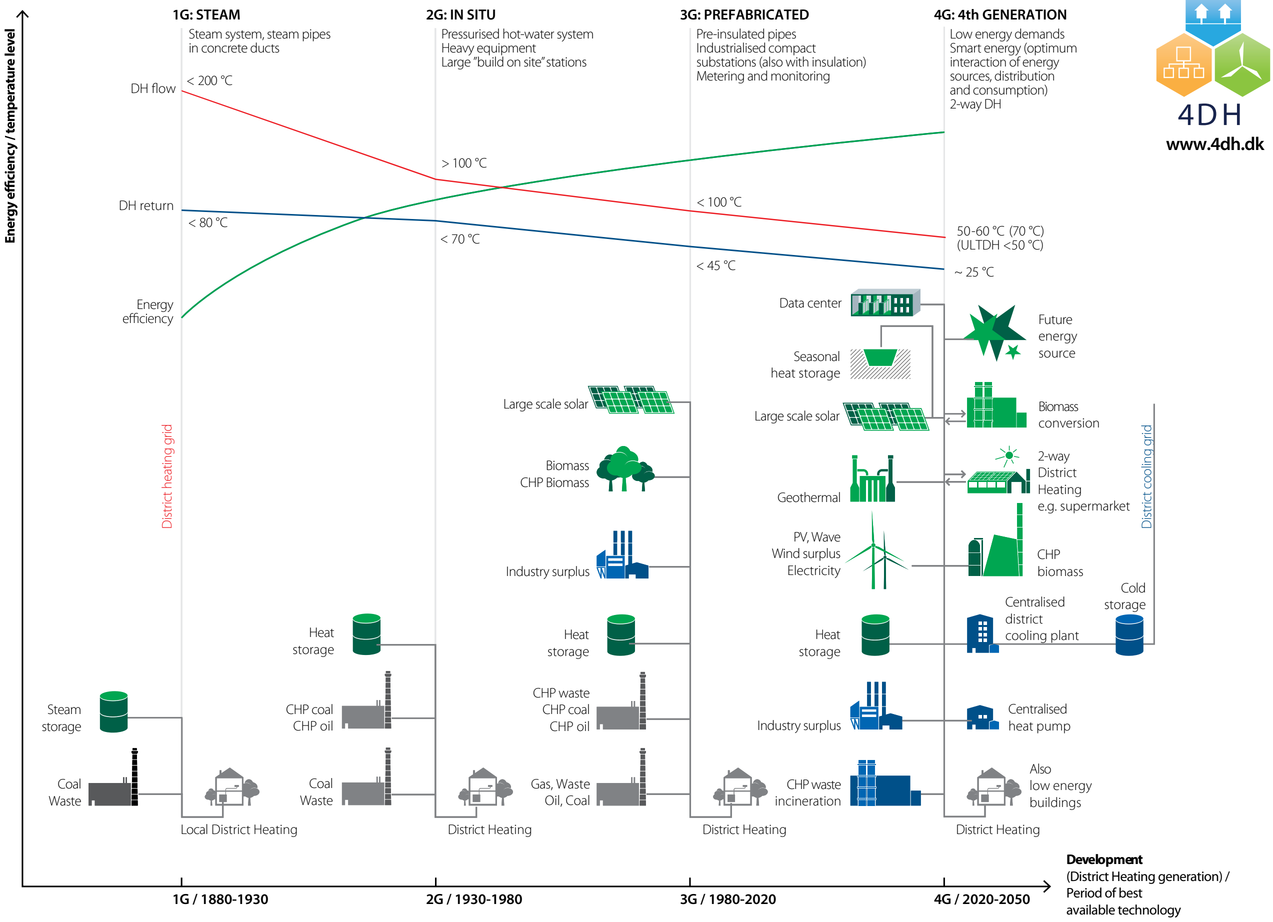
District heating, or heat networks, is a heat distributing system. Heat is generated in one (or several) central (or decentralised) location(s) and transported through a network of insulated transmission and distribution pipes and auxiliary equipment. This system meets the requirements of space heating and domestic hot water (DHW) for residential and tertiary buildings. The figure above 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).

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)

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. 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.

Developing strategic heating and cooling plans

To address energy-related challenges in a coordinated 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.

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 coordinated at all levels of governance and across all energy-related policy areas (Djørup *et al.*, 2019a).

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"

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.

> "Strategic heating and cooling plans identify opportunities and synergies and apply cost-effective policies and incentives"

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 coordinate 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.

Stakeholder engagement

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.

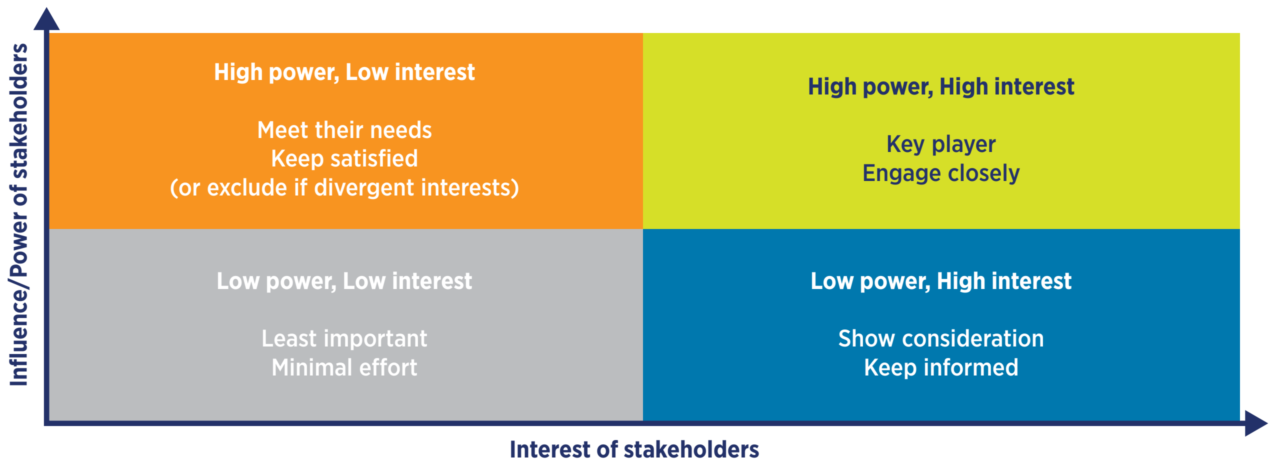
This leads to the need for:

- 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.

Coordination 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 the figure below.

Classification of stakeholders based on level of influence and interest



Source: UNIGE; based on Mendelow (1981)

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.

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

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.

Summary of challenges and recommendations for stakeholder mapping

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.

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

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.

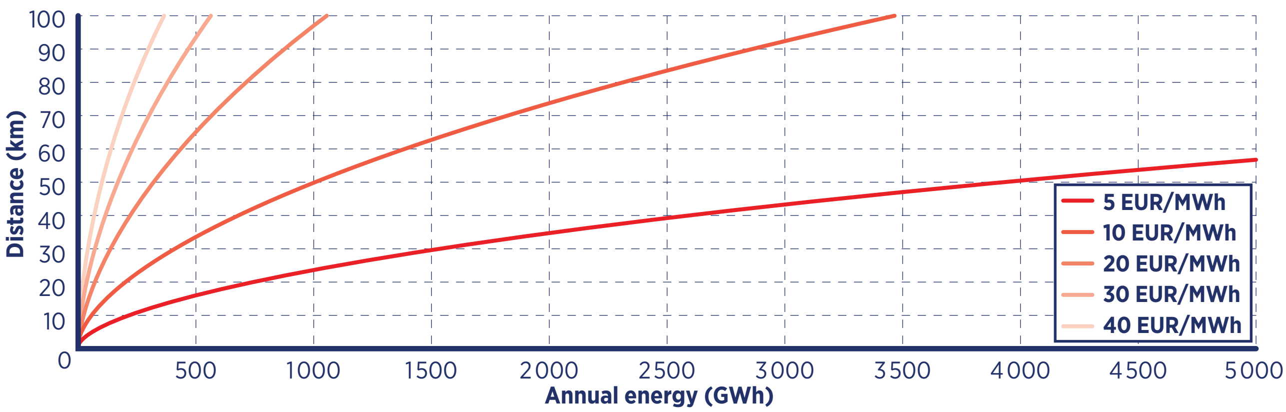
A significant difference between heat planning and other types of energy planning is the critical importance of the location of the demand and supply. Thus, having knowledge about the location of heating resources and the existing heating and cooling demand enables connecting these two together and assessing 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. The figure below 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.

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).

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).

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.

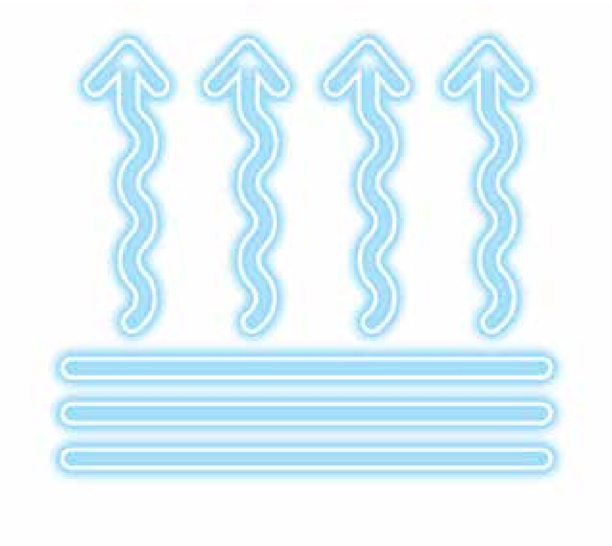
- Make decisions on which technical scenarios for heating and cooling are to be implemented based not only on business-economic considerations but also more importantly on socio-economic considerations. This will ensure that projects address wider societal goals such as decarbonisation, job creation 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.

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

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 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.

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

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 human 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.

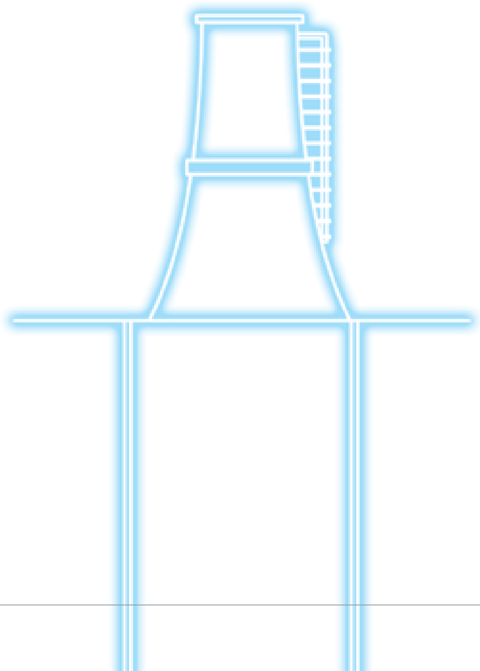
Build local capacity to address technical challenges for integrating low-temperature heat sources into existing networks and building stock.

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

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. 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.



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.

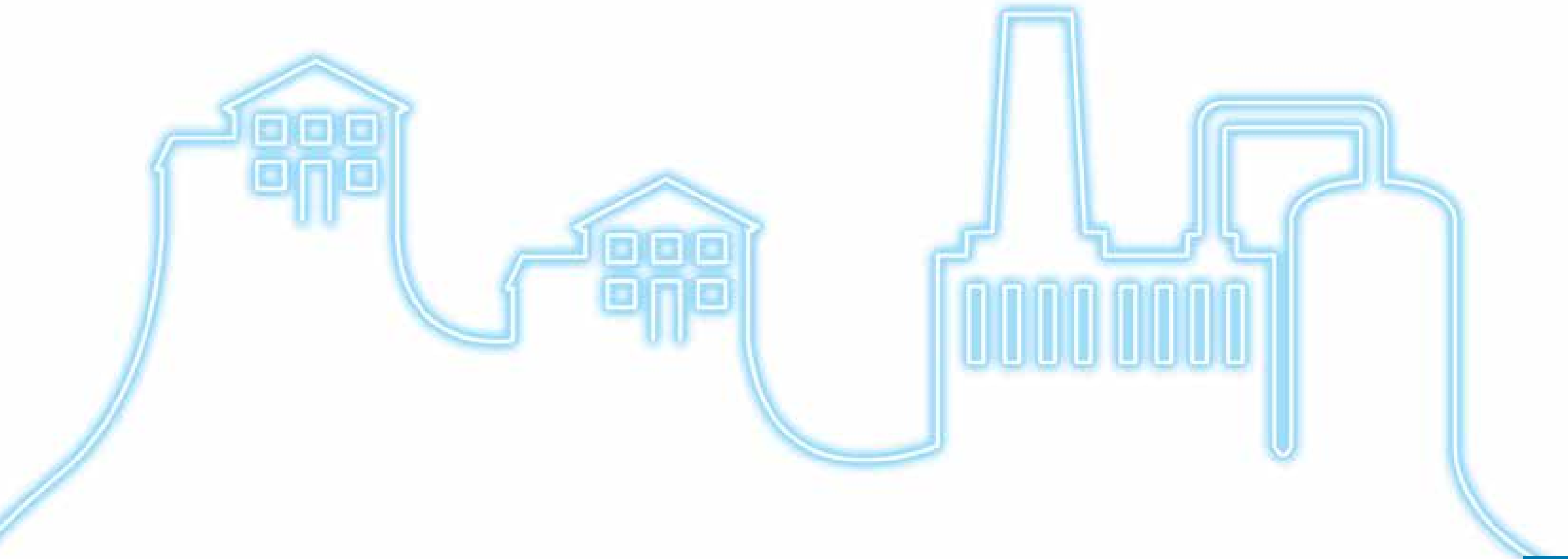
- Adhere to industry best practices regarding reservoir management as well as O&M of equipment in geothermal-based district energy systems. These best practices include reinjection of spent geothermal fluids for the sustainability of the reservoir and engineering strategies to manage scaling and corrosion.

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.

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



Enabling regulatory conditions, financing and business models

As demonstrated by the figure below, 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.

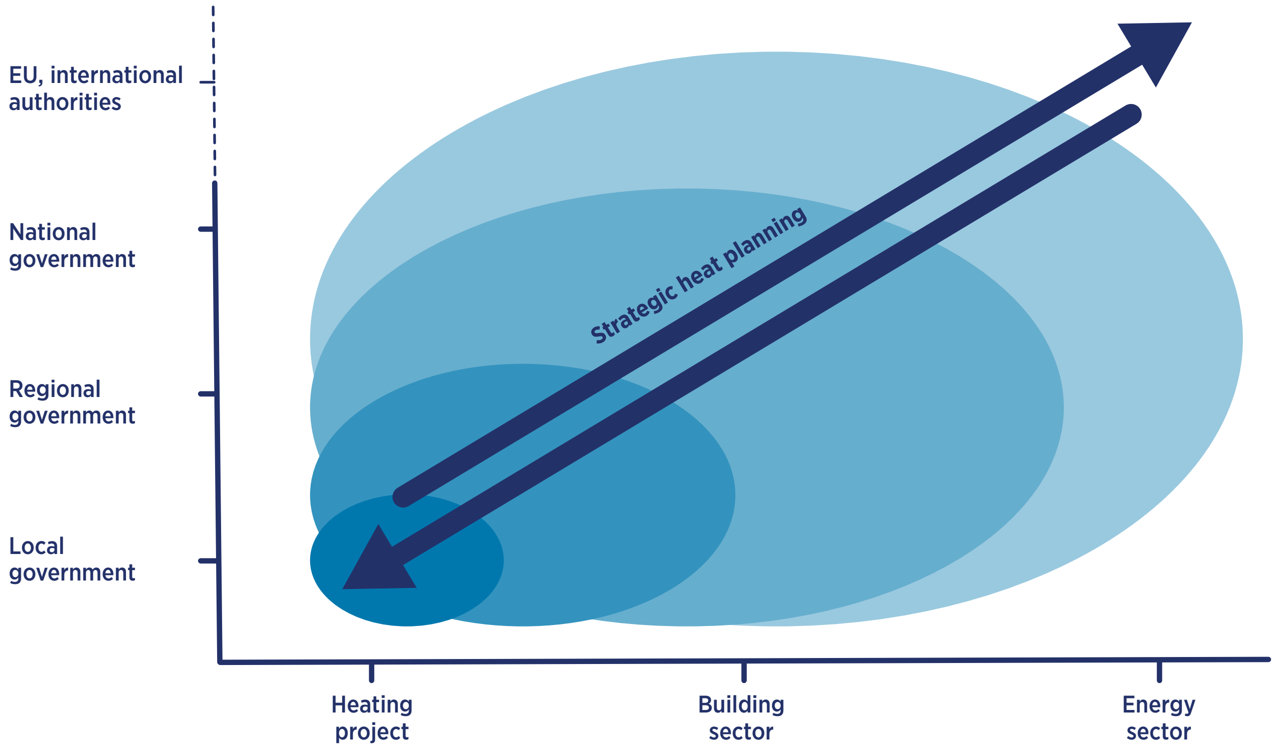
National and local authorities need to establish both financial and regulatory measures to ensure that the benefits of DHC systems are captured by the established pricing regimes. At the same time, the existing regimes must ensure they do not disadvantage DHC systems because of subsidies (direct or indirect)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

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



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

This section summarises the 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. 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.

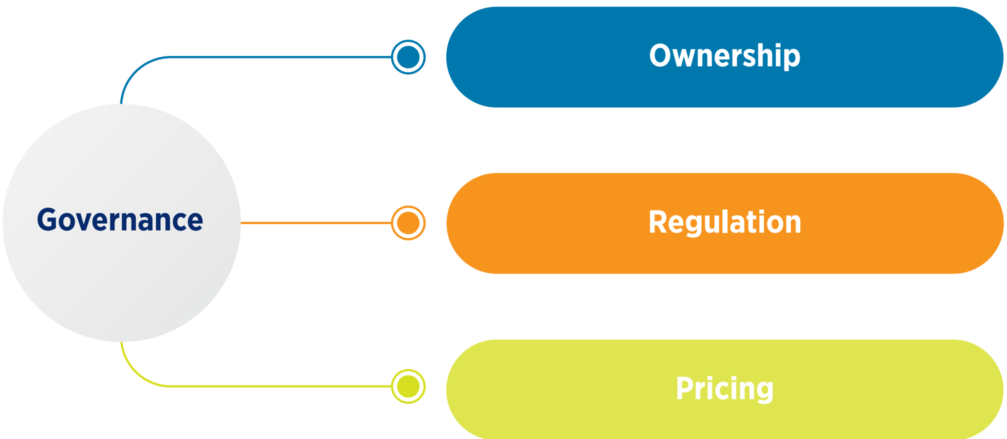
- Identify and implement a governance scheme that ensures that a district energy system produces the greatest societal benefits. This scheme could entail a combination of various aspects such as price regulation, ownership and legislation. For example, the true costs principle has produced low prices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

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.

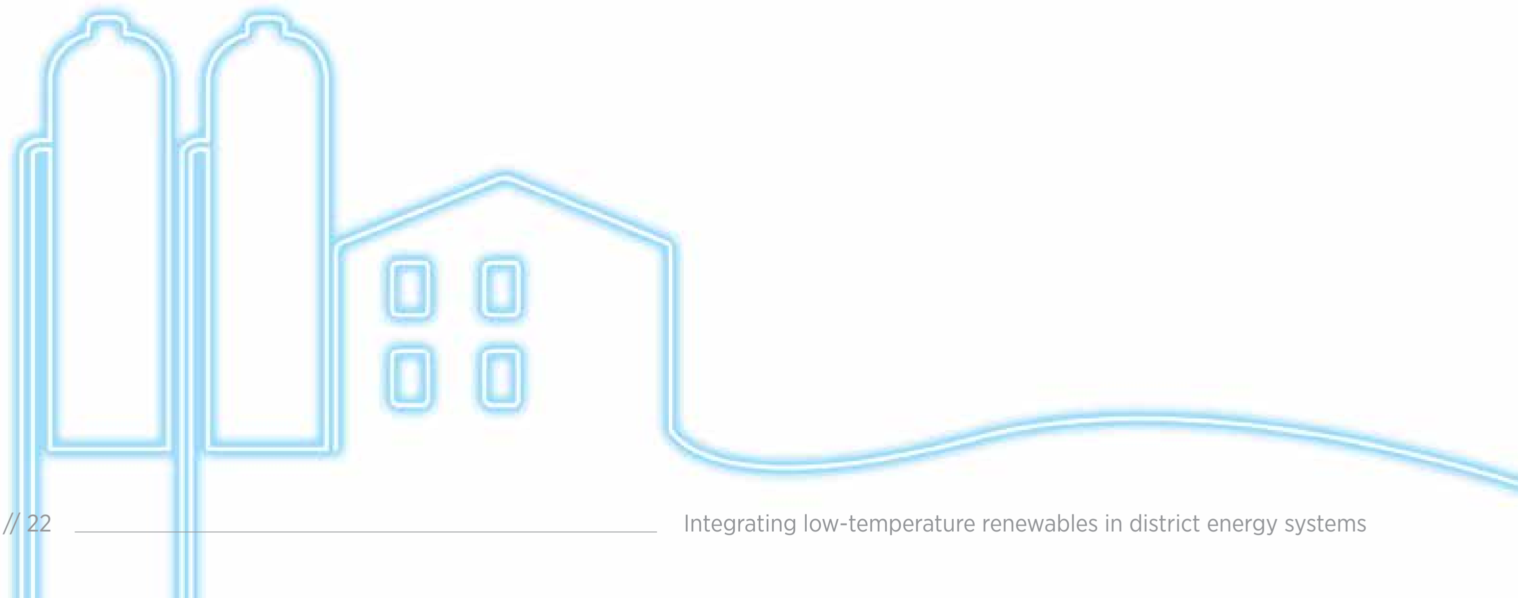
- Support the development of insurance schemes to de-risk renewable sources such as geothermal by compensating investors for drilling of unproductive wells and/or for declining well productivity.

- 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	DEMAND AND RESOURCE MAPPING FOR TECHNICAL SCENARIOS AND PROJECT IDENTIFICATION	ADDRESSING TECHNICAL CHALLENGES WITH BUILDING STOCK, NETWORKS AND ENERGY RESOURCES	ENABLING FRAMEWORK CONDITIONS, FINANCING AND BUSINESS MODELS
☑ 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	☑ 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	☑ For areas with existing district heating systems, assess the compatibility of the existing building stock and network ☑ Integrate DHC modernisation and building renovation plans if 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	☑ 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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