ISSN 1831-9424

European Commission

JRC TECHNICAL REPORT

District heat and the New European Bauhaus

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2023

Joint Research Centre

EUR 31579 EN

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EU Science Hub
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JRC133275

EUR 31579 EN

PDF ISBN 978-92-68-05219-8 ISSN 1831-9424 doi:10.2760/970521 KJ-NA-31-579-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report: Motoasca, E., Lygnerud, K., Gabaldon-Moreno, A., Neven, T., Särnbratt, M., Berda-Gonzalez, A., Vanschoenwinkel, J., Fransson, N., Pastor-De Paz, C. and Lyons, L., *District heat and the New European Bauhaus*, Vito, IVL and CARTIF on behalf of the European Commission Joint Research Centre Petten, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/970521, JRC133275.

Contents

Abstract

This study provides insights into the potential of District Heating and cooling (DHC) to contribute to the New European Bauhaus initiative (NEB), and the potential role of the NEB principles (Beautiful, Sustainable, Together) in the further development and accelerated uptake of DHC at EU level. The research finds mainly synergies but can also be used to identify areas where more research or funding may be needed to enhance synergies or avoid conflicts.

Acknowledgements

This study was carried out by Vito, IVL and CARTIF on behalf of the European Commission Joint Research Centre (JRC). Emilia Motoasca (Vito) was the project manager. Lorcan Lyons designed and supervised the study, under the guidance of Johan Carlsson and Evangelos Tzimas (all JRC). Lorcan also edited this version of the final report. Lorenzo De Simone and Malgorzata Wrobel (also JRC) provided helpful feedback from the perspective of the New European Bauhaus initiative. The project team are grateful to the interviewees from each case study, and to the Heat Academy for the organisation of the webinar.

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1. Introduction

Enhancing energy efficiency and increasing the share of renewable energy are essential pillars of EU energy policy and the European Green Deal (EGD). District heating and cooling (DHC) could help achieve these goals in the buildings sector, which accounts for about 40% of final energy consumption in the European Union. Yet despite its many positive features, the expansion of DHC in Europe in recent years has been slow.

President Von Der Leyen announced the NEB initiative in her 2020 State of the Union address in order to make the goals of the EGD more tangible. The NEB integrates three key values: Beautiful, Sustainable and Together (or inclusive). The co-design phase of the NEB ran from January to June 2021. Its website received more than 2 000 contributions about beautiful, sustainable and inclusive forms of living.[1]

The creation or expansion of a DHC networks is a large, complex undertaking that requires support from local authorities with long-term heat strategies. The NEB is an opportunity to highlight potential benefits of DHC that decision makers might have overlooked. DHC in turn could have an important role to play in delivering the NEB.

This study aims to identify and describe those synergies (and any potential conflicts). It can also be used to identify areas where more research or funding may be needed.

The links between DHC and the NEB were investigated first through a systematic literature review. The literature review spanned both academic journals and the “grey” literature, both in English and in the languages of three case studies (Swedish, Spanish and Dutch). It focused on aspects related to the NEB such as aesthetics, usability, innovation, inclusivity, sustainability and digitalisation.

A list of keywords was derived from the literature review, combining DHC terms with terms associated with the NEB. DHC keywords included renewable energy, flexibility and sustainable development. NEB keywords included aesthetics, wellbeing, sustainability, inclusiveness and affordability. That list of keywords was then used to analyse submissions to the NEB website for possible links.

Three case studies (from Sweden, Spain and Belgium) were selected, in order to confirm and complement the findings of the literature review and website analysis. Stakeholders were interviewed for each case.

Preliminary findings were presented in an interactive webinar, organised with the Heat Academy on 3 October 2022,[2] where further insights were collected from the audience. These insights were taken into account in the final part of this report, which provides conclusions and recommendations to maximise the synergies between the NEB and DHC.

[1] https://europa.eu/new-european-bauhaus/co-design/co-designing-new-european-bauhaus-0_en.
[2] https://heatacademy.eu/wp-content/uploads/2022/10/2022-10-04-INV.pdf.

2. Applying New European Bauhaus principles to district heating and cooling

The principles of the NEB are Beautiful, Sustainable and Together (inclusive). Beauty is included as an objective in urban planning to increase the city's liveability, the sense of belonging of the citizens, or even as a measure to include green areas and open spaces. Sustainability aims to improve the urban environment in order to contribute to achieving climate goals through enhancing circularity, reducing pollution and increasing biodiversity. Togetherness aims to achieve inclusion through various actions, from valuing diversity to securing accessibility and affordability, in order to enhance wellbeing and community spirit and make inhabitants more active in their neighbourhoods.

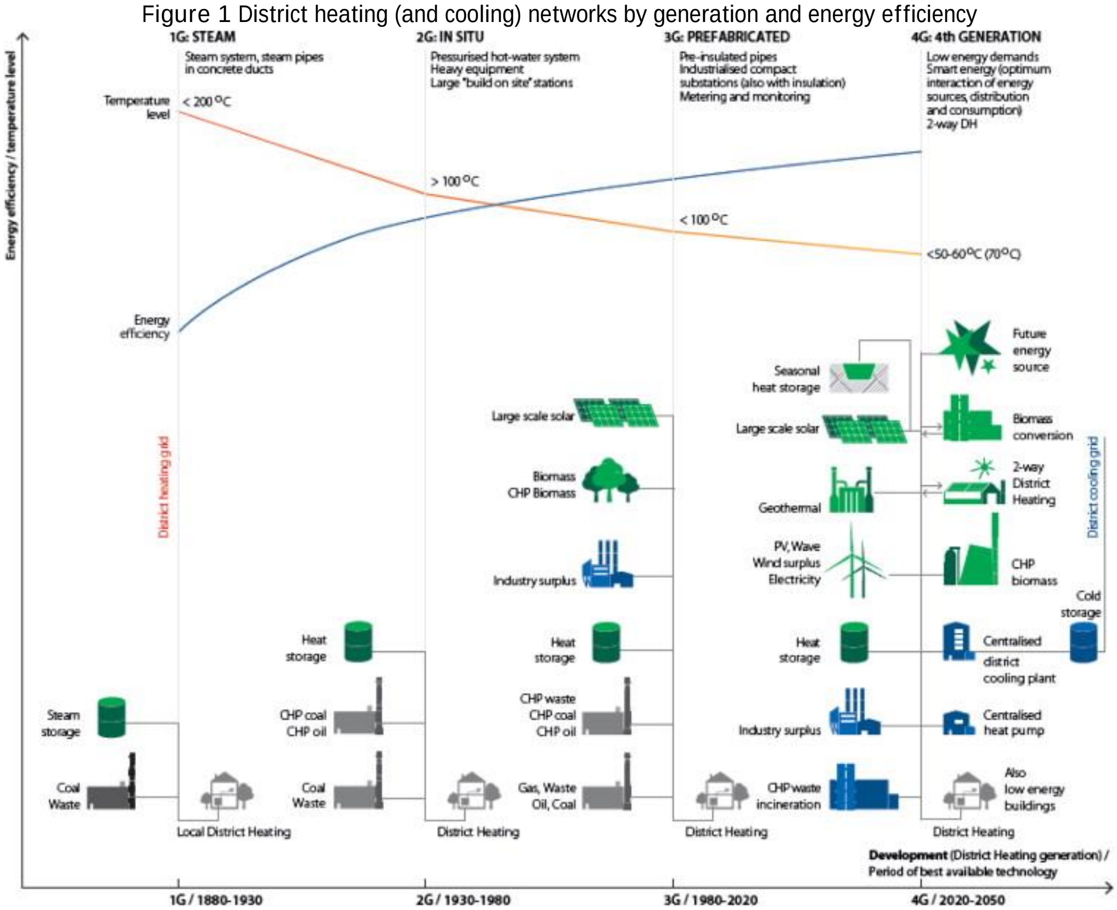
District heating and cooling – the story so far

DHC refers to the application of collective heating and cooling at district (neighbourhood) level, where residential and in some cases also commercial and public buildings are provided with heating and cooling from a network. To understand the current challenges and opportunities for DHC, a short introduction to the history of such systems is needed (EnergyVille, 2021).

Collective heating and cooling networks have been applied in industrial, residential, commercial and public contexts for more than a century. The first generation of district heating networks (1G DH) was roughly between 1880 and 1930, the second generation (2G DH) was between 1930 and 1980, and the third generation (3G DH) was between 1980 and 2020. The latest generation (4G DHC) emerged around 2020 and includes cooling. It is expected to play a growing role between 2030 and 2050. As the application of 4G DHC concepts has barely started, 90% of DHC networks being installed in the EU are still high-temperature 3G DH networks.

The transition from one generation to the next has been achieved through a series of disruptive innovations. From 1G DH to 2G DH, the transition from steam to water as an energy carrier was the disruption, while the transition to 3G DH was made when pre-insulated pipes were introduced. The current (and future) transition to 4G DHC adds a digital layer to the system, both in the design and operational phases. It also introduces more – and more diverse and decentralised – renewable and waste heat sources, as well as storage (Figure 1).

Figure 1 District heating (and cooling) networks by generation and energy efficiency

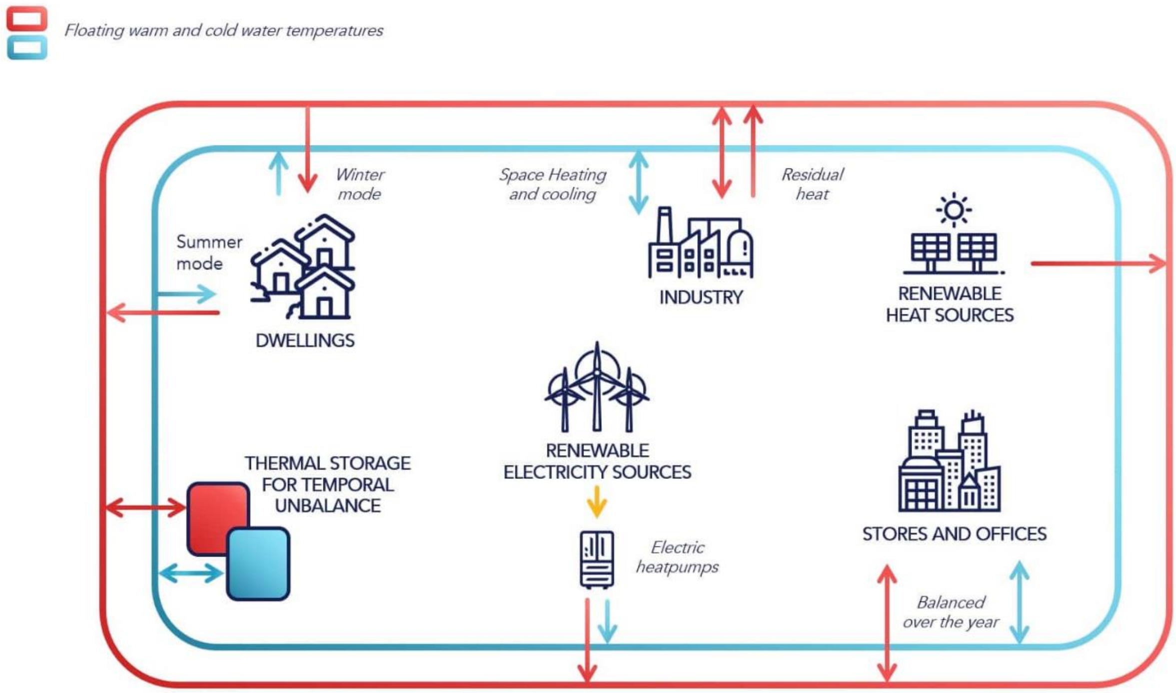


Source: Lund et al., 2014.

In recent years, 4G DHC has emerged with two new variants: Low and Ultralow Temperature (LT DHC and ULT DHC). The reduction of temperatures allows the integration of more decentralised renewable and waste heat sources, with domestic heat pumps then used to raise the temperature in a highly efficient way.

5G DHC concepts are also now being developed, although some would contest that they are not sufficiently disruptive to be classified as a new generation of DHC. 5G DHC networks would operate at temperatures close to ground temperature, use existing local low-temperature sources in a more optimal way, and stimulate the exchange of heat and cold among buildings. In such a network, producers and consumers of heat and cold become "prosumers" (Figure 2).

Figure 2 Fifth generation district heating and cooling



Source: D2Grids, 2022.

Historically, DHC networks have been developed considering only techno-economic factors such as the business model for the owners and operators, the availability of the energy supply, and heat losses in the distribution pipes and other parts of the system. Ideally, an integrated approach accounting for technical, economic, environmental, regulatory, legislative and social dimensions of these networks would be more sustainable.

The social dimension, in particular, covers not only individual comfort and wellbeing but also the sense of community of inhabitants who are emotionally involved in the cultural heritage of the places they live (Bergesen et al., 2017). Since collective heating and cooling systems must be located near communities, their infrastructure can be blended into the natural or urban landscape, or even take on an aesthetic design that creates a local landmark to which the community can relate and of which it can feel proud (DBDH, 2011).

Applying "Beautiful**" to** district heating and cooling

How does district heating and cooling affect neighbourhood aesthetics?

The aesthetics of neighbourhoods with DHC networks are largely the same as neighbourhoods without, but each generation of DHC introduces some differences. Older generations like 2G and 3G DH had (and still have) centralised heat production plants, while the newer 4G and 5G networks use distributed energy sources of various kinds with different visual impacts. Having several small heat producers rather than centralised production with one big district heating plant can help to reduce visual impact (Marijuan et al., 2020).

In neighbourhoods with individual heating and cooling systems, each building or household has its own chimney or external heat exchanger for heating or cooling; as well as corresponding indoor heat exchangers, boilers or fuel tanks. As a result, the visual impact of individual installations is usually higher than that of a DHC network. This can be seen for example with the removal of chimneys and heat exchangers in Montieri (Box 1).

Box 1. Geothermal district heating network, Montieri (Italy)

Montieri is a small village in Tuscany that has a traditional architecture style from the mediaeval era, including narrow paved streets and stone buildings with brick masonry and wood structures. The renovation of Montieri included a new geothermal DHC network, and the integration of solar thermal energy and solar photovoltaic (PV) panels. Chimneys and external exchanger units of individual cooling systems were cleared from the streetscape. Pipes were placed underground and the heat exchangers were installed in basements.

All the work was carried out with respect and care for the village's cultural heritage. For example, footpaths were restored using local stone (see construction phase and final result below). The inhabitants also benefited from reduced energy bills.

Sources: Marino and Pagani (2016), Cosvig (2017), www.youtube.com/watch?v=GBc9V9PegY0&ab_channel=RegioneToscana.

Once the installation of the DHC is complete, almost all the infrastructure is underground and not visible. Pipes are usually buried and substations are typically placed inside buildings, in technical rooms where boilers or fuel storage tanks would have been placed. In neighbourhoods with DHC, there is generally only a limited number of external elements (e.g. heat exchangers or chimneys). These elements can be fully integrated into the urban fabric, improving public acceptance.

Some of the main best practices to make DHC networks unobtrusive are to bury pipes underground; install substations inside buildings in rooms that are not accessible to the general public (e.g. basements); and integrate generation plants, centralised storage tanks or renewables such as PV with nature, buildings and existing local infrastructure. The latter aspect is exemplified in CopenHill (Box 2), Utrecht (Box 3) and Heerlen (Box 4). This strategy not only reduces the visual impact but also improves local green and blue infrastructure, underpins biodiversity, and creates buildings that are multi-purpose. That allows people to have open cultural spaces and leisure activities, as a strategy to reconnect with the environment through local culture and history (NEB High-Level Round Table, 2021).

Box 2. CopenHill waste-to-energy plant, Copenhagen (Sweden)

CopenHill, also known as Amager Bakke, is a waste-to-energy (WtE) plant (incinerator) in Copenhagen that provides electricity and district heating. The plant is also a multifunctional piece of infrastructure that includes an environmental education hub (for academic tours, workshops and conferences) and an urban recreational centre for extreme sports (skiing, hiking and rock climbing). Non-skiers can enjoy the rooftop bar and summer walks through the park.

The façade allows illumination of the workstations and administrative floors, reducing their energy needs. The bricks on the façade function as planters, creating a green façade and turning the plant into a "green mountain".

The CopenHill WtE plant is a good example of how a large district heating plant and chimney can have a positive visual impact. It is also a best practice on how a building can be designed to be aesthetic and multifunctional, with green façades and a slope designed to be used for several recreational purposes (skiing, hiking or even rock climbing). It also incorporates the "Together" principle, as people can be engaged inside the building in educational activities.

Sources: CIBSE Journal (2020), www.copenhill.dk/en.

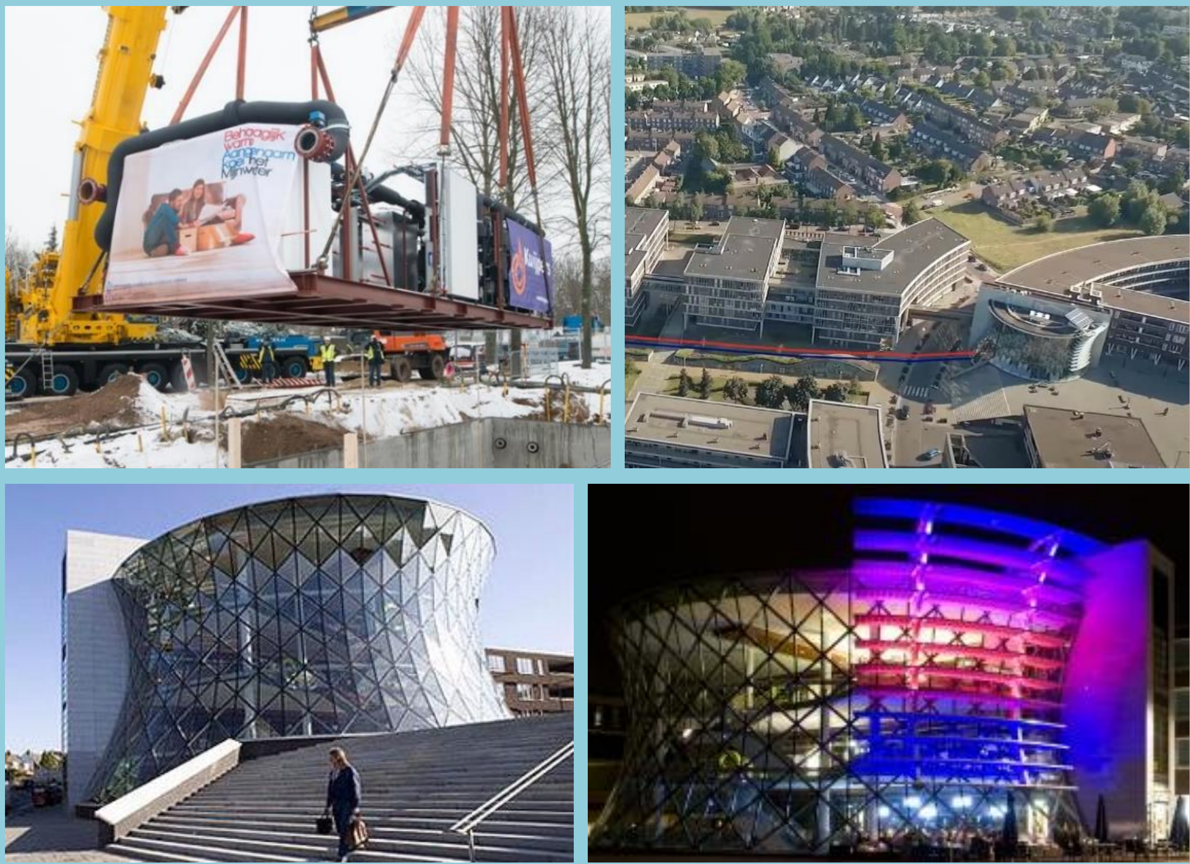
Box 3. Warmte Overdracht Station number 8, Utrecht (Netherlands)

This heat transfer station is part of the Utrecht DH network and was designed in 1999 to act as a node between the waste heat energy from a nearby power plant and several distribution loops connected to residential areas. The building's design is low-rise and organic in order to create a multifunctional structure that includes an urban recreation area (basketball and rock climbing), artificial nests for birds, and even a "spy" door that allows people to look inside.

Source: www.archiweb.cz/en/b/wos-8-warmte-overdracht-station-nr-8.

Box 4. Mijnwater, Heerlen (Netherlands)

The Mijnwater project is the first 5G DHC network in Europe, transforming an old coal mine into an aesthetically pleasing, open cultural space and multifunctional piece of infrastructure that uses geothermal boreholes and heat pumps to supply heat to 350 homes. The network uses waste heat from local industries, and the old mine as underground thermal storage, while people only see a new building that incorporates a supermarket and cultural space that increases their engagement.



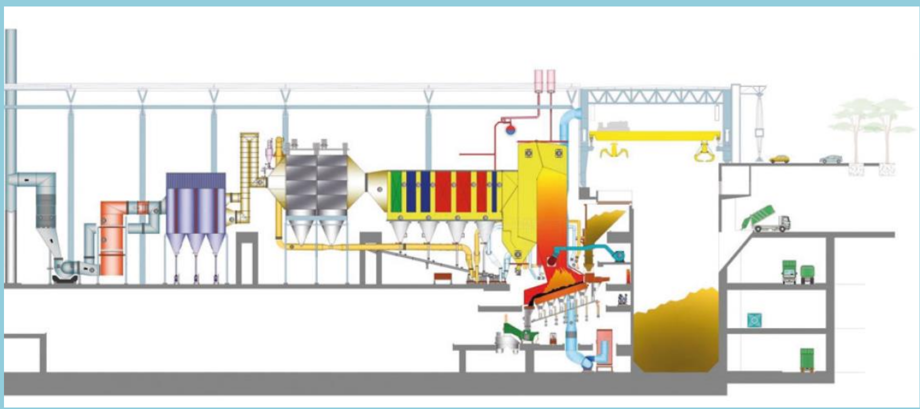
Sources: Interreg North-West Europe (2019), Inhabitat (2008), Demijnen (2011).

Other strategies are to blend the DHC network into the environment or to create local landmarks (DBDH, 2011). The Isséane WtE plant in Issy-les-Moulineaux (France) places the main facility underground and adopts a horizontal design to reduce the building's height further (Box 5). In Roskilde, the incinerator has been influenced by the town's cathedral (Box 6), the Spittelau incinerator is a local landmark and a colourful part of Vienna's skyline (Box 7), and the storage tank in Lund incorporates an element of visualisation (Box 8). Kara et al. (2018) identify six strategies for adapting WtE plants to urban contexts:

- Compacting the structure and reducing the size of the thermal energy production plant to fit into a typical low- to mid-rise urban block;
- Stacking elements to reduce the base and fit into a dense and high-rise urban landscape;
- Fragmenting the structure's components for more flexible integration into different parcels;
- Bridging with facilities for educational, social, cultural or leisure purposes;
- Surrounding by creating spatial continuity with the surroundings;
- Burying by designing horizontally to allow for green or blue infrastructure and open access to the public.

Box 5. Isséane waste-to-energy plant, Issy-les-Moulineaux (France)

This WtE plant was designed not just to operate efficiently but also to reduce its visual impact by burying its main structure underground with a horizontal design, resulting in a height of just 21 metres. To blend the structure into the surroundings even more, the building has landscaping and a green façade.

Sources: www.powerengineeringint.com/decentralized-energy/district-energy/new-waste-to-energy-plant-feeds-heat-to-western-paris-de-has-the-power-to-change-our-lives/, Hirtzberger and Roux (2019).

Box 6. Incineration Line, Roskilde (Denmark)

This incinerator was inspired by Roskilde Cathedral, a UNESCO World Heritage Site. It is known as the Incineration Line. Its innovative structure is now considered a local landmark, thanks also to the illumination effects that are visible at night. It is a best practice in using surroundings to reduce visual impact, and in engaging the public since its design was voted on by the inhabitants of the city.


Source: www.archdaily.com/544175/incineration-line-in-roskilde-erick-van-egeraat.

Box 7. Müllverbrennungsanlage Spittelau (Hundertwasser), Vienna (Austria)

The Spittelau incinerator was designed by the Austrian architect Friedensreich Hundertwasser and built between 1969 and 1971. It is connected to Vienna's DHC network, which has more than 1 200 km of pipes and is considered an international role model. The plant produces enough heating and cooling for more than one third of Vienna's households. With its colourful façade and smooth lines, the building is a Viennese landmark that attracts many tourists. Instead of hiding the big chimney, it has been incorporated into the city's skyline and covered in golden tiles to make it shiny and attractive for the citizens. There is a didactic intention in the design of the office building, which has red lines painted all over its façade as a way to show the building's function.

Sources: https://commons.wikimedia.org/wiki/File:Spittelau_%28Wien%29_-_Fernw%C3%A4rme_Wien,_Verwaltungsgeb%C3%A4ude_%282%29.JPG, www.wienenergie.at/privat/erleben/standorte/muellverwertungs-anlage-spittelau.

Box 8. Ectogrid at Medicon Village, Lund (Sweden)

Waste heat and cold from Medicon Village's buildings is recovered, balanced and redistributed through a DHC network. The balancing tank acts like a large thermal battery where the energy is stored and released at appropriate times. Since the tank is visible from the motorway, the developers wanted to make an appealing design. The LED lighting is controlled so that it shows how the temperature changes in the tank: blue for cold and red for warm.

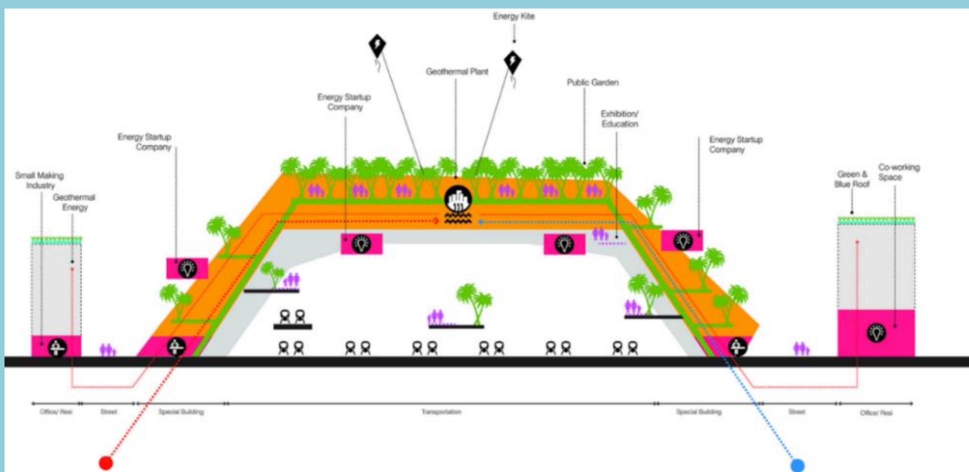
For comparison, examples of traditional storage thermal tanks are provided below: the accumulation tower from Theiss (Austria) on the left and the heat transfer station of Rotterdam (Netherlands), also known as "the pie of Rotterdam" on the right. These do not take into account the tank's aesthetics in their design.

Sources: www.futurebylund.se/post/lysande-innovationsarbete, www.wikiwand.com/en/Thermal_energy_storage, https://project.celsiuscity.eu/Demonstrator/heat-hub-to-increase-network-capacity.

The design of the pipe infrastructure associated with a DHC network is usually adapted to the street layout of the neighbourhood. This can be seen in a prototype for The Hague (Box 9), where all the installations are aligned with the city layout.

Box 9. "Geothermal cathedral", The Hague (Netherlands)

In this prototype for The Hague there is a union between design and functionality, where the need for an overpass structure resulted in the idea of creating a geothermal power plant that would allow free space for pedestrians to walk in comfort through a public garden. The prototype also complies with modern design and aesthetics by including light systems that indicate the plant's heating and cooling sources, adding an educational aspect. The streetscape does not need to be modified, because the network's route adapts to the city's layout with underground pipes.



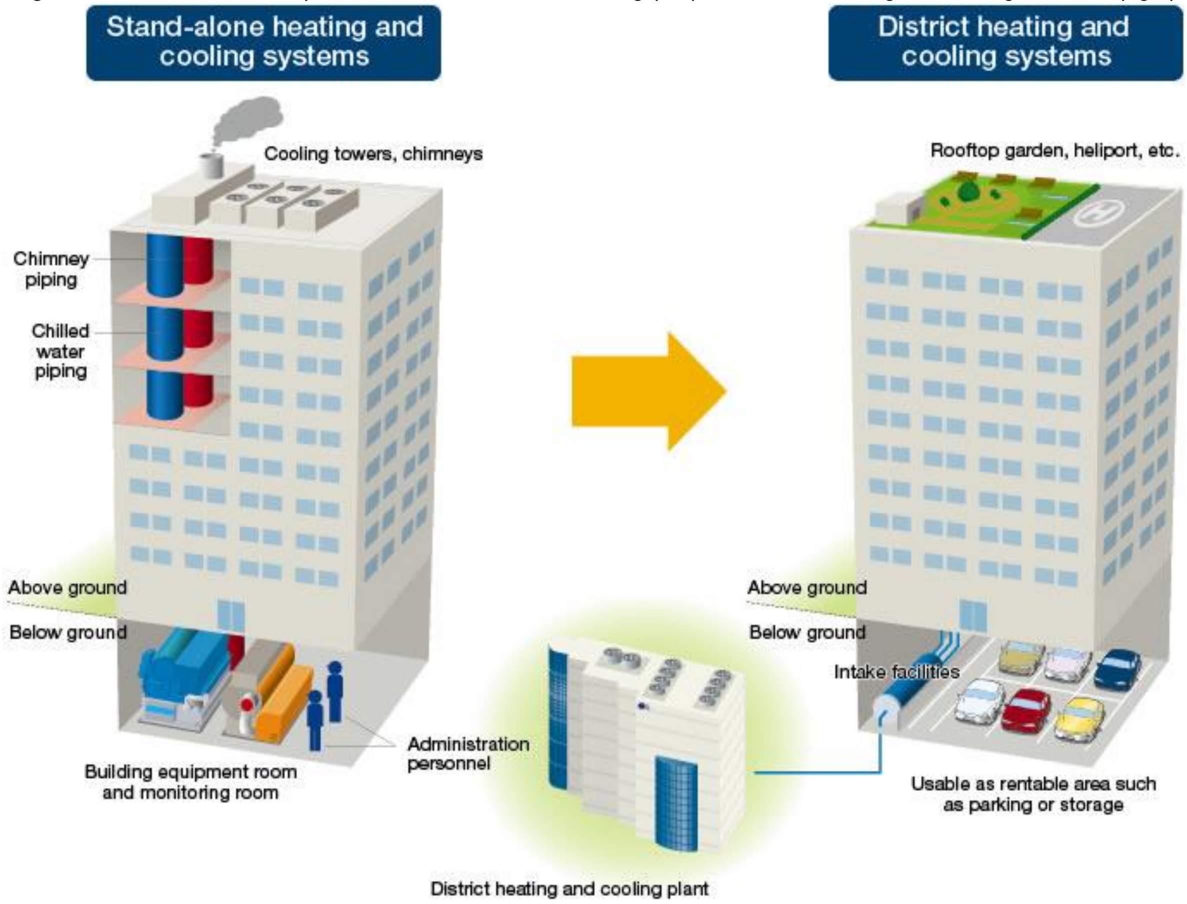
Source: Baldwin (2018).

The challenges in making DHC networks unobtrusive are the extensive and time-consuming civil engineering work at the construction phase, the space that is necessary to build the thermal energy production plants and associated thermal storage, and the additional cost of integration with the urban fabric. In general however, neighbourhood aesthetics are positively influenced by the deployment of DHC. Although heat production plants or thermal storage tanks can have a visual impact, the deployment of DHC present opportunities as well: to improve the aesthetics of neighbourhoods, to introduce more green areas, or even to create open cultural spaces through multifunctional infrastructure such as urban farming or a supermarket.

How does district heating and cooling affect individual building aesthetics?

At the building level, DHC networks reduce the number of individual heating systems required and therefore better use can be made of the space they would otherwise occupy. A typical configuration of individual heating and cooling systems takes up space in building interiors, roofs and façades. In a building connected to a DHC network, the heating system occupies less space and is less visible, having its main infrastructure hidden in buried pipes and the intake facilities located in the basement (Figure 3).

Figure 3 Infrastructure and space needed for individual heating (left) and district heating and cooling networks (right)



Source: Mm21dhc (2022).

When shifting from distributed individual heating systems to a collective network, several changes happen at the building level. First, an appropriate technical room is required, although it may already exist to contain a boiler. Second, the substations, pipes and end-user distribution systems are connected. Depending on the technical requirements of the distribution equipment, some adaptations or even replacements may be needed. Finally, any external heat exchangers, chimneys and individual boilers will no longer be necessary.

Similarly, one of the benefits of a district cooling (DC) network is space saving; individual external units can be removed from façades, rooftops and basements. Along with the freeing up of space, DC promotes noise reduction and reduces the rejection of heat into the urban environment, which is especially important in street "canyons".

Applying “Sustainable” to district heating and cooling

How does district heating and cooling affect energy systems?

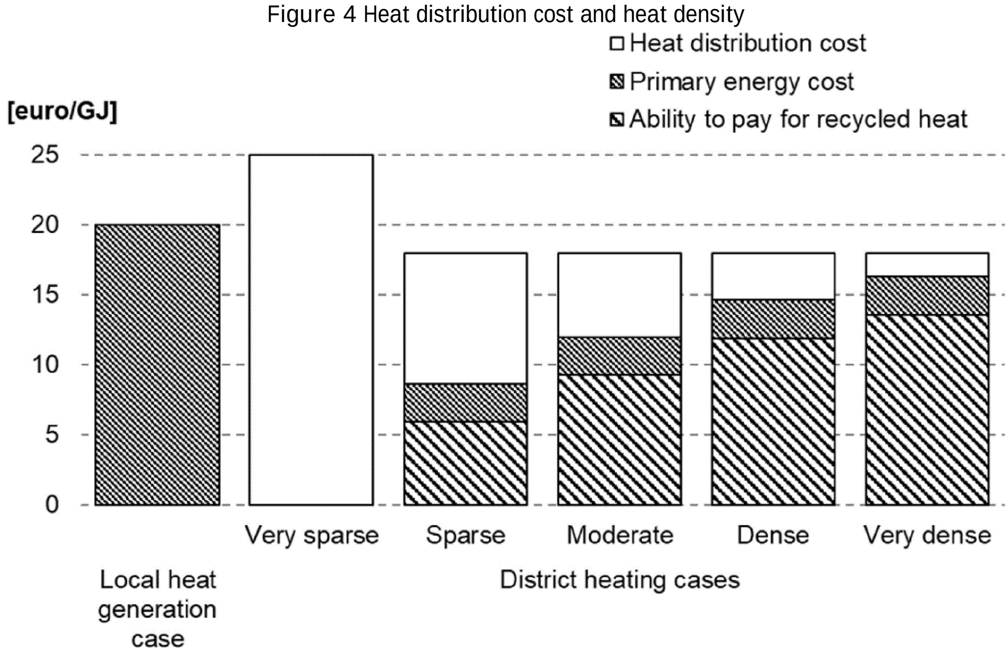
DHC networks are flexible and can incorporate a range of fuels, both fossil and renewable. They also enable the use of heat that is not generated through combustion of a fuel, such as urban waste heat, geothermal and solar thermal. Integration of such decentralised heat production and waste heat reduces total emissions (Saletti et al., 2020), while replacing individual systems with DHC results in a smaller number of emissions points, often located further from dwellings.

Use of waste heat in particular is beneficial both for the environment and local economies. It reduces overall fuel consumption and the temperature of exhaust gases, which in turn decreases the urban heat island effect (discussed later). For example, metallurgical producers in Norway (Eramet Norway, 2018) and Heerlen (Box 4) provide waste heat to a low-temperature DH network, avoiding the visual impact associated with a conventional heat production plant.

A strand of literature is emerging on sector coupling and how DHC can increase flexibility for electricity grids. Integration of waste heat could alleviate pressure on grid bottlenecks and allow for loads like electric vehicles (Boldrini et al., 2022). Indeed, DHC may balance the electricity sector and allow for higher shares of renewable and variable electricity production. Flexibility in DHC encompasses both shifting energy demand using heat storage or demand-side management, and reducing demand or peak power via heat pumps and energy efficiency (Dominković et al., 2020; Ottosson et al. 2020).

Areas with DHC often have a higher density of energy demand, which makes such systems more economically feasible (Zach et al., 2019). The higher the heat density of an area, the smaller the share of distribution costs (Persson et al., 2019) (Figure 4). The density gradient describes how heat demand decreases with distance to the supply point of heating or cooling: the higher the density gradient, the more concentrated heating or cooling demand is around the point of its supply, which reduces piping costs and pressure losses in the system (Shi et al., 2021). This is similar to how in some cases the layout of a district presents a high gradient in gross floor area relative to a public transport station.

Figure 4 Heat distribution cost and heat density



Source: Persson et al., 2019. CC-BY 4.0.

Apart from density, areas that are ideal for DHC are characterised by a certain land-use ratio, whereby residential buildings should hold a significant share of the land area. Moreover, the land-use ratio can be used to predict the origin of commuters, as most commuters begin their journey from districts with a larger share of residential buildings (Liu et al., 2020).

Areas characterised by lower density of demand could still be feasible for DHC. The projected decrease in heat demand of European buildings to 2050 and may in part be countered by increased urbanisation, and heat density in urban Europe will still be sufficiently high for DHC to be viable in future (Persson et al., 2019). The authors conclude that about 50% of the EU-28 heat market could be supplied by DHC if the technology obtained sufficient investment. However, with a higher ratio of distribution costs to other costs such as supply costs, finding low-cost sources like waste heat becomes increasingly important. This may on the other hand be promoted by building renovations, which are the cause of the projected decrease in heat demand, since renovated buildings could be appropriate for low-temperature DH.

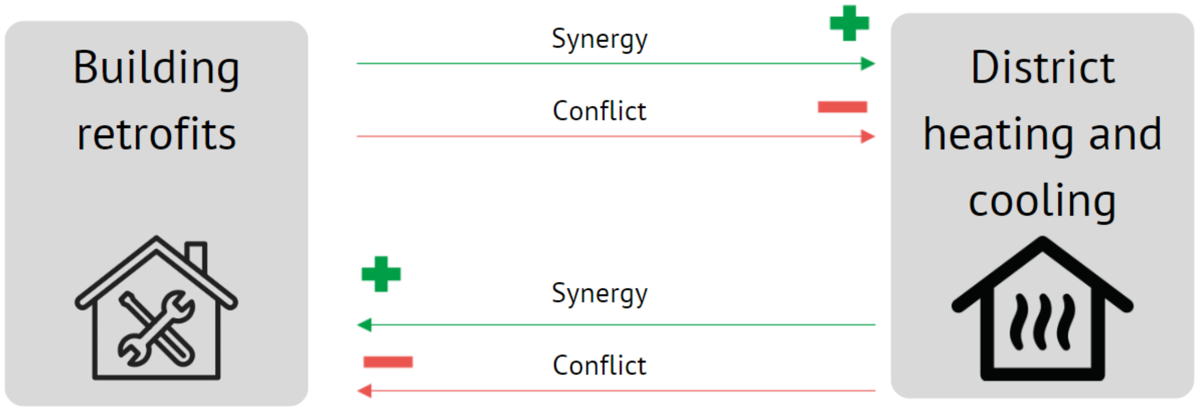
Lower heat density of an area could also be compensated by connection to an adjacent denser area or by achieving a high connection rate (Lichtenwoehrer et al., 2019). There are also examples of rural areas where district heating is being successfully implemented, for example in Denmark (Johansen and Werner, 2022). The establishment of district heating in sparsely populated Danish areas could be attributed to political measures such as high taxes on fossil fuels.

Coupling DHC networks to power grids makes both types of infrastructure more resilient. Resilient infrastructure is an action point for the NEB (European Commission, 2021). Electricity, heat and cold, transport, and industry have traditionally been treated as individual sectors. Smart control can play a key role in coupling these sectors, especially for DHC networks and power grids. Integration of renewable electricity sources such as solar and wind poses challenges to grids in terms of balancing and market prices. DHC networks, on the other hand, typically allow for a lot of flexibility (via water in the network pipes, thermal storage water buffers, or the buildings connected to the network). By switching heat production sources that have a connection to the electricity grid (i.e. cogeneration, heat pumps, Organic Rankine Cycle) at appropriate moments, the flexibility in heat networks can be used as a balancing service and the curtailment of renewable electricity can be reduced. In that way DHC can act as a thermal energy battery providing flexibility to the power system.

How does district heating and cooling affect renovation?

Building renovations (retrofitting) and DHC can affect each other in four different ways: DHC could either discourage or promote renovation, and renovation of buildings could in turn either promote or limit the use of DHC in a given area (Figure 5).

Figure 5 Building retrofits and district heating and cooling



Source: Icons licensed via Canva.

From the perspective of residents and building owners, the structure of the DH tariff could create a favourable case for reducing the energy consumption of a building. Low DH prices lead to lower lifetime profitability of renovation. In efficient DHC networks (Jiménez-Navarro et al., 2022) renovations might be disincentivised since buildings standards for primary energy use and efficiency may be met without further action (Attia et al., 2022). Gustavsson and Piccardo (2021) found that renovating the same building in a larger, more efficient DH network had little effect on the cost-optimal U-value.

The economic feasibility of DH is affected by the linear density and heat demand of an area. However, the decrease in heat demand as a result of renovations only increases distribution costs by a moderate amount (Persson et al., 2019). Moreover, the declining trend in heat demand could partly be countered by a forecast increase in urbanisation.

Whether low-energy detached homes could constitute viable DH customers in future is more uncertain, since the heat density of such areas could be too low to allow efficient distribution of heat and would require extensive investments. Local conditions need consideration in the decision to expand into an area with detached homes (Gustafsson et al., 2018).

Renovating buildings before investing in a DH network allows for smaller components and supply plants because of the lower energy consumption and peak demand, and this reduces capital costs (Cody and Duquette, 2021). Efficient use of energy also allows a greater number of customers to be connected (Zajacs et al., 2021).

Renovation could contribute to the feasibility of implementing 4G DHC by decreasing the supply temperature, although further technical adjustments would be needed as well (Pozzi et al., 2021). The lower temperature enables in turn the use of a wider range of heat sources and makes them economically feasible (Zach et al., 2019). For example, urban infrastructure like sewage systems, metro systems, hospitals and data centres could be viable future sources of DH, on condition that the spatial aspects of such sources are considered.

There are challenges associated with supplying renovated buildings with district heating. Energy use is reduced to a larger extent than the peak demand and that heating companies thus must adapt to a higher relative difference between peak demand and average demand, and a lower capacity factor (Hirvonen et al., 2019). There is also a potential conflict between recently established, community-owned DH and deep renovations due to the decreased heat sales that would reduce return on investment (Cody and Duquette, 2021). Decreased heat sales could induce a need to raise heat prices, which in turn could lead to customers disconnecting (Zajacs et al., 2021). However, this effect could be counteracted by lower system and operation costs obtained by lowering the supply temperature (Averfalk et al., 2021).

The question of synergies and conflicts between DHC and building renovations can thus be answered in two parts: first, apart from the effect of low heating prices, DHC does not pose a barrier to renovation; second, if buildings are renovated with consideration for the risk of aggravating demand peaks, they could have a neutral or positive effect on the deployment of DHC and in particular 4G DHC.

In practice, the deployment of DHC networks in existing neighbourhoods is sometimes coupled with deep renovation, especially when buildings belong to social housing companies and do not meet the conditions for decent indoor comfort. In such cases, DHC deployment is facilitated by renovation and vice versa, leading to energy efficient, sustainable, liveable and beautiful neighbourhoods.

How does district heating and cooling affect transport and mobility?

The layout of an existing neighbourhood is in principle not affected by the deployment of a DHC network. In new neighbourhoods however, planning can take into account the DHC network from the beginning. The design of the pipe infrastructure is usually adapted to the existing street layout. Water bodies or underground tanks can be placed so as to be used as thermal energy sources. In the proposal for The Hague (Box 9), all the installations are aligned with the city layout.

A possible disturbance to mobility occurs during the installation of the DHC network, in the burying of pipes and associated work (see Boxes 1 and 4). However, this is restored once the works are finished.

DHC could even promote a shift in modes of transport by heating bike lanes and footpaths in winter, which reduces the risk of injury from slipping and falling. In 1976, Sweden established the following definition: “Ground heat refers to devices for raising the surface temperature in order to avoid slipping, keeping the surface free of snow and ice or prolonging the vegetation period” (Blomqvist et al., 2019). The ground heating usually consists of a grid layer of heat pipes connected to the DH return pipe via a heat exchanger (known as a hydronic pavement system). Examples can be found in Gothenburg (Qvennerstedt and Palm, 2017), Uppsala (Larsson and Sirland, 2008) and Linköping (Figure 6).

Figure 6 Ground heating using heat from the district heating return pipe in Linköping (Sweden)

(a) (b)

Source: Blomqvist et al., 2019. CC-BY 4.0.

Notes: (a) A square at an outdoor temperature of -4°C with an active hydronic pavement system in the outer perimeter, plus conventional snow clearance and use of sand in the middle. (b) A walkway shortly after precipitation at 0°C. The positioning of the embedded pipes can be discerned when the surface starts to dry.

How does district heating and cooling affect circularity?

DHC plays a role in the circular economy through the use of waste heat and heat from incineration (Werner, 2017). Optimised control of the system enhances its efficiency further (Mahmoud et al., 2020).

When renovation materials are considered, a potential trade-off emerges where insulation materials might display worse performance in a life-cycle assessment than heat-recovery ventilation systems once their production phase is considered (Ramírez-Villegas et al., 2021). On the other hand, efficient DHC networks could decrease the need for renovations, since efficiency standards could be met based on the DH alone (Weinberger and Moshfegh, 2021).

In terms of energy storage, promoting simple hot water thermal tank storage rather than electrochemical storage reduces the use of critical metals such as lithium (Al-Ghussain et al., 2022). Energy storage in the form of heat is also cheaper in general than electricity storage.

Biomass is another material to be considered. Although biomass is a common fuel in DHC today, district heating has the potential to indirectly lower climate impact in other sectors through its ability to integrate waste heat. That could free up resources such as biomass for other uses such as in construction (Lidberg, 2020). This is in line with the sentiment of the EU Bioeconomy strategy, which promotes the use of natural resources in high-value applications to better fit into a circular economy (European Commission, 2018).

Plastic distribution pipes are another example of how material use in DHC is improving, although plastic is not a particularly sustainable material. With a lower system temperature and pressure, plastic piping can be used instead of steel pipes. This reduces the capital cost of the distribution network, decreases the installation time and trench size, and allows for a lifetime of 50-100 years when temperature is below 70°C.

European legislation on legionella prevention in water systems could be a barrier to achieving improved material efficiency in DHC. Presently, legislation in different European countries treats legionella differently, with varying requirements for circulation and temperature (Sernhed et al., 2018). The different ways of preventing legionella growth allow some countries to have more energy efficient domestic hot water systems (Toffanin et al., 2021).

How does district heating and cooling affect public spaces, and green and blue areas?

The deployment of DHC is an opportunity to improve the sustainability, aesthetics and togetherness of neighbourhoods by creating, or increasing the size of, green areas and water bodies. Taking local context into account through an integrated approach (economic, social and ecological), typical industrial locations can be integrated into the city landscape without interfering with quality of life, or even improving it.

These green and blue areas can be used to deploy renewables such as PV integrated with nature, buildings or other infrastructure; thermal storage tanks integrated with nature; or new water bodies that could be used as thermal energy storage for DHC. They would contribute to wellbeing, creating space for physical activity and leisure time, and thus also having a link with the NEB “Together” principle.

Application of green walls or building-integrated PV can improve aesthetics, provide better thermal insulation of buildings and help mitigate the urban heat island effect. As such they can be used in combination with DHC to improve indoor and outdoor comfort.

As regards the urban heat island effect, the heat expelled by air conditioners is one of many point sources of anthropogenic heat that contribute to the effect (Oke et al., 1991). DC reduces the rejection of heat to the environment, thus contributing to increased outdoor comfort and promoting the use of common city spaces.

Applying “Together” to district heating and cooling

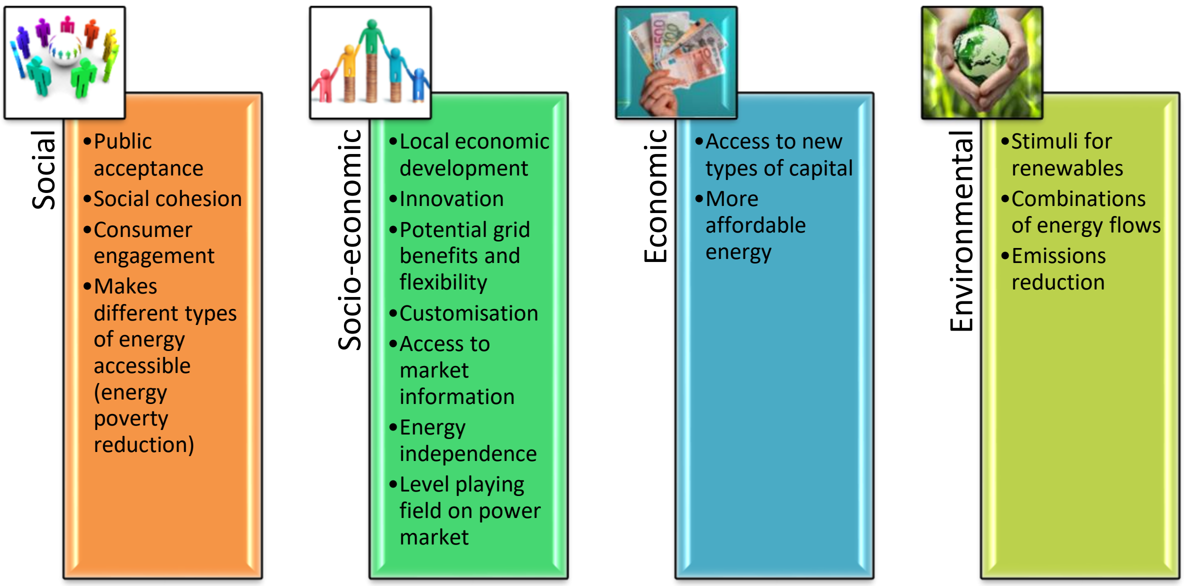
This section will focus on three aspects of the Together (inclusive) principle. First, the potential role of DHC as a collective action by communities and citizens, next its potential effect on affordability of heating and cooling, and finally access to and use of digitalisation. The first aspect is dealt with in the most detail: participative and inclusive approaches including energy communities, resulting in a more balanced distribution of costs and benefits and greater transparency, could become a pillar of new business models for DHC (Galindo Fernández et al., 2021).

How does district heating and cooling affect collective action by communities and citizens?

Community and citizen initiatives exist in the agricultural, social, health, environmental, financial, housing and other sectors (Holemans et al., 2018). In the 1970s, a movement advocating “soft energy paths” emerged, which put the focus on greater participation to increase democratisation (Bauwens et al., 2022). Over the years, the concept of energy community grew, leading to the recognition of collective energy concepts in the European Clean Energy Package in 2016 (European Commission, 2016) Consumers received the right to consume, produce, store, trade and share electricity and renewable energy. Today, renewable energy communities are supported by the Renewable Energy Directive, and citizen energy communities by the Electricity Directive.

The benefits of consumer empowerment are manifold. There are social benefits in the sense that engaging citizens increases public acceptance of new projects of any type (Graham and Rudolph, 2014). Consumer engagement also leads to more social cohesion and local economic development and in particular helps to make access to different types of energy open to all consumers (Delnooz et al., 2020). Furthermore, there are many economic benefits in the sense that citizen engagement leads to new types of (private) capital becoming accessible for investments in new projects (Fleiß et al., 2017). Other benefits can be linked to innovation, environment and sustainability, infrastructure and politics (Bauwens et al., 2022) (Figure 7).

Figure 7 Benefits of consumer empowerment



Consumer empowerment in general therefore has clear benefits that could also benefit the NEB. Many recent studies focus on enablers of local participation and communities. From consumer participation projects, there are numerous recent lessons learned that the NEB can draw upon. Many challenges and recommendations have already been formulated in various papers and reports. They range from internal organisational suggestions as to how to engage consumers and deal with group conflict, to financial aspects linked to the importance of financing. Other recommendations concern how to overcome regulatory and technical barriers. This section focuses on lessons learned from collective action in DHC networks specifically.

Most projects and literature on collective activities in the energy sector focus on electricity, ignoring collective thermal energy systems (Fouladvand et al., 2022). This is despite the importance of heating and cooling, which accounts for about three-quarters of energy consumption in households (Finney et al., 2013). Most likely this is explained by the fact that electricity grids are already widely rolled out and can more easily be complemented with community-based initiatives. Collective thermal energy systems take more time to implement, require more permits and might not always be techno-economically feasible in each environment. Nevertheless, Denmark is an example of how collective actions can help shape the energy transition for heating and cooling.

DHC often involves combining heating and cooling, different technologies, and different energy carriers. This makes it particularly interesting for the NEB, which is an interdisciplinary initiative. The key lessons learned are:

1 - Conceptual definition: Do not restrict the definition of collective action and citizen engagement

Many different terminologies, definitions and names exist to refer to collective actions and consumer engagement. Bauwens et al. (2022) analyse 183 definitions but a common definition or understanding of community energy does not exist so far in the context of energy generation. This diversity and flexibility in the use of the term "community" may have helped it grow in popularity. Therefore, the concept of a community should remain open (Creamer et al., 2019). Indeed, Denmark, a frontrunner, grew its DHC infrastructure significantly through joint investments of local groups that were allowed because there was "wiggle room for experimentation" and creative minds were encouraged (Johansen and Werner, 2022). Furthermore, new generations of DHC networks integrate a wider variety of energy carriers, which requires an open definition of energy-related collective action. For the NEB this is an important lesson learned, as a narrow definition of communities could lead to missed opportunities for some players or technologies. The role of Member States in implementation could also be relevant in this regard.

Conclusion for the NEB: It is good that the NEB does not limit itself to definitions of what consumer empowerment and collective actions imply because this encourages broader and more interlinked projects and innovation. On the other hand, if large companies are allowed to participate, they could undermine small consumers and block them from being more energy dependent.

2 - Motivations, values and norms

It is important to understand why people join the community: to keep them motivated, to understand which outcomes should be targeted, and to understand the process that should be followed to reach those targets. The Feldheim community in Germany, for instance, is an energy community including DH that combines many different types of energy source to become self-sufficient (Figure 8). They invested in wind, PV, biogas, biomass, a power station and a local DH network. Feldheim saves 259 000 litres of heating oil every year thanks to the DH network.

Feldheim is an example of an integrated village, with a visitor centre that provides guided tours and rents electric bicycles. The Feldheim community is perfectly in line with the Beautiful, Sustainable and Together vision of the NEB. When asked about the motivation to start the project, social cohesiveness and local economic development were key. This finding is in line with numerous other references from the literature (Callaghan and Williams, 2014). If people are only driven by economic incentives for instance, it is less likely that social objectives will be reached.

Denmark, a front runner with respect to collective DHC, also had more system-wide motives linked to energy import independence and stable affordable energy supply in the wake of the 1970s oil crises (Danish Energy Agency, 2017). The participatory process of collaboration and negotiation is important to get people on the same page. Nevertheless, such attributes often receive less attention in literature, which is problematic as such communities are formed when individuals act collectively (Fouladvand et al., 2022).

Figure 8 Feldheim, an energy self-sufficient community

Entrance to Feldheim

Absorption cooling equipment

Piping for district heat network

Wood-chip fired boiler

Source: http://snapshotsfromberlin.com/2014/06/19/feldheim-an-energy-self-sufficient-community.

Conclusion for the NEB: For the NEB, it is therefore important to ensure a community or project has a clear common vision that is shared by the whole community. Such a vision might not be created overnight but needs to be taken into account during the entire implementation and operation of the project.

3 – Planning: Decentralisation of planning is needed to integrate local ideas and initiatives

For this lesson we turn to Denmark, which is known for its heat planning strategies, technical solutions and combinations, energy efficiency and sustainability, ownership models and financing (Johansen and Werner, 2022). In Denmark, heat planning was decentralised in 1979 when Denmark passed its first heating supply law. Through that law, local municipalities were put to the fore as they had to map existing (and estimate future) heat demand for regional heat supply overviews. Next, the municipalities had to prepare options for future heat supply, followed by the setting up of regional heat plans. Municipalities therefore had a good overview of all projects in their region, and had insight into the remaining local needs. The final municipal heat plans set a vision of which type of energy carriers could be used in which zone. This avoided overinvestment in infrastructure and guided local authorities in the approval of new projects (Danish Energy Agency, 2017).

Conclusion for the NEB: Many lessons can be taken from this for the NEB. First, municipalities and citizens are best placed to understand the needs and added value for their region. Citizens can participate through open and inclusive consultations, considering the views of representative groups and stakeholders including more vulnerable and energy-poor households. Open consultation should lead to further engagement of citizens and communities in the decision-making process through a proper governance structure. Decentralisation towards local municipalities has not only proven successful in Danish DH networks (where more than 60% of heating is delivered via DH networks owned by 350 consumer co-operatives), but is also receiving attention in many scientific papers.

Second, collective agreement from citizens is necessary as investments in one technology might close the door to some alternatives. Decision-making and planning today have a long-term impact and will create either opportunities or limitations for future system planning (Creutzig et al., 2016). It is therefore important that interdisciplinary planning across different sectors and stakeholders is established, as integration of different planning strategies leads to significant synergy (Mendes de Almeida Collaço et al., 2019).

On top of this, and perhaps beyond the scope of the NEB, it should be noted that incentives to have collective decision-making and consumer engagement are sometimes given through regulation and legislation at a higher level. In Denmark, this consumer engagement is facilitated by supportive legislation for community energy. Indeed, an adequate legal framework at national level is needed to ensure proper regulations and subsidies are in place to support community projects. There are many examples of supportive legislation, including from beyond DH, that help projects to become more successful and grow.

For collective actions to be successful, the need for a good geographical location with access to specific resources is often seen as a barrier. Legislation (or local planning through municipalities) can prioritise access to specific resources for collective actions. For wind energy, there are examples of provinces that prioritised projects of co-operatives. For the NEB, this implies that centralised (national, regional) planning might be needed along with decentralised local planning that supports local actions.

4 - Socio-economics

A proper feasibility study that goes further than merely economic analysis is needed to set up long-lasting projects that strengthen citizens' trust in collective actions. Collective projects require investment and DH in particular requires large investments in underground heat infrastructure, which is expensive. It is important that there is favourable financing available that minimises investment risk (Johansen and Werner, 2022).

Danish experience shows that in this respect it is important to properly evaluate feasibility by considering costs over the full lifetime of the DH network. In Denmark, feasibility studies were based on socio-economic costs, which helped local authorities to choose among projects. Anyone that wanted to start a DH project needed to work out a project proposal that included socio-economic, user-economic and environmental analyses. The project with the largest socio-economic benefits was chosen by the local authorities (Danish Energy Agency, 2017). There are three parts of these Danish feasibility studies that need to be highlighted:

First, because most DH networks in Denmark are community-based initiatives, the above socio-economic analysis is always done for a "collective" DH network. While this is only natural for DH (which is collective by definition), it is also important to compare individual heating systems with collective heating alternatives. This is an important factor as collective engagement requires investment by citizens who could also invest in other (non-collective) initiatives. Economic and financial benefits are often very important for stakeholders.

Second, the "socio" part of the socio-economic feasibility study needs to be highlighted. Collective initiatives could bring other benefits that are harder to quantify and that are not necessarily (directly) economic in nature. Studies that only focus on economic benefits might miss other opportunities and might result in projects that perform less well from a societal point of view. The latter point is also recognised by RED Article 16/3, which indicates that a cost-benefit analysis needs to be done in order for energy communities to decide based on proven benefits, so that various opportunities and incentive schemes can be compared objectively.

Third, the Danish government provides a tool for analysing DHC projects.[3] Especially in projects where citizens are involved, who might be less accustomed to taking decisions or doing feasibility studies, offering guidance tools is recommended.

Conclusion for the NEB: The NEB can learn from this approach because an objective evaluation taking into account the criteria that are important for the NEB might help to select the project that contributes most to its vision. Focusing on economic benefits alone might ignore many of the non-economic objectives of the NEB. Consumer engagement and collective action in particular might contribute to specific NEB objectives yet when evaluated solely from an economic point of view, collaborative benefits might be overlooked. A socio-economic feasibility study is therefore needed to evaluate projects. Furthermore, in case different projects need to be compared, it is also important to identify proper "weights" based on NEB objectives. Finally, tools to support the analysis are recommended. This will also help to compare the results of different feasibility studies more easily.

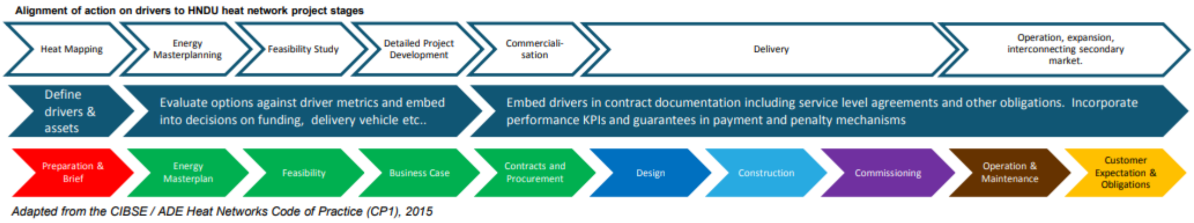
5 - Interactions network: interactions among different technologies, sectors and stakeholders

A recent review of thermal energy community applications showed that 53 initiatives focused only on heating and cooling, while another 81 studies also considered electricity generation (Fouladvand et al., 2022). For DH, in particular for the latest generation of DHC networks, links with other sectors (i.e. gas or electricity) or with other markets (energy and flexibility) is of utmost importance. When bringing consumer engagement into the picture, interactions might go beyond energy in the sense that links with the water and waste sectors become possible, or specific (non-)energy related services might be offered.

[3] See https://ens.dk/sites/ens.dk/files/Globalcooperation/dhat_report-10-17.pdf.

In order to achieve such integration of sectors, activities and stakeholders, it is important to link them with each other. ARUP (2016) summarises DHC stakeholders and the phases in which they need to interact (Figure 9). DHC networks require very long-term planning and stakeholder engagement is often considered a key success factor. It is important to have the right stakeholders involved at the right moment. At the planning phase in particular, many stakeholders need to be involved in order to maximise synergy and achieve a comprehensive development of the DHC community.

Figure 9 Stages in the planning and implementation of a district heating and cooling network



Source: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/717798/Strategic_and_Commercial_Case_development.pdf.

How does district heating and cooling affect affordability and equity?

The affordability of heating is an issue of growing concern in the EU. DHC networks can provide a response to energy poverty by delivering green heat at a reasonable cost. 4G DHC networks in particular can play a crucial role by increasing efficiency and maximising the integration of sustainable heat sources, i.e. renewables and waste heat (Lund et al., 2014). In doing so, such networks should reduce operating costs.

DHC further addresses the social dimension of sustainability through its ability to alleviate fuel poverty. Indeed, fuel poverty is becoming an increasingly important factor in the decision to implement DHC (Bush et al., 2016), whereby local authorities responsible for spatial planning see both economic and wellbeing benefits, especially for residents of social housing. However, attention needs to be paid to the risk that fossil fuel phaseout DHC networks leads to higher prices, which instead could worsen fuel poverty (Attia et al., 2022). In terms of equity, DC has been pointed to as a more equitable option than air conditioning, which is mostly afforded by upper and middle classes (Thomas and Butters, 2018).

Deep energy renovations are, regardless of synergies or conflicts with DHC, advantageous from an energy poverty perspective: if only the most cost-effective renovations are selected (from a building-owner point of view), occupants with poor social and economic conditions could still face the reality of not being able to afford enough heating to maintain a comfortable indoor temperature, while the opposite could result from deep renovations (Domingo-Irigoyen et al., 2015).

How does district heating and cooling affect access to and use of digital technologies?

Digital technologies are believed to make the whole energy system smarter, more efficient and more reliable. Digitalisation also has the potential to boost the integration of renewables into the energy system. The impact will be substantial on both the electrical and thermal parts of the energy system; here the focus is on digitalisation of the DHC sector.[4]

In the design and build phase of a DHC network, digital solutions have applications from the engineering of single components up to the level of complete networks. 3D printing makes it possible to easily customise elements, while digital twins are valuable to evaluate the technical performance of DHC networks even before they are built.

The potential of digitalisation during operation lies in data exchange and data intelligence. Data exchange refers to data going in two directions: from local active heating elements or buildings to central management and vice versa. Data intelligence includes smart algorithms, machine learning and artificial intelligence (AI) providing insights and making data-driven decisions.

Digital solutions give rise to myriad technological possibilities. However, the questions these technologies should answer go well beyond technology, engineering and materials. More fundamental questions concern politics, culture, behaviour and value (Bason et al., 2020), which are in the scope of the NEB.

[4] For more on district heat and cold management (control technologies, storage and cogeneration), see also Volt et al. (2022).

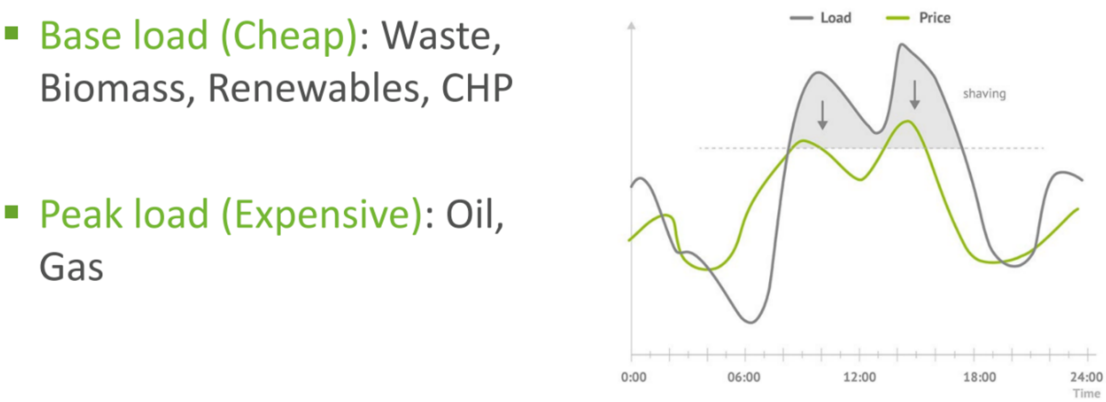
The NEB High-Level Round Table (2021) proposes a set of focus areas, which we mapped onto the various digital features of DHC networks, focusing on those to do with the goals of the NEB. This mapping revealed four ways that digitalisation in DHC networks can contribute to the NEB:

- making housing more affordable and sustainable;
- enabling data-assisted design and operation;
- reshaping urban planning; and
- making energy infrastructure more resilient.

Digitalisation is a prerequisite to achieving the objectives of 4G DHC and 5G DHC. On the production side, without digitalisation in the form of smart control, the maximisation of sustainable sources will not be possible. Sustainable energy sources are less controllable and predictable, leading to the need for new types of heat network controllers. Think of solar thermal energy, which is heavily influenced by the cloudiness of the sky. While waste heat from industry might be more controllable, it is unlikely that companies want to adjust their production process to optimise heat delivery to a heat network. After all, waste heat is a by-product. Such energy sources are usually combined with sources that are controlled more easily, such as cogeneration, boilers or heat pumps. Managing these controllable assets in a smarter way should lead to the prioritisation of sustainable heat delivered by the uncontrollable assets. This means that the controllable assets are managed in such a way that the uncontrolled ones can inject as much heat into the network as possible.

In addition, sustainable energy sources of heat networks are used to deliver a heating base load, while peaks in consumption are usually covered by expensive (fossil-fuelled) boilers (Figure 10). Base load is the minimum level of heat demand required during winter. Peaks refer to the times of the year that consumption is at its highest; typically when weather conditions are (very) cold. Peak shaving, a form of smart control, can maximise the operation of a sustainable source.

Figure 10 Peak shaving



Source: EnergyVille, 2020.

Data-assisted visualisation tools are useful for both heat suppliers and consumers. Using real data at, for example, hourly intervals provides insight into energy use, enabling benchmarking against other consumers and recommendations for energy savings. Tools to help customers control and monitor their energy use may help make DHC much more efficient and allow deployment of 4G DHC. Data can also empower energy providers to take more responsibility in monitoring and controlling the heat system. Energy providers can also develop new billing models and could ultimately sell comfort instead of energy (Birk et al., 2019).

However, visualisation tools only increase customer satisfaction if they are combined with financial or environmental benefits. Alternative pricing models, addressing the concept of heating as a service for example, could be developed to encourage customers to adjust their heat demand more in order to achieve a greater system benefit. Data and commitment from energy companies are required to achieve this. There is also potential for smart devices or AI in this matter to reduce the need for commitment from the energy company.

Increased flexibility can also increase customer satisfaction, by facilitating the introduction of heat from prosumers and simplifying the development of customer solutions (Canholm, 2021). Exploiting this flexibility opens up new possibilities for more innovative, resilient and sustainable forms of local ownership, engagement, care and maintenance of energy infrastructure, which is important from a NEB perspective.

Urban planning can benefit from data-driven design and planning of DHC networks. The NEB High-Level Round Table (2021) recognised cities, small towns, villages and regions as engines of the ecological transition. The connected countryside, villages, towns and smaller cities, developed through the lens of the NEB, could become locales of hopeful experimentation.

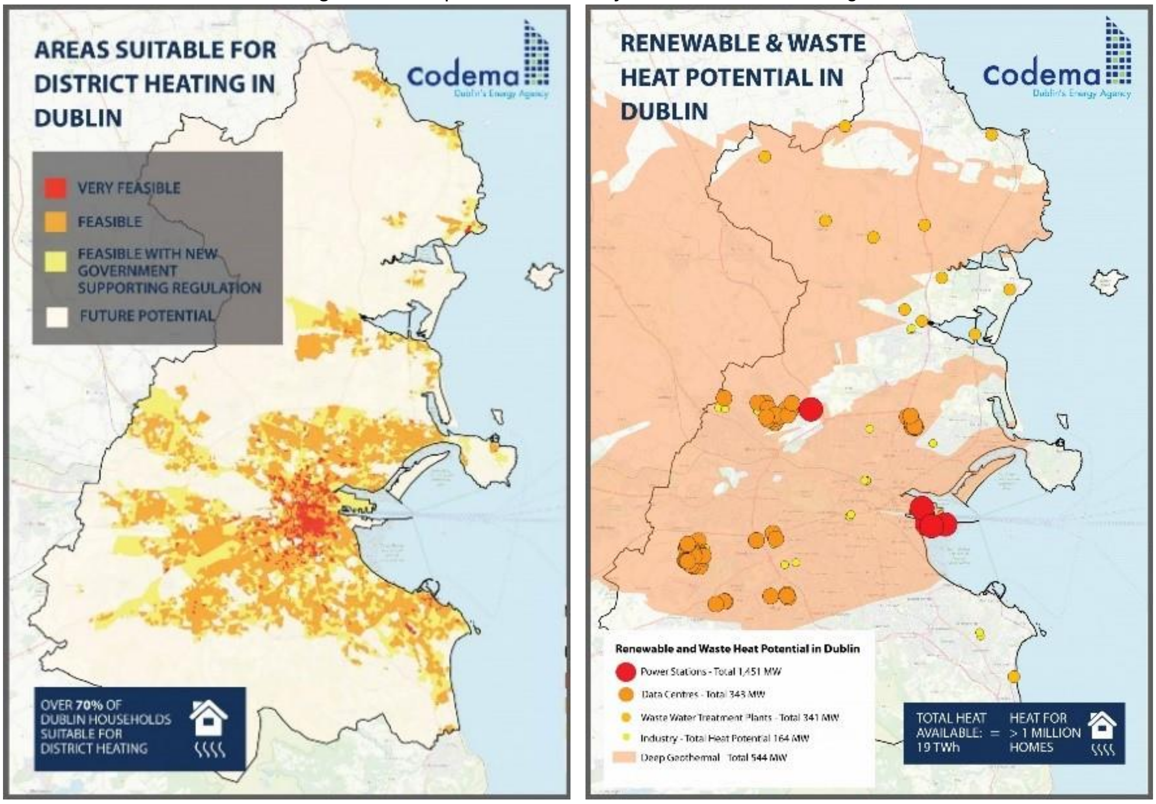
In larger cities, the 15-minute city model espoused by cities like Paris, Barcelona and Milan is a model for self-sufficient urban neighbourhoods, where every citizen is able to reach any needed services within 15 minutes. Equally, clustering of rural towns to better share capacities and resources can provide cross-cutting benefits and support resilience. The principle of the 15-minute city should therefore be implemented in small towns and extend also to smaller rural settlements supported by digital infrastructure that collects public data on energy and heat consumption, mobility, water, management, pollution, etc. This data can be considered a public good and used to improve the city and innovate, while respecting privacy, security and digital sovereignty.

As part of urban planning, digital infrastructure will empower citizens and communities to make the EGD a reality (NEB High-Level Round Table, 2021). In addition, digital solutions can facilitate a district approach to building renovation; renovation at the district level rather than at the level of the individual house can lead to significant cost reductions through economies of scale, the industrialisation of solutions and smart logistics. The district approach also fosters synergy between energy efficiency and local renewable energy sources.

A data-driven approach to DHC planning needs to consider three dimensions: the demand side, the required infrastructure and the supply side. As most buildings are privately owned, it is difficult to gain insight into energy needs. However, an accurate estimation of heating and cooling needs by building type is necessary, with enough granularity and for a substantial time period. There are two main ways of mapping a building stock's energy consumption: first, a top-down approach collecting aggregated real energy consumption data, split afterwards at district or building level based on various parameters (e.g. building age, building fabric, surface and height, heating and cooling systems); second, a bottom-up approach collecting or modelling the consumption of individual buildings. In reality, a combination of the two methods will be used, depending on the type of data available (Decarb City Pipes 2050, 2022).

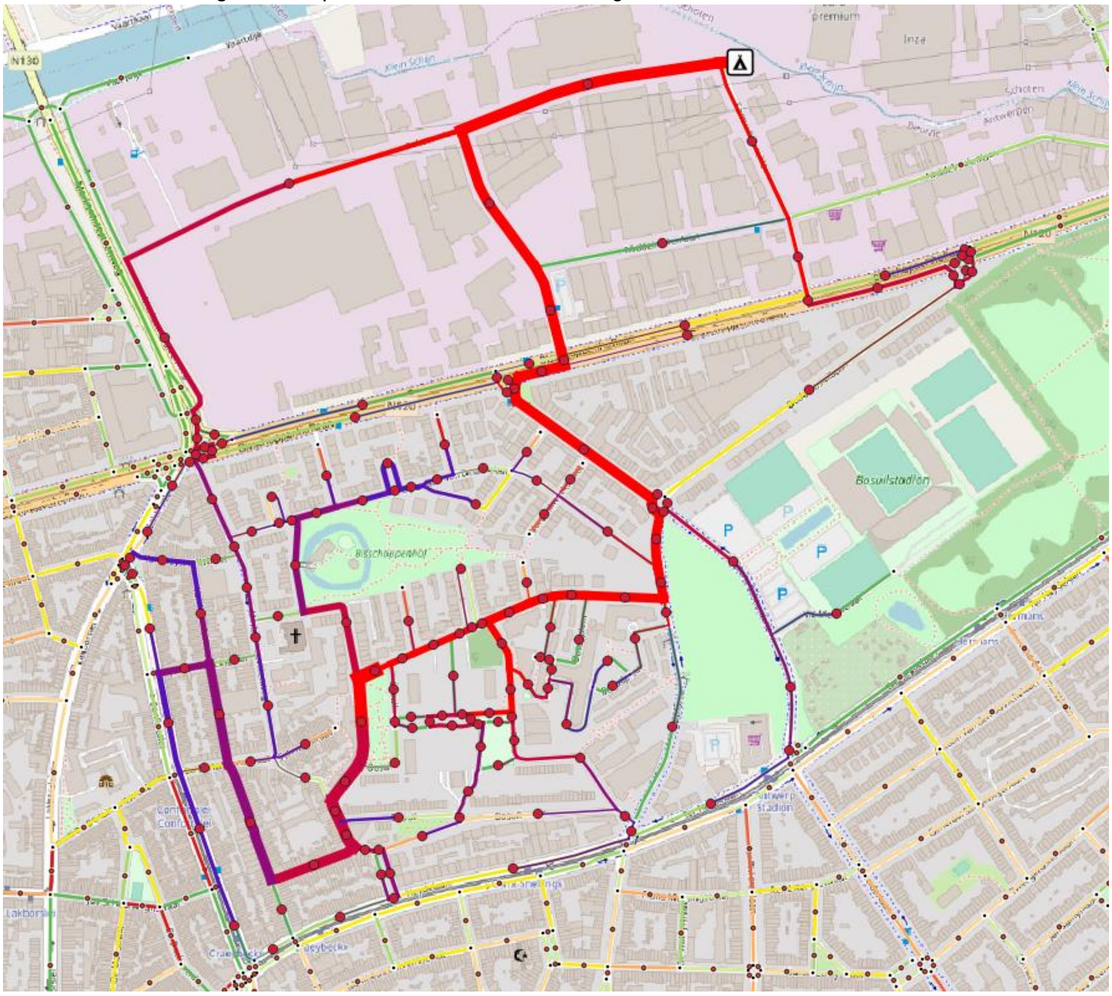
The planning process of DHC networks can be optimised by developing and applying various digital solutions. This includes big data approaches (e.g. use of metering data for design processes), mapping algorithms (as used by the Dublin energy agency in Figure 11), process planning tools, and sophisticated optimisation and simulation methods (Figure 12).

Figure 11 Output of a feasibility tool for district heating



Source: Codema, 2022.

Figure 12 Optimisation tool for connecting consumers to a DHC network



Source: Vito, internal.

Such solutions will be needed to overcome the challenges of traditional methods when designing DHC networks. For example, for sizing heat production installations and pipe diameters, the classic approach is based on ensuring these components meet the peak heat demands, at any time and anywhere in the network. Designers use safety coefficients to make sure that the DHC network always delivers and no bottlenecks occur. However, this usually leads to oversized systems. While the design process focuses on the peak times, which only occur a few hours or days per year, the DHC network will work at a partial load most of the time. New digital solutions can prevent this mismatch by calculating and iterating different scenarios for developing a new network or expanding an existing one. They could optimise the risk assessment at the design stage and ensure that the share of renewables and energy efficiency is maximised.

As a result, investment and operation costs can be reduced while network operators will be more at ease due to higher security of supply. For society, the potential benefit lies in reducing the socio-economic cost of achieving the energy targets of urban developments. Data-driven DHC networks can ensure a higher energy input from renewables, can lower CO_2 emissions, and are very energy efficient compared to traditional DHC networks (Birk et al., 2019).

Networks benefit from prefabrication, standardisation, circularity and modularity, which all help to streamline design and installation. They also use centralised digital management systems to enable use of multiple and unpredictable heat sources and more complex elements such as waste heat, while combining them with complex and highly efficient heat pumps. Centralised systems are highly adaptable and apply dynamic modelling, machine learning and instant data analysis coming from a diverse set of sensors and measurements (e.g. indoor temperature sensor data that also monitors external weather conditions and heating system constraints).

District heating and cooling concepts in the New European Bauhaus

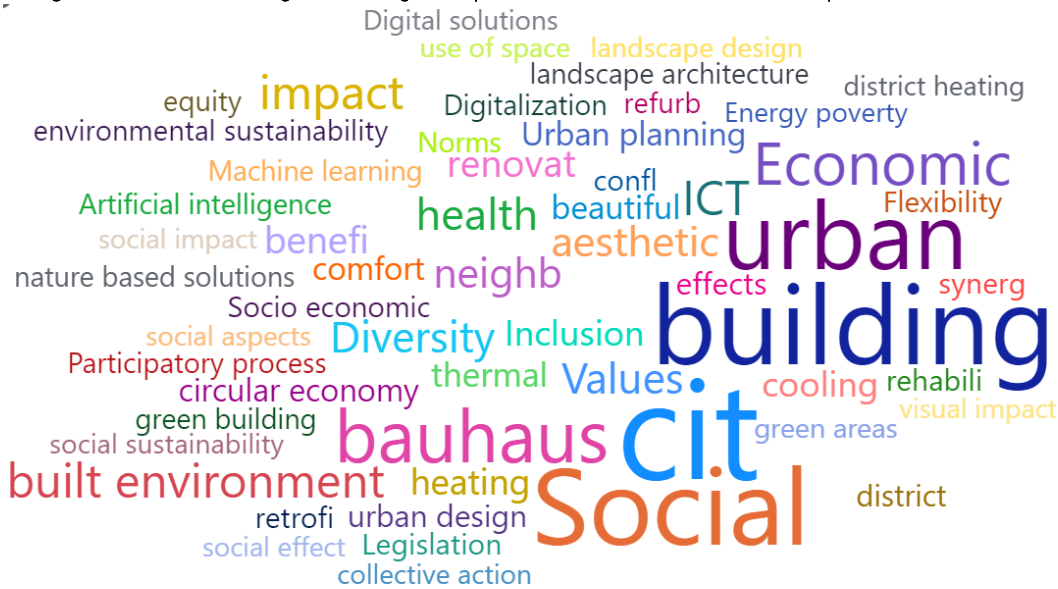
The co-design phase of the NEB received much engagement in the form of contributions uploaded to its website. We downloaded all contributions assessed them for their relevance to DHC by using keywords identified during the literature review. Selected contributions were analysed in more detail to assess whether concepts related to DHC, such as sustainability, renewable energy for heating and cooling, energy communities, collective and individual renovation, etc. are already included or not.

In order to assess the relevance of the contributions to the NEB website from the perspective of DHC, a keyword search was performed in R. The script screening results are represented below using WordCloud from Power BI. The most repeated words are: city, building, social, and urban. Heating appears 117 times and cooling 113, but none of those occurrences are related to DH. District heating appears twice, but just as a possible sustainable solution for a district or city rather than as an implemented example (Figure 13).

Figure 13 District heating and cooling concepts in contributions to the New European Bauhaus website (keywords)

As words can be mentioned several times in one document, the "Number of files containing keyword" was also analysed (Figure 14). The keywords with the most files (60 or more) were: city, social, building, impact, urban, economic, ICT and Bauhaus.

Figure 14 District heating and cooling concepts in contributions to the New European Bauhaus website (files)

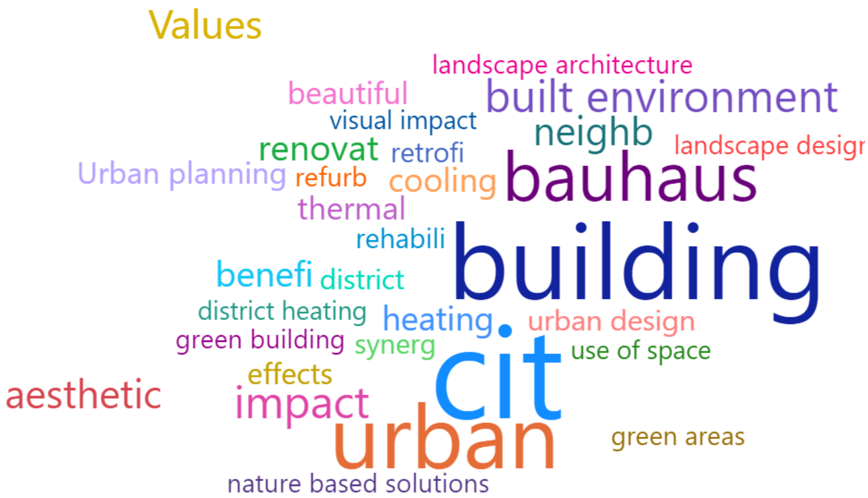


Comparison of New European Bauhaus keywords and district heating and cooling literature

During the co-design process of the NEB website, case studies were collected using a questionnaire. The questionnaire used open questions and keywords to tag each case study. We compared these keywords with the findings of our literature review. Of the 57 keywords from the literature review, some are used with the exact same nomenclature and others use similar or related words. In total, 53 are used in the content on the NEB website.

We first filtered by searching for keywords that could be related to the Beautiful principle or to DHC networks (Figure 15). Then the occurrences were scanned in order to find any link to DHC. The complete documents were then read but no links between NEB principles and DHC were found. Finally, some documents were selected for being related to urban planning and aesthetics, but without any mention of DHC networks.

Figure 15 Keywords related to the concept of Beauty in contributions to the New European Bauhaus website



Next, the keywords used for the Sustainable principle in the literature review were applied to the contributions to the NEB website (Figure 16). We identified 103 unique files that contain at least one of the keywords. Of those, 11 files also contained the word heating and 11 files contained cooling, for a total of 15 documents to review in detail. In general, heating and cooling is mentioned to state that buildings require energy for heating and cooling, without going into specifics on heating systems. DH is briefly mentioned in one document as a tool, along with other suggestions, to transition the energy system of a historic city in need of rehabilitation.

Figure 16 Keywords related to the concept of Sustainability in contributions to the New European Bauhaus website

3. Stockholm case study

Introduction

Stockholm, the capital and home to almost one million people (or almost 2.5 million at the county level), has the highest population density in Sweden. During the 2020s, Stockholm's population is expected to grow by 10%. Four DH companies are active in the city and their networks are increasingly connected, in order to enable collaboration and optimisation of production.

Stockholm is a particularly interesting case study to learn more about connections between DHC and neighbourhood aesthetics, and between DHC and sustainability. Stockholm is frequently assessed as being among the most beautiful cities in Sweden. Stockholm is also a large, dense city with extensive public transport and overall sustainability; in 2010, Stockholm was named the first ever European Green Capital.

The city has ambitious targets set out in the Climate Action Plan that align it with the Paris Agreement. The overarching goal is a fossil free and climate positive city by 2040. The municipality itself aims to be a fossil-free organisation by 2030.

The public transport system serves 900 000 people per day in Stockholm county, using a large metro system, buses, commuter rail, trams and boats. The city's increasing population creates higher demand for transportation infrastructure and is forecast to put strain on road traffic. Road traffic is the biggest environmental challenge for the city of Stockholm, resulting in air pollution, noise and greenhouse gas emissions. Of 570 000 people working in the city, 50% commute within the city and 50% commute from other municipalities and regions, so there is an ever-increasing need for efficient public transport. Multiple projects to increase the capacity, accessibility and reach of public transport are always ongoing.

Apart from enlarging the public transport network, the city is working with other strategies to encourage the use of alternatives to the car. These include increasing the amount of bicycle lanes, raising parking fees and using a congestion tax.

In Stockholm, about 30% of food waste (and rising) is collected and used to produce biogas, which replaces fossil fuels in the transport sector. Studies show that 40% of what goes into a typical household waste bin is food waste. While the city encourages reduction of food waste overall, there is a system in place to collect food waste and turn it into biogas with bio-fertilizer as a by-product. By 2023, all households in Stockholm will have the necessary infrastructure to separate food waste.

The city of Stockholm states that the most resource efficient waste management strategy is to reduce the occurrence of waste overall. Waste that is still inevitably produced should be reused or recycled. Proper management of waste must be made easy for citizens. To encourage reuse, the city has developed digital solutions for redistributing material and products left at recycling stations. For people unable to travel to recycling stations, pop-up recycling stations are common in residential locations around the city. Waste that cannot be reused or recycled is burned for energy production in a cogeneration plant owned by one of the DH operators in Stockholm. The city also has an action plan for enhancing circularity in the demolition, renovation and construction of new buildings.

Four interviews were performed for the Stockholm case study. In Stockholm there are four DH companies, three of which were interviewed. One of the DH companies is co-owned by the city and therefore also represents the municipal perspective. The fourth interview was with a large property company in Stockholm that represents the customer perspective:

— Stockholm exergi is the largest DH network in the greater Stockholm area, supplying heat to approximately 800 000 customers with a production of about 8 300 GWh of heat and 1 300 GWh of electricity. Stockholm exergi also has the largest DC network in the world, with 400 customers. The company is 50% owned by the City of Stockholm and 50% by Ankhiale, a European consortium that includes APG, Alecta, PGGM, Keva and Axa.

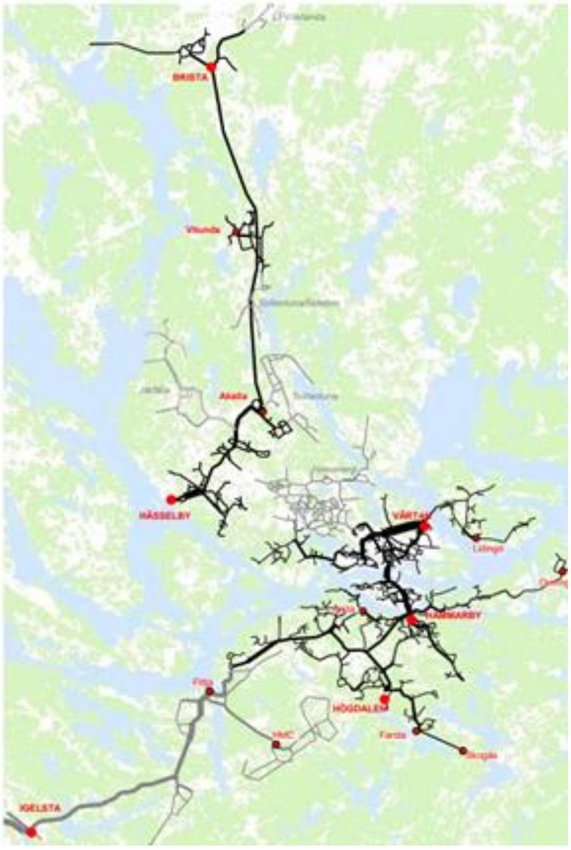
— Söderenergi has the DH network in Södertälje and Skogås, and supplies 300 000 people with heat. The yearly production is 2 500 GWh of heat and 550 GWh of electricity as well as steam and hot water for industry in Södertälje. Söderenergi is owned by Södertälje, Huddinge and Botkyrka municipality. The network is connected to the larger grid in Stockholm and about one third of the total production is exported to the other DH networks.

- Norrenergi serves 100 000 people in northern Stockholm and delivers about 1 TWh of heat and 63 GWh of cooling. It is owned by two municipalities: two-thirds by the city of Solna and one third by the city of Sundbyberg.
- AMF Fastigheter is a commercial property company with buildings in Stockholm and Sundbyberg. AMF Fastigheter is owned by the pension fund AMF with the purpose of creating long-term and stable returns for investors. AMF has a sustainability target of zero direct CO_2 emissions by 2030 and a 67% reduction in indirect emissions. A sustainable heating source is therefore of high importance to the customer.

District heating and cooling in Stockholm

DH in Stockholm has made a major contribution to reducing air pollution. The city has the world's largest DC network and 80% of the population receives heating from the DH networks (Figure 17). The remaining heat supply is mainly from electricity.

Figure 17 District heating in Stockholm



The four DH companies active in the greater Stockholm area (Stockholm exergi, Söderenergi, Norrenergi and Eon Järfälla) have a production collaboration agreement with the shared goal of creating increased operational value for customers. More than 100 production units are connected to the collaboration, making it complex to optimise. The benefits are increased security of supply through the possibility to cover unplanned interruptions to production, reduced fossil fuel use as less peak production units need to run, and better economics as less costly fuels can be used if available somewhere in the network. Currently there are plans to connect the networks further by building a new distribution pipe connecting the central grid with the north-western grid.

Beautiful

Integration in the cityscape

One DH company in particular could provide multiple best-practise examples of integrating production plants and pump houses into the cityscape. Before locating a cogeneration plant in an urban area, multiple architects were consulted to develop a building that could add value to the neighbourhood and protect and integrate old oaks in the area. A pump house erected last year made it to the final round of "Stockholm Building of the Year" in 2022 (Figure 18).

Figure 18 Pump house in southern Stockholm integrated into the hillside

Another DH company states that the municipality requires new constructions to be aesthetically pleasing, but that does not necessarily mean integrated into the cityscape. The customer highlights that, once in place, the distribution system has no impact on the cityscape as the pipes are located under the streets. In that way, DH does not compete for space. The customer further states that the production plants are located outside the built environment in industrial areas and therefore do not affect the urban environment.

Citizen experience

DH companies in Stockholm have quite low levels of engagement in providing an experience for citizens. One company places a Christmas tree on the roof of the building during December, another has an illuminated accumulator tank and a third has organised lightshows on a production plant. The potential for lightshows and other creative uses of DH buildings is however limited by the rules set out in the building permit. The customer is not aware of any examples where the DH companies provide designs for citizen experience.

Educational elements in the cityscape

Educational elements such as signs are mainly present at the production plants in Stockholm, which the customer is aware of. One company states that there is a conflict between the ambition to be transparent on the one hand, and national security laws that prohibit disclosure of technical and geographical details of DH networks on the other. When undertaking pipe maintenance work and construction around the city, informative signs are provided.

Building design and aesthetics

When the heat source is centralised and removed from residential areas, internal and external space is saved. One DH company uses this as a competitive advantage when convincing customers to transition to DH as the heat exchanger requires less space than many alternatives, e.g. wood pellets. In comparison to DC, cooling solutions such as air conditioners would make for a less beautiful outdoor environment for city residents.

DH has a much smaller effect on the aesthetics of a neighbourhood than the building design itself. The customer is of the opinion that DH does not affect the aesthetics of buildings because the equipment is in the basement.

Multi-purpose sites

The pump station in southern Stockholm is a good example of multifunctionality and features a recreational area on the roof (Figure 19).

Figure 19 Pump house in southern Stockholm with recreational space on the roof

Sustainable

District heating fuel mix

The DH networks in Stockholm are supplied to a very high extent by recovered and renewable sources. Energy is recovered from sewage plants, sea water, DC and urban waste heat sources by means of heat pumps (electricity). Fuels used in combustion are often from waste streams that would otherwise go to landfill. That waste often contains a share of fossil carbon, for example plastics in household waste. Other fuels used in combustion are to a large extent biomass (mostly waste from the wood and paper sectors) and only a very small share is fossil. Fossil fuels are used only in peak production, as starting oil and in case of technical disruption or malfunction.

One DH company states that the most important value creation comes from actively recovering energy from waste streams: materials that can be recycled must be, and the remaining share that cannot be recycled due to being unsuitable or polluted can be effectively managed in energy recovery through DH. That DH company believes that they will continue to play an important role in managing waste that cannot be treated in other ways, thereby avoiding landfill. However, they foresee a shift in which waste streams will be available for combustion due to higher competition from other industries looking to reduce their emissions.

Another company supports this view of a DH company's role in energy recovery of materials without other use, and expects energy recovery to remain in the fuel mix for the foreseeable future. That company also foresees an increase of waste heat in the fuel mix in future, where most DH will be waste heat from other processes (such as hydrogen production or data centres).

A third DH company is being forced to change their fuel mix as a sewage plant is closing. Due to lack of space in the area, the possibilities are limited to highly energy-dense fuels and addition of a wood pellet plant is under discussion, along with construction of a long pipe from another sewage plant in Stockholm and connection to their network. Most of the urban waste heat in the area is already being recovered and the remaining share would not be enough to replace the sewage plant production capacity.

In Stockholm, two of the DH companies have plans to implement bioenergy carbon capture and storage (BECCS) on a biomass-fuelled cogeneration plant and there is already a pilot in place. DH can play an important role in BECCS in future.

The customer in this case study has a close dialogue with the DH companies and are well informed of the current fuel mix, especially the greenhouse gas emissions. They are also involved in future development plans.

Contribution to the climate goals of the city

Emissions reduction in the heating sector in Stockholm over past decades can largely be attributed to DH – both in transitioning away from individual heating solutions and in the reduction of fossil fuels in the production mix to a very low percentage. Moreover, the customer is aware that the DH companies contribute to achieving the climate goals of the city because the fuel mix is already mainly fossil free and there are ongoing innovation projects to reduce carbon emissions further.

The level of dialogue between DH companies and the city on developing climate goals, energy plans and other shared goals varies. One DH company recently started intense collaboration with the city to develop sustainability goals and an energy plan. Another company has a dialogue with the city but is not involved in developing energy plans or similar strategies for achieving the climate goals of the city. A third company is highly involved by participating in a city-led working group that provides a platform for dialogue on climate impact and targets.

Circularity

The DH companies in Stockholm mainly work with circularity in the fuel mix where much of the energy is recovered waste heat, and waste streams that cannot be treated elsewhere are used in energy recovery. Two of the DH companies have developed a concept for urban waste heat recovery, making it easier and more standardised for potential prosumers to engage in waste heat recovery. The share of waste heat from these alternative sources constitutes a small share of the total heat supply today but the ambition is for them to meet 10% of the city's heat demand. Data centres are expected to provide most of the waste heat to the network.

Other examples of improving circularity are a sorting facility that was recently erected in Stockholm to pre-sort residual waste and remove fossil plastics for recycling instead of energy recovery. This facility is further highlighted by the customer as a good example of circularity. Another example is that the flue gas condensation in one plant produces enough freshwater to make the company a net producer of freshwater. Reintroduction of combustion ashes to the forest is performed by all companies.

Biodiversity

The DH companies are mainly involved in biodiversity through forestry. They are not actively engaged but they can have influence through the selection of suppliers. One DH company is involved in research projects to optimise the use of ash to allow for reforestation. The only example related to biodiversity that the customer is aware of is that carbon emissions are compensated by controlled forestry projects.

Renovation

There is ongoing densification in Stockholm and the growth in built area increase heating demand even when energy efficiency measures are implemented. One DH company has a neutral position on renovation, while another company encourages it in order to be able to connect new customers as they are unable to increase capacity. The encouragement is provided via a pricing structure that incentivises customers through their heating bill. The third company even offers energy efficiency in buildings as a service to customers through a subsidiary. The customer's experience is that DH companies do not push for increased energy efficiency directly. However, the structure of the tariff affects the way the customer uses energy because they try to minimise cost and thus the energy spent and peak power.

Together

Accessibility of the district heating company

All DH companies arrange study visits, though these were temporarily suspended due to the Covid-19 pandemic. One company targets adults for security reasons and because visits are time-consuming. Another mainly arranges study visits with customers but is discussing having more active engagement with children. A third company caters to a wider audience of local groups, schools and industry representatives.

The DH companies can be reached through a mix of customer call centres, mobile applications and webpages. The digital solutions also contain information about customer energy consumption and other parameters. The customer in this case study experiences the DH companies as accessible, with informative websites that provide access to the energy data of their properties. Larger customers also have key account managers with whom they are in continuous dialogue. One DH company frequently receives praise in surveys for being accessible to customers. For example, when a customer calls the company, they are immediately put in contact with a person. The company has a local presence in the region where it is active, which is a positive according to customers.

Ground heating

The customer in this case study states that the DH network in central Stockholm enables the ground to remain snow- and ice-free (Figure 20). The DH company located in central Stockholm states that features such as road- and bike-lane heating are only applied to a limited degree, though it is something that could be of interest in future when new districts are being developed. One current example is the cooling of a public ice rink, from which waste heat is also recovered. The DH company located a bit outside the city centre has ground heating in selected areas, such as steep hills, stairs and football fields. Ground heating is mainly beneficial for DH networks containing cogeneration plants, as it reduces the return temperature.

Figure 20 Ground heating in Stockholm

Sponsorship and social engagement

Various types of sponsoring of social initiatives such as youth sports, class coaching, homework support, educational material and outdoor clean-up initiatives are provided by all DH companies in the case study. Other examples of social engagement are mentorship and internship programmes, e.g. aimed at female engineers or new Swedish citizens with engineering backgrounds, involving the local university.

Comfort

The DH companies state that the choice of DH has a positive effect on user comfort because it is silent and comfortable in customers' buildings. Insofar as the alternative is boilers (rather than heat pumps for example), a neighbourhood supplied with DH also improves air quality. Production plants can be located far away from where people live, although expansion of cities shows a tendency of residential buildings to be built closer to production plants. Areas close to production plants might be disturbed by sounds or by the sight of industrial buildings.

Tariff structure

All DH companies have a tariff structure aimed at promoting efficiency measures that reduce peak capacity in the system. For one company this is especially important in order to connect more customers in an expanding region, without expanding capacity. A motivational component of the tariff lets customers that return low temperatures (i.e. efficiently use the heat provided) pay a lower price whereas customers with poor cooling in their system pay a penalty (a "bonus malus" system). One company offers customers connected to the DC network a payment for the heat they deliver to the network as their processes are being cooled during winter. Customers are offered advice on how to improve their efficiency, and equipment that could improve monitoring and control of energy use. The customer is aware of the tariff structure and has also been included in multiple dialogues on how to develop the structure and is well informed prior to changes in the tariff or pricing schemes. Through monitoring equipment and continuous improvement of the heating system, the customer in this case study steers the heat consumed in such a way as to minimise the cost while still maintaining a comfortable indoor climate. The customer states that the DH company does not help them to optimise the system to keep costs down.

It is important to the DH companies that the structure of the tariff is easily understood by customers and creates trust and transparency. Often customers, in particular building associations, are not aware of the motivational tariff and continue as usual.

One company offers optimisation solutions to customers to improve energy efficiency, to regulate based on indoor temperature for example. Another company offers energy efficiency services to customers through a subsidiary.

4. Torrelago case study

Introduction

The district of Torrelago belongs to the small city of Laguna de Duero, in the region of Valladolid in northwest Spain. With more than 22 000 inhabitants, Laguna de Duero is the second most populated city of Valladolid, and Torrelago is one of its main residential districts, with more than 4 000 residents.

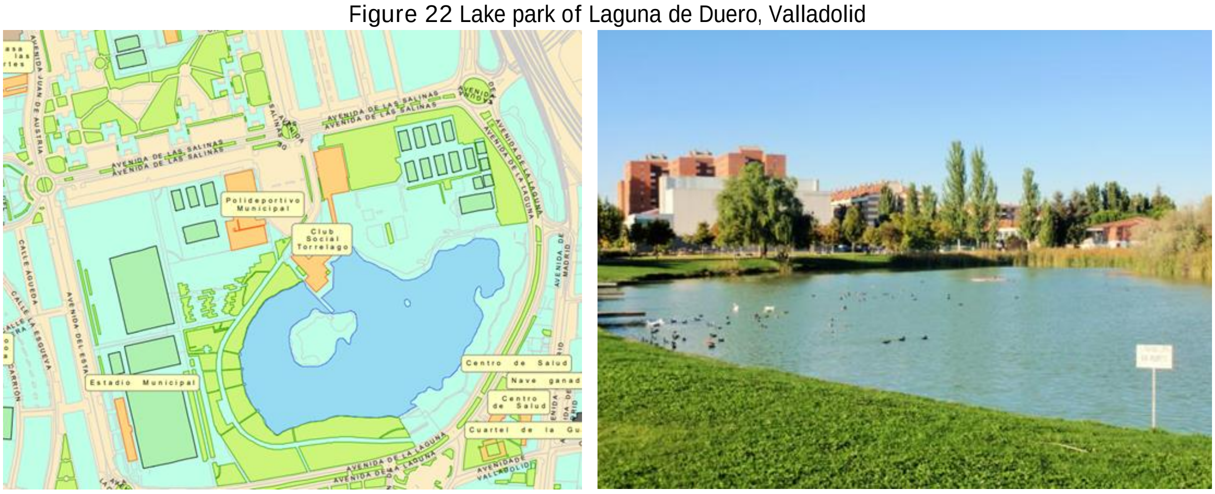
Laguna de Duero is very close to the city of Valladolid and is surrounded by pine forests so there is an available source of forestry biomass within 100 to 150 km. However, the district of Torrelago was built in the late 1970s as a result of urban sprawl, characterised by a great expansion in a short period of time. The buildings were made without much consideration regarding sustainability or the environment. In Figure 21, the district can be seen at the top of the picture, next to the lake.

Figure 21 Aerial view of Laguna de Duero, Valladolid (Spain) in the 1970s

Source: https://lafraguadelaguna.org/2020/03/24/el-parque-del-entorno-del-lago-en-laguna-de-duero.

Nowadays, the city has improved its aesthetics and takes more care of the environment, creating new green areas such as a lake park (Figure 22). The district of Torrelago has gone through the same process of renewal focused on sustainability whereby residents can enjoy better and cheaper heat, and its aesthetics are a source of pride for the city.

Figure 22 Lake park of Laguna de Duero, Valladolid



Source: www.lagunadeduero.org/historia.

District heating and cooling in Torrelago

In Torrelago, there is only one DHC network and one company – an energy service company (ESCO), Veolia. Veolia operates and maintains the network, and also invoices the useful "metered" energy consumed by each dwelling per month for hot water and space heating. With this model, the ESCO takes on the initial investment and the technical and economic risk of the project, and users only pay for their consumption.

In 2013, the district of Torrelago was chosen as a demonstration case for the European project Cityfied (Replicable and Innovative Future Efficient Districts and Cities), led by CARTIF and funded under the 7th Framework Programme.[5] The project involved the renovation and refurbishment of 31 multi-property residential buildings; the works focused on demand reduction, increased system flexibility, and an increased share of renewables. Its main goals were to increase end-user comfort and generate economic savings, with as efficient and sustainable a system as possible. For this purpose, the following measures were taken:

— First, circularity was applied by replacing gas boilers with three new biomass boilers of 3.5 MW, fed with a nearby source of forestry biomass. The DH network's fossil fuel consumption was reduced, and the plant now has a fuel mix of 80% biomass and 20% gas.

— Other technologies installed were a micro-cogeneration system able to produce around 33 kW of electricity and 73 kW of heat; and new pumps with a variable flow rate, which allows the system to be more flexible in meeting demand.

— System efficiency was upgraded by implementing a smart system that combines a monitoring platform and individual thermostats, allowing each user to modify their thermal demand and see their individual consumption. With this system, the DH network increased its flexibility by adapting to each user's needs in terms of temperature and timing. Furthermore, each user can adapt their thermal use to make economic savings.

— Passive measures were also applied, in order to reduce thermal losses in the buildings. Insulation improvements were made along with the renewal of façades, improving both appearance and thermal comfort.

Comfort was improved, mainly due to the insulation improvements and façade renovations but also due to improved continuity and flexibility of supply from the DH network. The façade renovation can be seen in Figure 23, where the original red-brick building façades appear on the left and the renovated buildings on the right.

Figure 23 Aerial view of Laguna de Duero being renovated

Source: www.districtenergyaward.org/torrelago-district-heating-laguna-de-duero-spain.

The overall impact on aesthetics is positive. The old boiler rooms were ground-level annexes to the buildings. Now, even with bigger facilities, their visual impact is much smaller because they are located underground and with green cover to integrate them into the urban environment.

[5] See http://es.cityfied.eu.

Beautiful

Integration in the cityscape

Following the project works, visual impact has been lessened because the ground-level annex building has been replaced by a new underground boiler room. There is also green cover and bushes to reduce the visual impact further (Figure 24).

Figure 24 District heating plant in building 6 of Torrelago district pre-renovation

After the renovation, the two original chimneys are still in use as well as a new taller one. However, they have little effect on the city's skyline. Due to the façade renovation, the skyline has a more modern and brighter look (Figure 25).

Figure 25 District heating plant with green areas and chimney integrated in building 6

Citizen experience

The DH company in Torrelago has a high level of engagement with the residents and has included them in the decision-making process. However, the residents have no dialogue with the municipality, which has been a barrier to obtaining licences.

Educational elements in the cityscape

The only educational elements are the tour visits organised for local schoolchildren, university students and neighbouring communities.

Building design and aesthetics

The buildings had red-brick façades typical of 1970s urban sprawl. Now they are better insulated and have a new renovated and brighter look (Figure 26). The façades are all white with some colour details and one colour per building. The old boiler room was a ground-level annex but the new boiler room is located underground and has green cover and a coloured stone park, reducing its visual impact.

Figure 26 Torrelago's new façades

Source: https://blog.cartif.es/distrito-de-torrelago-cuatro-anos-de-mejoras-energeticas/.

Sustainable

District heating fuel mix

The fuel mix of the heat production plant is 80% forestry biomass and 20% gas, coming from three biomass boilers and four gas boilers. However, there is an intention to change to the mix and consume 100% biomass, mostly due to the high and volatile gas price. They intend to achieve this by expanding the operation schedule.

Contribution to the climate goals of the city

The city itself has no clearly defined climate goals but the plant has a positive impact on climate targets overall, by removing fossil fuels and because of heat demand reduction due to the renovation of the façades.

Circularity

The plant uses a close local source of forestry biomass and waste wood obtained from industry. More measures are possible but are not being implemented. For example, ash from the biomass boilers could be used for agriculture. The DH company offers the ash but no stakeholder wants to use it for now and the municipality is responsible according to the law.

Biodiversity

Thanks to the new underground facilities there is more space available for grass, and there is green cover to reduce the visual impact. There is also an initiative of the community (rather than the DH operator) to expand the green area by creating a boulevard with more trees.

Renovation

The façade renovation was made through the Cityfied project but the community of neighbours wanted to improve the buildings' insulation even further, so they also renovated the rooftops and screed (cement) floors. Then some dwellings decided to change their windows too, and make more renovations to their interiors. Along with the renovation works, the ground-level annex was replaced by an underground facility with green cover and a coloured stone park.

Together

Accessibility of the district heating company

The DH company (an ESCO in this case) has a high level of engagement and arranges guided tours for schoolchildren, university students and other neighbourhood community groups. The tours visit the central plant building and show schoolchildren the principles of circularity and heat production.

Comfort

The main purpose of the project is to improve comfort and wellbeing, with as efficient and sustainable heating and distribution facilities as possible. After the renovation of the façades, end-user thermal comfort has increased; now they only lose about 0.5°C during a winter's night without space heating, end users also benefit from insulation during summer.

Comfort has also been improved through the flexibility that the smart system and individual thermostats generate, allowing each user to choose when to consume and at which temperature. The residents can see their individual consumption, along with historical data and bills, and download the data from the website platform. The community of neighbours can also see the total consumption and the operation parameters of the plant but cannot modify any parameter.

Another benefit is acoustic comfort, due to the façade and windows renovation. Moreover, DH itself is more silent and comfortable in the customer's building than individual systems and takes up less space.

Tariff structure

The company has a tariff with which it invoices the neighbours' community and then the community sends the bills to each user. Previously, neighbours all had the same "energy budget" per heating season, and only those that exceeded that amount of energy had to pay more. However, due to new regulations since November 2022, each user is now invoiced only for their individual metered consumption of heat. The intention is to promote energy savings.

5. Ghent case study

The 20th century neighbourhoods on the outskirts of Ghent (Flanders, Belgium) are a potential laboratory for various sustainability challenges and transitions: quality and affordable housing, densification and open space, social inclusion and diversity, migration and integration, accessibility and mobility, environment and health, greenery and biodiversity, etc. In addition to the targets at international level (e.g. the Paris climate agreement), Ghent has a 2020-2025 climate plan.

In recent years, the Oude Dokken district – pivotal in Ghent's industrial and harbour history – has undergone a metamorphosis and been given a new purpose thanks to several new neighbourhood projects. De Nieuwe Dokken, on the east side of the Handelsdok close to Dampoort station, was one of the first. It is being built in phases and completion will take several more years. A simulation of the most important residential buildings can be seen in Figure 27 below.

Figure 27 Buildings along the harbour envisaged as part of De Nieuwe Dokken project

Source: https://ducoop.be/en/.

In time, De Nieuwe Dokken will become a city district with 400 residential units, a school with sports hall and nursery, a bicycle repair workshop and a general practitioner's practice. Phase 1 has already been completed: about one hundred apartments, split between a 13-storey tower and a low-rise building, are already occupied.

DuCoop wants to stimulate sustainable mobility by offering a network of electric charging points for cars and bicycles. Eight shared electric cars are provided that you can rent on an hourly basis. Bicycle sheds and a bike repair shop will be constructed, which will allow you to repair your bicycle or inflate tires yourself. There will also be a bicycle washing area underground. The underground area would be arranged in such a way that it can be used for other purposes when car use is reduced. DuCoop also wants to encourage the use of steps, stairs and public transport as much as possible.

The roofs are used to the maximum by solar panels (Figure 28); this local energy is used for the central installations of DuCoop and for electric charging. The Rolling out of Local Energy Communities (ROLECS) living lab project developed intelligent software to optimally manage the demand, supply and storage of renewable electricity and waste heat in the neighbourhood. Surplus energy is stored in an electric battery so that all solar energy can be used and the consumption of the grid can be balanced.

Sustainability co-operative DuCoop is the heat supplier and waste stream manager of De Nieuwe Dokken, DuCoop is an ESCO that combines ground-breaking innovations in wastewater treatment, heat and water recovery, urban agriculture, and shared parking to create the first “circular neighbourhood” in Flanders within the broader framework of De Nieuwe Dokken. Two interviews were performed for the Ghent case study: with the CEO of DuCoop (Peter Smet) and with representatives of Ghent (Agnieszka Zajac, Leen Trappers and Elisabeth Kuijken).

Figure 28 Various parts of De Nieuwe Dokken neighbourhood

Source: @Emilia Motoasca, October 2021.

District heating and cooling in Ghent

DuCoop wants to turn the Nieuwe Dokken into a future-oriented, circular and climate-neutral neighbourhood. Their main focus was on creating closed cycles for energy (heating, electricity and mobility), water and raw materials (waste processing).

Closing the heat cycle was achieved by developing a heat network to which all individual homes in the district are connected. Residual heat from organic waste flows from the neighbourhood and from production processes at Christeyns, a neighbouring chemicals factory, covers two-thirds of the heat demand. Heat recovered from greywater covers the remaing third. Due to the circular cycle, there are therefore no additional emissions of CO_2 or other harmful gases.

DuCoop works with a decentralised, small-scale purification technology to close the cycle there too. They laid pipes for black- (excrement and organic food waste) and grey- (showers, sinks and washing machines) water to separately treat the wastewater of the 400 residential units and school. The blackwater stream is highly concentrated: vacuum toilets installed by Roediger use about one litre of rainwater per flush and organic food waste is shredded before being added to this stream. A fertilizer and biogas (which meets 1-2% of the heating requirement) are recovered from this stream. This biogas can be used to produce heat and electricity.

In the DuCoop co-operative, all homeowners are given the opportunity to participate in the company. If you buy a house in De Nieuwe Dokken, you receive one symbolic share and attend the general meeting. De Nieuwe Dokken has quite an exclusive character due to its location. However, the technology itself is affordable and DuCoop's ambition is that sustainable practices do not cost more than conventional ones. The project developer can offer prices in line with the market because the total additional investment (around EUR 5 million) is borne by DuCoop itself. DuCoop also aims to achieve about 20% budget homes, with the City of Ghent determining eligibility. A social tariff for the heat network is also provided, and since 2019 residents can acquire shares in the co-operative and thus receive a share of the revenues.

Beautiful

Integration in the cityscape

DuCoop operates in the old harbour of Ghent, an area that is already modernising and becoming more liveable, young, colourful and trendy. These new buildings connected to DH have been designed so as to become landmarks in the surrounding area.

DH has no effect on the cityscape because the piping distribution system is underground, while all the technical installations (substations, water management systems, electric batteries, etc.) are in basements in specially designed spaces. Because the DH installations are not visible, one might think that the inhabitants are not aware of their operation. However, the spaces in the basements are common areas where inhabitants can pass by and that can be visited during organised tours. The heat is produced as a by-product (waste heat) in a nearby company that is very visible, but it does not negatively affect the urban residential neighbourhood.

Citizen experience

The DH provider for this project has quite a low level of engagement with the residents. For example, as the installations are not visible, light shows or displays are not applicable. Both city representatives and the operator think that citizen experience related to energy in general is important, but they are not aware of how that relates to DH in particular.

Local produce

The residents have a small parcel of land for a common garden where food can be produced, but this initiative has more to do with wastewater management than the DH network. Residents engage in wastewater collection and in recovery of its waste heat. Moreover, by through organic waste collection for nutrients or for biogas production, the residents contribute to local production, though not yet to a great extent.

Educational elements in the cityscape

As the technical installations are often visited, many educational elements (signs, posters, technical details, etc.) are present. Only educational information is provided, rather than confidential technical details. The site is still in development, thus construction works also provide some educational elements: information about the current and future status of the whole project is provided on signs at appropriate locations. Educational meetings regarding the energy and water flows in the systems are organised for schools and residents.

Building design and aesthetics

As all the technical installations and the pipe distribution network are underground, DH does not affect the aesthetics of the buildings or neighbourhood. Nevertheless, the construction is dense and the apartment buildings provide storage and parking space underground. As such, the DH installations need to be taken into account in the design of the buildings.

Sustainable

District heating fuel mix

The thermal energy needed to heat the homes in this case study is mainly provided by Christeyns. Energy recovered directly from that company's production processes together with a small share of biogas produced from neighbourhood organic waste, meets two-thirds of the heating demand, while the rest is provided by heat recovery from wastewater. As the DH network does not have to burn fossil gas, CO_2 emissions are avoided.

Concerns arise with respect to the supply of waste heat from Christeyns: What if the company, one of the last chemicals factories in this part of the port, restructures or relocates? The scenario seems unlikely since the collaboration with De Nieuwe Dokken would be an asset for Christeyns if its environmental permit had to be extended in future. There are even options for expansion. However, laying pipes for expansion would cost a lot of money (one million euros per linear kilometre) and the decision to go ahead has been postponed.

Contribution to the climate goals of the city

This case study demonstrates emissions reduction in the heating sector. As the project was conceived, and is still being developed, in close co-operation with the city of Ghent, it is perceived as making an important contribution to meeting the climate goals of the city. In absolute terms, the contribution is not yet very large, since the DH network is not yet operating at full capacity. Nevertheless, the project already has a good reputation in Ghent, elsewhere in Belgium, and in the surrounding countries.

Aside from DH, electricity is produced via solar panels and surplus electricity is stored in batteries. Electric cars and bikes are charged with that green energy. There are charging points for electric vehicles in the neighbourhood, with the electricity coming from the rooftop PV. There is an extended network of cycling routes.

Circularity

The Ghent case study applies the principles of circularity in that the heat is sourced as waste energy from a nearby company. At the city level, waste heat from such alternative sources is still a small share of total heat supply today but the ambition is to use it to meet 10% of the city’s heat demand. Data centres are expected to provide most of that waste heat.

On site, circularity is also seen in the energy recovery from wastewater and in the systems for wastewater management. DuCoop contributes to the climate ambitions of the city of Ghent by closing loops: energy (heating, electricity and mobility), water and raw materials (waste treatment).

Biodiversity

The area in which DuCoop operates is newly built. The municipality created green areas among the buildings and the residents have a common green area. The co-operative does not play an active role in encouraging biodiversity.

Renovation

DuCoop is a newly developed area, so no renovation is needed.

Together

Accessibility of district heating company

As the co-operative energy and water projects of DuCoop are recognised in the EU as good practices, many study visits with local, national and international participants are organised. Participants in such visits include citizens and co-operatives, students, researchers, DHC professionals and policy makers. As this project is still in active development, there is a strong and direct connection of between the ESCO and its customers, who are not yet very numerous.

Ground heating

As this neighbourhood is still in development, there are no services using the heat in the return pipes of the DH network in place yet. Such services, e.g. heated bicycle lanes or bus stops, may become of interest if DH is also adopted in neighbouring areas.

Sponsorship and social engagement

The city supports various social and cultural initiatives to enhance the social cohesion of the neighbourhood. Activities are also organised with the active participation of the school and local businesses such as a café and bike repair shop.

Comfort

The DH is silent and comfortable in the buildings. However, the residents need time to grow accustomed to it, along with all the other systems used in this innovative project. For example, the vacuum toilets may seem noisier at first. The heat is delivered through an underfloor system that frees up space for the residents and thereby increases comfort, as mentioned by the interviewees. As the buildings are nearly zero energy, thermal comfort is very good in winter. However, residents have reported that indoor temperatures in summer are too high, as there is no mechanical cooling installed.

Tariff structure

The heat tariff structure is adapted to this specific neighbourhood and aims to attract more customers and new residents. The heat tariff is related to the gas price and has a fixed annual cost (access to power and maintenance) and a usage component (a monthly advance on the consumption) that is settled annually. There is also a one-time connection fee. As the approximately 400 dwellings are a mix of privately owned units (20%) and rented units (80%) at normal and at social tariffs, some categories of residents may benefit from reductions. Customers are aware of the tariff structure and, through monitoring equipment and continuous improvement of the heating system, can minimise the cost while still maintaining a comfortable indoor climate. The city of Ghent mentioned that the existence of the ESCO is a challenge as not all the technical and legal conditions were clear. Also, the affordability of the heating tariffs starts to become an issue as the heating tariffs are coupled to the strong rising gas prices.

6. Results

After the literature review and the investigation of the documents collected on the NEB website, we analysed three case studies that are considered best practices for the NEB principles (Beautiful, Sustainable, Together). The case studies selected are located in Sweden (Stockholm), Spain (Torrelago) and Belgium (Ghent). For each case study, semi-structured interviews were carried out to learn more. The results were then compared with the findings of the literature review.

Results from the case studies: **"Beautiful"**

Aesthetics at neighbourhood level are not considered to be affected by DHC networks once they are in place. Pipes are buried underground, and the technical installations are located in basements. Heat production plants are often located outside the neighbourhood in more industrial areas, although as a city grows the proximity of industrial and residential areas increases.

For heat production plants and other parts of the network in residential areas, multiple examples were found of best-practice cityscape integration. Only one multi-purpose building was identified in these case studies however, in Stockholm.

At building level, DHC is considered to require less space than alternatives. During new construction, space must be allocated in the basement to accommodate the technical installations. The aesthetics of a building could be improved with DHC installations as they have no visible external components.

In all three case studies, end-user comfort is expected to increase after transitioning from individual heating solutions to DH, although households need time to adjust. Indoor air quality improves and DH is known to have high security of supply.

Results from the case studies: **"Sustainability"**

In all three case studies, DHC has a positive impact on reducing greenhouse gas emissions. The key aspect historically has been the shift away from fossil fuels towards renewable energy sources such as biomass and biogas, and waste heat. Other examples of measures to improve sustainability are: a sorting facility to remove plastics from waste prior to combustion (Stockholm); BECCS (two units planned in Stockholm); and sourcing of sustainable biomass (Torrelago).

Another positive impact of DHC for citizens in cities with individual combustion units is that collective combustion improves air quality. In one case, the DHC network also helps keep bicycle and pathways snow- and ice-free through ground heating, thus facilitating mobility. One negative impact identified in the case studies is increased road traffic during construction.

The main impact on biodiversity is from the use of biomass, mitigated by DHC companies choosing sustainable suppliers. In the Ghent case, some of the new green spaces in the neighbourhood are limited to lower vegetation due to the presence of the piping system of the DHC network.

Several examples of DHC enabling for circularity have been identified. Two of the case studies include sewage water as a heat source and another includes sea water, urban waste heat sources and waste heat combustion, showing that there is a lot of potential for recovery of heat in the urban context that would otherwise be wasted.

More collaboration with municipalities and other stakeholders can further enhance circularity for DHC. In Torrelago for example, the DH company offers the ashes from combustion but no stakeholder wants to use them for now and the municipality is the manager of it according to the law.

There are incentives built into the tariff structure by charging the customer for energy consumed, and in the case of Stockholm customers are charged according to peak consumption. However, residential customers often miss the motivational tariff and could use additional help to improve their system.

The Ghent case study is an example of good practices that are planned to be extended and replicated by other districts; Ghent city is looking for new DH projects and new sources of thermal energy.

Results from the case studies: **"Together"**

All case studies involve citizen engagement but only one is working actively to engage citizens in the decision-making process. The most recent and smallest case study (Ghent) exhibits a high level of co-operation, partly because it involves collaboration beyond heating, and has a larger scope of responsibility in the area. Similarly, Torrelago is a co-operative project encompassing not only heating but also water and electricity.

Educational elements aimed at the general public mainly consist of informative signs around the heat production plants, along with organised study visits with various groups in the community. For example, in Torrelago there are guided visits for school children to show them the principles of circularity and heat production. Social engagement also takes place through sponsorships. In general, this is an area where the DHC companies would like to improve, especially after the break due to Covid-19.

The DHC companies in the case studies are accessible to their customers mainly through digital solutions and by phone. On a digital platform, customers can view their data. Such platforms are highly informative but not engaging or collaborative. In Torrelago, households were able to make some decisions such as with regard to the design of the building façades.

Comparison to the findings in the literature review

Beautiful

The literature review identified that DHC networks have historically focused on techno-economic rather than social aspects, but the case studies show that it is possible to integrate the network into the urban environment. For example in Stockholm, the older production units are more practical than beautiful. There has been a shift however, and multiple examples can be found of components being integrated into the urban environment as part of network expansion or renovation. At building level, both the literature review and the case studies confirm that DHC reduced the need for each building to have external components such as chimneys or heat exchange units. The best practices to make the network unobtrusive identified in the literature are already being applied in the case studies today: distribution networks are underground, substations are located in the basement of buildings, and more and more consideration goes into integrating components into the cityscape. Construction of the network and production plants has the biggest impact on citizens.

Sustainability

The key sustainability aspect for DHC, identified both in the literature and the case studies, is the reduction of greenhouse gas emissions and air pollution (relative to boilers). DHC has a further effect on environmental sustainability by improving the circularity of cities, which is reflected in waste heat utilisation in two of the case studies. This also improves the social sustainability of cities, by reducing the urban heat island effect. As DHC requires a certain population density, waste heat integration in the urban context is an important synergy. In northern Europe, DHC has the ability to provide ground heating to transport lanes, thus improving safety by keeping streets snow- and ice-free.

The literature review found that DHC does not pose a barrier to renovating buildings but there is an economic risk for DHC companies if renovation reduces energy demand without reducing peak load consumption. The DHC tariff was identified as a way to incentivise renovation. Two case studies mentioned the tariff structure in relation to reducing energy consumption, and one has a peak power component in the tariff to reduce the risk.

Together

The three case studies are of different sizes, constructed at different times and developed in markets with different levels of DHC maturity. They represent different levels and options for citizen engagement and serve as a good example of the importance not to limit the definition of collective actions and citizen engagement in the NEB, as was also identified in the literature review.

The literature review found that digitalisation of DHC can create many possibilities for improvement and optimisation, as is true for other sectors. Specific mentions are made of more affordable and sustainable housing, creating resilience in the energy system as a whole through sector coupling, visualisation tools to raise end-user awareness, and data-driven planning and design. However, only awareness creation through an online platform for customers came up in relation to the case studies.

Beyond energy, DHC was identified in the literature to have the ability to alleviate energy poverty. However, this aspect was only mentioned in relation to work performed by the DH companies for one of the case studies.

7. Conclusions

We saw in the examples and case studies that DHC networks have a visual impact on neighbourhoods but this impact doesn't need to be a negative one. The infrastructure and construction works for a DHC network can create new green areas and free up space in the neighbourhood for the community. DHC networks can have a positive impact not only from the environmental and customer satisfaction points of view but also for the community as a whole, creating local landmarks or freeing up space on building façades and rooftops. DHC also contributes less to the urban heat island effect than other cooling technologies such as air conditioners.

DHC networks are in general very sustainable as collective heating and cooling can be more efficient and more environmentally friendly than individual systems. Older DHC networks that are still operational use fossil fuel but the transition to 4G DHC or 5G DHC will make these networks more sustainable by using of more local renewable and waste energy sources with less or zero CO_2 emissions. That will also lead to better outdoor air quality in neighbourhoods connected to DHC networks and implicitly contribute to the improved health and wellbeing of inhabitants. Improved air quality may also be good for a range of indoor and outdoor activities for communities (sport, education, etc.), leading to an increased sense of belonging and in the long term to the formation of energy communities, either focused only on heating and cooling or combined with electricity.

DHC networks are also strongly related to the Together principle of the NEB, which encourages collective action. For the NEB, which focuses on interdisciplinary initiatives, properly co-operating with stakeholders from different backgrounds will be important yet challenging. Mapping stakeholders by project phase, sector and activity will be important in order to ensure that all potential synergies are captured.

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List of abbreviations and definitions

1G DH	1st generation district heating
2G DHC	2nd generation district heating
3G DH	3rd generation district heating
4G DHC	4th generation district heating and cooling
5G DHC	5th generation district heating and cooling
AI	artificial intelligence
BECCS	bioenergy carbon capture and storage
CEO	Chief Executive Officer
CO_2	carbon dioxide
DC	district cooling
DH	district heating
DHC	district heating and cooling
ESCO	energy service company
EUR	euro
GWh	gigawatt-hour
JRC	Joint Research Centre of the European Commission
kW	kilowatt
LED	light-emitting diode
LT DHC	low-temperature district heating and cooling
MW	megawatt
NEB	New European Bauhaus initiative
PV	photovoltaic
TWh	terawatt-hour
ULT DHC	ultra-low temperature district heating and cooling
UNESCO	United Nations Educational, Scientific and Cultural Organization
WtE	waste to energy

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