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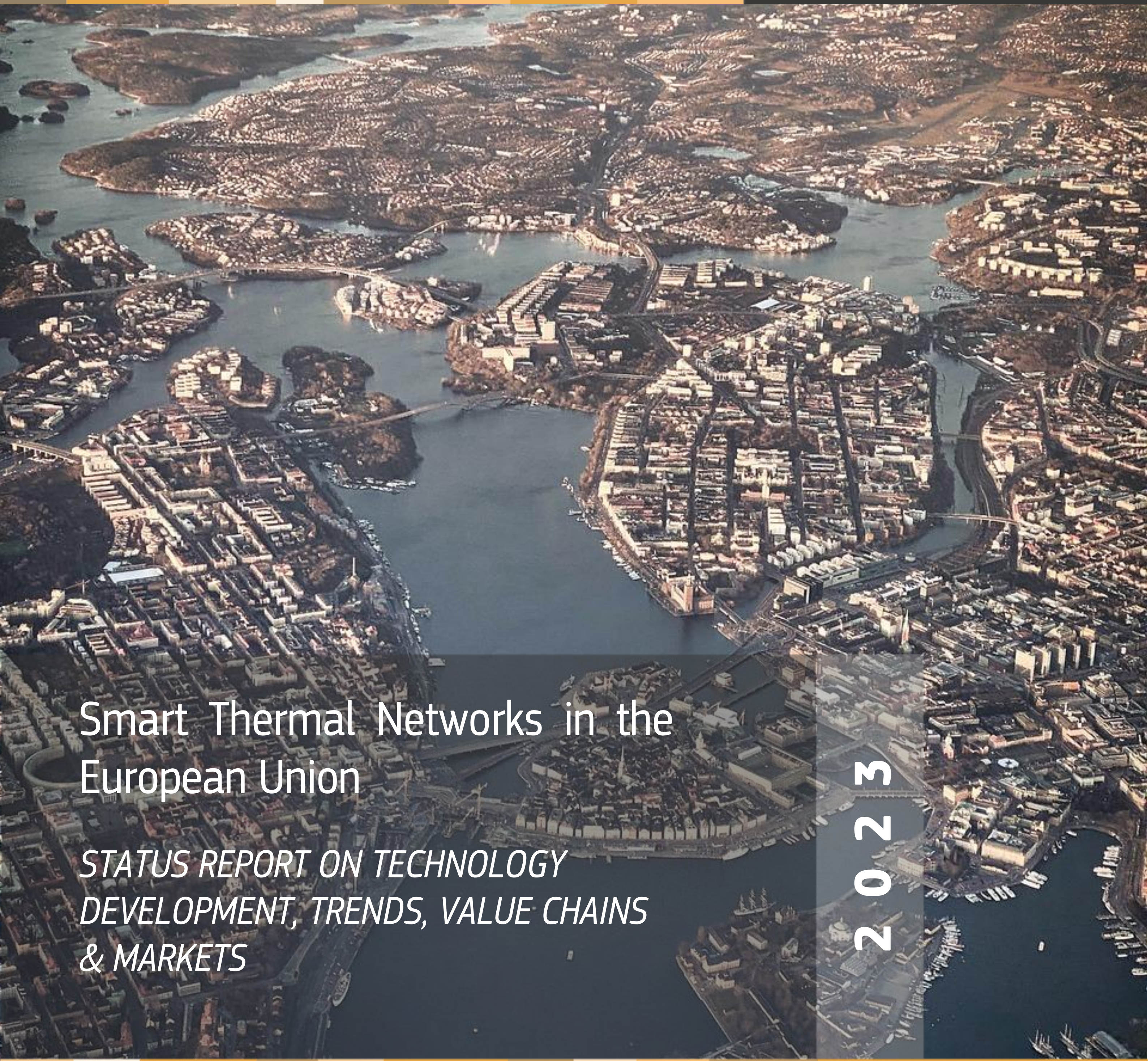

# Smart Thermal Networks in the European Union

*STATUS REPORT ON TECHNOLOGY DEVELOPMENT, TRENDS, VALUE CHAINS & MARKETS*

2023

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## Contents

## Abstract

This report is part of the 2023 Clean Energy Technology Observatory series and is focusing on smart thermal networks within the European Union (EU). It provides an overview of the current status, emerging trends, and the potential of this sector integration technology. Smart thermal networks offer a significant advancement compared to conventional district heating systems, operating with higher intelligence and efficiency while maintaining lower temperatures. This enables the integration of a larger share of renewables and positions these networks as versatile assets, offering balancing services to the wider energy system.

An increasing number of district heating and cooling systems in the EU are transitioning towards becoming smart thermal networks. Numerous cities are investing in expanding and modernising their existing systems to align with future energy needs, characterised by a growing reliance on variable renewables. Smart thermal networks encompass a variety of technologies, most of which are technologically mature, including intelligent control systems with sensors, waste heat, high-efficiency cogeneration, large heat pumps, and thermal energy storage systems. One of the most promising avenues for further innovation lies in digitalisation, which allows for seamless integration and control of energy flows. By fostering intelligent control and data-sharing across the entire system, smart thermal networks can optimise their operation in the short and medium term. The EU is a global leader in this field and well-positioned to lead the transition towards smart thermal networks, showcasing their value in the context of the low-carbon transition.

## Foreword on the Clean Energy Technology Observatory

The European Commission set up the Clean Energy Technology Observatory (CETO) in 2022 to help address the complex and multi-faceted character of the transition to a climate-neutral society in Europe. The EU's ambitious energy and climate policies create a necessity to tackle the related challenges in a comprehensive manner, recognising the important role for advanced technologies and innovation in the process.

CETO is a joint initiative of the European Commission Joint Research Centre (JRC), which runs the observatory, and Directorate-Generals Research and Innovation (RTD) and Energy (ENER) on the policy side. Its overall objectives are to:

– monitor the EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal;

– assess the competitiveness of the EU clean energy sector and its positioning in the global energy market;

– build on existing Commission studies, relevant information and knowledge in Commission services and agencies, and the Low Carbon Energy Observatory (2015-2020);

– communicate findings by publishing reports on the Strategic Energy Technology Plan (SET-Plan) SETIS online platform.[1]

CETO provides a repository of techno- and socio-economic data on the most relevant technologies and their integration in the energy system. It targets in particular the status and outlook for innovative solutions as well as the sustainable market uptake of both mature and inventive technologies. The project serves as a primary source of data for the Commission's annual progress reports on competitiveness of clean energy technologies. It also supports the implementation of and development of EU research and innovation policy.[2]

The observatory produces a series of annual reports addressing the following topics:

Clean energy technology status, value chains and markets: covering advanced biofuels, batteries, bioenergy, carbon capture utilisation and storage, concentrated solar power and heat, geothermal heat and power, heat pumps, hydropower and pumped hydropower storage, novel electricity and heat storage technologies, ocean energy, photovoltaics, renewable fuels of non-biological origin, renewable hydrogen, solar fuels and wind;

Clean energy technology system integration: building-related technologies, digital infrastructure for smart energy systems, industrial and district heat and cooling management, standalone systems, transmission and distribution technologies, smart cities and innovative energy carriers and supply for transport;

Foresight analysis for future clean energy technologies using weak signal analysis;

- Clean energy outlooks: analysis and critical review;

- System modelling for clean energy technology scenarios;

- Overall strategic analysis of clean energy technology sector.

More details are available on the CETO web pages.[3]

(1) https://setis.ec.europa.eu/what-set-plan_en.
(2) https://energy.ec.europa.eu/topics/research-and-technology/clean-energy-competitiveness_en.
(3) https://setis.ec.europa.eu/publications/clean-energy-technology-observatory-ceto_en.

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## Executive Summary

This report is part of the [Clean Energy Technology Observatory (CETO) 2023 series](), featuring technologies and their integration and contribution to a clean energy system. It describes how *smart thermal networks*, operating more intelligently, efficiently and on lower temperatures than conventional district heating systems, can enable the integration of a higher share of renewable energy sources and become a versatile asset for the wider energy system by providing flexibility services. This report summarises the status, trends and potential of smart thermal networks as a sector integration technology.

The term *smart thermal network* refers to an efficient heating infrastructure, distributing heating and cooling to multiple facilities within a district or a city. A smart thermal network is characterised by the use of intelligent control technologies and strategies to optimise the operation, as well as lower temperatures than conventional thermal networks. Smart thermal networks are also characterised by a higher complexity in terms of numerous supply points which enables more flexibility in the system operation. In particular, combined with large-scale thermal energy storage, they can provide enormous flexibility and optimisation potential to the wider energy system.

Smart thermal networks enable invaluable sector-coupling synergies. Firstly, the district heating and cooling infrastructure enables recuperation of waste heat. For example, the district heating and cooling network can recover waste heat from industrial processes but also provide them with cooling services, a win-win exchange. Secondly, with power-to-heat technologies (especially combined heat and power, large heat pumps and electric boilers), excess electricity can be stored as heat in the thermal network, for example in times of an abundance of sun or wind. With the same logic, when there is a shortage of electricity, production from combined heat and power can be steered towards producing more electricity while the thermal network uses the stored heat.

An increasing number of district heating and cooling networks in the European Union are undergoing a transition towards smart thermal networks. Many cities are investing in expanding and upgrading their existing networks to make them fit for future needs. Nonetheless, progress in markets with limited prior experience with thermal networks remains limited. The lack of an existing network is not necessarily a bad thing. Cities without an existing thermal network can more easily design and implement a system that is optimised for their specific needs.

The supply temperatures of district heating and cooling networks have decreased over time to reduce thermal losses and because heat demand temperatures have decreased, for example due to better insulated buildings. Most networks, defined as smart thermal networks, operate on a low temperature for the majority of the year (i.e. not over 80°C), making the integration of more renewable technologies, like geothermal heat, waste heat and heat pumps, more cost-effective. Thus, increasing efficiencies and lowering the temperature of the networks enables the faster implementation of renewables and waste heat, while at the same time, growing investment in renewables also increases the demand for smart thermal networks. Consequently, investments in renewables and smart thermal networks are mutually reinforcing.

A parallel trend is that thermal networks are growing in size, from covering individual districts to covering whole cities or even several neighbouring cities. As the systems grow larger (see for example the networks in Copenhagen, Stockholm, and Helsinki), comprising multiple thermal generation plants, they have more opportunities to balance supply and demand, and can offer greater flexibility to the wider energy system. However, smart thermal networks can also be utilised in smaller cities. For example, the district heating system in Sonderborg, Denmark, is not particularly large but uses a number of different heat generation technologies to balance the energy system and ensure stable heat prices for the residents.

Smart thermal networks are a system integration technology, utilising a number of (sub)-technologies. The most important of these sub-technologies all have a high level of technological readiness, meaning they are already applied in the market today, including sensors and smart control systems, high-efficiency cogeneration, large heat pumps and thermal energy storage systems. With the integration of machine learning/AI technologies, smart thermal networks have become much more intelligent and able to better predict consumption patterns and manage more complex systems. The management of smart thermal networks is evolving quickly. This trend is expected to continue following the development and application of artificial intelligence in recent years.

The greatest potential lies with digitalisation, enabling the integration of control across the different sections of the district heating and cooling system. Intelligent control and data-sharing across the whole system are needed to enable an optimised operation in the short and medium term. This includes planning of operations based on shared data from end-users and third-party heat providers.

Smart thermal networks enable a higher recovery of waste heat from industrial processes, data centres, wastewater, and supermarkets. They also increase the financial attractiveness of reusing waste heat by operating at a lower temperature. For example, wastewater can be used as the heating source for large heat pumps. There is an abundance of waste heat which is not currently being utilised across the EU. Studies indicate that this could meet most of the EU's total space heating demand in the building sector (Heat Roadmap Europe, 2017), assuming demand is always located nearby the supply. At the same time, waste heat recovery helps industry to dispose of its waste heat. In some cases, industries can save substantial amounts of money by making their waste heat available to the DHC system, as the operation of their own cooling systems is avoided, which in addition to being costly, is not part of their core operation and competences (Gudmundsson, 2023).

The European Union is a global leader when it comes to smart thermal networks, with more networks operating at lower temperatures and with a higher share of renewables in the systems. The United States and most parts of China do not have the same track record of establishing district heating systems. While most production and installation is local when it comes to smart thermal networks (except software and digital applications), Europe has the opportunity to spearhead the transition to smart thermal networks and showcase their value in the low-carbon transition.

**Table 1.** SWOT analysis of the competitiveness of smart thermal networks. *Source:* Analysis by European Commission's Joint Research Centre (JRC).

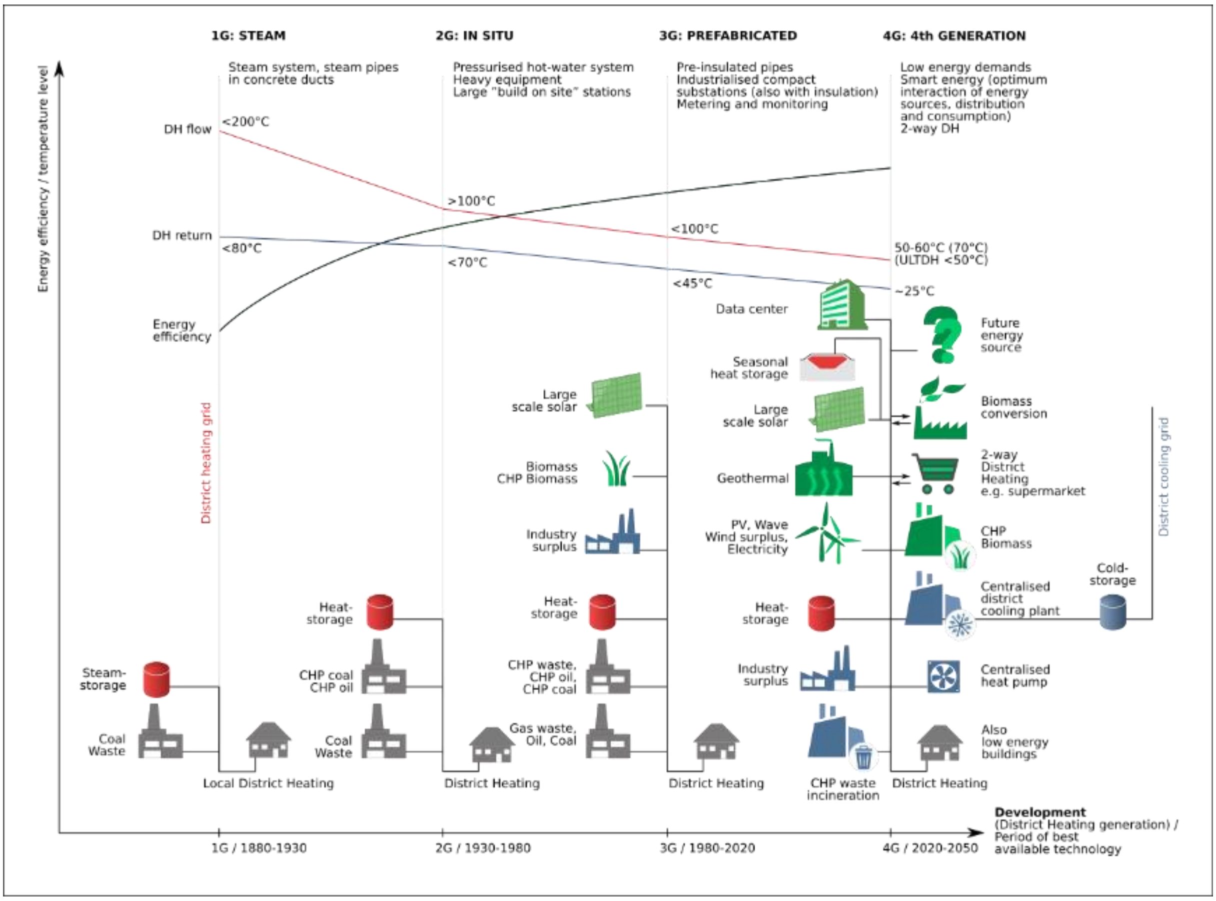
| | |
|---|---|
| **Strengths**<br>• Provides relative inexpensive flexibility to the wider energy system, which enables a higher integration of variable renewable energy sources and use of waste heat<br>• Easier to switch to renewable energy sources than for individual heating and cooling<br>• Advances the cost-effectiveness of renewable energy technologies<br>• Increases energy security. Cities with district heating system, with a considerable share of renewables, had more stable prices during the 2022 gas crisis<br>• Improves energy and resource efficiency | **Weaknesses**<br>• District heating and cooling networks are concentrated in a number of Member States, and are close to non-existent in others. They account for just 12% of thermal energy consumption on average<br>• Challenging/costly to upgrade and construct networks in densely built areas<br>• Requires agreement from several stakeholders to build a thermal network, and long-term commitment from the local energy authority |
| **Opportunities**<br>• Value creation as it enables the utilisation of local and existing resources (e.g. waste heat and renewable energy)<br>• The decreasing energy demand in buildings allows for lower temperature networks and the integration of low-temperature renewables and waste heat<br>• New business models valorising flexibility and thermal storage capacities | **Threats**<br>• Cost-effectiveness of individual heating/cooling appliances<br>• Shortage of construction workers in general and welders in particular |

# 1. Introduction

The purpose of district heating and cooling (DHC) networks is transforming, from simply ensuring a sufficient heat/cool supply to becoming an active part of the wider energy system. Traditionally, DHC networks heavily relied on dispatchable generation capacity, meaning fossil-fuelled generation and cogeneration. In the early stages of district heating (DH) development, fossil fuels were combusted, generating heat of up to 200 degrees, which was then distributed throughout cities via steam pipelines. The modern DHC networks, referred to as smart thermal networks in this report, operate with pressurised water at lower temperatures, a higher share of renewable energies (RES), and manage more complex systems with a multitude of supply and demand points. They utilise advanced control strategies and monitoring solutions (e.g., sensors and smart meters) to optimise the flow of heat or cold and integrate more RES.

The importance of smart thermal networks is growing as the share of RES is steadily increasing, bolstered by climate mitigation ambitions, improved competitiveness of clean energy technologies (e.g. solar and wind power), as well as imminent energy security concerns. This report provides an overview of the current status and trends of smart thermal networks in the European Union (EU).

**Figure 1:** 4th generation district heating and cooling system compared to predecessors.




*Source: (Lund, et al., 2014).*

Smart thermal network is a system integration technology that can help cities move towards carbon neutrality in a cost-effective way by offering relatively inexpensive storage solutions. DHC networks can be an integrated part of the wider energy systems by providing flexibility, through interface technologies, like combined heat and power (CHP) and power-to-heat. Simply put, DHC networks can produce and store heat when there is an abundance of electricity and increase CHP's electricity production when there is a shortage of electricity generation (i.e. when its economical for the DHC/CHP operators to do so)[4]. The potential of this sectoral integration is larger when the system becomes smarter, more efficient and operates on a lower temperature.

(4) Advanced control and management of generators in multi-source systems can serve the same purpose as thermal energy storage, except the energy is stored in the unburnt fuel.

The supply temperatures of DHC networks have decreased over time to reduce thermal losses and because heat demand temperatures have decreased, for example due to better insulated buildings. Most networks, defined as smart thermal networks, operate on a low temperature for the majority of the year (i.e. not over 80°C)[5], making the integration of more renewable technologies, like geothermal heat, waste heat, and heat pumps, more cost-effective. Increasing efficiencies and lowering the temperature of the networks enables the faster implementation of renewables and waste heat. Growing investment in RES also increases the demand for smart thermal networks. Consequently, investments in RES and smart thermal networks are mutually reinforcing.

Furthermore, waste heat from industrial processes can be a positive energy source for low-temperature district heating (DH) networks, with a supply return of about 50-60°C/25°C (Lund, et al., 2014). Depending on the level of temperature of the waste heat source and the level of temperature of the DHC network, whether the source will need an increase in temperature or not. For example, if the DH network works at 90°C and the waste heat is at 50°C this source is not directly useful. As waste heat is a place-fixed source of energy, the way to fix these situations is to increase the temperature with, for instance, heat pumps. As waste heat is a place-fixed source of energy, the way to fix these situations is to increase the temperature with, for instance, heat pumps. In this case, a water loop will recover the waste heat from various processes and deliver it to a central heat pump, which both cools the water loop via the evaporator and delivers the waste heat at useful temperature to the DH system via the condenser of the heat pump

The concept of a smart thermal network is identical to the one of a 4th generation district heating (4GDH) system. During the last decade, the concept has been used to describe advanced DH systems, characterised by lower temperatures and intelligent control technologies. The overarching goal of the 4GDH is to attain a fully decarbonised energy system. Large heat sources for these systems include recycled heat from service sector/industrial processes as well as RES. These smart and low-temperature DH are becoming more common in urban areas, as lower temperatures enable higher efficiency in heat supply and allow the use of alternative and low-grade heat sources, which before have not been feasible/cost-effective to use.

**Box 1: Definition – Smart thermal networks**

Smart thermal networks refer to efficient heating infrastructures that distribute heating and cooling to multiple facilities within a district or city. They are characterized by operating at lower temperatures than conventional DH networks and possessing a higher complexity with numerous supply and demand points. Smart thermal networks utilize advanced technologies and strategies to maximize energy efficiency, reduce emissions, and optimize thermal distribution. Additionally, they are typically integrated into the wider energy system, enabling them to provide valuable balancing services to power grids

While the 4GDH network is a natural evolution of its predecessor, the novel 5GDH is a new concept. DH networks have traditionally relied on centralized heat plants, which have converted the energy source and distributed directly useful thermal energy to the end-users. The idea with 5GDH is to directly distribute the energy source to the end-users, who convert it to useful heat or cold through a local heat pump. While 5GDH has the potential to considerably reduce distribution losses it comes at the cost of being input energy inflexible, for example, it is a power-dependent heat supply (Gudmundsson & Thorsen, 2021). Despite the fact that the terms 4GDH and 5GDH indicate they are different generations of the same system, the inherent logic and potential differ. While 5GDH could also be considered a smart thermal network, the logic and potential are different from what is being discussed in this report. Each city ought to select the system that best aligns with its unique needs and limitations, encompassing factors such as its existing DHC network, current heating technologies, buildings' insulation levels, power grid capacity, availability of RES, and any construction constraints. Local heat plans can serve as valuable tools in helping cities make this decision.

The improved competitiveness of RES and waste heat is a driver of change in DHC systems, in addition to digitalisation, energy policies, and financial support schemes. Industry waste heat and low-grade renewable heat have not been adequately represented in DHC systems because it was cheaper to build fossil-based heat-only boilers than investing in power driven heat pumps to boost the temperature level of low grade heat sources. Now there is a paradigm shift, renewable power and the phase out of fossil fuels mean most of the traditional heat sources for existing DH systems are disappearing. This is pushing the industry to reinvent itself and

(5) The future ambition of the low-temperature thermal networks is perhaps around 65-70 degrees but most current systems have more like 70-80 degrees (often dependent on system size) for majority of the year, and raise the temperature during high load periods.

innovate, not only to justify its existence in the future but also to make the rest of the energy system aware of the potential it has to support the future development of the energy system.

Low-temperature DH and the use of low-grade and renewable heat sources necessitate a larger role for digitalisation in heat networks. Thermal networks are becoming increasingly complex, with added considerations including multiple heat production sources and end-user engagement. Smart thermal networks also tend to be integrated with other energy sectors, like the gas and electricity networks. Specifically, in combination with the addition of thermal storage capacity, which provides means for decoupling the heat generation from the heat demand, and demand side management, which takes advantage of the thermal mass of connected buildings and influences end-users behaviours - are enabling technologies to increase variable RES. This kind of technology is often accompanied by other digital solutions, such as leak detection, predictive tool and smart controller on the demand side (DHC+ Technology Platform c/o Euroheat & Power , 2019).

The transformation of DHC networks into smart thermal networks is characterised by several key features:

- **Aggregated demands:** Aggregation of thermal demands are becoming valuable commodities because they enable:
  - Load shifting for both short and extended periods.
  - Effective balancing services for the energy system.
  - Cost-effective development and utilisation of low-grade thermal sources, such as waste heat.
- **Digitalisation and optimisation**: The use of digitalisation, in combination with optimisation, allows for a higher utilisation of resources while reducing the costs associated with future RES-based energy systems.
- **Low-temperature heat sources:** Low-temperature heat sources, including renewables and industrial waste heat, are central to ensuring the renewable powering of heat pumps.
- **Electrified thermal supply:** In an electrified thermal supply system, district/central thermal energy storage, combined with large-scale heat pumps and electric boilers, functions as a large energy battery capable of utilising excess power generation, particularly from RES
- **Multi-source and multi-duel DHC systems**: These systems offer the possibility of effective shifting between input energy supplies, reducing energy dependencies and providing stable thermal energy costs for societies.
- **Enlarging DH systems**: While not a prerequisite for a smart thermal network, integrating smaller DH systems into larger ones can offer operators more flexibility and optimisation opportunities.
- **Smart meters and improved data:** The use of smart meters and better data at the building level enables DH operators not only to optimise heat plants and networks but also to consider conditions at the demand side.

*Sources: (Euroheat & Power, 2023) (Interviews with experts, including Gudmundsson, 07.09.2022).*

***Policy framework***

The EU has developed a comprehensive policy framework to promote the adoption of DHC and increase the share of RES in thermal networks. Key directives include:

- The Energy Efficiency Directive (EED), which defines efficient district heating and cooling (Art. 2) and mandates Member States to conduct economic and geographic analyses to identify DHC potentials (Art. 25).
- The Renewable Energy Directive (RED), which sets a target for an annual increase in the percentage of renewable heating and cooling (Art. 23) and establishes an annual goal for increasing the share of RES in DHC (Art. 24). RED also requires Member States to facilitate access for energy producers using RES and waste heat and cold to DHC networks (Art. 24).
- The European Performance of Buildings Directive (EPBD), which contains several provisions aimed at improving the efficiency of both new and existing buildings, a prerequisite for the development of lower-temperature DHC networks.

The EU has also enacted a number of strategic plans and platforms in which DHC is explored and supported. The European Strategic Energy Technology Plan[6] is advancing the deployment of low-carbon technologies, with, innovation platforms on renewable heating and cooling and smart networks for the energy transition, among others. The related European Partnership for Clean Energy Transition[7], co-supported by industry, public organisations, research and citizens' organisations, aims to accelerate the energy transition by enabling energy research and innovation on different levels. Focus areas of the multilateral partnership include renewables, DHC, energy storage and system integrations. Furthermore, the EU has launched a mission to have 100 climate-neutral and smart cities by 2030. The Smart Cities Marketplace[8] supports this mission by offering knowledge, capacity-building support and facilitation of finance solutions for cities. Finally, DHC falls under the umbrella of EU's New European Bauhaus initiative[9], in which digitalisation of DHC is described to play a key role in advancing sustainability of urban environments. For example, digitalisation in DHC can empower end-users through awareness raising tools and by giving them more control of their energy consumption. Smart DHC systems can also contribute to resilience of the whole energy system through sector coupling (Motoasca, et al., 2023).

**Box 2: Success factors and remaining barriers**

An analysis by the European Commission's Joint Research Centre (JRC) identified ten key factors for the success of DHC networks (Fernández Galindo, Bacquet, Bensadi, Morisot, & Oger, 2021), which also are relevant for the uptake of smart thermal networks. These factors includes 1) adequate incentives for efficient DHC through national policies, 2) supporting new investments through direct and indirect funding, 3) commitment of local authorities and stakeholders, 4) integration of DHC planning in urban planning, 5) tuning of buildings regulation and urban planning to enable DHC connection, 6) mapping of the potential energy sources and ensuring technical compatibility, 7) employment of power-to-heat solutions, 8) exploration of synergies with other networks (e.g., power grids) and urban infrastructures (e.g., water), 9) valorisation of synergies and seasonality for district cooling, and 10) adoption of optimisation and flexible strategies (Fernández Galindo, Bacquet, Bensadi, Morisot, & Oger, 2021). In addition, interviewees for this report have stressed the importance of local heat planning, mapping the important supply and demand points, identifying the need and potential of a smart thermal network.

DHC networks provide an infrastructure-based service which require a relative high market share of connected buildings and industries within a limited geographical area. However, there are several challenges hampering a wider and faster implementation of these networks, including 1) financial challenges mainly related to the high capital investments required to implement or retrofit a DHC network, 2) sources of fossil fuels that receive subsidies or fail to consider negative impacts create an unfair playing field for RES (IRENA and IEA, 2020), 3) technical challenges include ageing networks and their switch to low-temperature operating conditions, 4) inefficiencies due to oversizing, hidden by poorly performing buildings (Reguis et al., 2021; IRENA and IEA, 2020), and 5) inconsistent and uncertain policies can cause instability and fragmentation in the market, undermining investment in new projects (IRENA and IEA, 2020).

*Main source: (Fernández Galindo, Bacquet, Bensadi, Morisot, & Oger, 2021)*

(6) European Commission "Strategic Energy Technology Plan" [Website] Available: https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en
(7) CETPartnership [Website] Available: https://cetpartnership.eu/
(8) European Commission "Smart Cities Marketplace" [Website] Available: https://smart-cities-marketplace.ec.europa.eu/
(9) European Commission "New European Bauhaus" [Website] Available: https://new-european-bauhaus.europa.eu/index_en

## 2. Technology State of the art and future developments and trends

The EU is a global leader of clean heating technologies, including DHC, high-efficiency cogeneration, large heat pumps and certain thermal energy storage systems. Smart thermal networks have proven effective and the key sub-technologies are mature. While only incremental improvement can be expected in the investment cost and efficiency of distribution networks and boilers, there are considerable innovation potentials in other parts of the system For example, large heat pumps (as discussed in a separate CETO report on Heat Pumps) are expected to deliver significant efficiency improvements when optimized for specific services. Furthermore, digitalisation can offer considerable energy savings for the end-users by detecting inefficient and faulty operations. Finally, the potential of integrating and utilising waste heat for heating of buildings is huge.

Most DHC systems in place within the EU cannot be considered smart thermal networks and must be upgraded before they effectively can offer the services discussed in this report. There is a lack of data to monitor the evolvement of *smart thermal networks* in the EU. First, there is a lack of data regarding the status of DHC systems, including the temperatures at which they operate and the technologies they utilise[10] [11]. Secondly, thermal networks are local in nature and local public and private actors can be hesitant to reveal sensitive information about technologies used. Third, in most cases a smart thermal network is an evolvement of a conventional thermal system, and is difficult to decide when it should be accounted for as a smart thermal network (e.g. the level of digitalization and control strategies, the number of thermal sources applied, or the level of integration with other sectors). Fourth, there is no mechanism in place to monitor the adoption of smart thermal networks in the EU. The lack of data is an obstacle for future development as more evidence and examples are needed in some regions to convince more cities to opt for this infrastructure investment.

(10) However, Member States, in line with Article 14 of the Energy Efficiency Directive (2012/27/EU), are requested to carry out a comprehensive assessment on efficient heating and cooling, including status quo and potential of district heating systems, cogeneration and waste heat. The comprehensive assessments do not include information making it possible to track the development of smart thermal networks across the EU. The assessments can be found: https://energy.ec.europa.eu/topics/energy-efficiency/heating-and-cooling_en

(11) The industry association Euroheat & Power are collecting data and information from their partners but also this data lacks the required granularity that would enable us to monitor its development over time. The data is available: https://www.euroheat.org/

## 2.1 Technology readiness level (TRL)

Most individual components of smart thermal networks have reached a high level of technological readiness, including sensors and intelligent control systems, high-efficient cogeneration, large heat pumps and thermal energy storage technologies. However, the integrated concept of smart thermal networks has considerable innovation potential left. There are local networks that have been incrementally built towards becoming smart thermal energy systems, although they still have quite some path to go before becoming truly smart.

With the integration of machine learning/AI technologies, smart thermal networks have become much more intelligent and able to manage more complex systems. Control systems are likely to evolve quickly, following the rapid development of AI language models during the last couple of year. A considerable innovation potential lies with the digital/control part of the thermal networks rather than with the actual networks themselves.

More information on TRL can be found in the related CETO reports, including the reports Heat Pumps, Novel Thermal Energy Storage systems, and Smart Grids.

**Table 2**: Technological readiness of a selection of (sub-) technologies relevant for smart thermal networks.

| | **TRL (Technology Readiness Level)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **(Sub-) technology** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| Smart thermal network[12] | | | | | ■ | ■ | ■ | ■ | |
| **Management and control** | | | | | | | | | |
| Advanced management and control | No data | | | | | | | | |
| Machine learning/artificial intelligence | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Digital twins | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Sensors | | | | | | | | | ■ |
| Smart meters | | | | | | | | | ■ |
| **Renewable and energy efficient generation technologies** | | | | | | | | | |
| Bioenergy | | | | | | | | | ■ |
| Industrial waste heat | | | | | | | | | ■ |
| Waste incineration | | | | | | | | | ■ |
| Combined Heat and Power | | | | | | | | | ■ |
| Electrolysers and fuel cells | | | | | | ■ | ■ | ■ | ■ |
| Pyrolysis and gasification | | | | | | ■ | ■ | | |
| Solar thermal | | | | | | | | | ■ |
| Geothermal | | | | | | | | | ■ |
| Heat pump <90°C | | | | | | | | | ■ |
| Heat pump <110°C | | | | | | | | ■ | |
| Heat pump <150°C | | | | | | ■ | | | |
| Heat pump <160°C | | | ■ | | | | | | |
| Electric resistance boiler | | | | | | | | | ■ |
| Electrode boiler | | | | | | | | | ■ |
| Electric resistance heater | | | | | | | | | ■ |
| Seawater source heat pump | | | | | | ■ | ■ | ■ | |
| Air source absorption heat pump | | | ■ | ■ | ■ | | | | |
| Distributed absorption heat pumps | | ■ | ■ | ■ | | | | | |
| **Thermal Energy Storage** | | | | | | | | | |
| Tank-Pit thermal energy storage | | | | | | | | | ■ |
| Tank thermal energy storage | | | | | | | | | ■ |
| Aquifer thermal energy storage | | | | | | | | | ■ |
| Borehole thermal energy storage | | | | | | | | | ■ |

*Sources: An assessment by the European Commission's Joint Research Centre (JRC) based on interviews with experts and existing literature (Rehman Mazhar, Liu, & Shukla, 2018) (Maruf, Morales-España, Sijm, Helistö, & Kiviluoma, 2022) (IRENA, 2020)*

(12) Indication based on literature review and discussion with industry experts. The TRL depends on the definition of smart thermal networks.

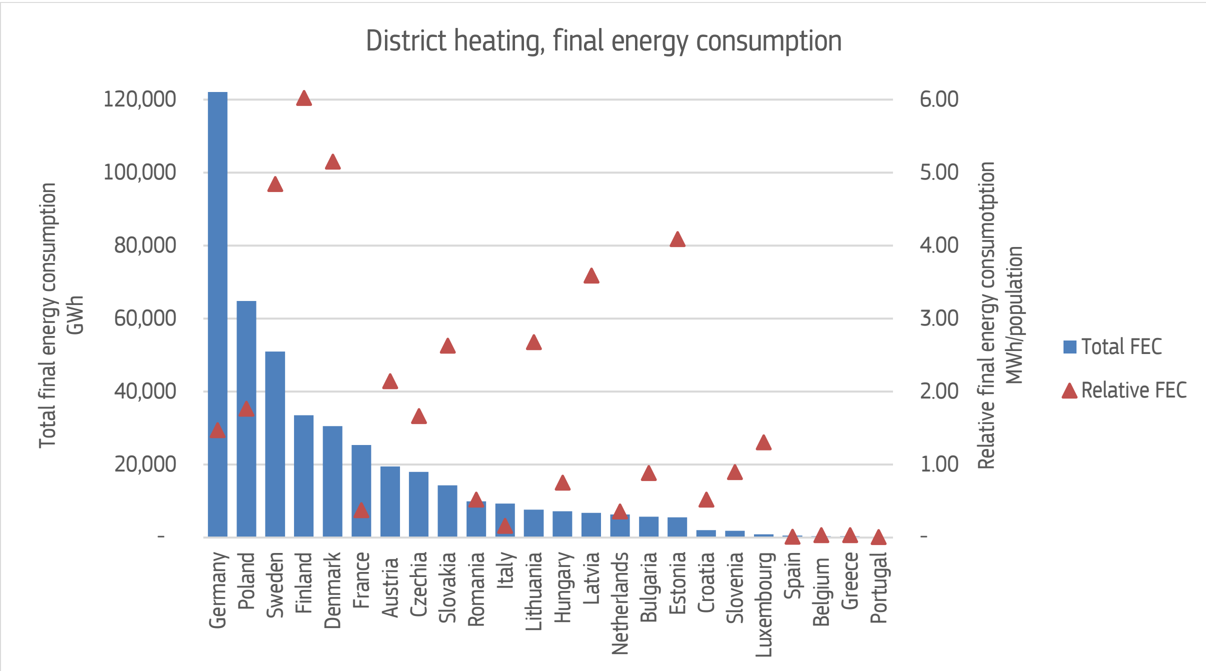
## 2.2 Installed energy Capacity, Generation/Production

Data on smart thermal networks is missing. This sections describes the status of DHC networks in the EU. The potential for smart thermal networks to be established is larger in countries with a considerable capacity and trench length installed already.

Heating and cooling in buildings and industries account for half of the EU's energy consumption, with 75% still generated from fossil fuels. While DH only represents 12% of the supply, the countries where this technology has been largely adopted (e.g. the Nordics) are among the best performers in decarbonising heating and cooling. In some EU Member States DH is well developed and central to their vision of a flexible, efficient and decarbonised energy system, while in others DH barely exists. Germany, Poland and the Nordic countries represent 68% (2018 data) of the EU's total DH final energy consumption (European Commission, 2022), while the use of DH in the Benelux and most south European countries is very limited.

District cooling (DC) is much less common in EU, with a total installed capacity of 7.74 (GW) and around 200 installations. Sweden represents 75% of the total installed DC capacity (Pezzutto, et al., 2022). DC systems not only allow higher efficiency compared to individual solutions and access to sources such as waste heat, but they also help manage power peak demands.

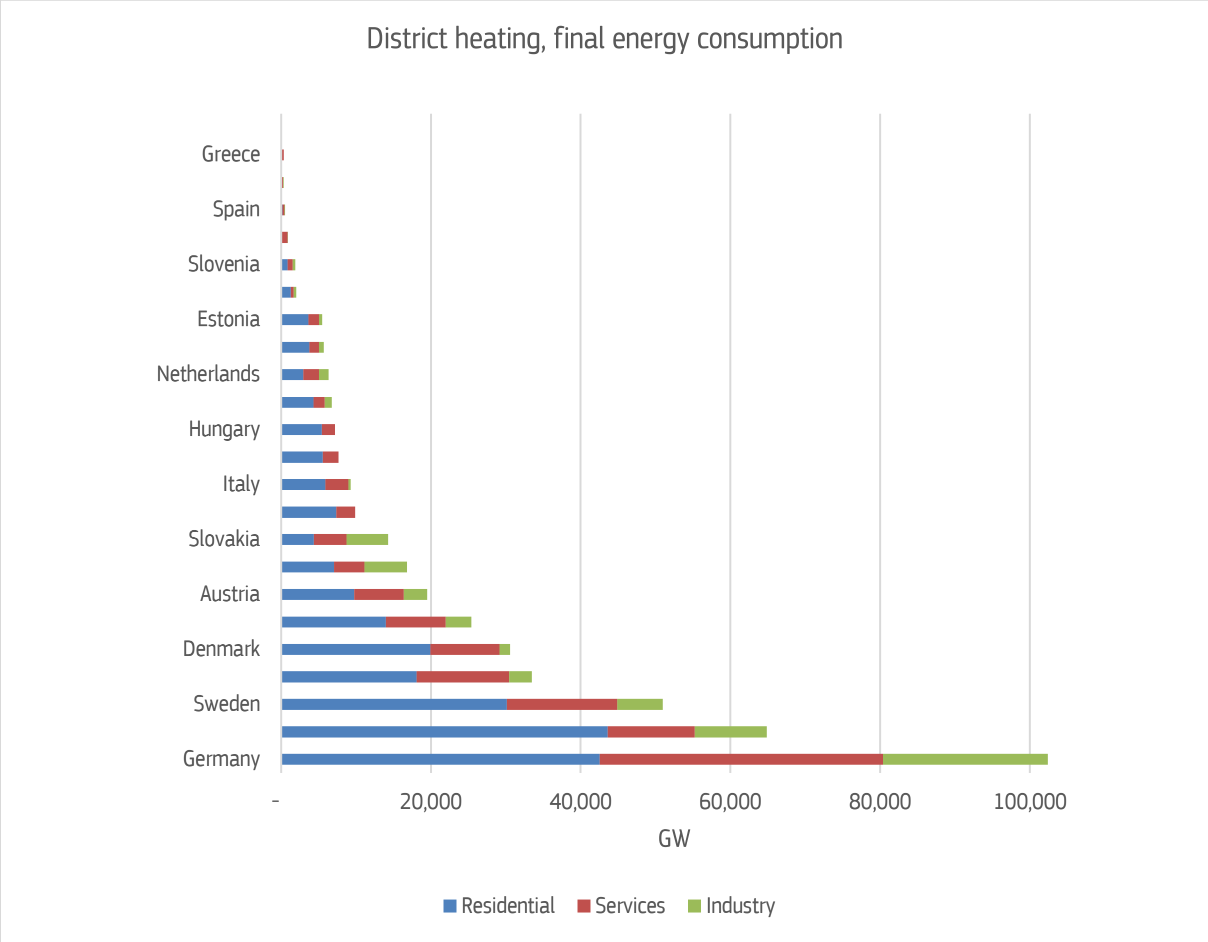
**Figure 2:** District heating, final energy consumption.




*Source: (European Commission, 2022). Data for the year 2018.*

Figure 3 illustrates that Germany and Poland have the highest levels of DH consumption among the EU countries. Conversely, the Nordic and Baltic states showcase the largest proportion of DH consumption relative to other heating methods. The figure also illustrate that the prevalence of DH in several Member States in close to non-existing, which is a considerable barrier for the uptake of smart thermal networks.

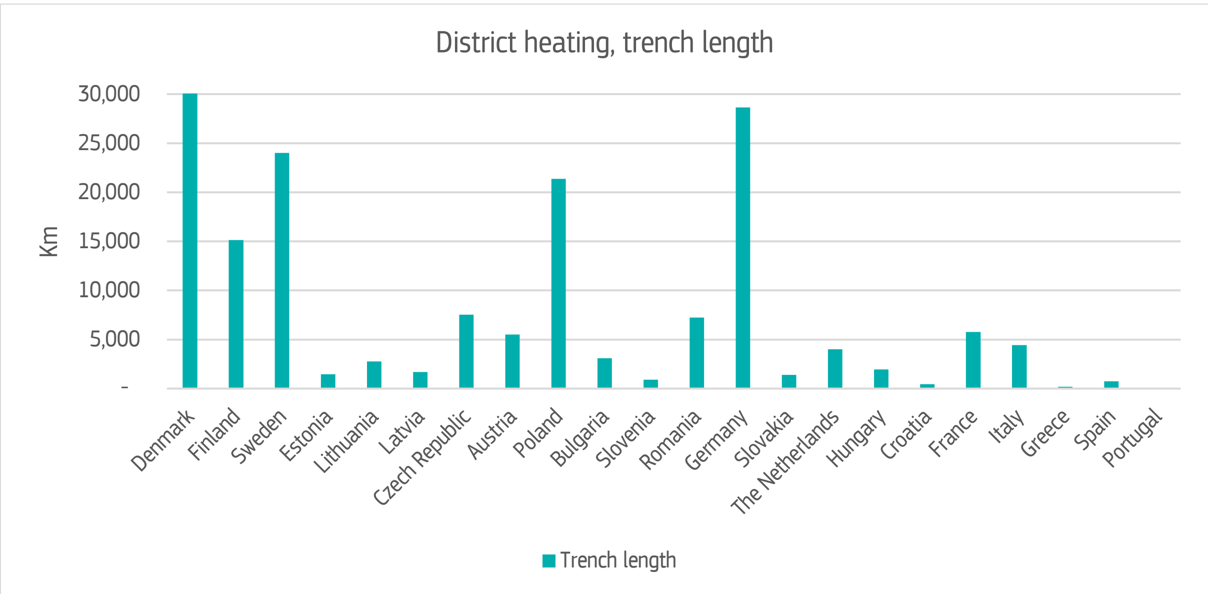
**Figure 3:** Total and share of district heating in final energy consumption per sector.




*Source: (European Commission, 2022). Data for the year 2018.*

Figure 4 illustrates the trench length (i.e. how much DH pipeline been installed) in the EU countries, where the bars indicate the actual length of installed pipelines. The results are heavily correlated with the consumption figures, where Germany, Poland, Denmark, Finland and Sweden are in the lead.

**Figure 4:** District heating, trench length.




*Source: (European Commission, 2022). Data for the year 2018.*

While reliable recent data is missing on the development of smart thermal networks, interviews with experts indicate that they are becoming increasingly popular, especially in countries with a history of DHC networks and a relatively high share of RES (especially Denmark and Sweden). However, France and Germany have implemented ambitious policies during the last years to support the implementation of smart thermal networks. For example, since 2009, France has almost doubled the length of their thermal networks, from 3,450 km to 6,529 km as of 2021 (Euroheat & Power, 2023). Table 3 shows a compilation of targets/projects of new DHC connections by 2030.

**Table 3:** Expected growth in installations until 2030.

| **Countries** | **Expected growth by 2030** | **Source** |
|---|---|---|
| Austria | + 350k new households | Forecast of Austrian Energy agency (2022) |
| Denmark | +250/300k new households by 2028 (Phase out of 400k gas boilers to be replaced by District Heating and individual heat pumps) | Estimate by stakeholders |
| France | + 215k households/year | Estimate by the national association |
| Germany | Between 300-600k households/year | Estimate by the national association |
| The Netherlands | + 500k households | Climate agreement between government and sectors - Klimaatakkoord (2019) |

*Source: Compilation by (Euroheat & Power, 2023)*

## 2.3 Technology Cost – Present and Potential Future Trends

Smart thermal networks require a considerable upfront cost. The initial setup requires constructing an extensive network of pipelines. Moreover, implementing efficient and modern heat generation technologies, such as CHP plants, large heat pumps or waste heat recovery systems, adds to the overall investment required. However, it's essential to consider that these upfront costs are usually offset by long-term savings and especially for cities moving towards a carbon neutral energy supply[13]. Furthermore, the flexibility offered though sector coupling can reduce costly capacity upgrades of the power grid.

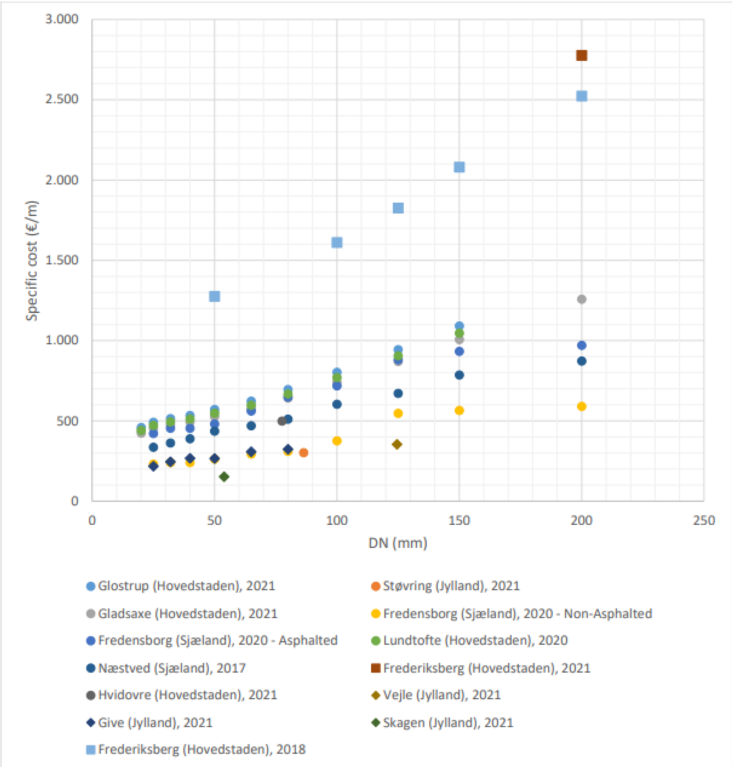
Table 4 shows the current and projected cost development for the piping networks. The expected cost-savings are modest until 2050 as the potential for innovation is limited when it comes to the actual pipes. The cost might even increase in the near future due to fluctuations in material prices and potential labour shortages.

**Table 4:** Projection of district heating piping costs.

| Projection (EUR/rm) | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Nominal investment (total) | 498 | 496 | 494 | 490 |
| Equipment cost | 199 | 198 | 197 | 196 |
| Installation cost | 299 | 298 | 297 | 294 |

*Source: (Grosse, Christopher, Stefan, Geyer, & Robbi, 2017)*

**Figure 5**: Construction cost of distribution district heating pipes in various Danish projects.




*Source: (Sánchez-García, Averfalk, & Persson, 2022)*

Similarly, Figure 5 illustrates total investments costs per meter of varying pipe nominal diameters (i.e. width) for establishing DH distribution pipelines from 16 projects in Denmark (Sánchez-García, Averfalk, & Persson, 2022). In the same report, the authors conclude project cost is correlated with the labour cost. In other words, it is cheaper to install new DH systems in countries and regions where the salaries are lower (ibid, 2022).

The cost of implementing new thermal systems come with a considerable cost for the public authorities and possess one of the main barriers. In countries with a long DH tradition, such as Sweden and Denmark, the thermal networks are seen as critical infrastructure or public goods, needed to cost-effectively provide the citizens with heating. The technology cost of smart thermal networks ought to be seen in the light of all the benefits.

Smart thermal networks operate on a lower temperature, making renewable technologies, like geothermal heat, industrial excess heat, and heat pumps, more cost-effective. The roll-out of DHC networks operating at lower

(13) What should be considered is that if fossil fuels are to be phased out other energy generation facilities will be needed, meaning that it is not so that the investments in heat generation plants would not be needed in case of electrified heating or transition to hydrogen. In other words, the decarbonisation of heating and cooling will require infrastructure investments.

temperatures enables a higher share of renewables and waste heat (Averfalk & Werner, 2020). Table 5 illustrates how smart thermal networks (i.e. 4GDH) enable a higher share of renewables by simply making them more cost-effective.

**Table 5:** Estimated annual heat supply costs for different operational modes for the 3GDH and 4GDH temperature levels.

| | Annual Heat Supply Costs [MV] | |
|---|---|---|
| **Technology/Operational mode** | ***3GDH*** | ***4GDH*** |
| Waste CHP | *-9.9* | *-10.7* |
| Biomass CHP | *5.1* | *3.4* |
| Biomass boiler | *12.7* | *11.2* |
| Geothermal | *10.8* | *3.3* |
| Geothermal investment | *11.0* | *6.0* |
| Industrial excess heat | *17.4* | *11.6* |
| Heat pump | *15.9* | *8.9* |
| Heat pump investment | *15.1* | *10.5* |
| Solar thermal investment | *14.5* | *10.2* |

*Source: Table and analysis comes from (Averfalk & Werner, 2020)*

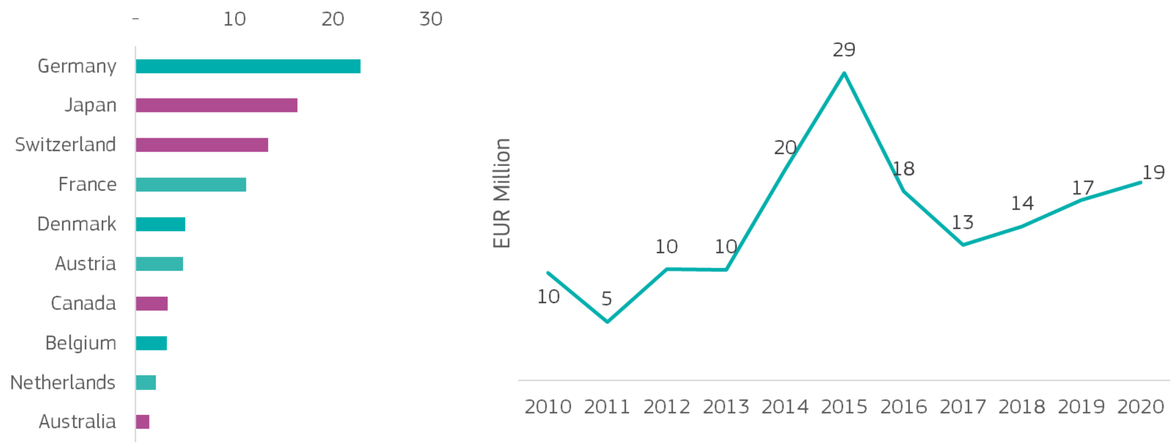
It should be noted that the actual pipeline is just the basic infrastructure of a smart thermal network. The following section presents some cost-estimates for other sub-technologies that can be integrated in a smart thermal network.

One trend is that utilities are increasingly recognizing the importance of ensuring that building level heat interfaces, substations, are continuously maintained and operated. This is leading to extended utility business models, where the utilities take ownership of the heat interface units and rent it out to the building owners. This enables the utilities to get better understanding of the system operation and condition. End-users benefit from this trend as it shifts large investments, maintenance requirements and operational optimization, from the building owners to the utilities.

## 2.4 Public R&I funding

Figure 6 shows the public research and development investments in thermal energy storage, which is used a proxy for the wider sector (i.e. DHC and smart thermal networks). The data reveals that Germany allocates the largest amount of public funds towards research and development. The data also shows public investments from the top 10 International Energy Agency (IEA) members have slowly increased over the last 11 years, while declining since the peak in 2015. Moreover, from 2014 to 2020, the EU funded 58 relevant projects through Horizon 2020 with nearly EUR 387 million (Saletti et al., 2020).

**Figure 6:** Top 10 IEA Members in 2018-2020 (left) and EU Member States public R&D investment (right) [EUR million].



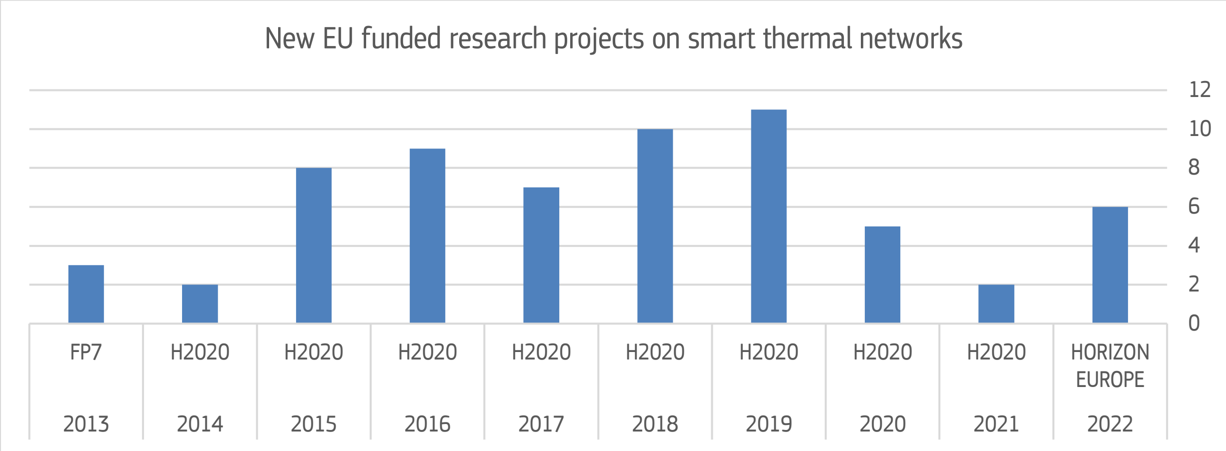

*Source: European Commission's Joint Research Centre (JRC) analysis based on IEA data ([14]) ( (Kuokkanen, et al., 2023)*

The EU has persistently funded research projects aiming to improve the implementation of smart thermal networks, including technical innovations, digital solutions and new business models[15]. Examples include Heat Roadmap Europe, THERMOS, COOL DH and 4DH which are examples of projects looking at the potential of smart thermal networks, while STORM, TEMPO, OPTi and FLEXYNETS are examples of projects exploring intelligent control and optimisation strategies of DHC networks. OpenLAB, ARV, PROBONO, W.E.DISTRICT, and Syn.ikia are projects developing and testing innovative smart district solutions, in which DHC play a central role. Several projects focus on specific technologies, such as ReUseHeat on waste heat, SmartCHP on cogeneration, HEATLEAP looks at waste heat recovery through large heat pumps, while CREATE and COMTES focus on thermal energy storage systems. A recent report provides a comprehensive overview of support activities and projects of the European Commission on DHC[16]

The EU granted EUR 438 million to 63 research projects related to smart thermal networks between 2013 and 2022. Most projects were enacted between 2015 and 2019, as shown in Figure 7. Spanish organisations were most active in these projects are received more than EUR 80 million, followed by Germany, Italy and Sweden, as depicted in Figure 8.

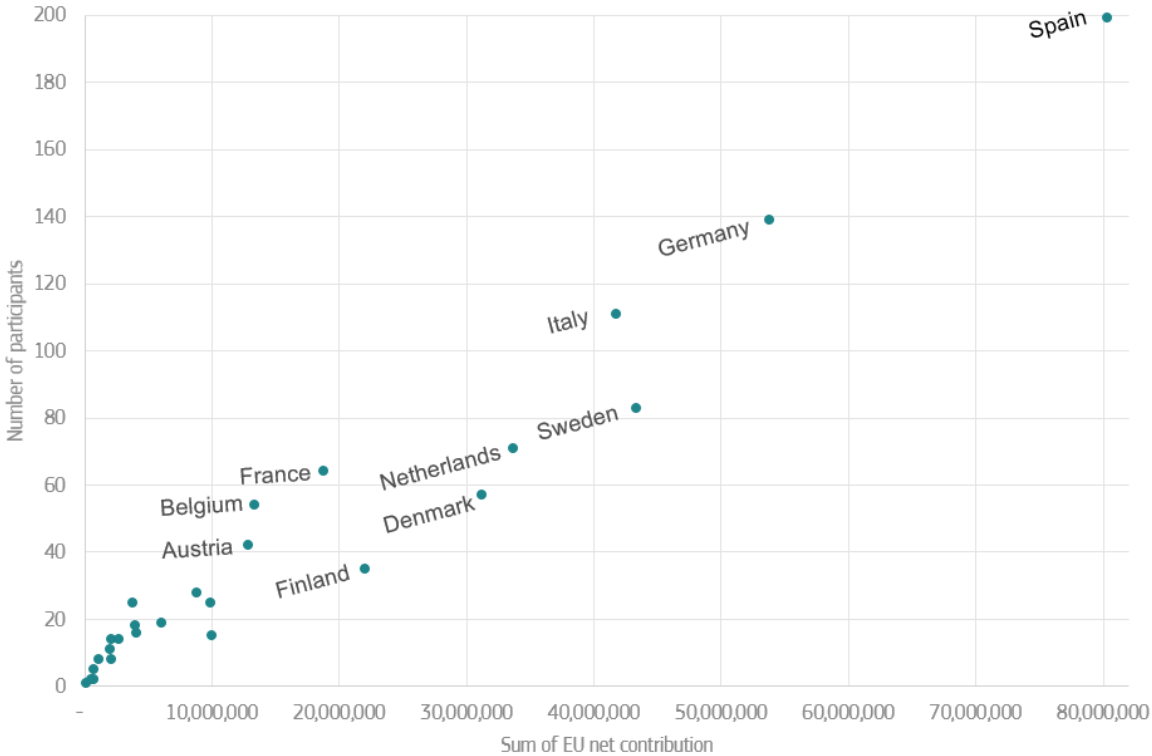
(14) IEA codes: 632. Thermal energy storage is used as a proxy for heating & cooling networks.
(15) Many of the projects have received funding through the Horizon Europe and the LIFE programme.
(16) European Commission, Directorate-General for Energy, Lettenbichler, S., Corscadden, J., Krasatsenka, A., Advancing district heating & cooling solutions and uptake in European cities – Overview of support activities and projects of the European Commission on district heating & cooling, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2833/51155

**Figure 7:** New signed EU funded projects related to smart thermal networks, per year.




*Source:* European Commission's Joint Research Centre (JRC) analysis based on CORDIS, 2023 data.

**Figure 8:** Relationship between participants in different smart thermal network projects and EU net contribution received for these projects.



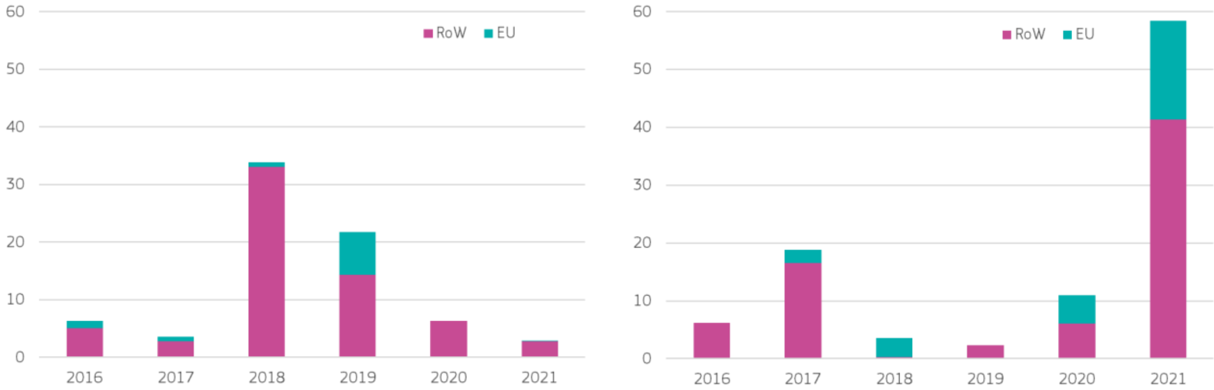

Note: the same organisation can be active in several projects but is counted as a new participant in every new project.
*Source: European Commission's Joint Research Centre (JRC) analysis based on CORDIS, 2023 data.*

## 2.5 Private R&D funding

The venture capital investments amounted to EUR 175 million over the 2016-21 period and are significantly higher than during the previous 2010-15 period, globally (1.8 times higher) and in the EU in particular (2.6 times higher). As shown on Figure 9, this is due to a peak in early stage investments in 2018 followed by an outstanding increase of later stage investments. In 2021, later stage investments reached an all-time high of EUR 58.5 million (x 5.3 as compared to 2020), driven by more numerous and larger deals realised outside of the EU.

During the 2016-21 period, the EU attracted 14 % of all early stage investments, amounting to EUR 10.2 million, and 28% of the later stage investments, amounting to EUR 27.6 million. Despite its good performance compared to 2010-15, investment levels remain below the average of the EU as it hosts 42% of identified venture capital companies. Most of the companies that raised over EUR 10 million of capital in the 2016-21 period are focusing on thermal energy storage solutions (Kuokkanen, et al., 2023).

**Figure 9:** Early (left) and later (right) stage investments by region [EUR million].

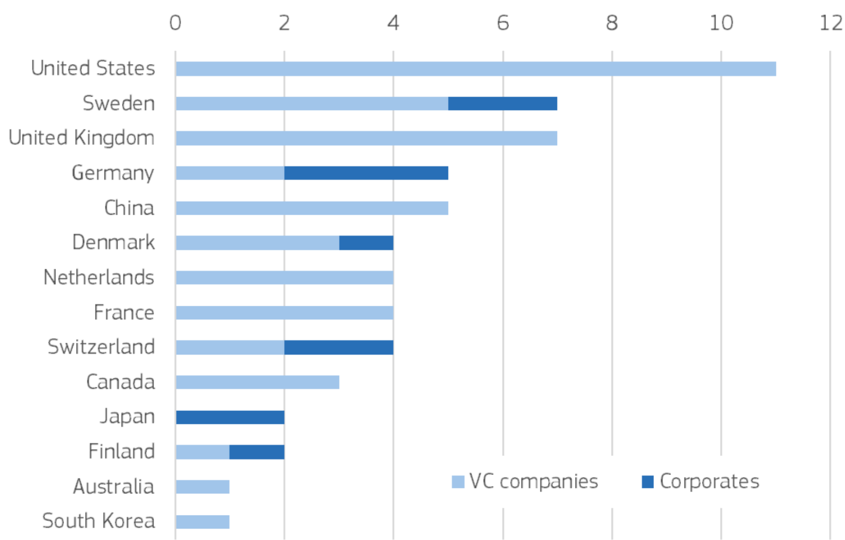



*Source: European Commission's Joint Research Centre (JRC) analysis based on Pitchbook (Kuokkanen, et al., 2023).*

The US has the largest number of companies investing in innovation, followed by Sweden and the United Kingdom. The US has most venture capital companies (11), while Sweden (5) has the most in the EU. The EU host 42% of all venture capital companies. As shown on Figure 10, venture capital companies constitute most of identified innovators and they are distributed across many countries. Led by the US, the top five countries host together 55 % of active companies. The EU has a strong competitive position and hosts 45 % of innovators. Five EU member states rank in the top 10 countries, including Sweden (2nd) and Germany (4th), behind the UK (3rd) but ahead of China (5th) (Kuokkanen, et al., 2023).

**Figure 10:** Number of innovating companies by type (2016-21).

**Figure 10:** Number of innovating companies by type (2016-21).




*Source: European Commission's Joint Research Centre (JRC) compilation from existing sources, see more in (Kuokkanen, et al., 2023).*

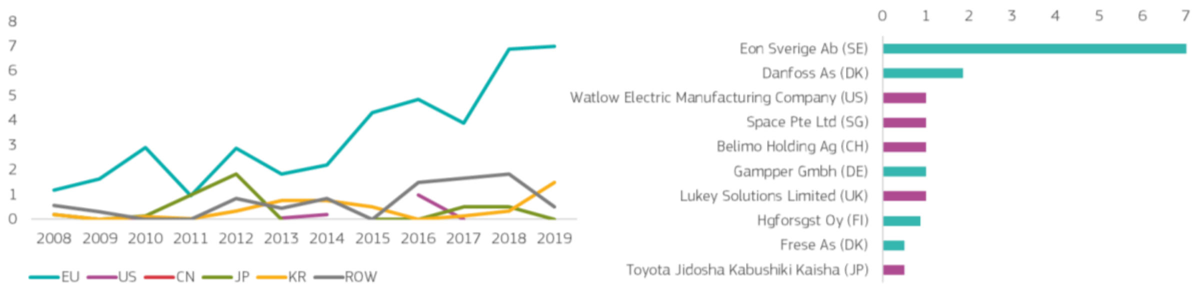
New technologies under development to improve the efficiency of the piping systems include sustainable insulation materials, coatings to reduce pressure losses, and quick-fit joints for easy installation (Moustakidis et al., 2019). Research efforts are focused on the design and retrofit of low temperature distribution networks, including simultaneous cooling distribution, while increasing the share of renewable and waste energy sources. The digitalisation of the sector focuses on optimisation, automation, and prediction and prevention techniques. However, the drive for innovation in the sector seems to rely on political intervention (Knutsson et al., 2021).

DHC networks are not equally represented in all member states and account for around 12% of the EU's total final heating and cooling demand. One of the key actions for a more integrated energy system, in the European Commission's Strategy for Energy System Integration, was therefore to "accelerate investment in smart, highly-efficient, renewables-based DHC networks". The uptake of new networks remains limited, but the climate mitigation needs and energy dependency concerns are triggering a growing interest among policymakers and companies.

## 2.6 Patenting trends

The EU is steadily increasing its patenting activity and holds 69% of all high-value inventions. Sweden and Germany, countries with a relative high penetration of DHC networks, are the leading patenting countries globally, followed by Denmark and Finland in the fourth and fifth position. Swedish E.ON Sverige AB is the leading patenting company, followed by the Danish company Danfoss (Figure 11) (Kuokkanen, et al., 2023)..

**Figure 11:** Trend in high-value inventions for major economies (left) and top 10 companies in 2016-2019 (right).




*Source: European Commission's Joint Research Centre (JRC) analysis based on EPO Patstat.. (Kuokkanen, et al., 2023).*

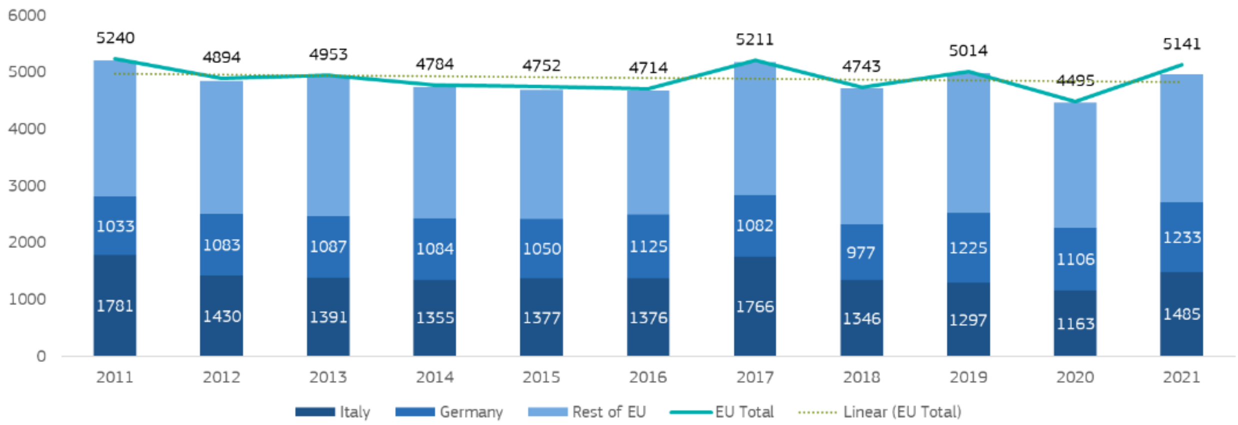
The EU scores highly in innovation-related indicators, showing leadership in the development of decarbonised heating and cooling networks. EU captured slightly smaller shares of venture capital investments due to expanding the scope to include thermal storage, still at later stage the EU captures nearly a third of all investment. The EU also hosts nearly half all identified innovating companies in the sector. In production of heat exchangers, the EU performance is medium as, while production is growing, it is growing less than the EU gross domestic product overall.

## 2.7 Value chain Analysis

In 2021, the global DH market was estimated at around EUR155 billion (17) and is projected to reach nearly EUR 327 billion (18) by 2028 (FBI, 2022). Globally, DHC systems primarily rely on fossil fuels, with coal being the largest energy source at 45%, largely due to China's national average usage of 70%, followed by natural gas (40%), RES (8%) and oil (3.5%).

The EU production of heating and cooling network components[19] has been rather constant over the last 10 years. The EU production decreased with 2% between 2011 and 2021, reaching EUR 5 billion in 2021. Italy and Germany are the largest producers, responsible for more than half of the total EU production in 2021 (Kuokkanen, et al., 2023).

**Figure 12:** EU production value and the biggest producers [EUR million].




*Source: European Commission's Joint Research Centre (JRC) analysis based on PRODCOM data. (Kuokkanen, et al., 2023).*

(17) Foreign currencies are converted to EUR based on the annual averages published by the European Central Bank

(18) Forecasted values are converted to EUR based on Bloomberg forecasted rates. For values later that 2026, a fixed rate is assumed at EUR 1.21 per USD 1.00.

(19) Heat exchangers are also used in other applications, not exclusively in heating and cooling networks. Therefore, production and trade data should be interpreted with caution.

# 3. EU position and Global competitiveness

EU companies are global leaders in DH systems and smart thermal network technologies.

Europe stands at the forefront of integrating renewables into DH systems, with 25% of its DH supplies generated from renewable sources. Leading this movement are Sweden, Denmark, Austria, and the Baltic states where the adoption of RES is high, accounting for over 50% of their DH production (IEA, 2023). The demand and use of smart thermal networks are also higher in markets with a higher share of renewables.

## 3.1 Global & EU market leaders (Market share)

The EU has been the global leader in the domain of efficient DHC networks for a long time and possess a head start in smart thermal networks. EU, its Member States, cities and companies have invested in state-of-the-art technologies and in integrating more RES and waste heat into DHC systems. There are over 17,000 DH networks in Europe supplying heat to around 70 million citizens (Euroheat & Power, 2023). The average carbon intensity of European DHC networks is lower than the rest of the world, due to a higher efficiencies and larger share of renewables (IEA, 2023).

The EU has also developed a broad policy framework to facilitate the uptake of DHC networks and increase the share of renewables in the thermal networks. The Energy Efficiency Directive (EED)[20] defines *efficient district heating and coolin*g (Art. 2) and requires Member States to conduct economic and geographic analyses to identify DHC potentials (Art. 25)[21]. The Renewable Energy Directive (RED) sets out a target of an annual increase in the percentage of renewable heating and cooling (Art. 23) and sets an annual target for increasing the share of renewables in DHC (Art. 24). RED also asks Member States to enable producers of energy from RES and from waste heat and cold to access DHC networks (also, Art. 24)[22]. In addition, the European Performance of Buildings Directive (EPBD)[23] sets out several provisions to improve the efficiency of new and existing buildings, which is a prerequisite for lower-temperature DHC networks[24] (Volt, et al., 2022).

The EU has also enacted a number of strategic plans and platforms in which DHC is explored and supported. The European Strategic Energy Technology Plan ([25]) is advancing the deployment of low-carbon technologies, with, innovation platforms on renewable heating and cooling and smart networks for the energy transition, among others. Positive energy districts are one of many explored topics. The related European Partnership for Clean Energy Transition[26], co-supported by industry, public organisations, research and citizens' organisations, aims to accelerate the energy transition by enabling energy research and innovation on different levels. Focus areas of the multilateral partnership include renewables, DHC, energy storage and system integrations. Furthermore, the EU has launched a mission to have *100 climate-neutral and smart cities* by 2030. The Smart Cities Marketplace[27] supports this mission by offering knowledge, capacity-building support and facilitation of finance solutions for cities. Covenant of Mayors for Climate and Energy[28] brings together local and regional authorities, which commit to the EU's climate and energy objectives. Implements in European cities can use the platform to exchange experiences and views (Volt, et al., 2022).

(20) Energy Efficiency Directive [2018/2002, 2012/27/EU] Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en

(21) Efficient DHC is defined as systems using at least 50% RES, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat

(22) Renewable Energy Directive 2018/2001/EU, 2009/28/EC. Available: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en

(23) European Performance of Buildings Directive 2018/844/EU, 2010/31/EU. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

(24) A new report carried out for the European Commission provides a good overview of the policy framework for DHC, with a special focus on the RED recast (European Commission, 2022).

(25) European Commission "Strategic Energy Technology Plan" [Website] Available: https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en

(26) CETPartnership [Website] Available: https://cetpartnership.eu/

(27) European Commission "Smart Cities Marketplace" [Website] Available: https://smart-cities-marketplace.ec.europa.eu/

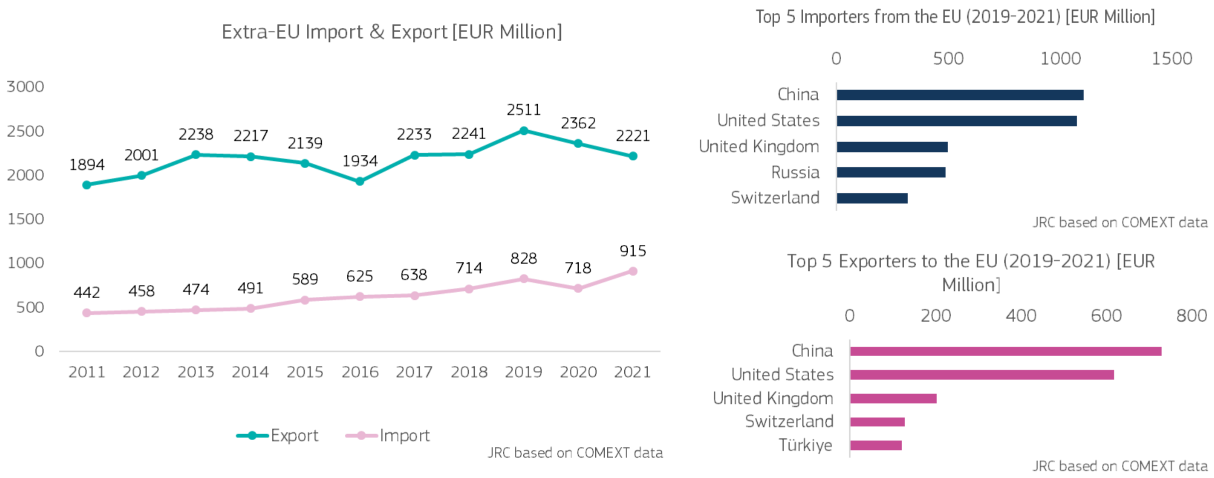
(28) Covenant of Mayors [Website] Available: https://www.eumayors.eu/en/

## 3.2 Trade (Import/export) and trade balance

It's important to acknowledge the limited availability of data pertaining to the trade of smart thermal network components. The data presented below primarily focuses on heat exchangers as a representative indicator of trade within the heating and cooling networks sector. While not perfect, it provides a decent indication of the situation.

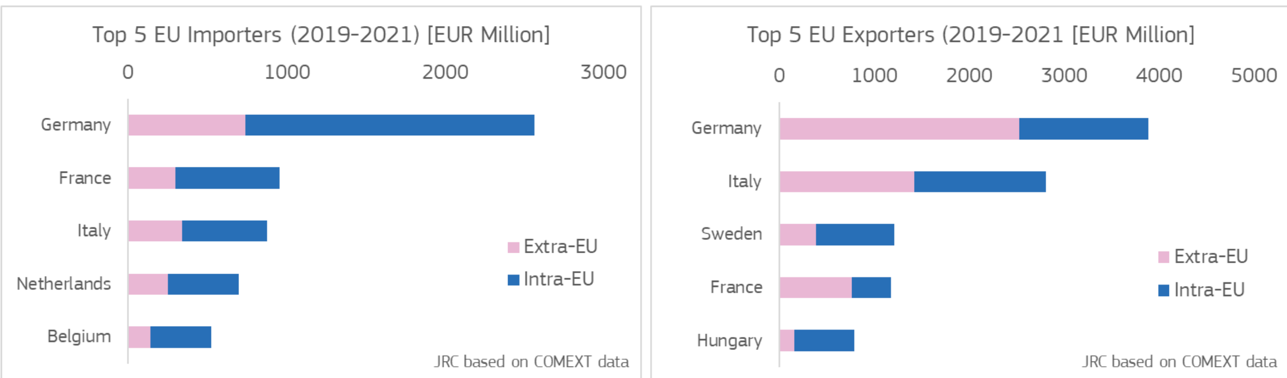
Extra-EU imports and exports have grown slowly since 2011, reaching over EUR 2 billion exports and nearly EUR 1 million in imported goods (Figure 13). China and the US are the largest exporters to the EU as well as the ones who importers the most from the EU. Extra-EU trade accounts for 33% of the global share, and there is potential for the EU to increase exports to the growing markets of India, Thailand, and Indonesia. Internal imports (i.e. imports from another EU member state) account for more than 70% of all EU imports. Germany is the largest exporter in the world and the largest importer in the EU (see Figure 14). The EU trade surplus was more than EUR 2 billion in 2021.

**Figure 13:** Extra-EU import and export (left); Top 5 importers from the EU (top right) and top 5 exporters to the EU (bottom right) in 2019 2021 [EUR million].




*Source: European Commission's Joint Research Centre (JRC) analysis based on COMEXT code: 841950*

**Figure 14:** Top-5 EU importers (left) and exporters (right) in 2019 2021 [EUR million].




*Source: European Commission's Joint Research Centre (JRC) analysis based on COMEXT code: 841950*

## Conclusions

Smart thermal networks can be a central and dynamic element of a low-carbon energy system, with the ability to integrate local low-temperature RES and offer flexibility to the wider energy system. Smart thermal networks operate at a lower temperature, making renewable options like geothermal heat, industrial excess heat and heat pumps, more energy-efficient and cost-effective. They ultilise advanced control strategies, using sensors and intelligent monitoring solutions, which improves the performance of the network and enables the integration of more RES. In many urban areas, a smart thermal network is a necessity for a cost-effective decarbonisation transition.

Furthermore, sector coupling between DHC and electricity systems allows the whole system to become more effective. The smart thermal network operator can respond to price fluctuations in the electricity market and help balance the grid by producing or consuming more electricity. This also enables significantly lower power generation capacity than would be needed if building heating and cooling demands were electrified at building level.

While reliable data is missing on the development of smart thermal networks, interviews with experts indicate that they are becoming increasingly popular, especially in countries with a history of DHC networks and a relatively high share of RES (especially Denmark and Sweden). France and Germany have implemented ambitious policies during the last years to support the implementation of smart thermal networks.

Most individual components of smart thermal networks have reached a high level of technological readiness, including sensors and intelligent control systems, high-efficient cogeneration, large heat pumps and thermal energy storage technologies. However, the integrated concept of smart thermal networks has considerable innovation potential left. There are local networks that have been incrementally built towards becoming smart thermal energy systems, although they still have quite some path to go before becoming truly smart.

The EU is a global leader when it comes to smart thermal networks, with more networks operating at lower temperatures and with a higher share of RES than non-EU countries. The opportunity is there for the EU to spearhead the transition to smart thermal networks and showcase their value in a low-carbon reality.

Trends:

- Digitalisation and the increased use of smart meters and sensors in the networks have dramatically increased the amount of data available, which can be used for advance planning and operational optimisation. Thermal networks are becoming more complex, making it possible and necessary to collect more data at various stages of the system's operation and to use advanced digital tools to process and acquire insights that can be transformed into actionable solutions. New control strategies are emerging could further boost this development, and thus the performance of the system.
- DHC networks are moving from relying on one or a few single heat or CHP plants to utilising numerous smaller heat sources, including renewables and waste heat. In other words, they are transforming from a single-source system to a multi-source one. Energy systems are becoming more integrated, where smart thermal networks can play a key role as a balancing actor. DHC networks are increasingly used to balance the electricity grids, and by doing so, they enable a higher share of wind and solar power.
- System integration represents a great opportunity for the EU's power and heating and cooling sectors. Networks with multiple thermal generation plants can offer great flexibility, especially if coupled with thermal energy storages. Advanced control and management of generators in multi-source systems can serve the same purpose as thermal energy storage, except the energy is stored in the unburnt fuel. It can also contribute to resilience of the whole system, which was shown during the 2022 gas crisis, where cities with DH networks and a higher share of RES, also experienced relative lower energy prices.
- Utilities are increasingly recognising the importance of ensuring that building-level heat interfaces – substations – are continuously maintained and operated. This is leading to extended utility business models, where the utilities take ownership of the heat interface units and rent them out to the owners of buildings. This allows the utilities to get a better understanding of the system's operation and condition. End-users benefit from this trend as it shifts major investment, maintenance requirements and operational optimisation from the owners of buildings to the utilities.
- The role of DHC networks has shifted from simply ensuring sufficient supply to optimising the whole system, from supply point to end-users. Smart meters can help by giving a better understanding of the current condition of the network and supporting advanced short-term forecasting of heating and cooling demand. Buildings are increasingly being viewed an as integrated element of the DHC system.

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## List of abbreviations and definitions

| | |
|---|---|
| 3GDH | Third generation district heating |
| 4GDH | Fourth generation district heating |
| 5GHD | Fifth generation district heating |
| CETO | Clean energy technology observatory |
| CO2 | Carbon dioxide |
| DC | District cooling |
| DH | District heating |
| DHC | District heating and cooling |
| EED | Energy efficiency directive |
| EPBD | Energy performance of buildings directive |
| EU | European Union |
| GHG | Greenhouse gases |
| JRC | Joint Research Centre |
| RED | Renewable energy directive |
| RES | Renewable energy sources |
| TRL | Technology readiness level |

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