DISTRICT HEATING AND COOLING SOLUTION BOOKLET

EU Smart Cities Information System

SCIS Smart Cities Information System | February 2020

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WHAT IS THE SMART CITIES INFORMATION SYSTEM?

The Smart Cities Information System (SCIS) brings together project developers, cities, institutions, industry and experts from across Europe to exchange data, experience, know-how and to collaborate on the creation of smart cities and an energy-efficient urban environment.

WHAT IS A SOLUTION BOOKLET?

A summary of the management framework, primarily written for cities. It seeks to reduce the effort, speed up the process, strengthen quality and confidence in outputs, align across disciplines, and generally prepare a city to engage the market to acquire a solution.

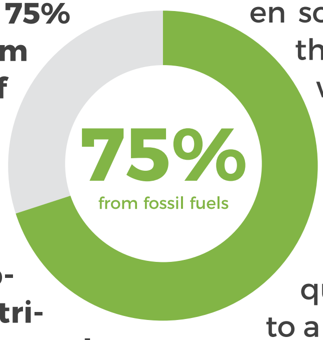
WHAT IS "PACKAGING"?

'Packaging' addresses the societal needs, technical solutions, business models and financing for a measure – and offers ways to put these in the particular context of the city/ cities in question. It is supported by a growing number of templates to speed up and make consistent the resulting output.

WHAT & WHY

WHAT & WHY

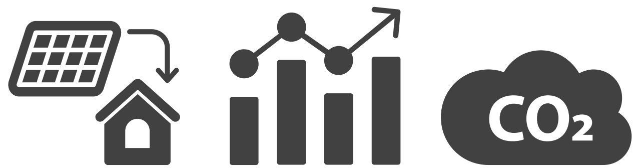
Half of the energy consumed in Europe is used for heating and cooling, and 75% of this energy is still coming from fossil fuels. Additionally, much of this energy is wasted due to inefficiencies in the heating and cooling systems. State-of-the-art, sustainable district heating and cooling systems offer a unique opportunity to make significant contributions to decarbonise EU cities through the efficient distribution of heat and cold from renewable energy sources.



District heating networks (initially centralised heat production, delivered through distribution networks) have been present in cities for more than one hundred years, evolving from the early **high-temperature heat distribution** (steam) networks towards more **efficient lower temperature schemes** that reduce heat distribution losses and enable the **use of renewable energy sources**, as well as the **integration with the electricity grid.** Also, current intelligent management systems allow for **increased operational benefits and new paradigms such as decentralised networks.**

District heating and cooling networks constitute a proven solution for **large scale thermal energy distribution** that has been deployed in a growing number of cities worldwide, using a diversity of technologies that can enable to develop synergies between the **production and distribution of heat, cooling, domestic hot water and electricity.**

Many district heating systems around the world require modernisation (i.e. retrofitting) to bring them to a reliable, state-of-the-art standard. Currently, district heating and cooling technologies enable the use of a variety of heat sources that would otherwise be often wasted, as well as of renewable heat. Nowadays, cities are currently looking at state-of-the-art district heating and cooling networks to achieve energy and climate related goals, including affordable energy provision; **reduced reliance on energy imports and fossil fuels; local air quality improvements; CO_2 emission reductions; and an increased share of renewables in the energy mix.**



increased share of renewables — air quality improvements — CO_2 emission reductions

Sustainable, state-of-the-art district heating and cooling systems integrating renewable generation can present **many benefits for cities and society,** linked to both the local and global challenges urban environments are currently facing:

- Efficiency benefits from **centralised energy production** (economy of scale).
- **Reduced greenhouse gas emissions** from heating and cooling, minimising CO_2 penalties and contributing to targets on emission reduction of the building stock.
- Good **synergy potential with local renewable energy sources** and waste heat/cold.
- **Reduced dependency on fossil fuels,** reducing exposure to international energy trade.
- **Local green jobs creation potential** through increased focus on local energy sources.
- Potential **income sources** when combined with waste incineration or the use of other residual sources like landfill biogas and industrial or commercial waste heat.
- **Better air quality,** entailing reduced costs in the public health system.

CITY CONTEXT

CITY CONTEXT

"Today, around 75% of Europeans live in cities. Urban areas account for 60 to 80% of global energy consumption and around the same share of CO_2 emissions. Climate change has the potential to influence almost all components of the urban environment and raises new, complex challenges for quality of urban life, health and urban biodiversity. ... Climate change will affect many aspects of urban living from air quality to consumption patterns. The EU has put in place ambitious policies and initiatives to promoting solutions on the ground. These include initiatives to increase resilience and promote renewable energies and low-carbon technologies" [1]

This global urban concentration trend entails a **growing thermal energy demand in cities,** where domestic space heating or cooling and distribution of hot water are the main elements. Sustainable, state-of the art district heating and cooling systems, together with sensible **building retrofitting schemes,** are one of the most promising technology combinations to address this urban challenge. The scale of district heating and cooling systems, in addition, can provide excellent opportunities to introduce smart features, such as **thermal storage technologies,** in a cost-effective way. However, district heating and cooling systems should be carefully designed considering the **specific urban context** they are to serve. Different aspects affecting energy demand, such as urban density, climate, building stock condition and local availability of excess heat sources or renewable energy sources will play a key role in selection and design of the most appropriate district heating system.

Specifically, in urban contexts, the existing building stock conditions as well as the potential trade-offs with building energy retrofitting policies and targets need to be carefully assessed[2]. Last-generation low temperature district heating and cooling systems might not be suitable for all urban and suburban scenarios, since they are best suited to low-demand, energy-efficient buildings. For this reason, careful attention must be paid to the context in order to design a district heating network and to select the technologies to be used. Heat zoning plans can be developed to assist in city-wide planning. They identify zones that can well be serviced by specific types of district heating networks, versus areas where 'stand-alone' solutions (for example, based on the use of individual heat pumps) will be more appropriate.

1 European Commission, 2019.
EU action at international level; Climate Action in Cities

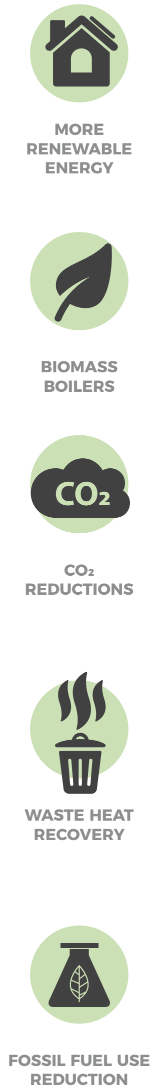
2 H. Vandevyvere, G. Reynders, R. Baeten, I. De Jaeger, Y. Ma, 2019. The trade-off between urban building stock retrofit, local renewable energy production and the roll-out of 4G district heating networks

What are cities able to achieve through district heating and cooling systems?

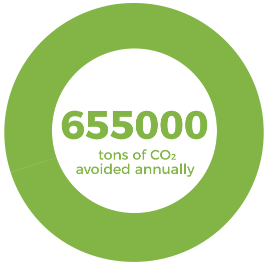
District heating and cooling systems deliver added **value from many perspectives.**

Some real-world examples are listed below:

1. Through the Smarter Together project, Lyon, Munich and Vienna aim to provide their citizens with 17,2 MW of newly installed renewable capacity in the project districts.
2. Through the Replicate project, San Sebastian is developing a district heating system that will:
   - service more than 1500 new properties and 156 existing dwellings;
   - be partially powered by two 1400 kW biomass boilers;
   - and lead to a reduction of primary energy consumption of 35%, where 90% of this energy is renewable, and 85 % reduction of CO_2 emissions.
3. Through the Pitagoras Project, a pilot generation plant in Brescia is expected to achieve, through a combination of waste heat recovery and power generation by an Organic Rankine Cycle (ORC):
   - a reduction of 39 057 MWh/yr. of primary energy demand;
   - and a reduction of 7220 tonnes of CO_2/yr.
4. Through the SINFONIA project, Innsbruck's district heating network has been extended and optimised to increase its use of renewable energy sources by 95% and reduce the system use of fossil fuel by 22%.
5. Danish cities have reduced their CO_2 emissions with 20% since 1990, reportedly due to district heating systems.
6. Paris has district heating systems at the core of its 75% CO_2 reduction strategy by 2050.



7. In Copenhagen, a waste-to-heat recycling process avoids 655.000 tons of CO_2 annually, displacing 1.4 million barrels of oil each year.



8. In Gothenburg, district heating production doubled between 1973 and 2010, while CO_2 emissions fell by half and the city's nitrogen oxide (NOx) and sulphur dioxide (SO_2) emissions declined even more sharply, due to the reduction of fossil fuel use.

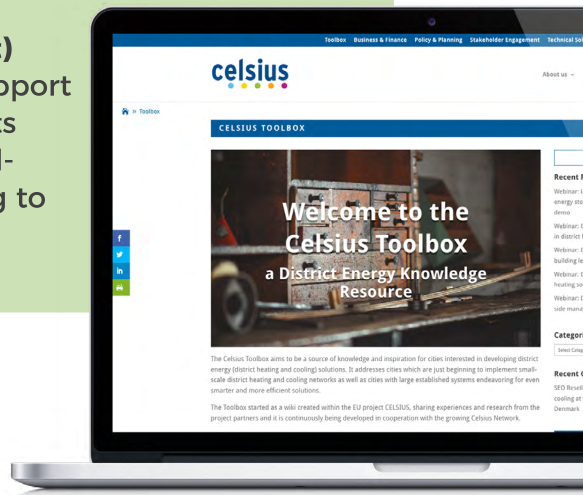
> "The main challenge of these systems to become mainstream is their integration in existing environments. In new developments it is less challenging."

Frank Soons, Sustainability and Innovation manager at Ennatuurlijk

The CELSIUS initiative for Cities

Stemming from the successful, award-winning CELSIUS project, the CELSIUS initiative is a collaboration hub for efficient, integrated heating and cooling solutions supporting cities in their energy transition to carbon-neutral systems. CELSIUS gathers and shares technical, economic, social and policy expertise, allowing members to connect, exchange and foster innovation, leading to solutions that accelerate sustainable development in Europe and across the world. The CELSIUS initiative offers the following main resources for cities:

- **The CELSIUS toolbox:** Conceived as a technology independent wiki-based knowledge-transfer platform, the toolbox condenses social & technical knowledge, lessons learned and best practices compiled throughout the project, in an effort to assist cities with practical information necessary for the development and maintenance of their district heating and cooling systems - including technical, social, economic and legal advice. The wiki is divided into four main elements: Business and Finance, Policy and Planning, Stakeholder Engagement and Technical Solutions.
- **Events (including a yearly summit) and webinars**, as well as tailored support actions for specific cities and projects which are grouped forming demand-driven "forerunner groups" according to their specific needs and challenges.



Heat Zoning in your city

Municipalities can use **heat zoning as a planning tool** in their decision making towards design and deployment of **district heating and cooling networks.** Heat zoning plans are already compulsory in some EU countries and drive many cities in their strategies in transitioning towards clean energy.

By mapping and quantifying locally available renewable energy and waste heat sources, as well as heat demand in urban and suburban environments, an initial assessment on whether district heating networks are desirable or not can be made, including initial considerations on the type of technologies to be used.

Although the preparation of proper heat zoning plans entails much locally sourced, detailed information, a good starting point can be the **Pan-European Thermal Atlas (PETA)**, produced by the **Heat Roadmap Europe project**, which maps diverse parameters related to thermal energy in EU cities: heat and cold demand, district heating distribution costs, geothermal heat potential, biomass resources, excess heat resources, district heating recommendation levels, etc.

The map is available online at:
heatroadmap.eu

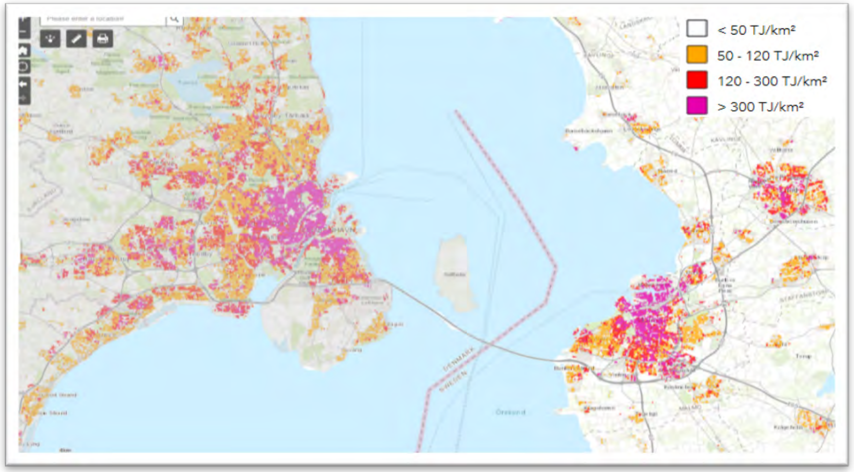


Figure 1. Heat demand in Oresund area; Copenhagen, Malmö and Lund (source: PETA)

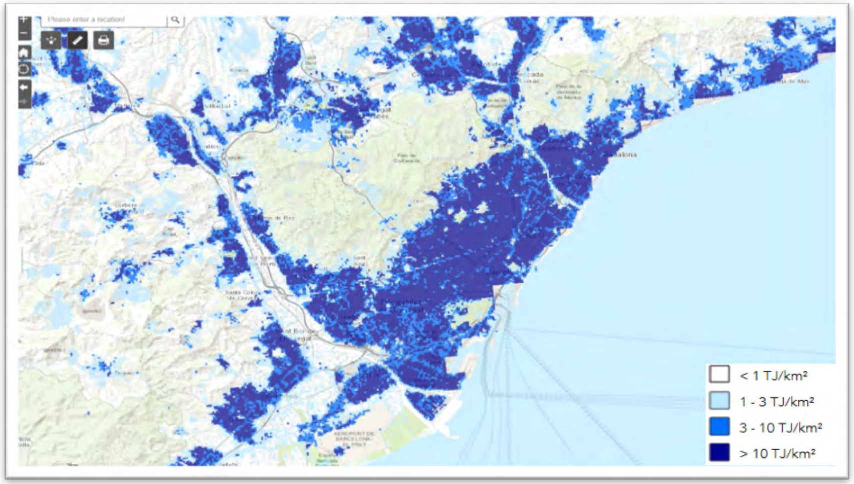


Figure 2. Cold demand in the Barcelona metropolitan area (source: PETA)

SOCIETAL & USER ASPECTS

SOCIETAL & USER ASPECTS

Stakeholder support & citizen engagement

Developing district heating systems can be a challenging action, mainly in areas where energy supply is based on individual production systems. This change involves actions in both the domestic and community spaces, as well as implies a shift of paradigm for people, who are used to behave in a particular way during their daily life. Structural changes to these routines can generate social resistance. Therefore, it is important to **carefully inform and involve key local stakeholders and citizens** in these shifting processes, explaining very well the procedures and benefits entailed to the new approach.

For effective community engagement, the city may well set up a **collaborative reflection** process regarding the integration of district energy systems. When this process is well developed and designed with a relevant target in mind (e.g. city carbon neutrality), future plans, strategies, commitments and projects will be shared by the community, enforcing the feeling of belonging and contribution to a shared meaningful goal by everyone.

There are two main stages when this engagement can be fostered:

1. The **city energy visioning,** where the municipality can co-formulate key goals, strategies and projects with key local stakeholders and citizens.
   - For an engaging city energy visioning process, check Sonderborg Roadmap2025.[3]
2. The **master plan design,** where the municipality, key stakeholders and future customers can exchange views about the system and its features /conditions with the promoters. This is key as long-term commitments are necessary to confirm the viability of operations. At this stage, it is crucial to involve the main groups of the area addressed by the master plan in order to inform them and avoid foreseen barriers.
   - For an engaging master plan, check the stakeholder involvement in Lolland municipality.[4]

CITY
ENERGY VISION

MASTER
PLAN DESIGN

CITY
PARTNERSHIP

3 Sonderborg Roadmap2025. 50 steps towards a carbon neutral Sonderborg
4 Broad stakeholder involvement in district heating masterplan for Lolland municipality

For such large-scale actions, a **city partnership** joining the municipality, all district energy utilities, citizens' and business associations, and large heat/cold consumers is highly recommended.

Main benefits for stakeholders

Broad societal benefits become tangible for stakeholders involved in district heating and cooling operations; particularly, end users can feel significant differences when this system is compared to the traditional individual production systems:

- **More reliable energy source,** even working at extreme weather events.
- **More predictable energy costs** due to fuel source flexibility. The **exposure** to fluctuating gas and electricity prices is **reduced**.
- Ability to **pursue better long-term energy contracts.**
- **Increase of indoor space and safety and reduced indoor noise and pollution** by externalising thermal energy production, fuels and storage from the building.
- **Lower** overall **operation, maintenance and insurance** costs.
- **Easier upgrade/replacement of equipment** (centralised) to more efficient and cleaner technologies.

For further reference, please visit the CELSIUS Toolbox area on **Stakeholder engagement**, where materials such as articles and webinars provide in-depth exploration of citizen and stakeholder engagement.

TECHNICAL SPECIFICATIONS

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Technology evolution

Since the initial district heating system deployments over a hundred years ago, development of district heating systems has gradually achieved higher levels of efficiency, a more widespread diversification of heat and cold sources, and increased potential of integration with the electricity grid. This is a direct consequence of technologies and processes that gradually enabled the use of lower operating temperatures.

Through the conversion of electricity into heat with subsequent heat storage, smart system management and flexible supply, these systems present moreover an inexpensive solution for creating the flexibility required to integrate high levels of variable renewable energy into the electricity grid. Such smart exchange between electricity and heat production is better known as sector coupling.

So-called fourth-generation systems are located closer to load centres and generators than traditional central-station generating plants, and the distributive nature and scale of these systems allows for a more nodal and web-like framework, enhancing accessibility to the grid through multiple points.

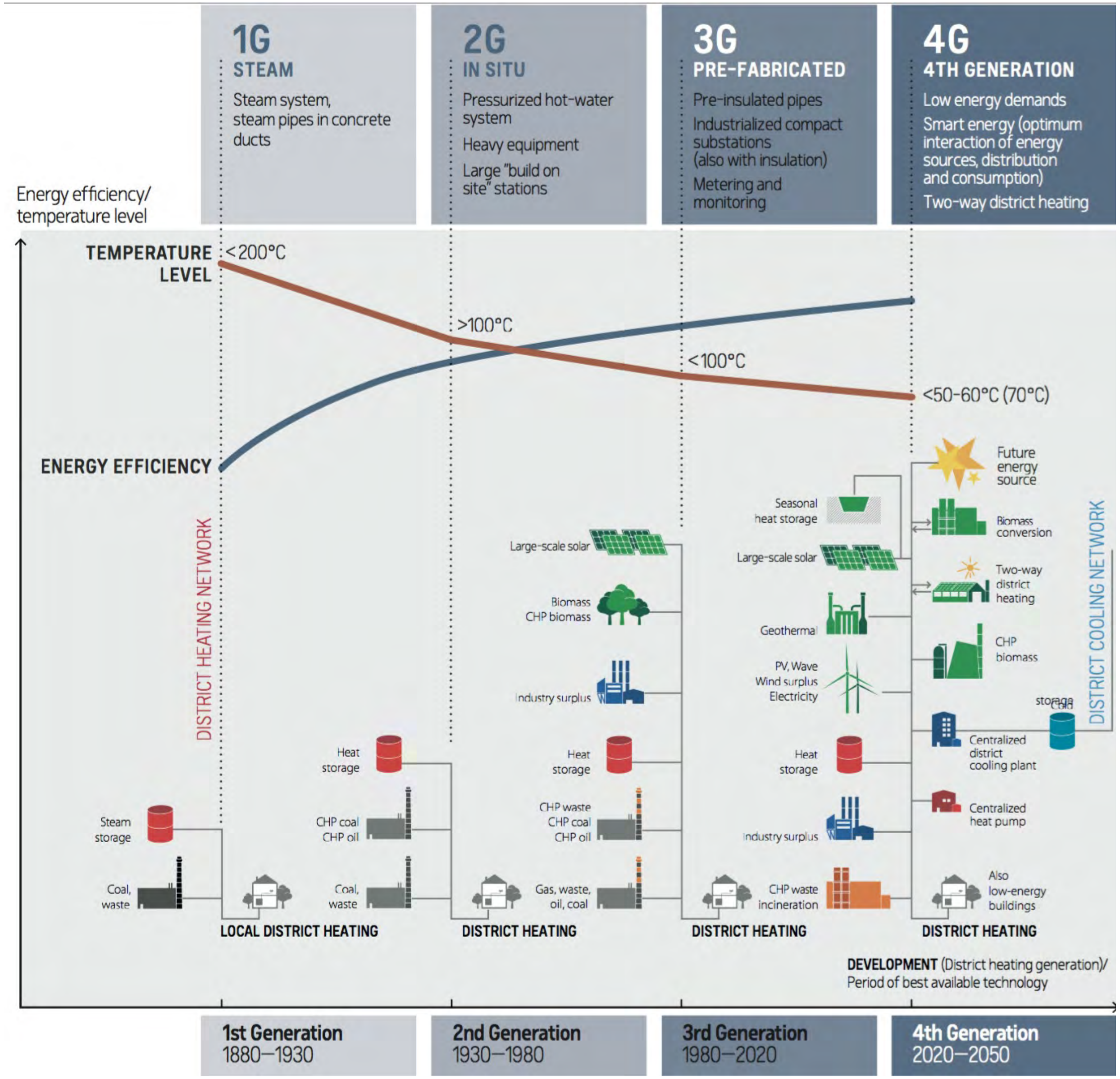
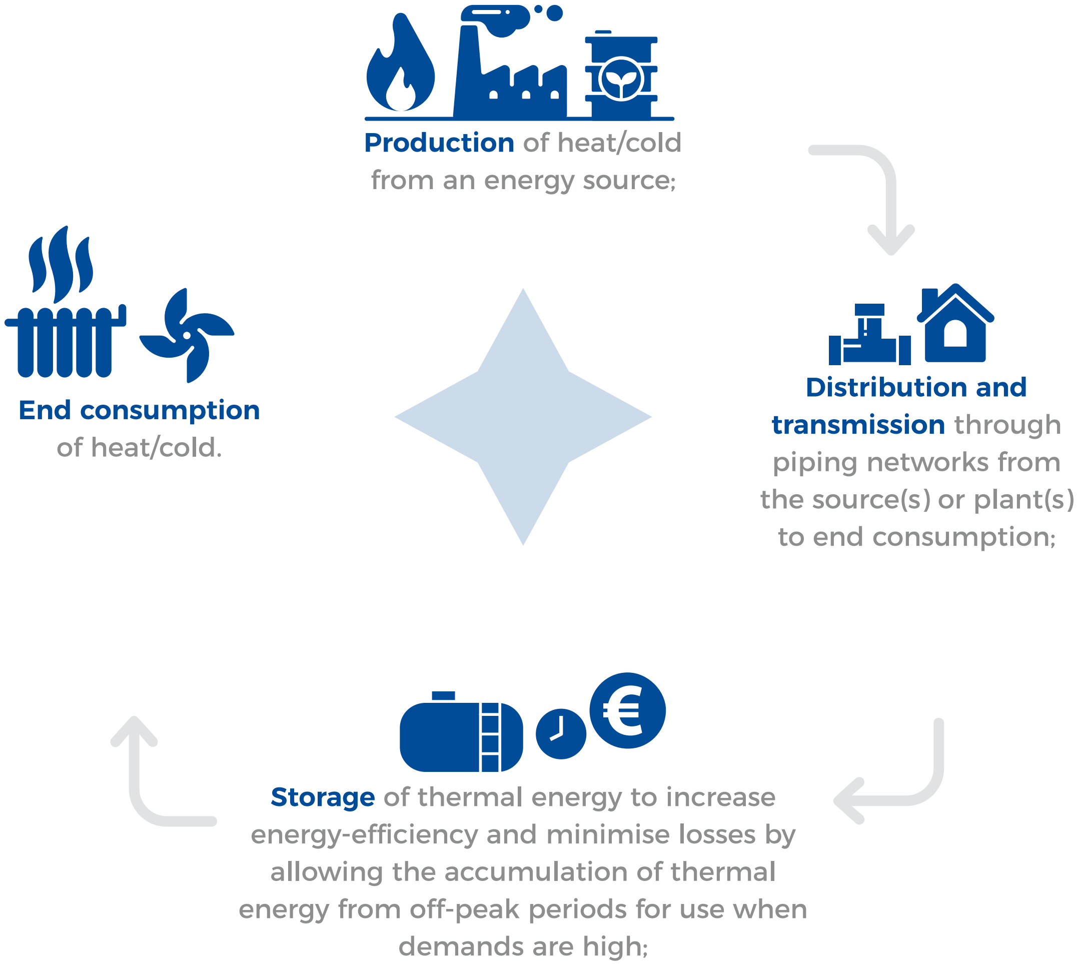


Figure 3. Historical development of district energy networks (Aalborg University and Danfoss District Energy, 2014)

Components and Technologies

According to their main functions, district heating and cooling systems can be broken down into **four different parts:**



Through the City-ZEN project, the city of Grenoble implemented different storage solutions such as seasonal storage with dry geothermal boreholes, centralised phase change materials storage to help meet peak demand for heating and solar thermal generation coupled with phase change material (PCM) storage solutions.

Achieving sustainable modern district heating and cooling begins with the energy source. New-generation district heating and cooling systems lean towards decentralised generation of heat and cold, taking advantage of all available local energy sources – many of which are renewable and produce minimal greenhouse gas emissions.

"In the near future, systems will shift from high to lower-temperature sources, where waste heat recovery, solar-thermal and geothermal sources will be progressively introduced."

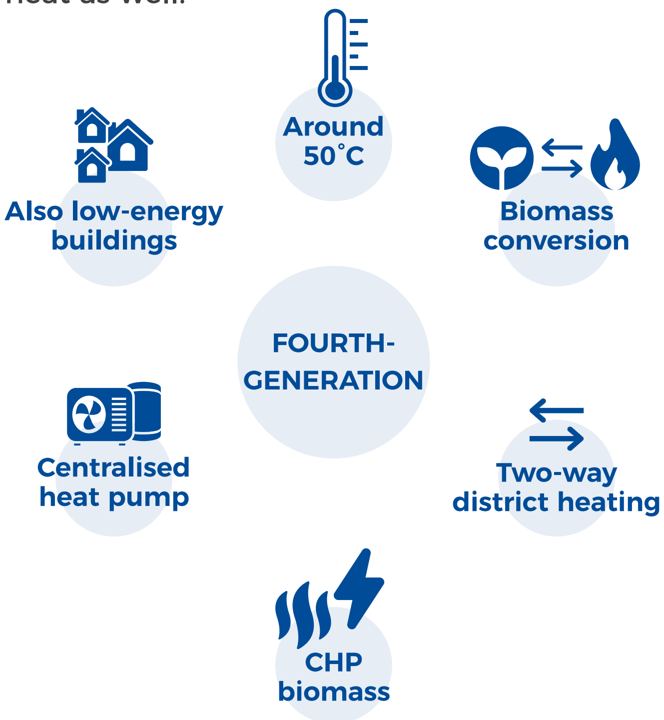
Frank Soons, Sustainability and Innovation manager at Ennatuurlijk

Technologies for District Heating

Current district heating enables the use of a variety of heat sources that are otherwise often wasted, as well as of renewable heat.

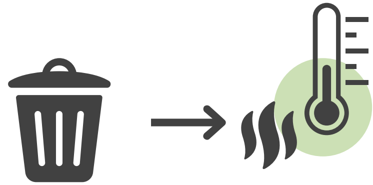
Modern (fourth-generation) systems operate at **lower temperatures** (typically around 50˚C), resulting in **reduced heat loss** compared to previous generations, and making it feasible to **connect to areas with low energy demand buildings.**

Fourth generation systems can use diverse sources of heat, including low-grade waste heat, and can allow consumers to supply heat as well.

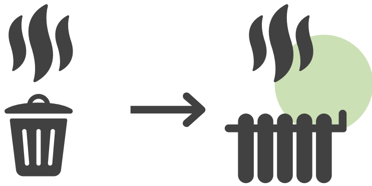


The main heat generation technologies currently in use are the following:

- **Waste to Energy:** Energy content of municipal solid waste (MSW) and other combustible wastes is reused through incineration in a plant for heat production. This technology produces low-cost heat and can be paired with electricity production as well; it has been often used in the initial development of a city's district heating network. Potential air pollution is a problem addressed in modern incinerators, that require lesser distances to the city.



- **Waste heat recovery:** Waste heat from nearby industrial processes, as well as low-grade heat from sewage can be reused in a district heating network. This increases energy efficiency of the overall system, as part of a circular economy. Typically, these waste heat sources will not guarantee supply, and may require some degree of redundancy in the system.



Through the Pitagoras Project, a pilot plant in Brescia that uses high temperature waste heat recovery (≈600°C) from a steel foundry and Organic Rankine Cycle (ORC) unit (2.1 MWe) for heat and power generation, is connected to the existing city district heating network.

Through the Growsmarter project, the city of Stockholm is utilising waste heat from the sewage system, from data centres and from fridges and freezers in supermarkets to feed it into the city district heating network.

- **District heating boilers:** Boilers burn fossil fuels (natural gas, oil products, coal) or renewable fuels (biomass, biogas) to produce heat. This is a highly flexible heat production technology, used to cover base loads with minimum CO_2 emissions (through renewable fuels sustainably and locally sourced) and to provide peak load supply (gas, oil, coal).
- **Combined heat and power (CHP):** This technology captures and uses the surplus heat coming from electricity generation turbines fed by fossil or renewable fuels in mid-sized to large, centralised plants. It can operate to follow both heat demand or electricity prices and is best used in combination with heat storage technologies.
- **Biomass/Biogas:** Biomass and biogas systems create energy from renewable organic matter. In order to be sustainable, the used biomass will preferably come from waste streams or be locally sourced from sustainable production. Non-waste resources may be used if an environmental impact assessment proves their sustainability. Materials once considered waste, such as clean wood construction waste and other wood residue sources (slash piles, hog fuel, etc.), can be put to good use. Methane gas produced in decomposition of garbage and manure can be collected and used in a power plant to generate electricity and heat, or sold as a renewable natural gas source. Combustion eventually combined with prior gasification of residual wood biomass or wet biomass waste streams delivers thermal energy in the form of steam or hot water. As the produced heat has a high temperature, it can be used both for heating and for electricity production (using a CHP plant).

Through the SmartEnCity project, Vitoria-Gasteiz is deploying a new biomass (wood chip) district heating network with advanced management and control capabilities integrating demand and supply.

- **Heat pumps:** Heat pumps use electricity to extract heat from free, renewable low temperature sources (ambient air, water, ground…) with high efficiency rates (which depend of the difference between the used source temperature and the desired temperature). Some models are reversible, and capable of producing both heat and cold. Heat pump use is best suited to low-temperature demands, and can provide renewable, efficient heat at low operational costs. Additionally, use of heat pumps promotes synergies with the electricity grid.
- **Geothermal:** heat is extracted through exchangers from saline waters in deep underground reservoirs. This heat resource is only available in certain areas and presents high upfront costs and relative uncertainty in resource availability. When available, it is a renewable and environmentally friendly technology with high operational stability and lifetime, best oriented to producing baseload heat. Deep geothermal heat comes at high temperatures and is not to be confused with shallow geothermal heat, available at low temperatures and processed through heat pumps.
- **Solar thermal:** Energy from the sun can be harvested with thermal solar collectors and used to feed a district heating system. Since solar energy is intermittent and seasonally variable, district heating networks with solar thermal energy are usually combined with other fuels and seasonal storage systems, which allow shifting the delivery of solar heat from periods of higher production and lower demand (summer) to the heating season. Flexible configuration of solar collectors (e.g., solar field vs. distribution over different buildings in an urban area) can also facilitate the decentralisation of systems. For this type of application, collectors need moreover a significant amount of land or roof space.
  Solar energy collected from PV panels producing electricity can also be used in district heating and cooling schemes, in combination with electric boilers or heat pumps, and heat storage solutions; this way of coupling the electricity and heating systems can help to efficiently manage intermittency from solar PV (and other renewable electricity sources like wind) at an affordable cost. Dependency from the sun or wind means that a backup/peak load source is required.

> “A combination between wind power or PV, air-to-water heat pumps, and storage of cold and heat seems the way to go in district energy systems, with currently similar prices to a biomass-based boilers supply.”

Per Alex Sørensen, DHC consultant at PlanEnergi

Technologies for District Cooling

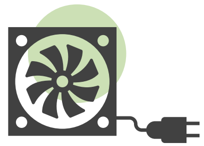
District cooling can be more than twice as efficient as traditional decentralised chillers such as air-conditioning units. It can reduce electricity consumption significantly during peak demand periods through reduced power consumption and the use of thermal storage. Use of free-cooling technologies can further improve these benefits.

The integration of mixed heating/cooling networks is made possible by current technologies; this facilitates the increasing relevance of district cooling as cooling demand surges worldwide, spending on energy services increases, climate change effects become noticeable (heat waves, but also average temperature rising) and the population in cities increases.

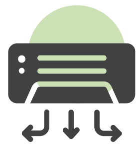
Adoption of district cooling schemes in urban settings can also help to reduce the consumption of environmentally damaging refrigerants such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). Both refrigerants are one of the main causes of ozone layer depletion and present strong global warming potentials (GWPs) at the same time

The main technologies currently in use for district cooling are the following:

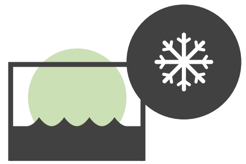
- **Electric chillers:** Electric chillers use electricity to power a vapor-compression refrigeration cycle. In comparison with decentralised air conditioning, they average better efficiency, and use refrigerants with less global warming potential (GWP).



- **Absorption chillers:** This kind of chillers use surplus heat from different processes (industrial heat, waste incineration, commercial uses…), achieving high energy efficiency and avoiding the use of refrigerants. It is frequently combined with CHP to seasonally adjust its operation.



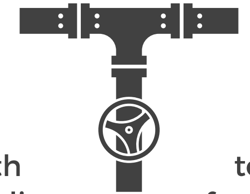
- **Free cooling:** This technology uses natural (water bodies mainly) or waste cool sources for refrigeration. Seasonal availability of the resource, and the need for environmental permits and associated costs need to be factored in.



Through the READY project , the city of Växjö (Sweden) has connected two district cooling networks as to increase the renewable energy sources input and increase the amount of waste heat used in the system. The integration of the city district heating network and the district cooling network is performed with absorption cooling machines, making it possible to produce cooling with heat when the electricity price is high and to produce cooling with electricity when the price is low.

Distribution

Distribution networks manage the delivery of heat to the end users and the return of lower temperature fluid to the heat production facility. Several configurations can be used based on specific needs (scale, temperature, operating pressure, building connections...). District heating networks differ in size, layout and conditions in cities and urban areas around the world.



The piping is often the most expensive portion of district heating and usually consists of a combination of preinsulated and field-insulated pipes in both concrete tunnel and direct burial applications. The upfront investment for the transmission and distribution system, which usually constitutes most of the capital cost for the overall system, often ranges from 50% to 75% of the total cost for district heating systems. Because the initial cost is high in distribution systems, it is important to optimise its layout and use. The progressive adoption of low temperature and pressure networks, together with the more widespread use of insulated pipes and leak detection technologies have allowed for reduced heat losses and the corresponding substantial increase of efficiency in heat distribution.

Storage

Heat storage technologies are key for current district heating and cooling systems. They contribute to reduce the gaps between heat demand and generation caused by both time difference due to intermittence of heat generation sources (e.g. solar), or cost fluctuations of the thermal energy throughout the day. In general, heat storage can also allow for more stable and efficient heat production operation, and for the enhanced integration of variable renewable energy sources into the power system through sector coupling.

Heat storage technologies offer many options, which need to be carefully assessed according to the design specifics and operational demands of every case: thermal energy can be stored daily or even seasonally, allowing the decoupling of heat demand and production and enabling heat to be supplied in the most cost-effective way. There are several available technologies for this, which can be classified according to the physical phenomenon used for heat storage (sensible, latent or chemical heat storage), to the location within the network (centralised or distributed), or to the time span of the storage (daily or seasonal storage).

While latent and chemical heat storage technologies are currently less developed, sensible heat storage (where advantage is taken from temperature changes in the storage material) is the most mature and widely used for both short-term (daily, e.g. water tanks) or seasonal (e.g. boreholes, tanks/pits, aquifer...) storage.

End Consumption

In addition to heat generation, distribution and storage, the in-building equipment (or customer installation) necessary for end user consumption needs to be considered as well.

There are two main components for the customer installation:

The in-building **heat distribution system** (radiators, pipes, HWD system), which may vary.

The substation connecting the general distribution network with the in-building heat distribution system. A **heat exchanger** transfers heat from the distribution network to the building system and can be coupled with additional equipment such as individual **heat storage or accumulation tanks**, or a **heat pump** for temperature boosting in case of low temperature networks. Control and billing systems are often installed with the substation.

Figure 4: Architectural integration of a district heating water storage tank in Hildesheim. Lighting colour fades from red to blue according to the amount of energy stored in the tank.

© Lighting design + photo: www.licht-raum-design.de

Digitalisation in district energy systems

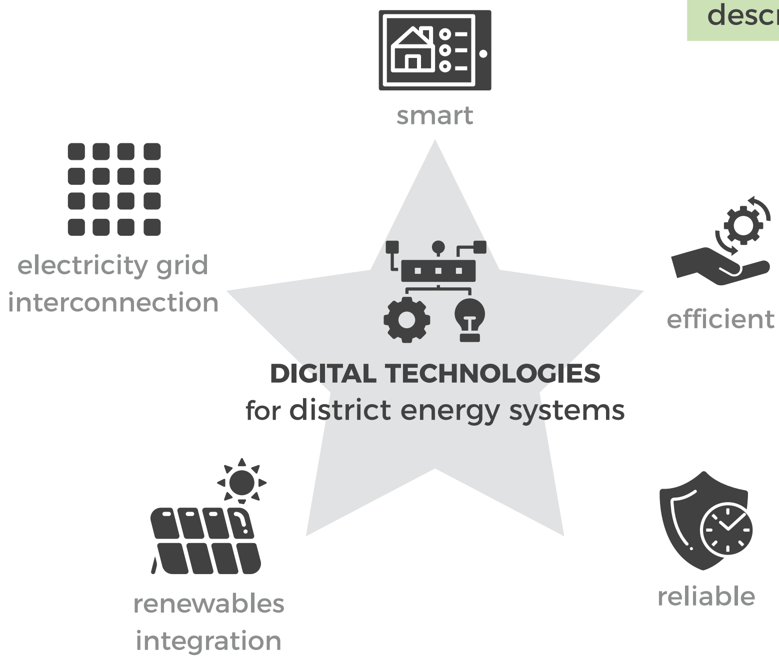
Digital technologies are being integrated into district energy systems in order to make them smarter, more efficient, and reliable. They also help to boost the integration of renewable sources into the system, as well as the interconnection with the electricity grid. In the future, smart management systems will enable district heating and cooling networks to fully optimise their plant and network operation while empowering the end consumer. These connected infrastructures will be used as efficiently as possible, time their production according to forecasted demand and maximise the use of renewable energy sources.

The STORM project is developing an innovative district heating & cooling (DHC) network controller, based on self-learning algorithms, in order to maximise the use of waste heat and renewable energy sources in DHC networks. This controller is tested and assessed in two demonstration sites, Mijnwater BV in Heerlen (the Netherlands) and Växjö Energi in Rottne (Sweden).

"Digitalisation is key in the evolution of these systems; we can improve 10 to 20% their efficiency by monitoring leakages, heat losses, better insulation configurations. The next step is to use digitalisation to influence the demand side (alarms, incentives, etc.) to reduce peak loads."

Frank Soons, Sustainability and Innovation manager at Ennatuurlijk

The CELSIUS Initiative Toolbox area on **Technical Solutions** offers a number of resources (articles, webinars, case studies), covering a wide range of last-generation, clean technologies in all the areas related to district heating and cooling described above.



Digitalisation will enable....

AT PRODUCTION LEVEL:

- The simultaneous integration between production and consumption control systems.
- The consumers to adopt an active role in selecting tariffs and to contribute to demand side management.
- The network operators to have the "power to operate" substations themselves, so that they can control the demand side with an extra degree of freedom to optimise the efficiency at system level.
- Increased flexibility and the development of effective forecast models of the network through machine learning approaches and data-driven, real-time models.

AT DISTRIBUTION LEVEL:

- Automated fault detection supervision to recognise anomalies in the networks and the buildings' substations.
- The development of advanced self-learning digital twins, based on artificial neural networks, of the thermo-hydraulic networks with which one can:
  - Monitor and remotely operate the network.
  - Simulate and evaluate operation and renovation scenarios.
  - Test new operation algorithms and assess their performance before physical implementation.

AT BUILDING LEVEL:

- The development of the connection between operational grid optimisation and efficient heating controllers (implying demand side management, for example through heat buffering in the building's structure).
- The cost-effective communication and data management hardware/ software of substations.
- The development of integrated control solutions allowing for the efficient operation of hybrid

BUSINESS MODELS & FINANCE

BUSINESS MODELS & FINANCE

Description – possible business models

The business model for a district energy system is very project specific. It needs to ensure that all the players involved – including investors, owners, operators, utilities/suppliers, end consumers and municipalities – can achieve financial returns, in addition to other benefits that they might seek.

Showcasing innovative approaches from cities around the world can help planners make **better-informed decisions** on how to develop and financially structure a district energy system. Categorisation of such approaches can help planners identify similarities that may apply to their own cities and distinguish specific circumstances.

An useful source of information can be found in the CELSIUS Toolbox area on **Business and finance**; several webinars on business models and financial instruments are available for a comprehensive overview of the financial-related aspects of district heating and cooling networks.

When designing a business model for a new district energy system, it is important to consider **site-specific circumstances**, including the type of project finance that is available. Most business models for district heating and cooling networks involve the public sector to some degree, whether as a local policymaker, planner, regulator or consumer, or more directly through partial or full ownership of projects. Public sector involvement can be critical in coordinating diverse projects around a broader city-wide vision. Even projects with a high degree of private sector control are often still facilitated or supported by the public sector. Although the business models and ownership structures described here vary significantly, they can be grouped along a continuum from **public to private**.

The involvement of the public or private sector depends broadly on two factors:

- the return of investment for project investors, and
- the degree of control and risk tolerance taken up by the public sector.

Return on Investment (ROI)

The ROI is a financial metric that is dependent on both a project's **Internal Rate of Return (IRR)** and its **Weighted Average Cost of Capital (WACC).** The IRR is extremely site-specific and is developed initially by the project sponsor, which could be a private district energy company or private utility, or a public body such as a local authority or public utility. The IRR will depend on the costs and incomes of the project. The WACC depends on the project's risk profile and its current and future sponsors, as well as on the debt-to-equity ratio of its financial structuring. Typically, while private sector investors will focus primarily on the financial IRR of a given project, the public sector, either as a local authority or a public utility, will also account for additional socio-economic costs and benefits that are external to standard project finance.

"Initial investment costs are high and constitute a big potential barrier. If there is a private business case, everything is easier (...) It's important to keep in mind that Distribution Systems (pipes) are the most expensive component. The first economic estimation must consider a pre-calculation according to the piping system; otherwise it will entail too much uncertainty"

Per Alex Sørensen, DHC consultant at PlanEnergi

What is the Internal Rate of Return (IRR)?

The IRR is the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero. The IRR is used to evaluate the attractiveness of a project or investment. If the IRR of a new project exceeds a company's required rate of return, that project is desirable. If the IRR falls below the required rate of return, the project will be rejected.

What is the Weighted Average Cost of Capital (WACC)?

The WACC is the average rate of return a company expects to compensate all its different investors. The weights are the fractions of each financing source in the company's target capital structure.

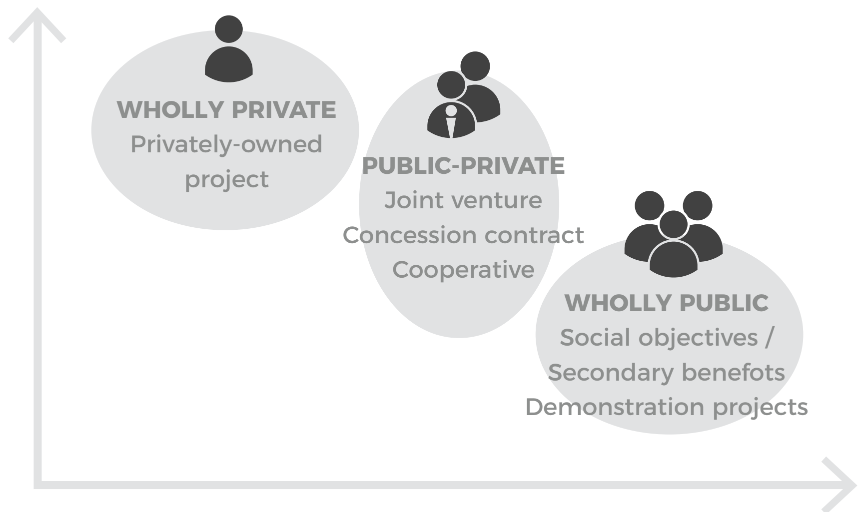
Degree of control and risk tolerance by the public sector

The public sector may wish to steer a district heating or cooling project towards a variety of local objectives, including cheaper local energy for public, private and/or residential customers; local job creation; local wealth retention; low-carbon power generation and renewable energy input; and/or local air pollution reduction. By quantifying these objectives through economic modelling, it is possible to realise additional ROI outside of the standard financial modelling. Such advantages are also called **secondary benefits** and they provide a strong incentive for public authorities to invest in societal value beyond a mere financial business case, effectively increasing the financial risk a local authority could be willing to admit (risk tolerance), when compared to a primarily private driven investment. Local authorities may have a specific interest in controlling the roll-out of district heating and cooling infrastructure with a view on realising this surplus societal value. The degree of public sector control over a project can vary widely, ranging from full development, ownership and operation to a role focused mainly on project coordination, local planning and policy (see also the Governance section). The public sector also may wish to showcase the business case for district energy projects in the city by developing demonstration projects. Some cities and countries are more inclined to have energy services provided by public utilities, while others are more open to private sector participation.

The degree to which private sector involvement in the district energy provision is the norm will influence the business model. The involvement of the public sector is however important in project development because of:

- its regulatory role,
- its ability to leverage finance for projects, such as through access to senior levels of grant funding and better access to capital,
- its ability to be a large, stable consumer and to provide off-take agreements, and
- its longer-term planning focus, greater interest in meeting social and environmental objectives and ability to coordinate the multiple stakeholders involved in district energy.

Figure 5: Public – Private sector involvement in district heating and cooling projects.



The "Wholly public" business model

Of the various ownership models for district energy systems, the "wholly public" business model is the most commonly used. Here, the public sector, in its role as local authority or public utility, has full ownership of the system, which gives it complete control of the project and makes it possible to deliver broader social objectives, such as environmental outcomes and the alleviation of fuel poverty through tariff control.

In this model, the city takes on most of the risk associated with the investment: consolidated urban areas develop such projects via a public utility, and the low return is spread across other projects that have higher IRRs. Projects in new urban areas can be developed by creating a "Special Purpose Vehicle" (SPV) or subsidiary (such as a new public utility) to reduce the administrative burden on the local authority, with governance typically overseen by a board of directors that represents the local authority. Shifting to a subsidiary can provide additional benefits, including limiting the city's financial liability, increasing the flexibility and speed of decisions, and offering greater transparency and a more commercial operation. The local authority can outsource the technical design and construction (and sometimes operation) of the project to reduce risk related to the delivery cost and time frame.

To the extent that a district heating system contributes to a city's strategic objectives – such as reducing carbon emissions, improving resilience or energy security, or providing affordable heat supply – projects often leverage the city's cash reserves and/or public debt raised based on the balance sheet of the local authority. The lower interest rate of public debt is why many proponents of district heating systems argue that cities can (and should) be investing in this way and why several district energy models are locally led.

"For district energy systems it is sometimes difficult to compete with cheap natural gas; we are always in competition with fossil fuels. It is important to have planning commitments, other than free market dynamics."

Per Alex Sørensen, DHC consultant at PlanEnergi

The "Public/Private" business model

When a district heating system's project has a return on investment that will attract the private sector, a "public/private" model can be adopted. Here, the local authority is willing to carry some risk and has a desire to exercise some control, but it also seeks private sector participation to bring in expertise and/or private capital. A challenge with such projects is ensuring that all parties have a clear, aligned vision of what the objectives are and how they will be achieved.

This public-private collaboration can take several forms:

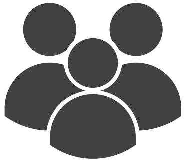
- **Public/Private joint venture:** Typically involves the creation of an SPV, with ownership split between the public and private sector. Risk and investments are shared between partners. The public sector can mitigate some risks by committing to long-term contracts and can deal with regulatory barriers to project development. The private sector typically takes care of the design, construction and operation, while on occasion also benefitting from connection to the network.

The presence of the public sector often means access to additional funding sources such as development bank loans. Governance is typically via a board of directors appointed by each project partner, with board representation reflecting the ownership split between the public/private sectors.

- **Concession contract:** In this model, the public authority often makes the first steps of the district heating and cooling project, and then tenders it to the private sector. The ESCO or utility with the concession (private sector or public-private) bears completely the risks of designing, building and operating the district energy system. The presence of the local authority as designer of the concession contract is likely to mitigate many of the risks associated with gaining project approvals. The ESCO may be limited in the tariffs it can charge due to local competition or by contractual levels set to avoid monopolisation of energy distribution.
A concession model is particularly applicable for retrofit projects in towns and cities where public streets are used for network routes and where residential, institutional and commercial buildings are connected. The concession provides the option of the city getting back a project after the concession period.
- **Community-owned not-for-profit or cooperative:** a municipality may wish to establish a district energy system as a mutual, community-owned not-for profit or cooperative. This is most widespread in countries where district heating has a strong administrative support, and end users are obliged to connect to networks.
In these cases, district heating operators are legally obliged to be not-for-profit and are therefore either cooperative, mutual or municipal companies.

The "Private" business model

If a local authority has a proposed district energy project with a high return on investment but at the same time it favours a low risk tolerance and a relatively low desire for control, it may be able to attract interest from private sector companies.



This does not mean that the local authority is removed from the project; many successful privately-owned district energy systems still have arms-length local authority involvement. For example, the local authority may have been the original project proponent and/or it could still attract financing and grants for the project; it needs to provide the planning and regulatory support in all cases, and may help with any connections deemed socially optimal that are too high risk for the private sector. It could also develop initiatives that encourage social or environmental objectives, such as mechanisms that support low-carbon generation.

In a purely private model, risk is carried by the private company, although the company could enter into a Joint Cooperation Agreement (JCA) with the local authority to mitigate risks in planning or expansion, or to encourage connection of demand through planning policies. This is often called a Strategic Partnership Model. In return, the local authority may benefit from reduced tariffs, profit sharing, connection of customers with higher credit risk (who are more likely to be in fuel poverty), and other social or environmental objectives

Financing is provided by the private sector company. The private sector company may require a capital contribution in the form of a connection charge for any public buildings connected to the network. Local or national authorities may be able to attract international loans or grants for the project.

GOVERNANCE & REGULATION

GOVERNANCE

Role of municipalities and decision-making processes

"Local governments are uniquely positioned to advance district energy systems in their various capacities: as planners and regulators, as facilitators of finance, as role models and advocates, and as large consumers of energy and providers of infrastructure and services"

UN Environment Programme, 2015

The quote above gives a good idea of the important role municipalities have when fostering and facilitating district energy systems, as they can be present in most of the key enabling capacities of the district energy chain: regulating, planning (in particular heat zoning), facilitating, providing, consuming, (...). That is why it is so important for municipalities to envision the future energy system of their city, including interactions with other assets (built stock condition, electricity grid); that way, both planners, suppliers, financers and customers will have a framework to effectively implement these kinds of systems and to limit associated risks.

One of the first steps for cities to achieve this envisioning goal is to develop heat zoning plans which allow to obtain a comprehensive assessment of roll-out potential of district heating and cooling systems. These planning tools can serve as a guide on where it is most feasible or convenient to develop district heating or cooling networks, the available supply and demand, and help making early decisions on the technologies to deploy and use.

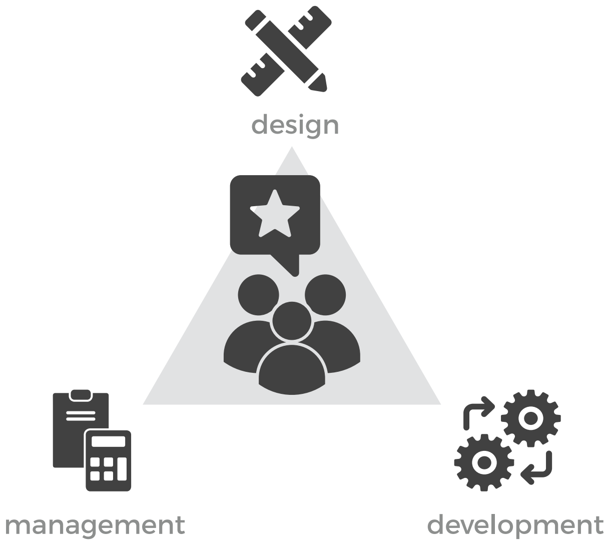
Some resources related to heat zoning, as well as more general policy and planning aspects can be found in the CELSIUS Toolbox area on **Policy and Planning**.

In addition to heat zoning plans, the following activities can be performed by the municipality to foster district heating and cooling:

- **Procurement** & infrastructure **investments.**
- Facilitating **financing and taxing** incentives.
- **Capacity building** of planners, developers, owners, suppliers, industry, investors.
- Stakeholders' and citizens' **awareness raising campaigns.**
- Energy **commercialisation** (at district level) for public purpose.
- **Act as an agent of change, promoting and disseminating DHC initiatives in public infrastructures.**

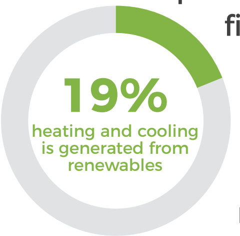
During the design, deployment and operation of the district heating and cooling network, the governance model will largely depend on the business model adopted (see Business Models and Finance section)

Regarding the core **decision-making team from planning to implementation stages,** experts in district energy systems deployment recommend looking for a **compact group of stakeholders,** so the team involved in design, development and management tasks can **work closely together.** In most cases, the municipality must be on board and participate in all decisions. In parallel to this compact group, an effective engagement with key local stakeholders and citizens' representatives must be a priority, as described in the section on Societal & User Aspects.



EU and cities' district energy strategies

Regarding European district energy strategies, the EC published the **Heating and Cooling Strategy - At the Heart of Europe's Energy Transition in February 2016.** This has been a significant step to provide a framework for establishing a sustainable heating and cooling model in Europe. During next years, the challenge will be to deploy the strategy's principles into practice (according to 2018 figures from Eurostat, 75% of heating and cooling is still generated from fossil fuels while only 19% is generated from renewable energy), through ambitious and well-crafted regulatory measures and taking into account that national contexts still present major differences.



Aligned with this Heating and Cooling Strategy, cities can include ambitious objectives within their energy strategies, considering district energy systems a key element of their proposals. As already discussed, cities can develop heat zoning plans to obtain a comprehensive assessment of roll-out potential of district heating and cooling systems. In the Netherlands, all municipalities must have a 'heat transition vision' by the end of 2021; in Flanders (BE), all municipalities must have heat zoning plans by 2025.

Regarding the possible targets, some generic examples are presented below, and a selection of exemplary UE frontrunner city goals is included thereafter (table 1):

- **Expansion of the district energy system** (amount of homes, offices, shops, etc. connected to the system)
- **Interconnection of segregated district energy networks** through transmission pipes
- Share of total **greenhouse gas reduction target** to be met by district energy systems in the city
- Share of electricity/ heating/ cooling **capacity or consumption provided by district energy** systems
- Share of **local government's energy usage** that should come **from district energy** systems
- Share of **renewables or waste heat to be used in district energy** systems
- Percentage of **energy efficiency increase due to district energy** use
- **Replacement of existing individual** heating/ cooling **systems**

Table 1 District energy goals in cities (UNEP)[5]

City	District energy goals
Amsterdam	100,000 residential equivalent unit connections by 2020 (up from 55,000 today); 200,000 by 2040 Fuel switch from electricity and gas in heating and cooling to higher use of waste heat Target to interconnect multiple systems using a ring transmission network
Bergen	Use district heating in all new buildings and major renovations within the concession area for district heating Waste incinerators must utilise 80% of energy (higher than national target of 50%)
Copenhagen	By 2025, 100% share of renewable energy and waste incineration heat in the district heating system (up from 35% today) By 2016, ban oil-fired installations in existing buildings where district heating (or gas) is available
Frankfurt	Connect waste heat from incinerator and industry; interconnect three district heat grids into a closed-loop system; integrate renewable energy such as biomass and biogas in CH
Helsinki	By 2015, cooling capacity of over 200 MW By 2020, expand cooling to new residential areas

5 District Energy in Cities. Unlocking the Potential of Energy Efficiency and Renewable Energy (UNEP)

How to get started in my city?

Key questions and summary of reflections

As a starting point for cities, there are some key questions to be answered. A thorough reflection on them can lead to a successful implementation.

Regarding sustainable and/or renewable heat/cold resources; what is the local potential? (check “Technical specifications” on page 15)

A city- or region-wide mapping of available and planned energy resources must be performed. Depending on the specific context of each city, there will be better conditions for some energy sources than others; sun, wind, geothermal, waste heat/cold, etc. In this city-mapping, it is key to look at the amount and temperature level of the resources to make an informed decision. As renewable energy sources often benefit from substantial open space for their production, it is recommended to consider the regional energy potential rather than the strictly urban energy production potential. Hereby an optimal energy exchange between the city and its hinterland can be achieved. A similar argument holds for the recuperation of waste heat and/or valuable waste streams, e.g. from industrial and agricultural complexes adjacent to the city. In addition, other aspects need to be carefully assessed. Urban density and energy intensity of the areas to be served, along with consideration of building uses, potential synergies and need for cooling are key aspects to early decision making.

Is it feasible?

It is important to quantify the thermal energy demand and to assess which specific system can fit it better. The first step to start a new district heating network can be to get all large consumers on board (swimming pools, hospitals, offices, supermarkets, large residential complexes…), as this will significantly ease the process. Involving them in a working group can be a good choice, to exchange advantages and needs of the system and its customers. Identifying these opportunities in a setup coordinated by the municipality can be very supportive; even more so if this is connected to urban planning procedures, and to local heat zoning planning (see above) in particular.

Is it financially viable? (check “Business models & finance” on page 26)

Without a business case, it will be very difficult for an initiative to succeed. **What are the distances from source to consumers? What kind of distribution is going to be used? Does the urban characteristics allow profitability?** (E.g. urban density, heat demand density, corresponding urban retrofit strategies). The high initial investments and the long-term commitments needed will test the viability of each operation (ROI + risk/control degree by local authority).

Considering an **implementation timeframe in cities,** there is a substantial difference between new grids and extensions of existing grids. Regarding **new grids** in new developments, where everything must be implemented from zero, the process can take at least 3 years to be in operation. However, in **existing grids,** an expansion project can take even less than a year, depending on the particularities of the project. In both cases, these timeframes can be extended mainly due to bureaucratic, financial and technical obstacles.

Let's get started! Key steps in developing a district energy system

In case those pre-reflections are leading the city to develop district energy systems, the following steps will guide the preparation of a welcoming environment for this kind of project, according to the specific city characteristics.

Table 2. Key Steps in developing a District Energy System[6]

1.	Assess **existing** energy and climate policy objectives, strategies and targets, and **identify catalysis**
2.	**Strengthen** or develop the institutional **multi-stakeholder coordination framework**
3.	**Integrate** district energy into national and/or local **energy strategy and planning**
4.	**Map local energy** demand and evaluate local energy resources (Heat Planning)
5.	Determine relevant **policy design considerations**
6.	Carry out project **pre-feasibility and viability**
7.	Develop **business plan**
8.	Analyse **procurement** options
9.	Facilitate **finance**
10.	Set measurable, reportable and verifiable **project indicators**

6 District Energy in Cities. Unlocking the Potential of Energy Efficiency and Renewable Energy (UNEP)

GENERAL LESSONS LEARNED

GENERAL LESSONS LEARNED

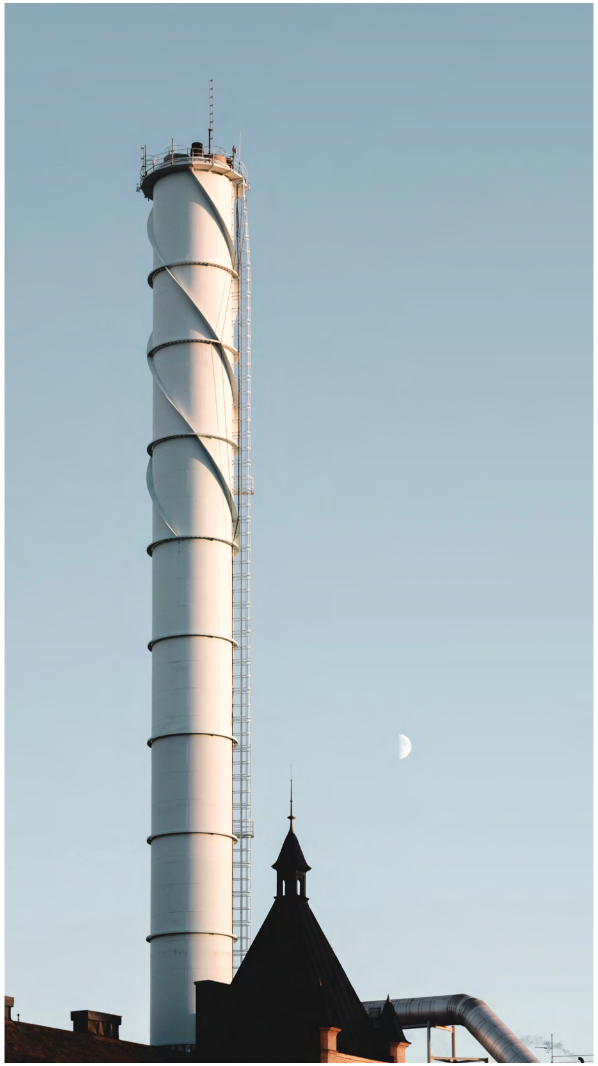
District heating plays an important role as cities identify its ability to deliver secure, clean and cost-effective municipal heating supply.

District cooling has a huge potential to reduce the increasing electricity demand and the rejection of waste heat into the urban environment linked to massive use of air conditioning and chillers. This can be a significant factor in reducing the Urban Heat Island effect. Moreover, this potentially translates into cost savings by avoiding backup systems or oversizing the electricity capacity; common measures adopted for the prevention of blackouts.

The low supply and return temperatures of modern district heating systems allow the integration of local, **distributed heat and cold generation as well as waste heat and cold reutilisation.** This can lead to significant energy savings and a drastic reduction of primary energy use and CO_2 emissions. Such strategy however requires that the **building stock is prepared for receiving the low temperature heating, respectively the high temperature cooling.** Integrated urban planning and the development of proper heat zoning plans shall first guarantee a coherent energy strategy at the level of districts, the city and its hinterland. But this also implies that proper **building retrofit strategies** are put in place.

District heating can, through interaction with the electricity grid, enable **higher penetration of** intermittent **renewable energy sources,** such as wind and solar from the electricity system, using large-scale heat pumps and thermal storage.

Digital technologies are foreseen to make the energy system smarter, more efficient, reliable, and to boost the integration of more renewables into the system. Technologies such as IoT, artificial intelligence and machine learning will enable district energy systems to fully optimise their plant and network operation while empowering the end consumer.



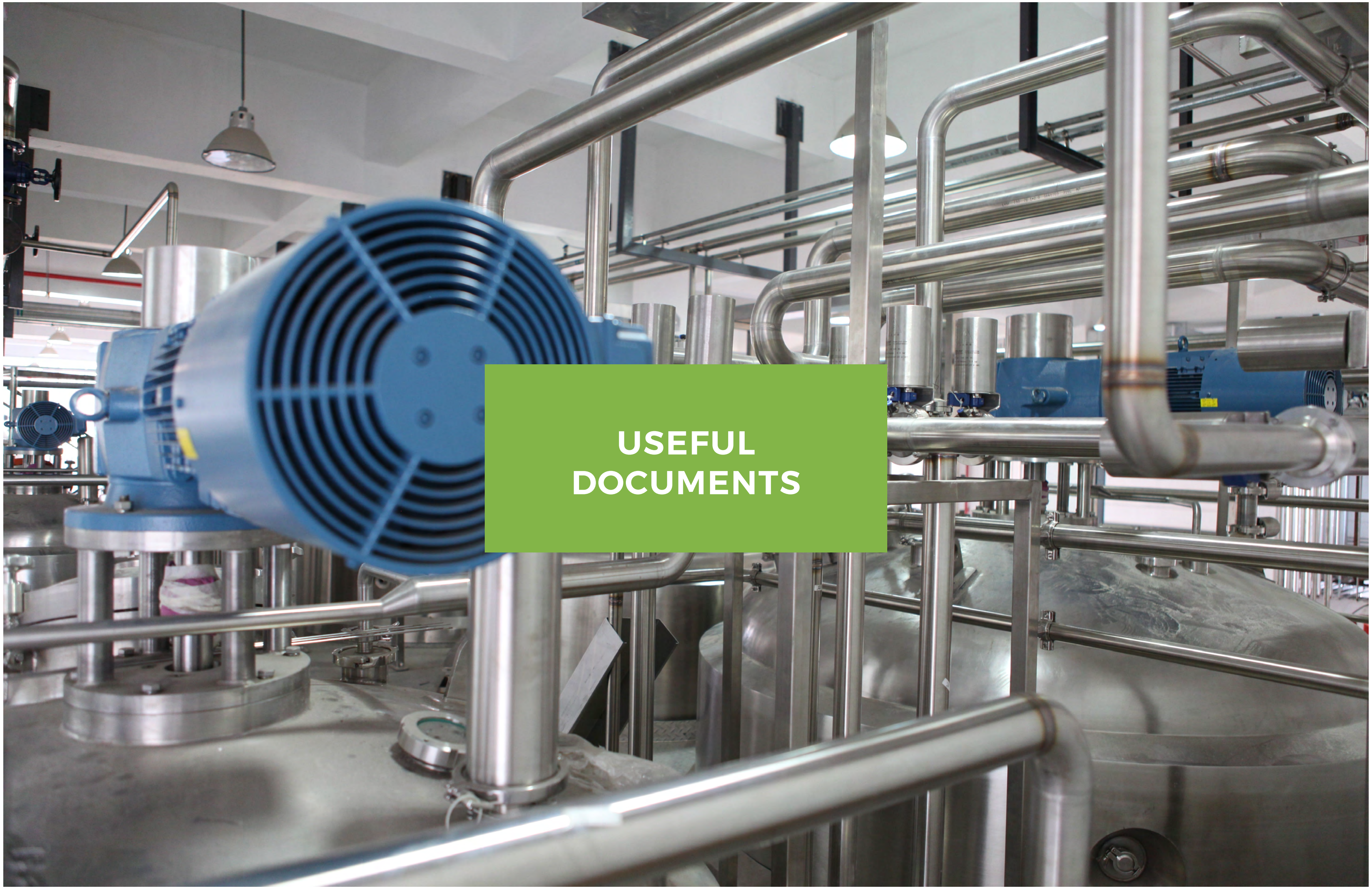
District heating in central Gothenburg

Local governments are uniquely positioned to advance district energy systems in their various capacities: as planners and regulators, as facilitators of finance, as role models and advocates, and as large consumers of energy and providers of infrastructure and services.

The ideal business model for a DHC project is defined by the degree of ownership that the public sector desires over the project and by its expected revenue (ROI), resulting in 3 basic paradigms – wholly public / hybrid public-private / private. The local administration should have a higher involvement if the district energy project contributes to local objectives, such as local climate action plans.

The **integration of energy planning into urban planning procedures can pave the way to DHC deployment;** including heat zoning, DHC requirements in master planning, fostering denser urban areas, setting up urban retrofit strategies, combining mixed uses in the building sector and the like. In many instances there is still a long way to go in this integration process.

District heating in central Gothenburg



USEFUL DOCUMENTS

USEFUL DOCUMENTS

Relevant documents and tools

- District Energy in Cities. Unlocking the Potential of Energy Efficiency and Renewable Energy (UNEP)
- EU Strategy on Heating and Cooling
- EuroHeat&Power - The international network for district energy, promoting sustainable heating and cooling in Europe and beyond
- Danish Energy Agency publications: catalogues of technology data for energy technologies
- Pan-European Thermal Atlas – Heat Roadmap Europe
- District heating & cooling. Delivering sustainable energy to the heart of the city (Euroheat & Power, 2015)
- EnergyPRO modelling software
- EnergyPLAN software

Projects & initiatives

SmartEnCity (SCC1)

- DC supported by residual heat in Tartu
- DH network in existing areas in Vitoria-Gasteiz

Smarter Together (SCC1)

- Cogeneration heating power for new local DH in Lyon
- Redensification of DH and Integration of data center waste heat into DH in Vienna
- Geothermal plan covering base load of DH and innovative heat substations to ensure low-return temperature to DH in Munich

Remourban (SCC1)

- DH using low-temperature return heating in Nottingham
- Biomass DH in existing areas in Valladolid

GrowSmarter (SCC1)

- Smart local thermal grids and virtual analysis on DH and DC rings in Barcelona
- DH with waste heat recovery in Stockholm

MySmartLife (SCC1)

- DH optimisation through renewables and storage system in Helsinki
- DH monitoring thorough decision-making tool in Nantes

Replicate (SCC1)

- New DH systems in San Sebastian and Bristol

Other research projects

- CELSIUS – Combined efficient large scale integrated urban systems
- CELSIUS INITIATIVE, CELSIUS Toolbox
- STORM - Self-organising Thermal Operational Resource Management
- OPTi - Optimisation of District Heating Cooling systems
- FLEXYNETS - 5th generation, Low temperature, high EXergY DH and DC NETworkS
- INDIGO - New generation of Intelligent Efficient District Cooling systems
- H-DisNet - Intelligent Hybrid Thermo-Chemical District Networks
- E2District - Energy Efficient Optimised District Heating and Cooling
- CoolHeating - Market uptake of small modular renewable DH and DC grids for communities
- progRESsHEAT - Supporting progress of renewable energies for heating and cooling in the EU on a local level
- InDeal – Innovative Technology for DH and DC
- E-HUB – Energy-Hub for residential and commercial districts and transport
- Micro- TRIGENERATION
- Heat4Cool - Smart building retrofitting complemented by solar assisted heat pumps integrated within a self-correcting intelligent building energy management system
- COOL DH - Cool ways of using low grade Heat Sources from Cooling and Surplus Heat for heating of Energy Efficient Buildings with new Low Temperature District Heating Solutions
- Planheat - Integrated tool for empowering public authorities in the development of sustainable plans for low carbon heating and cooling
- HotMaps - Heating and Cooling: Open Source Tool for Mapping and Planning of Energy Systems
- THERMOS - Thermal Energy Resource Modelling and Optimisation System
- PITAGORAS – Sustainable Urban Planning with innovative and low-energy thermal and power generation from residual and renewable sources
- Sinfonia – Smart initiatives of cities fully committed to invest in advanced large-scaled energy solutions
- READY project
- CITY-ZEN: a balanced approach to the city of the future

The Celsius Toolbox

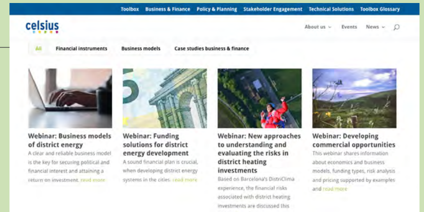
The Celsius Toolbox aims to be a source of knowledge and inspiration for cities interested in developing district energy (district heating and cooling) solutions. It addresses cities which are just beginning to implement small-scale district heating and cooling networks as well as cities with large established systems endeavoring for even smarter and more efficient solutions.

The Toolbox started as a wiki created within the EU project CELSIUS, sharing experiences and research from the project partners and it is continuously being developed in cooperation with the growing Celsius Network.

The Celsius Toolbox consists of four main elements:

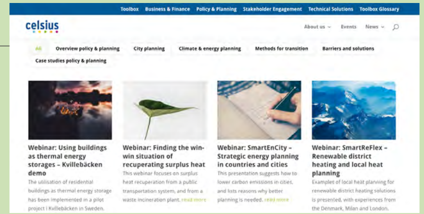
Business & Finance

- Financial instruments and business models and policy are the key to success.



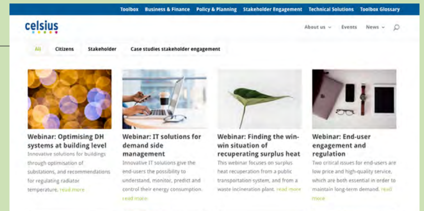
Policy & Planning

- Municipal city planners, developers, politicians, decision makers – this is for you.



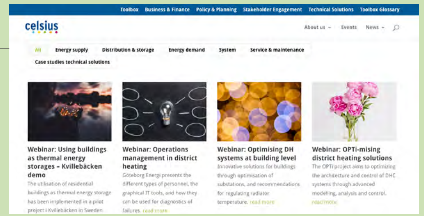
Stakeholder Engagement

- Citizen and industrial engagement: How to reach out to important stakeholders and the community?



Technical Solutions

- The place for technologies and research, from supply to smart use and system integration.



CONTRIBUTIONS

EU Smart Cities Information System

SCIS

The Smart Cities Information System (SCIS) is a knowledge platform to exchange data, experience and know-how and to collaborate on the creation of smart cities, providing a high quality of life for its citizens in a clean, energy efficient and climate friendly urban environment. SCIS brings together project developers, cities, research institutions, industry, experts and citizens from across Europe.

SCIS focuses on people and their stories – bringing to life best practices and lessons learned from smart projects. Through storytelling, SCIS portrays the "human element" of changing cities. It restores qualitative depth to inspire replication and, of course, to spread the knowledge of smart ideas and technologies - not only to a scientific community, but also to the broad public!

smartcities-infosystem.eu

SCIS is funded by the European Union