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Deliverable 3 – Overview of monetary and non-monetary incentives for the uptake of District Heating and Cooling and Heat Pumps

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Content

1 Executive Summary

This Report covers Subtasks 3.1 to 3.4 of the project 'Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation' funded by the European Commission (EC). The objective of Task 3 is to provide an overview of incentives for the uptake of District Heating and Cooling / District Heating (DHC/DH) and Heat Pumps (HP), which can make a significant contribution towards energy system flexibility and decarbonisation. The geographic scope of the analysis is the former EU28 members (EU27 + UK), Norway, Switzerland and Iceland.

Subtask 3.1 involves a literature review to assess Framework Conditions (FC) for DHC and HP, in terms of their influence on the uptake of these technologies. Subtask 3.1 explores nine Framework Conditions (FC) based on work by Sneum (2021). The FC are mapped across a literature set and a selection of EU and non-EU countries. **Subtask 3.2** draws on the ECs database of State Aid cases, the National Energy and Climate Plans (NECPs) and MS National Resilience and Recovery Plans (NRRPs) to assess the type of support mechanisms most used for DHC and HP and whether the focus is on efficiency or decarbonisation. **Subtask 3.3** involves an overview of heat planning and integrated spatial energy planning as a means of supporting the uptake and acceptance of heat technologies. **Subtask 3.4** has the objective of analyzing the cost structures for supply, transmission and distribution in the context of DHC systems and networks.

Subtask 3.1: Framework Conditions (FC) for DHC and HP

Operational signalling (FC1) refers to the need for technologies with flexibility potential, such as HP and newer DHC concepts (particularly 4th and 5th generation) to have market signals to respond to. Certain barriers can weaken or remove DHC and electricity market signals for flexible technologies:

- Operational taxes should be used in a manner which does not affect the competitiveness of flexible technologies, such as DHC and HP.
- Flexible tariffs, such as time of use tariff schemes can provide greater flexibility, as the operation of technologies such as Power to Heat (PtH) can be managed around peak prices.
- Operational standards and procedures should avoid adding transaction costs for market access to smaller participants in the DHC and HP sector, for example through the removal of overly restrictive technical conditions for certain technologies.
- The natural monopoly of DHC systems presents particular challenges but flexible pricing is seen as a way of managing the tension between the aim of minimizing costs for consumers, without negatively affecting the income of DHC companies.

The investment climate (FC2) is critical to the uptake of DHC and HP technologies as financial constraints are common barriers:

- As investment subsidy might reduce the competitiveness of some technologies if they either support competing technologies or are not market-based, access to capital can present a better way to address investment issues.
- Lack of capital availability can be a barrier to implementing efficiency measures, including in relation to DHC and HP. Recommendations include lower interest rates and long-term loans. The characteristics of the building stock are also relevant to capital availability, both for renovation and/or new building stock.
- The rate of return can affect investors' choice of technology and discount rates can vary between countries depending on: (i) normative and positive considerations of discounting (ii) maturity of the project, and (iii) risk aversion.

- One way to consider investment policy is to break down related policy recommendations according to the existing share of renewable heat within a country to determine the level and nature of policy intervention required. This allows for a more context-specific approach to investment policy.

The length and ease of the **permitting process (FC3),** including procedures in relation to consenting and licensing, can pose barriers to DHC and HP projects:

- Permitting processes should be streamlined. Planning procedure should allow energy supply to be aligned with energy efficiency measures (demand). Enabling providers of DHC and HP technologies through smart meters, for example, can provide the information required for such alignment.

Ownership and access rules (FC4) can affect the uptake of DHC and HP:

- Some vertical integration is considered necessary for all but the largest DHC businesses, because the separation of different DHC business functions (e.g. sales, production) can entail ongoing transactional costs between those functions. Solutions include reforming regulation to enable deployment of special categories of generators and bespoke conditions aimed at certain types/sizes of organisations.
- The natural monopoly characteristics of DHC networks mean that third party access (TPA) regulation can be a means of maintaining competition in DHC networks. However, it is necessary to consider the networks' specific characteristics in terms of technical characteristics and economic viability. TPA may offer good options for smaller waste heat production and renewable energy sources to gain access to the network. An important factor can be the type of ownership structure in place for DHC companies in different markets, in terms of public/municipal or private ownership for example. A variety of TPA models should therefore be considered.

Certain **technical factors (FC5)** can limit the deployment of technologies which provide flexibility:

- Investments can be large, especially for renewable DHC, flexible thermal power plants, HPs and waste heat extraction. Support is therefore required for increased innovation, for example in the form of subsidies or tax rebates.
- The availability of skilled staff can inhibit supply chain maturity in terms of growth and recruitment. Policies to support supply chain growth should therefore be considered, such as enabling recruitment in relevant industries and support for enhancing staff competencies.
- In relation to high temperature systems, policies for the modernisation of networks, particularly where older systems of DHC are due to be decommissioned, should focus on the conversion to lower temperature systems.

Electricity grid access (FC6) addresses access to the physical electricity grid:

- High grid connection costs can be managed by improving non-discriminatory interconnections, either by socialising the cost of electricity lines, or interruptible grid connection agreements. In the case of a flexible system-serving operation, the connection cost of HP could be reduced to acknowledge its potential contribution to local peak demand reduction and therefore reduced grid costs.
- Standardised interconnection agreements can incentivize expedient connection and clarify applicable regulation and codes relating to bi-directional flows of electricity. Grid codes could alternatively mandate minimum criteria for connected technologies.

Physical environment (FC7): flexible technologies depend on energy sources, whose economic potential may be limited by geography (e.g. distance from source to sink), demand characteristics (e.g. heat density) and policy/regulatory measures:

- Region-specific constraints on the availability of heat sources must be considered, as they determine the available heating options, which can increase costs.

- Efficient technologies should be integrated into renovation projects and new infrastructure developments. Spatial planning and zoning to integrate DHC priority zones can strongly support the economic effectiveness of DHC grids.

Bounded rationality (FC8) refers to a lack of awareness amongst relevant stakeholders, due to constraints in knowledge and experience. **Acceptance (FC9)** refers to uncertainty about technologies, a perception that DHC and HP technologies and flexibility do not represent a core business activity and/or a concern about the extent of opportunity costs:

- Future policies should reduce consumer uncertainty by targeting information asymmetry and imperfect information, and improving access to metering technology. Communication programmes, including normative lifestyle campaigns, should focus on comfort and indoor climate as key elements in a household’s valuation of benefits of investments in heating and cooling technology.
- Barriers to uptake also derive from the knowledge and acceptance of different levels of authority, governance bodies, plant staff who may have limited authority to implement new technologies and/or incumbent utilities who can be resistant to new entrants to the DHC sector and also to HP. Solutions include disseminating information on national and local heat systems and pilot projects for information and training.

Links between FCs and proposed further research: **Sector coupling** is a particularly strong thread between the FCs, which is a key means of improving the uptake and deployment of DHC and HP. Countries with rapid growth in renewables should place great priority on sector coupling, including the use of HP for demand response. Sector coupling can make market signals more effective but market prices must be consistent across the relevant sectors. **Little consideration is given to gender aspects** in heating and cooling policy in the reviewed literature. Gender as a factor can impact consumer willingness to adopt and pay for heating and cooling technologies. Policy indicators should address the extent of gendered participation in energy transition in addition to energy poverty, as a result of the gendered nature of decision-making on energy infrastructure.

Subtask 3.2: Overview of State Aid

The vast majority of **State Aid cases** relating to ‘district’ and ‘heat’ in the ECs database of state aid cases[1] were not investigated further by the Commission. The cases in which further investigation was initiated suggest that the EC will object to state aid for renewal or upgrade of DHC infrastructure, where such activities would lead to a lock-in or extended lease of life for existing fossil fuel-based power plants.

The review of NECPs shows that more countries (14 out of 16) target the increase in share of renewable energy production than energy efficiency (11 out of 16). The three most frequent support schemes are (i) public funding and tax mechanisms, (ii) tariffs and premiums, and (iii) grants. Soft loans and guarantees were least frequent. Where heating and cooling technologies are considered in the NECP, the focus is primarily on DHC systems overall. Although HP are mentioned in all NECPs, assessments of the heating and cooling chapters of the NECP recommend that all MS show trajectories of how HP will develop in future and provide more detailed analysis of how to increase the use of HP.

The Commission’s analyses of a set of NRRPs have been examined to show where the EC has commented on not only the compatibility between the NECP and NRRP but also to highlight specific references to energy efficiency in buildings and/or heating. The review highlights the extent that COVID recovery initiatives and funds in the NRRP also support countries’ NECP objectives in particular where these target heating and cooling technology. All reviewed countries showed a degree of compatibility between their NRRPs and NECPs, however the EC highlights that countries tended to focus either on efficiency or decarbonisation. Where both decarbonisation and efficiency measures were prioritised, this leads in certain instances to issues with the extent of funding required to fulfil those targets.

Subtask 3.3: Heat and Spatial Energy Planning with and overview of MS NECP provisions on heat

Step 1 of Subtask 3.3 involves an overview of heat planning and integrated spatial energy planning as a means of supporting the uptake and acceptance of heat technologies. It examines the background and relevance of the concept of heat planning and integrated energy spatial planning as governance tools for the uptake and acceptance of heat infrastructure. Step 1 also provides the legislative context to the Member State (MS) requirement to report on heating and cooling plans. As this is a requirement within each MS's National Energy and Climate Plans (NECP), Step 1 examines the treatment of heat planning and energy spatial planning in the 27 MS NECPs. In order to show the role of heat planning and spatial energy planning in heat infrastructure uptake, the task involved examining the link between the concept of heat planning, which has proven successful for the uptake and integration of DH in countries such as Denmark over the past four decades. With the proposals for a recast Energy Efficiency Directive (the proposed recast EED), the concept of municipal heat planning is now also embedded within the draft legislation. This provided the impetus for examining the status of heat planning and spatial energy planning for heat in selected EU MS in addition to Scotland (UK) and Switzerland. The case studies are preceded by a general overview of MS approaches to heat in the National Energy and Climate Plans (NECP).

Step 2 provides detailed case studies from six jurisdictions in relation to the status of heat planning and spatial energy planning for heat in those countries. Four of the countries are MSs (Denmark, Germany, Austria and Poland), and two are non-EU countries (Scotland UK and Switzerland), which have been examined for comparison and due to their constitutional governance structures that can helpfully inform EU policy. The case studies in Step 2 serve to illustrate where heat planning and spacial energy planning for heat have been successful (e.g. Denmark), are increasingly implemented at different regional and national levels (Austra, Germany, Scotland and Switzerland) and where there is no formal heat planning but there is some potential in the regulatory framework (Poland).

Heat planning and spatial energy planning to strengthen infrastructure uptake

Spatial energy planning and heat planning are considered important tools for the energy transition. However, heat planning is still at the very beginning of broader implementation in Europe, with only some countries, notably Denmark, leading the way. Heat planning is a means of enabling municipalities to plan and decarbonise their heat supply within a defined geographic area. It takes into account the local characteristics and potential of heat supply. In order to develop heating and cooling infrastructure at a local level, heat planning has been recognised as an effective way to implement decarbonisation in a cost-effective way that is also appropriate to the local area. Heat planning is therefore a key tool for implementing heat transition whilst fostering local solutions by incorporating local participation of municipalities and permitted local citizens. The engagement of relevant stakeholders is considered an essential way of ensuring the long-term success of heat planning and a spatial approach has a key role in infrastructure transition, which is particularly relevant in the context of heat system transition and uptake or acceptance of heat technologies. Heat planning is a form of spatial planning approached at a very localised level with local participation. Municipal heat planning could go towards addressing that spatial dimension for the uptake of heat infrastructure. However, a stronger link needs to exist between goals set out in the NECPs and regional spatial planning laws or regulations due to the importance of land use for renewable energy and heat infrastructure integration. This entails a streamlining of provincial and municipal spatial planning regulations, especially in terms of mandatory goals to support the NECP and national climate neutrality targets. This approach should be extended to heat planning and energy spatial planning for heat and place them between the various regional approaches and goals of the NECP. As spatial energy planning for heat involves municipalities and can affect citizens, the acceptance of infrastructure investments for the energy transition is likely to be more acceptable through the use of spatial planning approaches. The impact of public acceptance of additional energy infrastructure has a spatial dimension. Spatial planning tools should support municipalities and local stakeholders with implementing national renewable energy and efficiency goals in a way that is suitable for the local scale.

Overview of NECPs

In light of the provisions for heat planning at municipal level under Article 23 of the proposed recast EED, the extent to which MS have integrated municipal heat planning as a form of energy spatial planning in the NECPs was reviewed. MS must continue, as part of their integrated NECPs, to notify the Commission of their comprehensive heating and cooling plans. The NECPs of the 27 MSs were reviewed for their coverage of or reference to (i) (municipal) heat planning, (ii) spatial planning in relation to energy, (iii) spatial energy planning in relation to heat, (iv) a national strategy or programme for heat (planned or implemented, including as part of a national energy strategy, and (v) reference to the requirements of Article 14 the EED 2012 currently in force. The NECP review revealed that none of the MS referred expressly to municipal heat planning as a term. Several countries do specifically link spatial energy planning to heat. Spatial energy planning is a broader term that can include not just heat but all spatial planning aspects of the energy value chain. These countries are Austria, Denmark, France, Luxembourg, Netherlands, Poland and Slovenia. Several countries indicated that they have implemented or are planning a national strategy or programme for heat. These countries are Cyprus, the Czech Republic, Germany, Hungary, Ireland, Lithuania and Slovenia. Finally, most MSs refer to some aspect of the comprehensive assessment required under Article 14 EED 2012, such as heat mapping or assessing the potential of heat demand or more general heat studies. However, there is not much focus on the local/municipal level as now contained in the proposed recast EED. The review of the NECP revealed that in most NECPs, apart from Austria, Denmark, France, Luxembourg, the Netherlands, Poland and Slovenia, spatial planning is mainly referred to in the context of maritime spatial planning and transport infrastructure but not in relation to heat or energy more broadly. This represents an opportunity to highlight and encourage the use of spatial energy planning more specifically in relation to heat, due to its use of many of the tools of a heat planning approach, including heat mapping and zoning and a spatial planning approach from a regulatory perspective.

Step 2 of Subtask 3.3 provides case studies of 6 European jurisdictions (4 EU + 2 Non-EU). The countries examined were Austria, Denmark, Germany, Switzerland, Poland and Scotland (UK).

To be effective, spatial planning requires governance powers across sectors and levels. Those countries which have sought to align their energy planning and spatial planning approaches through integrated spatial energy planning in addition to alignment between different governance levels are showing more progress with heat planning. This is particularly the case for Denmark, a leader in heat planning approach and Austria, which has integrated heat planning into its spatial energy planning. The case studies show that spatial energy planning initiatives relating to heat and heat planning benefit most from a combined top-down and bottom-up governance framework (as shown in the sections on Denmark but also seen more recently in Austria). Further discussion is then set out in Section 2.5. A combined top-down and bottom-up approach has contributed to broad acceptance and uptake of heat technologies, especially DH systems in Denmark. However, it is important to understand that where integrated spatial energy planning for heat or heat planning are being implemented, these can originate from different governance levels, depending on the governance framework of the jurisdiction. In Germany and Austria, the powers for spatial energy planning and heat planning reside with the regions or states. In Denmark, although national legislation and policy has empowered municipalities to take on responsibility and autonomy in relation to heat planning activities, these powers originate from the national level. The key to the success of heat planning in Denmark is the local autonomy coupled with the strong support from top-down policies and government decisions issued over decades and regularly strengthened through legislation and policies.

The other jurisdictions examined here, such as Germany, Austria and Switzerland have implemented heat planning and spatial energy planning for heat more recently. Although Austria and Germany have initiated heat planning and spatial energy planning at a regional level due to the framework of competencies for planning activities relating to heat in those jurisdictions, Austria has made more progress in aligning national heat strategy with regional integrated spatial energy planning approaches by creating a joint mandate between the national level and the regions in relation to transitioning towards sustainable heat provision. In both Austria and Germany, although the regional approaches are very promising, they can lead to an uneven implementation across the country and continued difficulty with aligning planning approaches for heat between regional and national levels. As in Germany and Austria, energy planning, in relation to heat, is conducted at the level of the Swiss regions using regional laws. Similar to Austria and Germany, there has therefore not been a uniform approach to energy and heat planning across Switzerland. Unlike Germany, although some Swiss regions take a lead on a spatial approach to heat as part of their energy spatial planning, it is not a dedicated heat planning approach. Apart from the obligation to align with national energy policy and strategy there is also not a top-down governance structure aligning with the bottom-up approach and responsibility of some of the regions as there is in Denmark and to some extent in Austria. In Switzerland as in Denmark and to some extent in Austria, a broad variety of stakeholders participate in this energy planning exercise, which includes spatial planning consultants, municipal council departments, such as urban planning and energy providers. Similar to Denmark, these actors are obliged to participate in energy planning, which can achieve broader acceptance of the proposed plans.

Scotland has similarities with Denmark in that strong national legislative and policy signals are being provided in relation to heat infrastructure. The approach in Scotland to national planning, especially relating to energy including heat, is considered to be distinctive and pioneering in the UK context, as it links national infrastructure priorities with the spatial energy planning system from the very beginning of a project through National Planning Frameworks. Scotland shows a particular strength in seeking to align its energy and spatial energy planning both at national (Scottish) level and at local level through the Scottish Planning Policy. As in Denmark, this combines a top-down and bottom-up approach in enabling cities or municipalities to take ownership of their spatial energy planning in relation to heat. It should be noted though that unlike Denmark, Scotland is a nation within the overall constitutional framework of the United Kingdom with certain devolved powers relating to energy infrastructure planning. Heat planning is not yet more developed in Poland, however there are some promising initiatives, for example Heat Roadmaps Europe has conducted a study for Poland primarily in relation to heat mapping, which can be a useful tool for initiating wider heat planning measures. Poland has also identified local authorities and local energy planning as a key role in the implementation of national policy for DH. There are some promising legislative tools in place, which might be used to support the wider implementation of heat planning.

Subtask 3.3 makes the following recommendations:

Heat planning, whether as a dedicated approach (as in Denmark) or as part of integrated energy spatial planning for heat (as in Austria) should be more widely implemented, because it has proven to be an effective tool to develop measures locally to decarbonise the heat sector. Further importance is added to a municipal heat planning approach in light of the new proposed provisions for municipal level heat planning in the recast EED. This provides a framework for improving the uptake of heat infrastructure in a way that is appropriate to each local context. This is particularly facilitated by a simultaneous top-down and bottom-up approach to heat governance.

To be effective, the municipal level heat planning must be implemented by MS in a manner that horizontally aligns or integrates the usually separate regulatory frameworks for energy planning and spatial planning, as has been demonstrated in Austria. However, it is also necessary to integrate vertical governance levels as demonstrated in Denmark. Heat planning as part of a spatial planning approach can link the local, regional and national levels but requires to be made effective via the appropriate cross sectoral governance mechanisms. A key issue is that heat can be governed in separate regulatory frameworks, either energy or energy efficiency frameworks and not in planning frameworks. The push for municipal heat planning in the proposed recast of the EED is an opportunity to support a more integrated approach between these frameworks, thereby providing a better overall system perspective to avoid the inefficiency of governing heat in separate regulatory frameworks and not aligning with the important spatial or land use aspect of heat infrastructure.

This report supports the position that polycentric energy governance approach to heat planning and integrated spatial energy planning is beneficial in parallel with the design and transformation of heating systems. A polycentric governance approach is able to integrate multiple levels from the local to the national (and beyond), whilst involving a wider range of stakeholders in the policymaking process, including municipalities and citizens. This is why Denmark can be considered to provide a best practice example for successful heat planning for heat transition. However, that conclusion is caveated by the observation in other case studies, that the governance or constitutional structure of a state matters for the efficacy of implementing a polycentric approach to heat planning and integrated spatial energy planning, as it will not always originate from a national scale (as in Denmark). The enabling framework may emanate from a more regional level (as in Austria or Germany).

The differing constitutional and governance structures in each jurisdiction must be taken into account when considering how to effectively implement heat planning, whether individually or as part of spatial energy planning. It is necessary to align the approach to heat planning with governmental structure of the jurisdiction in question with particular focus on where the powers to develop and implement heat planning and energy strategy emanate from, i.e. at national or regional level. The constitutional structure is therefore important, whether as a federal structure (Germany, Austria, Switzerland) as opposed to powers emanating from the national government (Denmark) or even as part of a devolved system as in Scotland.

Conceptualising heat planning as part of an energy spatial planning framework (e.g. Austria, Scotland and Switzerland) can support a whole systems approach that integrates the local level with decarbonisation and emissions targets at national and international levels.

Even in MS where heat planning is not yet implemented as a dedicated programme, there are windows of opportunity via national legislation for such implementation, via energy and planning legislation and regulation (e.g. Poland), however these must be effectively and consistently enforced. They should also be aligned with each other to avoid gaps in competencies for implementation.

Subtask 3.4: Cost Structures for supply, transmission and distribution of DHC

Subtask 3.4 has the objective of analyzing the cost structures for supply, transmission and distribution in the context of District Heating and Cooling (DHC) systems and networks. This section therefore reviews the literature on cost assessment methods for DHC distribution and transmission. To this end, it presents the necessary background on the supply, transmission and distribution of heat or cold as well as different methods to determine the technical characteristics of the system and its costs. Top-down and bottom-up approaches are discussed and the development of a meta-level approach that combines the strengths of both is proposed. Furthermore, the available data on a European level is reported and a case study applying such an assessment method to the whole of Germany is presented.

Subtask 3.4 has the following high-level conclusions:

For district cooling, the supply can come either from heat or from electricity whereas district heating has a much larger array of options. While CHP based on fossil fuels or bioenergy dominates the current fuel mix, alternatives such as geothermal, solar thermal or heat pumps allow for a cleaner heat supply. The generated heat is then carried to the site of demand, first through large transmission pipes that use higher pressures/temperatures to reduce losses and then through distribution grids to the destination, which have lower costs at the expense of higher losses.

The viability of DHC systems is only ensured if the combined cost of centralized heat supply and the transmission and distribution networks together is less than the cost of individual heat supply. For this to be the case, the heat demand must be sufficiently concentrated, either due to population density or because of a concentration of energy-intense demands. Indeed, dense urban areas in Europe, which constitute less than 1% of the total land areas but nearly half of all heat demand, are ideal locations for the development of DH. However, predicted improvements in the building energy efficiency might harm the viability of DH by reducing the heat demand.

The viability of DH networks can be evaluated using top-down or bottom-up approaches. Bottom-up methods such as Thermos provide a detailed spatial planning of DHC for specific locations while tools like Hotmaps or the Pan-European Thermal Atlas (PETA) have increasingly been used to generate inputs for top-down assessments. The state-of-the-art top-down approaches estimate the distribution capital costs using the method developed by Persson & Werner (2011). This approach re-quires information on the heat density, i.e. the heat demand per unit area, and on the plot ratio, i.e. the ratio of building area to land area, as well as the tuning of input parameters to the local con-text. The distribution capital cost only reflects a part of the total network cost which in turn does not constitute the total cost of the DH system.

The heat/cold supply is another critical component of DHC systems that is frequently neglected from bottom-up and top-down approaches. This can be justified if excess heat is exploited but DHC systems might even be viable with a completely new source of supply, in which case this represents an important cost component. Supply technologies can be characterized according to their investment and operational costs as well as the operational hours into baseloads and peaks. These cost components can be combined to cost functions, which in turn dictate the areas of operation of these plants in terms of capacity and full load hours for a given application.

Part 2 makes the following recommendations:

To enable integrated spatial and heat planning at national, but also regional and local levels, the development of tools and methods at the so-called meta-level is recommended. Such approaches combine the strengths of top-down methods, which have a broad coverage and are easily transferable but not spatially explicit, and bottom-up methods, which are highly accurate but require detailed and frequently difficult-to-obtain data. Furthermore, they consider not only the DHC network but also the generation of heat or cold, either excess from existing plants or new supply. Thus, such methods can achieve much higher accuracy with moderate data requirements.

The development of such methods requires the provision of additional data that is currently of limited availability or completely unavailable. There have been vast improvements in recent years but the following areas in particular exhibit significant deficits:

- Existing heat networks (e.g. German District Heating Atlas)
- Currently available heat sources, including waste heat and existing power plants, with location, capacity and temporal profiles (e.g. Pan-European Thermal Atlas)

- The potential of new heat/cold supply sources, particularly renewable ones such as geothermal, solar thermal or indirectly heat pumps, according to their economic viability and technical characteristics
- Building-level information relating to demand characteristics
- Geospatial data, including topology, road networks and tuning parameters

In order to enable the above two recommendations, policy needs to support the development, provision and regular updating of reliable data sources for DHC systems and technologies. Some innovative and useful sources have been highlighted in this report, but there is still a need to invest resources into ensuring widely available, open data is available for DHC systems, especially but not only in the above areas. Whilst the focus has been on heating systems in this report, DHC systems are likely to increase in importance in the future in the context of energy system integration, increased urbanisation and climate change resulting in greater cooling demands.

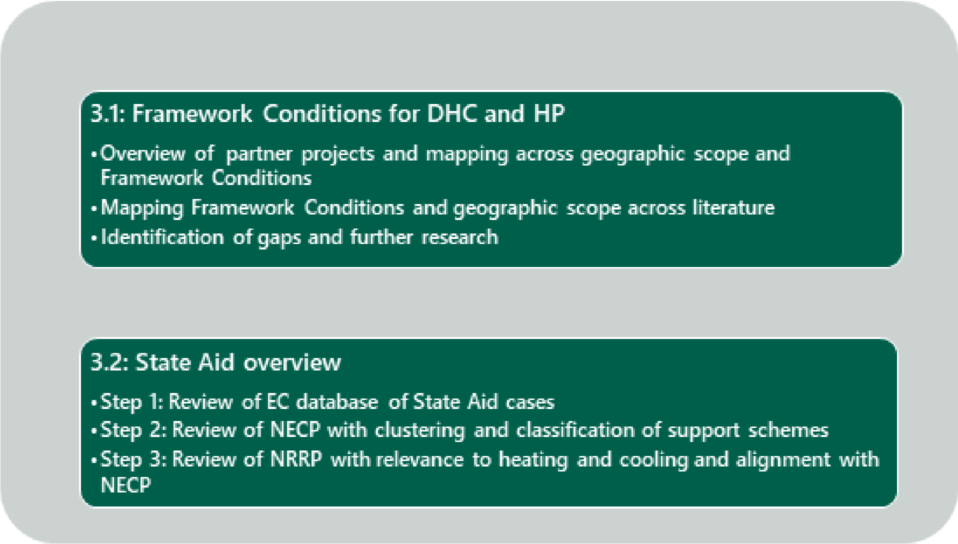
2 Introduction and overview

This is the combined report for Subtasks 3.1 to 3.4 of the project 'Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation' coordinated by the Fraunhofer Institute for Systems and Innovation Research (F-ISI), and in partnership with the Austrian Institute of Technology GmbH (AIT) and the European Heat Pump Association (EHPA), funded by the European Commission (the Project). The objective of Task 3 is to provide an overview of incentives for the uptake of heating and cooling technologies, with a technology focus on DHC and HP.

District Heating and Cooling (DHC) systems are set to make a significant contribution towards attaining climate and energy targets. This is particularly the case in more densely populated areas, where DHC is key to the decarbonisation of the heating and cooling sector. The key role of DHC in decarbonisation is supported by greenhouse gas (GHG) reduction scenarios which show high shares of heat demand via DHC networks. DHC is estimated to increase to a share of 50% of the entire heat demand in the EU by 2050 (David et al., 2017). For heat supply companies to be economically efficient, a high heat density is required. This means that heat networks are mainly located in urban areas (de Rochefort, 2018). Fleiter et al. (2017a) show that heating and cooling represent approximately 50% of total final energy demand in 2015. DHC technology is categorised into five technology generations that can be distinguished by temperature and pressure, with newer generations able to use well below 100 °C (Cf. Figure 2). This increases their energy- and cost-efficiency because of the lower primary energy requirements (Lund et al. 2014). Fifth generation heating networks that can provide both heat and cold (Buffaa, Cozzinia, D'Antonia, Baratierib, & Fedrizzia, 2019). Renewables-based DHC is derived from sources such as geothermal energy, solar thermal energy, biomass and waste heat from industrial processes. However, in most EU countries, non-renewable sources still make up a significant proportion of DHC systems. The extent of DHC deployment in the EU varies widely: some countries have an extensive track record of DHC deployment, while others still only have minimal shares of DHC in their heating technology mix (Fleiter et al., 2021b)

With increased cooling needs and energy efficiency requirements in buildings and the need to integrate greater volumes of intermittent renewables in electricity generation, Heat Pumps (HPs) also represent a key technology for decarbonisation and increasing efficiency in the heating and cooling sector (Toleikyte & Carlsson, 2021). The estimated increase of the DHC share to 50% of the entire heat demand by 2050 includes a share of 25–30% of supply from large-scale electric heat pumps (David et al., 2017). HP using renewable energy are a highly efficient technology for heating and cooling (Nowak, 2018). HPs are projected to be the second most-deployed renewable technology to 2030, supporting the growth of renewable energy in the heating and cooling sector in the EU27 from 2020 – 2030 (Toleikyte & Carlsson, 2021). Although HPs have only recently been deployed more widely, the technological concept has existed for over 150 years. However, HP are becoming essential to the energy mix for the decarbonisation of heating and cooling. HP can also provide storage and demand response services to enable larger volumes of intermittent renewables. Barriers to wider HP deployment relate mainly to policy incentives rather than technology (Nowak, 2018)

Figure 1 sets out the approach to Subtasks 3.1 and 3.2, which breaks down each task into component steps.



3.1: Framework Conditions for DHC and HP

- Overview of partner projects and mapping across geographic scope and Framework Conditions
- Mapping Framework Conditions and geographic scope across literature
- Identification of gaps and further research

3.2: State Aid overview

- Step 1: Review of EC database of State Aid cases
- Step 2: Review of NECP with clustering and classification of support schemes
- Step 3: Review of NRRP with relevance to heating and cooling and alignment with NECP

Figure 1: Approach to Subtasks 3.1 and 3.2

3 Framework Conditions for deployment of HP and DHC

This task explores the Framework Conditions (FC), which influence the deployment of HP and DHC technologies. These technologies are considered to make a significant potential contribution towards energy system flexibility and decarbonisation, however this contribution remains subject to substantial barriers, which are examined via a set of FCs based on work by Sneum (2021) (see Table 1). This paper identifies the barriers and related solutions to flexible technologies such as DHC (primarily more recent generations of DHC, the range of which are shown in Figure 2) in addition to HP. The 3rd generation of DHC systems were introduced in the 1970s and have taken a major share of all DHC systems in place since the 1980s (Lund et al., 2014). Figure 2 below, from Revesz et al. (2020), provides a visual overview of energy network development stages, including the 5th generation concept and its capabilities, showing the increase in efficiency and decrease in temperature over time. The main challenges for wider deployment of DHC systems relate to newer generations of DHC system (4th and potentially 5th generation), including in relation to regulatory and planning processes (Lund et al. 2014) – hence why this report focusses on these generations.

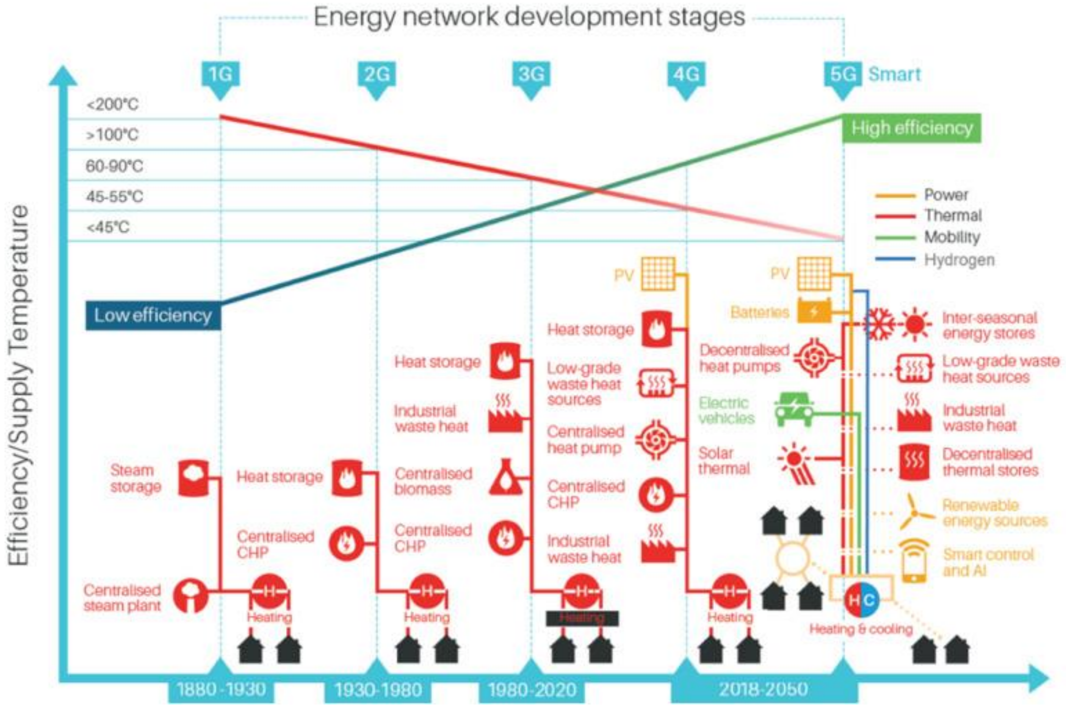


Figure 2: **DHC network development stages up to 5th generation from Revesz et al. (2020)**

Subtask 3.1 involves a critical assessment of the Framework Conditions for DHC and HP in terms of their influence on the uptake of these technologies in European countries, including the former EU28 member the UK, in addition to Norway, Switzerland and Iceland. Subtask 3.2 draws on the European Commission's database of State Aid cases, the National Energy and Climate Plans (NECP), in which the Member States (MS) of the European Union (EU) list respective financing measures, and MS National Resilience and Recovery Plans (NRRP). The approach to Subtask 3.1 summarizes the spread of partner projects, as set out in Figures 3 and 4 across the relevant geographic scope and FC, using previous and ongoing projects of partners relevant to Task 3. The reports from the partner projects and a representative selection of the literature used for Task 1[1] are then each mapped across the Framework Conditions. Gaps and further areas of research are subsequently identified.

3.1 Overview of Framework Conditions (FC)

The FCs are set out in Table 1 below and explained in more detail in each section on individual FCs.

Table 1: Overview of Framework Conditions and categories (based on Sneum, 2021)

Framework condition	Categories/barriers
1. Operational	• Operational taxes and subsidies • Electricity grid tariffs • Operational standards and procedures
2. Investment	• Investment subsidies • Capital availability • Risk premiums for financing • Pay-back time and internal rate of return/discount rate requirements
3. Permitting	• Technology bans and mandates • Legal framework for evaluation of projects related to DE • Friction in the permitting process • Physical planning • Tendering processes • Conditions for (dis)connection to the DH grid as a user
4. Ownership	• Tax- and ownership regulation • Utility regulation e.g. of rate of return and direction of revenue streams • Network governance (market/DH grid access/third-party access)
5. Technology conditions	• Technological cost • Business process costs • Supply chain maturity • Existing high-temperature systems
6. Electricity grid access	• High grid-connection cost • Limiting grid codes • Limiting grid capacity
7. Physical environment	• Limited access to energy sources • Land availability and spatial planning
8. Bounded rationality	• Organisational Community • Authority • Plant staff
9. Acceptance	• Organisational Community • Authority • Plant staff • Incumbent utilities

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[1] https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccx/2021/perceptions_final_deliverable_D1_Task_1.pdf

The partner projects are mapped across these FCs in Task 3.1. For each of the nine FCs, there is a set of identified barriers to adoption of such flexible technologies as set out in Table 1. These are particularly useful, as the barriers to flexible technologies can also present barriers to the uptake of DHC and HP technologies. It is important to note that in terms of DHC technologies, 4th and more recent 5th generation concepts provide the greatest flexibility to the energy system (cf. Figure 2). In contrast to previous iterations of DHC technology, recent generation concepts of DHC technology are aimed at contributing towards higher shares of renewables, more energy flexibility and efficiency, not just in buildings but also as part of smart energy systems, particularly in order to integrate (or couple) smart electricity, gas and DHC networks (Lund *et al.*, 2014). The individual FCs and the results from the literature review mapping process across the FCs are set out in Figures 3 and 4.

3.2 Step 1: Summary of geographic scope and Framework Conditions for project partners

Literature from partner projects has been mapped in terms of geographic scope and spread across the Framework Conditions. Partner projects are set out in Table A1 in the Annex. The partner projects were examined in the context of the FC and available output documents as set out in Figures 3 and 4 below.

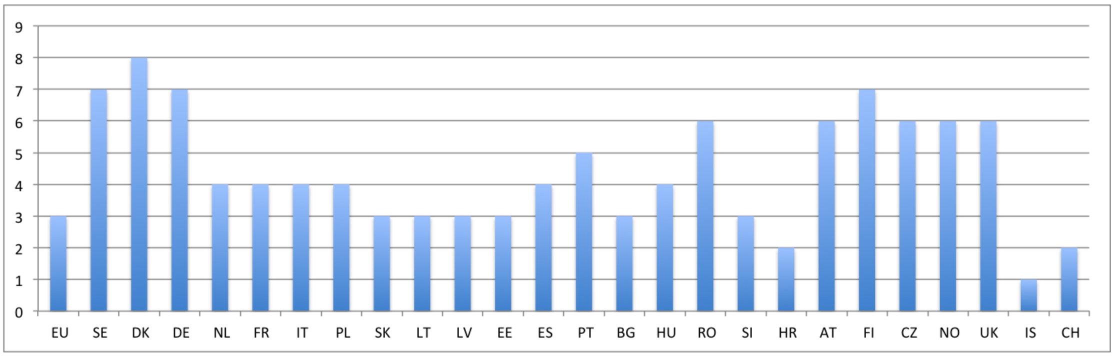


Figure 3: Geographic representation of partner projects, showing number of projects per MS

Figure 3 the extent of geographic representation across the reviewed partner projects. The count of EU countries is lower as only 3 items focused on the entire EU. The least represented countries are Switzerland, Iceland and Croatia. Out of the 26 countries represented, 6 countries, generally Eastern European countries (i.e. Slovenia, Bulgaria, Estonia, Latvia, Lithuania, Slovakia) are also less well represented. The most represented locations were Sweden, Denmark, Germany and Finland. Apart from Romania, the Nordic states and North/Western EU states were well represented.

As part of the methodology for Task 3.1, output from the partner projects was mapped across the Framework Conditions. Figure 4 shows the results of this mapping, with several Framework Conditions least represented, including *FC3 (Permitting)*, *FC6 (Electricity grid access)*, and *FC8 (Bounded rationality)*. Step 2 requires the mapping of additional literature across the Framework Conditions and geographic scope to expand the coverage of the research and with a particular focus on the Framework Conditions and countries less well represented in the partner projects.

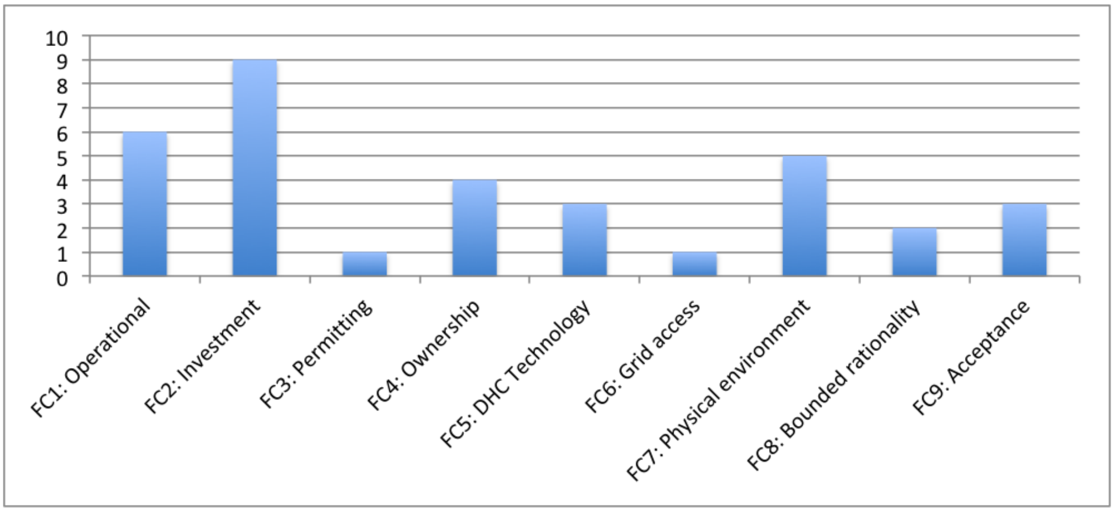


Figure 4: **Spread of Framework Conditions across partner projects, showing number of projects per FC**

3.3 Step 2: Mapping Framework Conditions across wider literature

This step requires additional screening to achieve a broader, more holistic overview of the region of interest. The literature is obtained in part from the database of literature used for Task 1 of the Project but does not include the partner projects themselves. The collection of publications encompassing relevant data from academic and policy-related studies has been used as part of the basis for the wider literature review in Step 2. This additional literature has been reviewed and mapped across the FCs and geographic scope. The results are reported below against each individual FCs. Step 2 also uses the FCs to highlight specific aspects of monetary and non-monetary incentives, such as ownership, network access and operation, in addition to policy frameworks and financial aspects.

The review of the literature shows that overall, *FC6 (Electricity grid Access)*, *FC7 (Physical environment)* and *FC3 (Permitting)* are the least represented conditions, whilst *FC2 (Investment)*, *FC9 (Acceptance)* and *FC5 (DHC Technology Conditions)* are the three most represented conditions. This is represented in Figure 5.

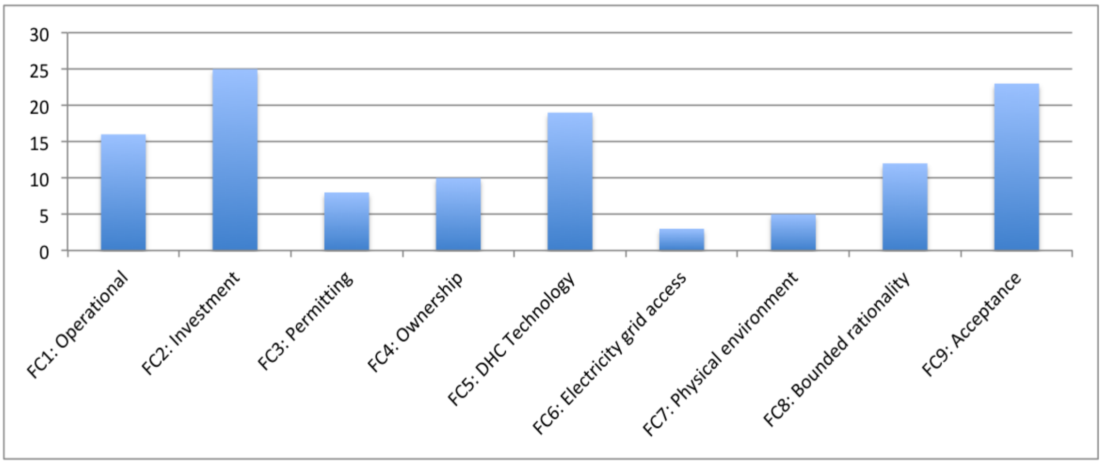


Figure 5: **Spread of FCs across wider literature, showing number of sources per FC**

In terms of geographic scope, the top five most represented geographic areas across the reviewed literature shown in Figure 6 are Germany (38), Sweden (31), Denmark and Spain (both 27), Bulgaria and Italy (21). With the exception of Bulgaria, most of the better-represented countries remain Northern and

Western European countries. The least represented countries within the EU are the Czech Republic and Croatia (both 18). With the exception of Portugal and Bulgaria, most of the less well-represented countries are Eastern and Southern European countries. This may be partly due to a focus on countries where the deployment of heating and cooling technologies has been relatively successful, such as Denmark, Sweden and Germany. The EU is measured as a separate category, as several items in the literature review refer to an overall EU-wide study, mostly still encompassing the former EU28 and therefore including the UK, but excluding Switzerland, Iceland and Norway. Where these countries are included, Iceland and Switzerland are the least represented countries in the reviewed literature.

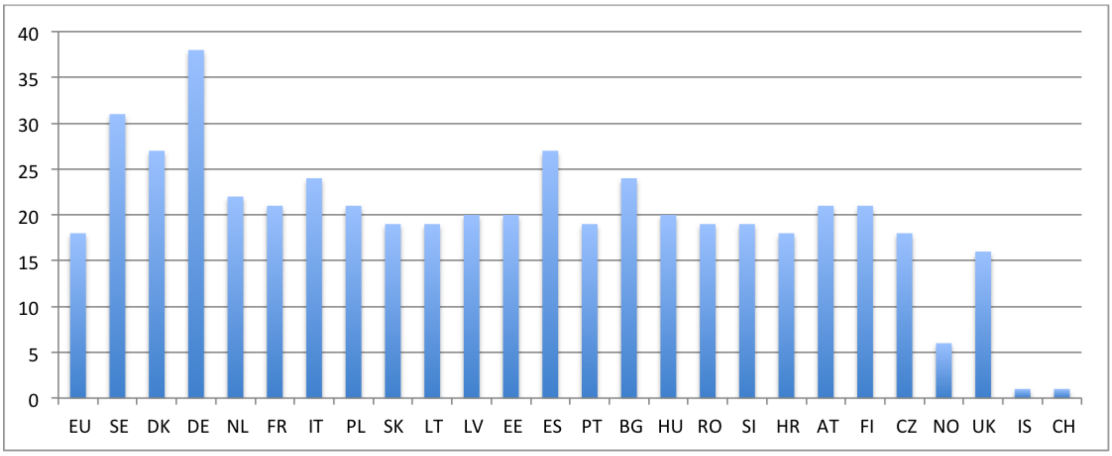
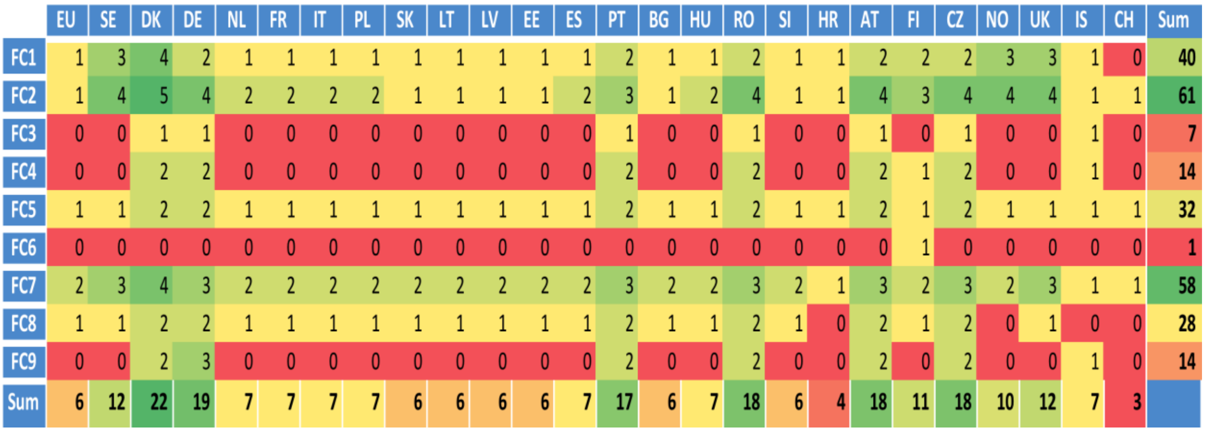


Figure 6: **Spread of literature across geographical scope, showing number of sources per MS**

Figure 7 below provides an overview of the FCs in each MS according the literature reviewed. The table is presented as a type of heat map, showing the most (green), less (yellow) and unrepresented (red) FCs in the countries within the geographic scope. Denmark, Germany, Portugal, Romania, Austria and the Czech Republic are the most represented countries across the FCs, even if countries such as Sweden and Spain have more literature content than those countries (apart from Germany), as shown in Figure 6.



	EU	SE	DK	DE	NL	FR	IT	PL	SK	LT	LV	EE	ES	PT	BG	HU	RO	SI	HR	AT	FI	CZ	NO	UK	IS	CH	Sum
FC1	1	3	4	2	1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	2	2	2	3	3	1	0	40
FC2	1	4	5	4	2	2	2	2	1	1	1	1	2	3	1	2	4	1	1	4	3	4	4	4	1	1	61
FC3	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0	1	0	7
FC4	0	0	2	2	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	2	1	2	0	0	1	0	14
FC5	1	1	2	2	1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	2	1	2	1	1	1	1	32
FC6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
FC7	2	3	4	3	2	2	2	2	2	2	2	2	2	3	2	2	3	2	1	3	2	3	2	3	1	1	58
FC8	1	1	2	2	1	1	1	1	1	1	1	1	1	2	1	1	2	1	0	2	1	2	0	1	0	0	28
FC9	0	0	2	3	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	2	0	2	0	0	1	0	14
Sum	6	12	22	19	7	7	7	7	6	6	6	6	7	17	6	7	18	6	4	18	11	18	10	12	7	3	

Figure 7: **Overview of FCs in MSs, showing number of sources per FC and MS**

3.3.1 FC 1: Operational signalling

Operational signalling refers to the need for technologies with flexibility potential, such as HP and newer generations of DHC to have electricity and DHC market signals to respond to. These operational signals are typically provided by electricity markets. Certain barriers can weaken or remove market signals for flexible technologies. These barriers include the following and are discussed in the following sections:

- operational taxes on flexible technologies and subsidy schemes
- electricity grid tariffs and energy costs
- operational standards and procedures
- price regulations such as maximum price limits.

3.3.2 Operational taxes on flexible technologies and subsidy schemes

Operational taxes on flexible technologies, such as taxes on the use of DHC and HP technologies tend to reduce their competitiveness (Sneum, 2021). Taxes for electricity and fuels have an effect on the marginal cost between different DH technologies. For example, in the Nordic and Baltic states, the lack of taxation on biomass in addition to levies on the use of electricity, inhibit the uptake of electric boilers (EB) (Münster *et al.*, 2020). Subsidy schemes are considered in further detail under Task 3.2.

3.3.3 Grid tariffs and energy costs

Where technologies are in the early phases of deployment this can create certain risks for projects. There is a lack of price volatility and limitations on design, which prevents the efficient functioning of markets for flexible technologies. This causes inflexible operation from, for example HPs’ baseload operation. Levies on electricity may also inhibit the operation of HP. The operation of PtH technology more broadly can be particularly dependent on the level of electricity grid tariffs. Revenues from grid tariffs tend to increase as the share of PtH increases (Sneum, González and Gea-Bermúdez, 2021). As such, for example time of use tariff schemes provide greater flexibility, as the operation of PtH can be managed around peak prices. Alternatively, load demand or capacity tariffs based on the maximum monthly electricity load can inhibit the flexible use of PtH, in turn reducing the integration of wind power and contribution to decarbonisation (Münster *et al.*, 2020).

3.3.4 Operational standards and procedures

This barrier relates to the standards and procedures for not only connecting to the electricity system but also for the sale of produced energy. This particular form of barrier is closely linked to several other Framework Conditions, including *FC3 (Permitting)*, *FC4 (Ownership)*, *FC5 (Technology conditions)* and *FC6 (Electricity grid access),* which are discussed in detail in the relevant sections below. However, in general, any discriminatory entry requirements in the form of standards and procedures, can negatively affect the access flexible technologies like DHC and HP have to markets, which would otherwise provide efficient market signals (Sneum, 2021). For example, under *FC4 (Ownership)*, this means strict rules on third party access (TPA) and limitations in ownership, such as unbundling rules. Existing rules on standards and procedures or high costs for review and inspection of technology and connections (*FC3 (Permitting)*), may be caused by markets and governance frameworks which are not prepared for particular technologies. To overcome such barriers, the transaction costs of market access (particularly smaller participants) and removal of TPA restrictions for certain technologies and capacities should be considered (Sneum, 2021).

3.3.5 Price regulations

Regulated price setting and price control can be a barrier to the operational signalling through markets (Sneum, 2021). In a review of price regulation covering the countries within the geographic scope of this study, Bacquet et al. (2021) show that there are three categories in terms of degree of regulation: no specific regulation or oversight, just competition law enforcement, (ii) prices are defined by the DHC operator via a price setting mechanism, and (iii) prices are defined by the regulator or operator via ex-ante control or approval. In the majority of countries (41%) prices are required to be approved or set ex-ante by the regulatory authority. 31% of countries have no specific price regulation relating to DHC. 28% of countries implement a price rule, for example in the form of a proportion or cost-based mechanism (Bacquet et al., 2021). Ex-ante price control is mandatory in some countries for all supply of DHC, whereas in others, price control is only available on request and governed by competition law, for example if implemented as a result of complaints from individual customers (Bacquet *et al.*, 2021). Egüez (2020) examines the connection between the unregulated price of DHC in Sweden, which differs substantially among different networks and network ownership status of the heat network companies in terms of private or municipal ownership. Data is taken from the period 2012-2017. The study reveals that unregulated district heat prices are higher in DHC networks under private ownership than in municipal ownership, especially in relation to the fixed component of the price. The variation is in part explained in terms of the differing objectives of private versus municipal companies. The study also finds that DHC prices have a positive correlation with the market prices for HP, whether integrated into a private or municipal network. Egüez (2020) suggests that this is due to a general price-setting strategy based on the price of substitutes. DHC networks are generally considered natural monopolies, similar to other grid-based systems, creating the need for regulation of prices (Wissner, 2014). In a review of pricing regimes, Bacquet et al. (2021) show that most European countries examined have some form of price control, because they regard DHC as a natural monopoly due to lack of competition on the retail market. This warrants a degree of price control to protect connected consumers against unjustified price increases. Liberalised prices for DHC are still not the norm. The review shows that in more than half of the analysed countries, DHC prices and price-setting mechanisms are regulated either ex-ante or ex-post, even if the degree of regulation varies greatly. DHC prices are liberalized in less than half the reviewed countries. Some jurisdictions have mandatory price control applicable to all DHC suppliers, whereas other countries apply price control on request to the regulatory authority, pursuant to consumer complaints (Bacquet et al., 2021).

Pricing models are a key way to improve market signals and encourage flexible technologies like DHC. According to Bouw (2017), customer choice can be increased by applying different price models. Yet, these are not often implemented in existing DHC networks. This may be due to particular challenges associated with regulating the pricing of DHC systems. The supply of DHC is not in direct competition with any other source, in contrast to the electricity and gas sectors, as DHC systems are mainly unconnected and isolated systems. This removes customer choice between different DHC providers (Wissner, 2014). Several price models are based on examples of Nordic DHC networks. However, there are other instruments that may be used to create a good deal for consumers, such as offering a discount to competitive alternatives, long-term price guarantees, investment support to allow consumers to participate and invest, and technical guarantees. Bouw (2017) therefore recommends a set of general conditions for the effective implementation of price models. These are (i) legal support for implementation of pricing models and allowing experiments with different options on a smaller scale, and (ii) sufficient financial options in order for district heating companies to apply alternative price models, as some price models entail more risk, such as variable tariffs. The tension is that the aim of many alternative price models is to minimize costs for consumers, but this can negatively impact the income of DHC companies. Cost reduction may therefore need to be achieved in a different manner. District heating companies must convince consumers to switch through attractive deals and ensure customer satisfaction. This means factoring customer needs to encourage a willingness to pay. A good deal for consumers therefore links to customer satisfaction. One recommendation is flexible pricing options for consumer choice to fit in with customer needs (Bouw, 2017). Generally, tariffs structures fall into two categories, (i) period or time-dependent rates and (ii) quantity-dependent rates (Bacquet et al., 2021). Rates can also depend on the return temperature or efficiency of the product. Further specific examples of flexible pricing options within those categories are provided by Bouw (2017) and include:

(i) different weighting of connection fee in terms of fixed and variable costs;
(ii) different price structure for different buildings;
(iii) linking price to capacity;
(iv) different prices depending on the sustainability of the product; and
(v) differentiating through extended service offers.

Context is a critical factor when assessing consumer response to energy prices. It is recommended that identification of choices and behaviours relating to DHC technologies requires further study taking into account demographic diversity, economic constraints and institutional contexts (Magdalinski *et al.*, 2017). This approach is supported by Bacquet et al. (2021), who emphasise the importance of carefully assessing the selected tariff option, supported by technical and economic impact evaluation.

3.3.6 FC 2: Investment

Investment incentives can be impacted or limited by certain barriers, including:

- investment subsidies
- capital availability
- risk premiums for financing
- pay-back time and rate of return/discount rate requirements.

The investment climate is critical to the uptake of DHC and HP technologies. Financial constraints are common barriers for new technologies, including for example heat from waste heat technologies (Brueckner *et al.*, 2014). Certain support mechanisms, such as subsidies can sometimes reduce the competitiveness of new technologies. Further barriers to investment include the level of access to capital, to create reliable streams of revenue. In addition, uncertainties relating to the boundary conditions such as availability of waste heat sources, energy prices and the economic benefits of increased flexibility, can also present barriers to uptake. Subsidies for competing technologies, but also lack of financial institutions and instruments and high capital costs resulting from the perceived risk of certain technologies also present barriers to investment. Overall, financing challenges may create more difficult conditions on pay-back time, discount rate or rate of return (Sneum, 2021).

3.3.7 Investment subsidies

Sneum (2021) points out that investment subsidies for competing technologies such as gas boilers may reduce the competitiveness of flexible technologies. In addition, as for operational subsidies set out in *FC1 (Operational signalling)*, subsidies that distort or dampen market signals can also affect the competitiveness of flexible technologies. Therefore where this is an issue, it can be better to address issues relating to access to capital, e.g. lower interest and long-term loans to reduce perceived risks, or more market-based subsidies such as premium schemes (Sneum, 2021). However, it should be noted that subsidies have played an important role in supporting wider deployment of renewables-based DHC. To meet renewables targets and achieve higher shares of renewables-based DHC, MS have used a range of support schemes (Bacquet et al., 2020). Investment subsidies can provide economic incentives generally (Sneum et al., 2016). Support mechanisms and subsidies are considered in more detail in the discussion of Task 3.2 (Overview of State Aid). However, in a study that seeks to address this issue, Steinbach et al. (2013) evaluate policy instruments for financing renewables-based heat without public funds and argue that premium-based remuneration or support has greater acceptance. Investment incentives are provided in terms of one-time payments similar to investment grants. To receive the premium, investors must provide a one-time verification of the installment and operation of the renewable heat based generator issued by a certified installer. In terms of a link with *FC4 (Ownership)*, different forms of organizational and ownership models for DHC and design of economic incentives, such as subsidies, tariffs and loan conditions are also an important determinant of investment levels (Krog *et al.*, 2020a).

It should also be noted that financial incentives are not always the only rationale for investment and that investment support needs to be combined with clear information. Clear and concise information about existing incentives and funding options, and easy access to funding with support through consulting and clear forms can be effective. Where existing policies or regulations are not supportive, often the determination and pro-environmental attitude of consumers can motivate uptake and participation in a burdensome process, more than funding and other incentives (Carrus, Chokrai, *et al.*, 2019), which also links to *FC8 (Bounded rationality)* and *FC9 (Acceptance)*. Substantially increasing the direct subsidies for renewable heating can be a strong motivation to residential users to replace existing heating systems. However, where potentially higher costs to public budgets is a policy issue, a different option may be a scrap bonus scheme on replacing old heating systems with renewable and efficient ones (Decker and Menrad, 2015). Support mechanisms are considered further in the assessment of State Aid in Task 3.2.

3.3.8 Capital availability

Access to capital, in terms of lower interest rates and long-term loans can be more effective than price-based subsidies for enhancing competitiveness of DHC and HP technologies (Sneum, 2021). The UK's former Department of Energy & Climate Change (DECC) conducted a study to assess the barriers and drivers for energy efficiency measures generally, including heating systems, in Small and Medium Sized Enterprises (SMEs). Access to capital was commonly cited by interviewed businesses as a barrier to implementation of efficiency measures. Yet, their data also shows that 30% of improvements do not actually require capital expenditure. This may suggest a possible misconception amongst SMEs that energy efficiency improvements require capital, acting as a barrier to uptake. Some of their data also suggests that the value of capital investment does not have much effect on implementation rates. SMEs seem as willing to invest in high-cost improvements as much as they are in low-cost ones, which suggests that other drivers and barriers apart from capital can be an issue. Where no capital investment was required, the implementation rates remained the same. As such, the requirement for capital investment is not a significant barrier on its own (DECC, 2015). It may also be helpful to distinguish between types of building stock: in retrofit buildings, the cost of system installation can sometimes be significant but this also provides an opportunity for wider efficiency improvements; in relation to new builds, where opportunities can arise early on, capital costs for laying pipes might be reduced, for example, through sharing civil engineering costs with other infrastructure. If new builds are very efficient, these can connect to more efficient 4th and 5th generation heat networks which are capable of operating at lower temperatures and can therefore be more efficient and support low carbon heating technologies (de Rochefort, 2018).

3.3.8.1 Risk premium for financing, pay-back time and rate of return/discount rate requirements

Rate of return can affect investors' choice of technology. Risk in relation to DHC is connected to uncertainties relating to the future conditions of DHC, for example in terms of the return on investment. Risks might relate to overall performance, product quality, manufacturing warranties, viability, availability of fuels, uncertainty over future prices, and cost or availability of servicing. Additional risks also relate to the uncertainty of future revenue, and market risk (Sneum, 2021). Applying a discount rate that is 'too high' within the regulatory framework can lead to rejection of projects that support decarbonisation. In Denmark, for example, it is acknowledged that the appropriate discount rate should vary with the maturity of a project. Overall, Freeman et al. (2021) show that in the context of the OECD, different countries take different approaches to discount rates. Different approaches incorporate varying views on: (i) importance of normative and positive considerations of discounting, (ii) maturity of the project, and (iii) the treatment of risks (Freeman et al., 2021).

Another way to consider investment policy is to break down the related policy recommendations according to the share of renewable heat within a country. Collier (2018) makes the following proposals for polices, depending on renewables share. In countries with a medium share of renewables-based heat (20-40%), countries should set targets and develop strategies for further decarbonisation of DHC. In countries with lower shares of renewable heat (10-20%) and some DHC as opposed to extensive DHC networks, countries should develop regulations for building renovations that require a specific share of renewable heat or connection to DHC. Such countries should incentivise DHC expansion with a specific focus on low carbon heat sources. For countries primarily relying on natural gas with extensive gas grids, low gas prices and low shares of renewable heat or DHC, in order to increase the share of renewable heat over time policy approaches should start by setting clear targets and developing trajectories and strategies. This should be combined with the introduction of carbon pricing that is progressively increased over time and support should be provided for Research & Development (R&D) on innovative solutions. Finally, for countries which have no renewable heat policy, long-term ambitions should be set out for example to 2050 so that heat can contribute towards low carbon transition goals. In the medium term, renewable heat targets to 2020 and 2030 should be set out. Such countries should implement a package of policy measures, which target both economic barriers in terms of availability of support mechanisms or carbon taxes and non-economic barriers in terms of for example building codes, obligations and installation certification (Collier, 2018). This ties in with Hvelplund and Djørup's (2020) proposal that a multi-faceted approach is needed for decentralised energy systems to support investment in technologies like DHC and HP.

A multi-faceted approach aligns with the argument that policy packages, which combine several policy measures, even where these may be weaker measures are effective for deployment of DHC and HP whilst supporting decarbonisation (Büchele, Kranzl and Hummel, 2018). A contextual or multi-faceted approach may also be able to for example address the potential energy efficiency paradox (EEP). The EEP denotes the phenomenon where consumers fail to adopt cost-effective, energy-efficient technologies in favour of less efficient technologies which undermines initiatives to reduce energy consumption and CO_2 emissions (Burlinson, Giulietti and Battisti, 2018) or where firms that otherwise behave in an economically efficient manner make choices that do not optimize profits (DeCanio, 1998), including choices relating to energy efficiency measures (van Soest and Bulte, 2001). This concept is also referred to as the energy efficiency gap (Jaffe and Stavins, 1994). DeCanio (1993) links the failure of energy efficiency investments to issues with bounded rationality discussed further in *FC8 (Bounded rationality)* below. In an analysis of attempted improvement to energy efficiency in the residential sector in the UK (which produces around 13% of total direct greenhouse gas emissions), Burlinson et al. (2018) show that policy intervention to improve energy efficiency had limited success. Partly in response to cuts in subsidies for renewable technologies since 2012, UK residential consumers' uptake of cost reducing technologies, which include DHC technologies, has slowed. The authors conclude that the technology uptake decisions for DHC of residential consumers is indeed associated with internal rates of return which are much higher than market rates, which adversely affects decisions to invest in energy efficient technology and propose this as evidence of the existence of the EEP (Burlinson, Giulietti and Battisti, 2018).

3.3.9 FC 3: Permitting

Projects usually require a permitting phase in order to be installed and operated. This Framework Condition therefore relates for example to technology bans and spatial planning and siting. Another aspect is the permitting process itself, including the legal framework for DHC and HP projects. The length and ease of the process, including procedures in relation to consenting and licensing, can pose barriers to projects. One cause is outdated or inadequate regulation. Permitting is therefore considered to be a subset of the broader term regulation (Sneum, 2021). Barriers to DCH and HP technologies presented by the permitting process can include the following as discussed here:

- Technology mandates and legal frameworks
- Length and ease of permitting process and physical planning

3.3.9.1 Technology mandates and legal frameworks

Obligations as to the use or prohibition of certain technologies may inhibit their uptake. Examples from the Danish regulatory framework include giving priority access to non-flexible technologies or mandating the use of specific technologies, such as heat supply from cogeneration in large Danish cities, or mandates on fuel sources that may not contribute towards decarbonisation to the same extent, such as natural gas. There may also be a lack of legal and regulatory frameworks for some technologies, for example having to comply with separate regulatory frameworks for different technologies, such as electricity and heat supply regulations (Sneum, 2021).

Some examples of technology bans or barriers with an equivalent effect to technology bans are provided by Braungardt et al. (2019) in relation to the lack of methodology for calculating the renewable share in the Renewable Energy Directive (RED) 2018 (Directive 2001/2018/EU), and by Persson and Münster (2016) who emphasise the need for alignment of waste management policies, relating to waste to energy conversion, with energy system regulations to increase access to heat distribution infrastructure. In relation to cooling at the EU level, Braungardt et al. (2019) highlight the lack of methodology for calculating the renewable share of cooling in Article 5 of the Renewable Energy Directive (RED) 2018 (Directive 2001/2018/EU), despite the Commission's obligation to establish a methodology for calculating the quantity of renewable energy used for cooling and district cooling by December 2021. Most cooling systems are currently based on electricity (Braungardt et al., 2019). The RED 2018 does not set out a methodology for reporting renewable cooling. This means that MSs are not able to factor in renewable cooling in terms of its renewable energy contribution. One solution is the use of minimum requirements for cooling relating to the efficiency of the cooling system, minimum requirements for temperature of the heat sink that the heat is transferred to and requirements in relation to the type of heat sink (Braungardt *et al.*, 2019). In relation to heat from waste incineration, Persson and Münster (2016) maintain that waste is an important alternative fuel for power and heat generation, as energy recovery from waste is an effective way to reduce landfilling and avoid disposal emissions whilst also reducing the equivalent demand for primary energy supply. However, a key means of obtaining the full benefits of heat from waste incineration is an existing local heat distribution network, otherwise large-scale recovery and utilisation of heat from waste incineration is not possible. This is why EU waste management policies need to align and interact effectively with corresponding energy system related regulations and concerns. Although there are already supportive provisions in the Waste Framework Directive (Directive 2008/98/EC) whereby it has become possible for efficient plants to be categorised as energy recovery operations instead of just waste disposal activities, higher targets for recycling shares in addition to complete landfill bans for all recyclable and biologically degradable wastes would strengthen support for heat from waste incineration.

Until recently, despite recognition of the role of efficient and flexible heating technologies to meet decarbonisation goals, there are no legal obligations at the EU level to implement this technology specifically (Colmenar-Santos, 2017). There is support for heating technology in several provisions of EU law. For example, Article 23 of RED 2018 includes a target for an annual increase of the percentage of renewable heating and under Article 24 RED 2018 an annual increase in the share of DHC from renewables. Article 24 also encourages MSs to implement regulations that provide third party suppliers who are producers of renewable energy with access to DHC grids. Article 14 of the Energy Efficiency Directive (Directive 2012/27/EU) includes provisions for developing the economic potential of efficient DHC but no mandate to use DHC. Under the Energy Performance of Buildings Directive (Directive 2010/31/EU) MSs need to include the concept of nearly-zero-energy buildings in building codes and regulations. Article 15(4) of RED 2018 contains a requirement for a minimum level of renewables in buildings, for example through renewable heating from efficient DHC systems. Therefore, only recently has the legislative framework at EU level provided a stronger signal to DHC implementation.

3.3.9.2 Length and ease of permitting process and physical planning

Complexity and uncertainty in permitting has the effect of undermining uptake of DHC and HP projects. This also relates to the extent of time and financial cost for zoning or inspection, complexity and duration of procedures for connecting low-voltage distributed generation. Regulations on siting and authorities' lack of knowledge on certain technologies in terms of siting and construction, and complex administrative processes generally contribute to lengthy processes. This includes difficulty in amending license or permit conditions for existing technologies to incorporate DHC and HP. To overcome these barriers, Sneum's (2021) proposals include the streamlining of the permitting process, introducing Megawatt (MW) thresholds which allow eligible projects to be subject to less stringent requirements and more certainty in relation to planning timelines. Overall, reform of legal frameworks and regulations should take a broader energy system perspective to avoid some of these barriers (Sneum, 2021). Planning and permitting processes are particularly important to all generations of DHC technology (cf. Figure 2). To contribute towards future sustainable energy systems, policy and regulatory approaches for DHC have to support suitable planning structures within a broader institutional framework that also includes appropriate cost and motivation structures, such as subsidies. Planning processes need to also facilitate the transition to 4th and 5th generation DHC in the current supply chain in new supply areas, such as new neighbourhoods. Planning for 4th and 5th generation DHC should focus more on integrated resource and energy system planning than previous concepts of DHC. The planning procedure should allow for aligning energy supply with energy efficiency measures (demand), as this enables the integration of larger volumes of variable renewable energy cost-effectively into the overall energy system. In existing buildings, smart meters, for example, could provide the information required for such alignment. The information for such synchronizing would rely on improved communication in smart energy systems. This means that providers of energy efficient and intermittent renewable energy systems should be given analytical ability and a means of communicating with existing supply companies (Lund et al., 2014).

In addition, a shift to smart energy systems and 4th or 5th generation DHC necessitates a different approach in planning and implementation for heating sector development to allow for better and effective system design that avoids over-investment in larger infrastructure (Krog et al., 2020). Although focusing more broadly on enabling factors for collective action in the energy transition but also looking at heating and cooling and the extent that such factors have on consumer behaviours and therefore uptake, Carrus et al. (2019) find that specific barriers must be addressed. This also relates to FC9 (Acceptance). Those relevant to FC3 (Permitting) and DHC/HP in particular include the following by Carrus et al. (2019):

- clearer legislation, which harmonises regulatory frameworks;
- harmonisation and compliance between national, regional and local policies as regards funding, incentives, regulations;
- clearer and concise information on existing incentives;
- easy access to funding through, for example, support and consulting, clear documentation;
- clearer and better administrative procedures, particularly in terms of speed of handling of cases and simplified procedures; and
- in relation to buildings, and therefore relevant to DHC and HP, simplification of administrative procedures generally.

3.3.10 FC 4: Ownership

Ownership and taxation can influence decisions on operation and investment, since expenditures can be treated differently depending on the applicable tax code. Absence of ownership and access may also inhibit stakeholders from taking action in relation to flexible technologies (Sneum 2021). Barriers include the following:

- Ownership regulation
- Utility regulation
- Network governance (market/DHC grid access/ TPA)

3.3.10.1 Ownership regulation

Ownership regulation is also associated with various degrees of unbundling, which entails the legal or administrative separation of different segments of the energy supply chain integrated into one company or entity. So far, and in contrast to electricity markets, the EU has not set out unbundling requirements for DHC companies and they remain largely integrated. According to a survey conducted by Bacquet et al. (2021), the few countries which do have some degree of unbundling requirement for DHC are Hungary, Lithuania and Romania but to varying degrees. It is not yet clear that unbundling for DHC markets would lead to greater efficiency and lower heat prices (Bacquet et al., 2021). A degree of vertical integration is generally seen as necessary for all but the largest, city and regional-wide DHC businesses. This is because heat networks are not considered large enough for economically viable unbundling to be implemented, and as discussed below, TPA can be challenging in a closed-loop system. Significant expenditure is linked to the separation of different DHC business functions, including ongoing transactional costs between the different interconnected parties (Snodin, 2020). Ownership models are also relevant to enabling waste heat integration, as set out for example by Schmidt et al. (2020). The authors highlight Denmark as an example of good practice in terms of successful business and ownership models, where several models are used to allow the DHC operator and the company which produces the waste heat to coordinate. The three moost common models are (i) where the DHC operator has the investment and ownership, (ii) the waste heat producer has the investment and ownership, or (iii) where the investment and ownership are mixed. Further solutions to ownership issues more generally include reforming regulation to enable deployment of specific categories of generators, such as universities, but also ensuring that regulatory conditions are attractive through bespoke conditions aimed at certain types or sizes of organisations (Sneum, 2021).

3.3.10.2 Utility regulation and network governance

The key question in relation to the extent of utility regulation and heat network governance, is whether to consider DHC networks as natural monopolies and regulate them accordingly. According to Wissner (2014), DHC systems are natural monopolies, due to the characteristic of being a grid-based supply system like gas or electricity (Wissner, 2014). To prevent the abuse of that natural monopoly position, a certain degree of regulation is usually applied to companies operating networks to ensure a level playing field. Under the RED 2018, one of the means by which MSs can maintain competition in DHC networks is to grant rights to access the DHC grid to producers of renewable heat and cooling but also waste heat. Such rights are termed Third Party Access (TPA) and are a form of access regulation, which allows parties who are not the network operator to access the network, as a supplier or producer. As such, it is a policy tool used to correct the market failure of imperfect competition in grid-bound infrastructure. The advantages of TPA particularly for consumers are the potential for wider choice of retailer or producer and lower costs (Bouw, 2017).

Greater choice generally strengthens competition and should lead to lower prices for consumers. It should be noted, however, that although a DHC grid itself is likely to constitute a natural monopoly, other parts of the heating and cooling supply chain, such as production or retail are not. Wider competition in those segments can therefore be economically viable, as parties do not have the same level of high sunk costs as with network infrastructure. Although technical restrictions for smaller grids could prevent the economic operation of further production units, it is considered that competition in a heat production market is viable in larger DHC networks (Bacquet et al., 2021). Gas and electricity networks are already subject to TPA under EU regulation. However, when considering the application of TPA to DHC networks, it is necessary to consider their specific characteristics. DHC networks are closed systems and the return temperature determines the performance of production units and efficiency of the overall supply chain (cf. Figure 2). The effect of individual consumers on each production unit in a network regulated by TPA, in addition to which incentives are available to lower temperatures, is as yet unknown, which could cause issues with system optimization. In relation to DHC networks, TPA could actually lead to higher costs for operating and coordinating the network. Overall, the separation of distribution and generation may not only lead to technical challenges in terms of operating and coordinating the networks but also inefficiencies due to a lack of integrated operation and therefore higher costs (Bouw, 2017).

Although some of these technical issues with the supply chain and economic inefficiencies can be addressed through contracts between network operators and producers, TPA may lead to increased costs for the system operation due to issues with an unbundled or separated supply chain (Bouw, 2017). Bürger et al. (2019) also highlight that increased regulation of the heat network can have both positive and negative effects on the overall efficiency of the DHC network (Bürger et al., 2019). Important to consider here are the technical characteristics of the DHC grid, for example highly-local nature. Unlike the electricity sector, it is not economically viable to transport heat long distances due to efficiency losses, meaning production units should be situated near to end consumers. The result is a restriction of additional production units, leading to less production competition. However, TPA may offer good options for smaller waste heat production and renewable energy sources to gain access to the network (Bouw, 2017).

In relation to the link between TPA and facilitating decarbonisation, Bürger et al. (2019), argue that TPA cannot sufficiently enable the expansion of renewables for the DH sector. Parallel and complementary policy measures are needed to help shift the DH sector towards 4th and 5th generation DH systems. This means that more variety in models of TPA should be considered and ownership structures in different markets are important factors for determining appropriate TPA models. Together, Germany, Poland, Sweden, and Denmark account for about 52% of all DHC customers in Europe. Denmark is distinct because the DHC market is dominated by non-profit ownership structures, such as cooperatives and municipalities. The Danish regulatory framework is very customer-focused, which means that enforcement of TPA is not a big priority for Danish policy makers. These conditions are however unusual in the European context (Bürger et al., 2019). The authors provide a helpful visual of ownership structure in the main district heating markets in Europe (Poland, Germany, Sweden and Denmark) by number of companies between 2008 and 2016, reproduced in Figure 8 below.

Vertically integrated, profit-oriented businesses still hold a significant share of the DHC sector. Denmark has introduced competition for the production and retail elements of DHC for large scale systems with a capacity of more than 100 MW, minimum network distance of 50 km supplying over 25,000 customers, and where customer rights are not guaranteed through the governance framework and business ownership structures (Bürger et al., 2019), however further changes are due to be implemented via the revisions of the Renewable Energy Directive (EU/2018/2001).

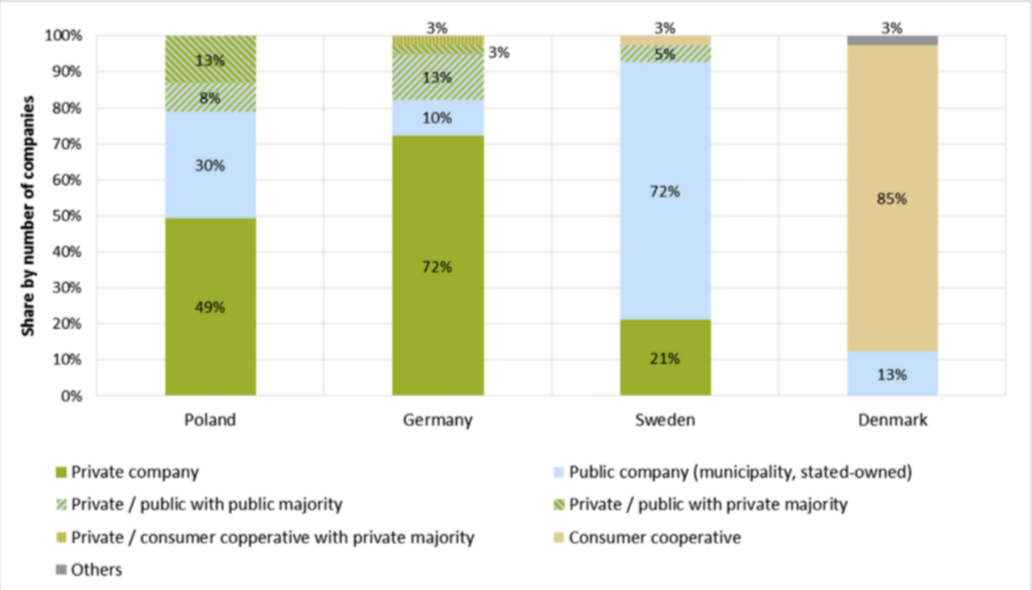


Figure 8: **Ownership structure in main district heating markets in European MSs by number of companies (different base years, 2008–2016) from Bürger, et al. (2019)**

Even though DHC networks have monopolistic characteristics, a vertically integrated district heating company can be more or at least not less efficient than a TPA based network. This is particularly the case where the network is operated by a local public body, such as a municipality for example, on a cost-covering basis, which restricts the incentive for monopoly rents. Ironically, there is a risk that a publicly owned cost-covering company could be replaced through the introduction of TPA and opening up of the market to other types of businesses by an (often privatised) profit-maximizing business (Bouw, 2017). Wissner (2014) shows that in Germany, the DHC sector is not liberalised but represents an important share of about 14% of the heating market (as at 2014). After gas and oil, district heat is the third biggest heat provider for the residential sector. Importantly, the ownership structure of DHC companies varies from large transnational, shareholder-owned companies to municipal entities. Most DH grids are shorter than 1 km and so do not represent the larger systems which might benefit from TPA (Wissner, 2014).

DHC networks are not subject to the incentive regulation applied to electricity and gas utilities and networks. At a local level, there is only weak ex-post regulation of end-user prices. In terms of ownership regulation, therefore, accounting unbundling of generation, distribution, and retail services may achieve better cost transparency and incentivise heating companies to provide fairer prices (Wissner, 2014). Bacquet et al. (2021) show that for DHC systems generally, public ownership is the predominant model, yet for cooling systems, private ownership is more frequent in comparison with heating systems. The ownership of heating systems is shown in Figure 9 below.

In relation to TPA, although regulation could be technically feasible, it may not be economically necessary. Bürger et al. (2019) explain that the benefits and drawbacks of different TPA models strongly depend on specific policy targets. Where the goal is to increase consumer choice, the opening of the retail market would be essential. For lower consumer prices, TPA for production can be appropriate. The extent and cost of TPA regulation acceptable to policy makers in each MS are key factors in deciding whether mandatory and negotiated or fully regulated grid access is the best option (Bürger et al., 2019). Bacquet et al. (2021) provide a very useful overview of TPA regulations in ten priority countries, encompassing Bulgaria, Denmark, Finland, France, Germany, Lithuania, Poland, Slovakia, Sweden, and the Netherlands. Their overall findings show that TPA regulation is not yet well-developed in the majority of countries. Approximately half of the countries have some form of TPA, yet there are significant variations in the degree or extent of regulation. The remaining countries have no express form of regulation regarding TPA. In some countries with TPA regulation, such as the Czech Republic and Slovakia, mandatory TPA is restricted to renewables-based heat. Some DHC markets with TPA have specific restrictions, for example in terms of the sources eligible for TPA, such as renewables, waste heat or excess heat. Estonia requires a tender process for any additional capacity that is required, where several producers bid. In Lithuania, only where heat from third party suppliers is cheaper, grid operators must purchase heat from those suppliers. Poland, Slovakia and the Czech Republic have similar requirements. Slovakia allows derogation from TPA if third party heat might marginalize renewable or efficient Combined Heat and Power (CHP) heat. Most countries focus on TPA relating to production of heat. In Poland, consumers can theoretically choose between DHC suppliers, if a competing retail company is offering DHC supply. In practice however, supply is not provided to small consumers and so competition is limited to large consumers. Some countries have mandatory grid access, which means that the grid operator is required to provide grid access provided minimum requirements are met and this is set out in the regulatory framework. Other countries require TPA but allow for negotiation of specific conditions (e.g. Sweden). In countries with no TPA requirements, any degree of TPA is entirely voluntary. As set out in relation to FC3 (Permitting), a large degree of variety is evident in ownership and access regulation of utilities and networks in relation to DHC. This reaffirms the point made by Carrus et al. (2019) that clear and better governance frameworks are required for effective uptake of DHC, which also connects to FC2 (Investment) in terms of providing market certainty for DHC operators.

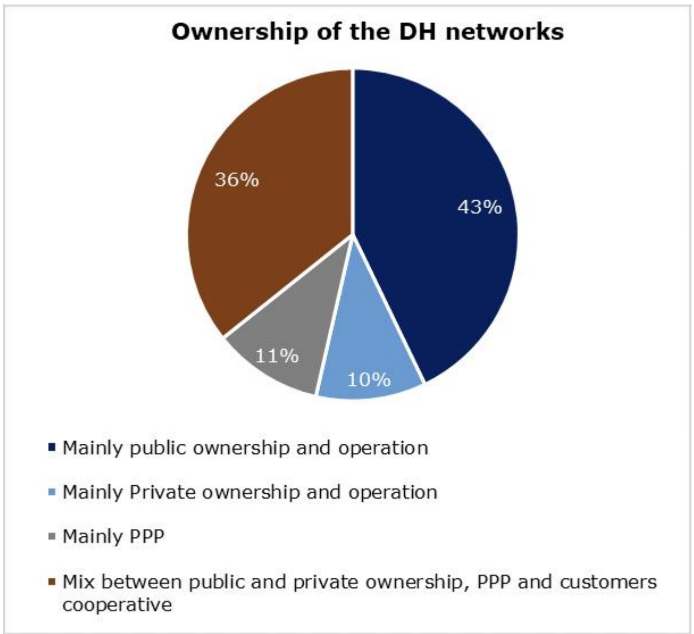


Figure 9: Ownership of district heating networks in the EU27 and the UK, Norway, Iceland and Ukraine in 2021 (excluding Cyprus and Malta due to lack of heating network and Luxembourg due to lack of data), reproduced from (Bacquet et al., 2021)

Overall, there remains a concern in relation to the introduction of TPA in DHC networks that increased competition may not lead to lower prices, which undermines part of the purpose of TPA. The continued need for and resulting cost of TPA regulation in addition to the characteristics of DHC networks being locally placed and usually closed networks, means that the introduction of TPA for DHC networks is not straight-forward and may not yield the same results as have been observed for gas and electricity networks. It is concluded that the efficacy of TPA depends upon the size and location of the DHC network, giving larger-scale networks better chances for successful applications of TPA. Technical characteristics and economic viability are important factors to consider when applying forms of TPA to DHC networks. An alternative is to use administrative separation (unbundling) between the production and distribution functions of monopoly district heating companies to enhance transparency and to focus more on price regulation for monopolist companies operating DHC networks (Bouw, 2017). Although the focus and primary impact of TPA is usually enhancing competition, the benefits for renewables and heat technologies can be limited unless TPA is combined with additional measures which target support for renewables and waste heat, for example (Bürger et al., 2019).

3.3.11 FC 5: Technology conditions

Certain technical factors can limit the deployment of technologies which provide flexibility (Sneum, 2021). Barriers in relation to DHC technology conditions include the following:

- Technology cost
- Business process costs
- Supply chain maturity
- Existing high-temperature systems

3.3.11.1 Technology and business process costs

In the investment phase, technological conditions relate to technology types, their associated costs and maturity. In the operation phase they relate to the technical ability to operate flexibly, for example storage capacity and ramping, which is relevant to HPs and is the adjustability between minimum and maximum levels of generation or the speed at which generation can be changed and lead-time, which relates to the advance notice required for availability. These are key aspects of operating flexible technologies such as HP and more recent generations of DHC (Sneum, 2021). There is a challenge in the ability of technology to satisfy these optimal operational capabilities. Procurement costs may affect choice of technology. Various technological options may have very different costs in daily operation. These are business process costs, which include legal, accounting and other costs, in addition to overhead and administrative costs. The supply chain may be lacking or immature if the workforce or suppliers are under-developed. The ability to meter, control and communicate with the technologies may be limited and there might also be a lack of standards and procedures. If technologies connected to the grid are "not fully visible or controlled at the system level, and most have no economic incentive to respond to either system level or more local distribution level flexibility needs" (Sneum 2021), they fail to bring the potential benefits of integration in the system. Technology costs also impact the uptake of DHC and HP technologies. Investments can be large, especially for renewable DHC, flexible thermal power plants, HPs, PtH, and cogeneration. Support is therefore required for increased innovation and subsidies or tax rebates (Sneum, 2021). This links to the barriers considered in FC2 (Investment).

3.3.11.2 Supply chain maturity

The availability of trained or skilled staff can inhibit supply chain maturity in terms of growth and recruitment (Sneum, 2021). In relation to PtH technologies, their feasibility and practicability depends strongly on the industrial sector and process and ultimately on the supply chain. EB and induction furnaces can assist flexible operation as can HP, but HPs are still at early stages of deployment which may add risk (Münster et al., 2020). In relation to energy efficiency measures for SMEs, a study for the UK's former government body, DECC, indicated that supply chain pressure in relation to efficient heating technology acted as a driver for efficiency measures in some instances, for the private and public sectors. The study recommends the influencing of supply chains to promote the value of energy efficiency, which may increase uptake levels of efficiency measures including heating technologies among SMEs (DECC, 2015). Ways to address supply chain issues relating to the training and skills of staff include long-term policies to support supply chain growth, such as enabling recruitment in relevant industries and support for enhancing staff competencies. For example, a long-term policy could be push-pull mechanisms, which entail a push for establishing flexible technologies and a pull among contractors to obtain sufficient competencies (Sneum, 2021).

3.3.11.3 High temperature systems

The efficiency of HP can improve where there is only a small rise in temperature between the heat source to the heat demand. Therefore, using high temperature district energy such as steam-based systems in areas where the heat sources are at a significantly lower temperature, which is the case for much of Europe, can limit the efficiency of HP. This also applies to individual HPs which, if installed in older and less energy efficient buildings, can suffer from higher losses and therefore lower COP values. Examples of solutions for upgrading systems generally, including to 4th generation DHC technology, are the modernisation of networks, particularly where steam-based systems are due to be decommissioned and policies should focus on the conversion of such systems to lower temperature systems (Sneum 2021). Research employing energy-economic assessments to show evidence-based energy-related and monetary benefits of reduced system temperatures suggests that low temperatures improve economic benefits and monetary savings in DHC systems, and similar trends are identified in the case of alternative heat generation technologies, including HP (Geyer et al., 2021). Although not focusing specifically on issues with high temperature systems, Lake et al. (2017) review design considerations for different DHC systems and provide an overview of technologies which increase efficiency. For example, absorption chillers can optimise supply and return temperature to improve performance. In pipe networks, supply and return temperatures have a significant efficiency impact in terms of optimal supply and return temperatures, which improves performance (Lake, Rezaie and Beyerlein, 2017).

Papapetrou (2018) considers existing high temperature systems, including from waste heat and seeks to assess the heat potential of different sources of waste heat. Thermal carriers are primarily liquids and gases. Heat is collected from thermal carriers via a range of different types of heat exchangers and the temperature difference can depend on the type and quality of the carrier and existing technology (Papapetrou et al., 2018). The modernisation of DHC networks can be a means of solving problems and potentially costs associated with high temperature system, particularly if this entails the retiring of steam-based systems. However, such an approach requires a direct policy priority to shift towards lower temperature systems (Sneum, 2021). Lund et al. (2014) propose that for DHC to contribute towards future sustainable energy systems, it will need to meet several challenges. These challenges include (i) the supply of low-temperature for space heating and domestic hot water to existing buildings, which have had energy upgrades and to new low-energy buildings, (ii) distribution of heat in low grid loss networks, (iii) ability to recycle heat from low-temperature sources and integrate renewable heat sources, and (iv) be integrated or coupled with smart energy systems, such as smart electricity, gas, fluid or thermal grids in addition to 4th and 5th generation DHC systems (Lund et al., 2014). The regulatory framework will need to enable these technical and market capacities.

3.3.12 FC 6: Electricity grid access

Whereas *FC1 (Operational signalling)* relates to electricity market access, grid access addresses access to the physical electricity grid (Sneum, 2021). Barriers in relation to *FC6 (Electricity grid access)* therefore include:

- High grid connection costs
- Limiting grid codes and capacity

3.3.12.1 High electricity grid connection costs

High connection charges for connection of an asset such as HP or CHP to the electricity grid can be prohibitive for new entrants, especially if the type of heating technology used is not price-categorized on equal terms with comparable grid connecting technologies. In addition, uncertainty in relation to the duration of processing and cost of connection add further risk (Sneum 2021). High grid connection costs can also be a result of the (lack) of proximity of the thermal plant to the DHC network or a weak grid connection nearby at the location of the consumers. One way to manage high grid connection costs include the improvement of non-discriminatory interconnection, which can mean socialising the cost of (additional) cable length/grid reinforcement. An alternative way could be interruptible grid connection agreements, under which grid operators are allowed to interrupt load where necessary. In the case of a flexible system-serving operation, the connection cost of HPs and CHP, for example, could be reduced to reflect their potential contribution to local peak demand reduction and therefore reduced grid costs

(Sneum, 2021). Rosales-Asensio and Borge-Diez (2016) propose that as approximately half of installed capacity for electricity from conventional thermal power plants in the former EU28 is at a feasible distance to consumers in terms of losses, it would be possible to convert such plants into cogeneration with use of waste heat for DHC networks. Doing so would multiply the percentage of citizens with access to DHC networks from 12% to 50%, which could also reduce connection costs. The authors maintain that the main barrier to achieving such a level of DHC network access is primarily of an institutional and economic and therefore regulatory nature (Rosales-Asensio and Borge-Diez, 2016).

3.3.12.2 Limiting electricity grid codes and capacity

There are two aspects of electricity grid connection, (i) from a supply perspective and (ii) from a demand perspective. Regulation of grid connection for supply usually takes the form of TPA as examined under FC4 (Ownership). Regulation of grid access for demand usually entails the type of a connection agreement with the supplier. Grid codes and connection rules may cause barriers through inconsistency and lack of transparency, restrictions on bi-directional power flows for both consumption and generation, for example due to a lack of regulations on the buy-back of any generated electricity fed back to the grid. Network protection rules can also cause this issue. Grid access for generators can be met with high transaction costs for any legal and technical advice. Standardised interconnection agreements can address these barriers by making grid operators subject to performance-based regulation which incentivizes expedient connection and through clarification of application regulation and codes relating to bi-directional flows of electricity. Grid codes could alternatively mandate minimum criteria for connected technologies, including degree of flexibility for ramp rates, which is the case in Denmark (Sneum, 2021).

3.3.13 FC 7: Physical environment

Barriers in relation to the physical environment include:

- Limited access to energy sources
- Land availability and spatial planning

3.3.13.1 Access to energy sources

Flexible technologies depend on energy sources, which can be limited as a result of different policy and regulatory measures. For example, HP requires heat sources and cogeneration requires fuel. It may be helpful to map resources onto existing or potential plants (Sneum, 2021). In relation to efficiency, physical conditions for technologies are also a determinant of heat sources for HP throughout the year and affect the flexibility and competitiveness of HP sources in comparison to alternatives (Bacquet et al., 2021). Access to energy sources may also be affected by issues of competition between sources, for example with natural gas (Münster et al., 2020). Lake et al. (2017) set out the advantages and disadvantages of different types of primary energy sources for DHC and propose that the environmental impact and economic feasibility of different sources should be integrated into the consideration process. The authors also provide a summary of technologies which improve efficiency. For example, although geothermal or ground source HP provides year-round heating and cooling, they are geologically limited as a source and efficiency is dependent upon the temperature zone in which the source is located. In addition, air source HP can also be a solution for individual buildings, and waste heat from industrial and commercial processes can provide excess heat to nearby buildings and offset certain DH fuel costs, but needs to be coupled with an existing DHC system and so is dependent upon the extent of existing DHC infrastructure (Lake, Rezaie and Beyerlein, 2017).

Sources such as waste heat still face several technical, financial and regulatory barriers, as set out by Brueckner et al. (2014). For example, profit-making from waste heat may not be the main business rationale for manufacturing companies, which also goes towards *FC9 (Acceptance)*. Technical barriers are also present, which can be the primary barrier to industrial waste heat recovery. For example, for effective waste heat recovery, a large amount of excess heat must be available as high temperature exhaust or byproduct gases. These can constitute highly corrosive materials and particulates, which makes them difficult and expensive to recover for heat. Persson and Münster (2016) emphasise the importance of access to heat distribution infrastructures to recover excess heat. As such, the deployment of DHC systems in Europe is linked to the geographical distribution and spatial spread of certain sources, such as waste heat capacity. Therefore, EU waste management policies need to align with related energy system priorities and regulations. This is supported by Colmenar-Santos and Borge-Díez (2017), as according to the authors approximately 50% of installed electric capacity in the former EU28, from conventional thermal power plants, is at a viable distance in terms of losses for conversion into cogeneration plants in which waste heat might be used for DHC networks, as stated in relation to *FC(6) Grid access*. Therefore, if policy is aligned and prioritises development of more DHC networks and cogeneration, an increasing number of power plants could be erected within efficient distance to thermal loads (Colmenar-Santos and Borge-Díez, 2017). In terms of locating the availability of proximate waste heat, Brueckner et al. (2014) recommend extending heat infrastructure including pipes but also better provision of information on waste heat potential. To address the business rationale for prioritising waste heat, it may be beneficial to apply waste heat in different ways, such as power generation or feedback to the power grid and storage (Brueckner *et al.*, 2014).

Other sources of heat include biomass, for example from wood or energy crops. Although this is a renewable resource if sustainably managed, its availability is limited in Europe (Lake, Rezaie and Beyerlein, 2017). Sneum et al. (2021) examine biomass in terms of its potential for flexibility and sector coupling characteristics, particularly compared to PtH. Biomass is shown to be neutral or not necessarily beneficial to the deployment of other forms of renewable DH. Biomass is a direct competitor to PtH. Constraining the use of biomass can increase PtH, shifting the heating system away from combustion for heat. In terms of variable renewable energy, offshore wind shows the highest increase resulting from a complete restriction of biomass (Sneum, González and Gea-Bermúdez, 2021). Overall, the importance of region-specific constraints on the availability of heat sources must be considered, as they determine the available heating options which can add to costs. Security of fuel supply and operational cost are relevant factors in the adoption of sustainable heating systems (Sopha *et al.*, 2010). A key barrier to the deployment of flexible technologies can also take the form of competition with other heating technologies, including for example heat-only-boilers based on oil, gas or biomass. The integration, for example of PtH technologies is restricted due to lower investment and operation costs of existing fuel fired heating systems, including natural gas boilers This also points to the importance of sector coupling as discussed in more detail below, as the heat source has an effect on the extent of coupling. For example, PtH technologies are also limited by economic constraints due to the lower investment and operation costs of traditional fuel fired heating systems like natural gas boilers. Due to their efficiency, HP can viably compete with fuel-based systems. However, HPs are also affected by the availability of heat sources. The implementation of HPs, which can economically compete with fuel-based systems due to their high efficiency, is limited by the maximum supply temperature and availability of suitable heat sources (Münster *et al.*, 2020).

Lund et al. (2014) critically examine biomass in relation to 4th generation DHC, supporting the argument that biomass use can pose significant challenges in renewable energy systems. DHC systems are important in limiting biomass dependence and providing cost effective solutions (Lund *et al.*, 2014). However, where countries already have high shares of renewable heat, meaning above 40%, Collier (2018) proposes that to attain long-term energy transition and climate change goals, policies should make sure that biomass resources are allocated optimally between DH and other sectors where they are required for decarbonisation (Collier, 2018). However, in relation to enabling renewable heat deployment, particularly in urban areas, DH networks may represent the only option. This is because other technologies, such as biomass boilers, solar thermal systems or HP can be constrained by, for example, limited availability of space, access or noise restrictions. DHC can also integrate short-term and seasonal thermal storage to utilise excess heat and to provide flexibility for variable renewable electricity generation, using Power to Gas (PtG) or EB. In 2017, Sweden, Finland, Latvia, Lithuania, Estonia and Denmark still used biomass as their main renewable heat source (Collier, 2018). This is also the case more widely for the EU and internationally (Werner, 2017).

3.3.13.2 Land availability and spatial planning

In terms of land availability, some technologies need more space and urban environments can be restricted. Certain interests including agriculture, leisure, or development can impose competition for land use and availability. It may be helpful to integrate technologies which promote decarbonisation and efficiency in the course of renovation projects and during the planning process for new infrastructure developments (Sneum, 2021). Spatial planning and zoning to integrate district heating priority zones can strongly support the economic effectiveness of DHC grids. Municipal heat planning in Denmark, for example, has illustrated this positive effect, resulting in wider deployment of DHC (Bacquet et al., 2021). However, similar approaches, in terms of DH priority heating zones and supporting regulatory measures, have provided important signals to encourage DHC adoption. In France and Denmark, municipalities combine DHC zoning with mandatory connection to DHC for new buildings (Bacquet et al., 2021). Energy infrastructures have to be planned including their location rights that need to be set and granted. This includes urban planning, usually in accordance with regional and national spatial planning frameworks. The potential for heating and cooling sector decarbonisation depends on spatial planning issues for best alignment of demand and supply. Member States and local authorities have a key role in supporting the decarbonisation of heating and cooling, in terms of national legislation and policies, which determine planning for heating and cooling at the local level. Municipal energy system development is usually the domain of the local municipal government, which tends to set land use plans for building schemes or DHC priority zones (Bacquet et al., 2021).

3.3.14 FC 8: Bounded rationality and FC9: Acceptance

FC8 (Bounded rationality) and FC9 (Acceptance) will be considered together as they relate to most of the same barriers. FC8 (Bounded rationality) refers to a lack of awareness amongst relevant and potentially relevant stakeholders, including organisations and consumers. Even where awareness does exist, that awareness might be limited through constraints in knowledge and experience. The level of knowledge of a technology can impact trust and confidence in that technology, which might be reduced if, for example, the benefits of a technology are unclear or there is low credibility or poor past performance (Sneum, 2021). In relation to FC9 (Acceptance), barriers refer to a lack of acceptance and priority amongst relevant stakeholders (organisational communities) for technologies like DHC and HP due to the perception that these technologies do not represent a core business activity and a concern about the extent of opportunity costs. Linked to this, organisational culture or values can undervalue the economic costs and benefits of energy or environmental issues. Organisational risk perception and inertia are also key components of acceptance, for example if behavioural change takes time, despite important benefits (Sneum, 2021). Barriers relating to FC8 and FC9 include:

- Organisational community (including consumers)
- Authority
- Plant staff
- Incumbent utilities (FC9)

3.3.14.1 Organisational community (including consumers)

In relation to FC8 (Bounded rationality), Burlinson et al. (2018) find in a study examining choice of heating types by households that residential consumer adoption decisions are linked to internal rates of returns which are much higher than market rates (Burlinson, Giulietti and Battisti, 2018). This links in with the discussion of internal rate of return under FC2 (Investment). Braun et al. (2018) find that consideration of internal rate of return can affect the decision to adopt certain energy efficiency measures quite strongly and adversely. The authors tested the size and significance of discount rate for consumer behavior and found that the discount rate can be greatly reduced by controlling for behavioural factors such as inattention and heuristic decision-making. This means that consumer decision-making strategy does not integrate all the available information due to the perceived need to make a decision quicker, more cost-effectively or accurately than when taking into account more complex methodologies. These factors seem to strongly and negatively affect the likelihood of technology adoption. Policy measures which target higher levels of technology adoption need to account for this consumer behaviour and develop measures to mitigate their negative effect (Braun, 2010).

Community acceptance is taken here to include consumer involvement in strengthening the uptake of DHC and HP. The degree of knowledge of the organizational community impacts both FC8 (Bounded rationality) and FC9 (Acceptance) in terms of the level of trust and confidence, leading to difficulties recognising potential benefits, uncertainty about credibility or poor past performance. Solutions include information campaigns, financial support for feasibility studies or capacity building schemes and information exchange and pilot projects, certification standards and engagement with experienced actors. The automation of certain processes may also address bounded rationality issues within the actor groups. An understanding of the environmental and financial benefits also affects the degree of bounded rationality for an organizational community. Solutions for bounded rationality relating to authority groups include targets for the authority, such as for efficiency or decarbonisation. Individual plant staff bounded rationality can be caused by the operator's lack of experience. This may be addressed also through targets and training or information provision (Sneum, 2021). A survey relating to SMEs by the former UK Government body, DECC (2015), supports this issue with understanding of energy efficiency information. For example, difficulties with quantifying and understanding financial savings resulting from energy efficiency improvements, including heating and cooling technology, were reported in the interviews conducted. The result is a potential undervaluing of efficiency measures and barrier to implementation. Proposals include improving access to metering and monitoring technology for more transparency and availability of information (DECC, 2015).

Factors such as reputation also affect technology uptake. Bouw et al. (2017) show that in some countries, like the Netherlands, DHC has had a negative image relating to old block heating systems. In Denmark and the UK, both old and new DHC systems have been subject to complaints about technical performance. The authors note that this is unexpected as in most of Scandinavia, on the other hand, high technical performance in categories such as comfort and reliability has contributed to a high level of acceptance and therefore success. To overcome perceptions of technical unreliability, the strengths of DHC in terms of ease of operation, comfort, reliability and cost stability need to be emphasised in marketing approaches but mechanisms are required to monitor and guarantee these strengths (Bouw, 2017). The analysis by Bjørnstad (2012) also supports this approach in relation to households. Communication of programmes to motivate households to make the desired investments should focus on heating comfort and indoor climate as key elements in a household's valuation of benefits relating to investment in heating technology (Bjørnstad, 2012). A similar approach is proposed in relation to HP. Hafner et al. (2019) find that for large-scale one-off purchases such as heating technologies, normative information from peer behavior and financial information on investment benefits appear to be the most effective strategies in promoting uptake of new technologies. Normative lifestyle campaigns can represent effective means of increasing the attractiveness and uptake of heating technologies (Hafner et al., 2019). Once adopted, these types of marketing approaches and communication programmes may also help to mitigate the negative effect on consumer adoption of what Sorrell et al. (2009) refer to as rebound effects. For example, energy efficiency measures have the effect of lowering the cost of energy services, which increases consumer consumption of such services, effectively undermining the implementation of effective demand-side measures. These effects are also observed in relation to household heating. The direct rebound effect counteracts the energy savings that might have been obtained. For example, as a result of the cost savings achieved from energy efficiency measures such as DHC and HP, consumers may heat their homes for a longer duration or at a higher temperature. This increase in consumption reduces any savings achieved by the energy efficiency measures, potentially offsetting them entirely. Accurate calculation of this effect is not straightforward, but may be supported by sufficient energy service or energy consumption data (Sorrell, Dimitropoulos and Sommerville, 2009).

A further way of making consumers more aware of the value of their energy efficiency measures is to improve communication between DHC consumers and suppliers. Krog et al. (2020) examine consumer involvement in 4th generation DHC R&D projects in Denmark. Their findings support the approach of making communication between DHC consumers and suppliers engaging in building refurbishment as straight-forward or easy as possible. Consumers should be well-guided and supported in strengthening their decision competences. Any transition to 4th generation DHC will not be achieved by just DHC suppliers but instead supplemented by close engagement with consumers. The authors also recommend coordination across different professional competences to move to low-temperature DHC. DHC customers should therefore be engaged in the implementation of demand-side measures for their homes (Krog et al., 2020). Lack of trust may in turn influence, for example, the level of investment (FC2), Permitting (FC3) in terms of physical planning and technology bans, and Ownership (FC4) in terms of extent of regulation. FC8 (Bounded rationality) relates to the ability to choose optimal solutions in line with the priorities of an organisation, level of ability, available time and information, trust in alternative solutions. This can be impacted by a lack of awareness for stakeholders, such as land agents in terms of the possibilities and options for DHC (Sneum, 2021). In a choice experiment relating to energy retrofits for existing houses in Germany, Achtnicht (2011) concludes that the environmental benefits of certain technologies have a significant impact on consumer choice of heating system. The residential building sector is highly regulated in Germany, however the adequacy of the regulations is not clear. It is proposed that the key criterion for regulations should be cost efficiency, in terms of integrating technologies at the lowest possible cost. The standards set by applicable regulations are not likely to promote cost efficiency because consumer preferences should be given more consideration to help design policy instruments that make economic sense to consumers and allow for environmental and climate policy benefits to display better value. Achtnicht (2011) concludes that consumers are generally aware of their responsibilities and wish to contribute to climate protection measures. Residential households are therefore a promising target for future climate and energy policy but in practice, uncertainties and information gaps inhibit investments in energy-efficient technologies. Consumers are not sure, for example, about long-term energy prices, the tangible energy and CO2 savings of new technologies, how long it will take for the investment to be recovered, and the effect on quality of life in the home. Seeking information on available energy-saving measures can also be associated with a degree of cost. This causes a degree of inertia when consumers consider heating options for efficiency, which can lead to under-investments.

Future policies should aim to reduce consumer uncertainty, by targeting issues with information asymmetry and imperfect information (Achtnicht, 2011).

Further analysis from Germany also supports information provision for consumers, finding that influences on chosen heating technology is generally the same, whether looking at all households or more specifically house owners. It is possible to distinguish in relation to other factors, however, such as building features, including construction period, which are found to have a stronger influence on the type of heating chosen overall in all households rather than amongst house owners only (Braun, 2010). Other distinguishing factors, such as income, do not appear to represent as significant an influence on type of heating technology adopted. This result makes it difficult to determine target groups for financial incentives, such as investment grants. Nonetheless, information provision and education play a key role in determining residential energy consumption behaviour, making such approaches worthwhile for increasing heating technology uptake (Braun, 2010). On the other hand, a report by Gerganov et al. (2019) focusing on energy choices, including heating, in Bulgaria, takes various case studies together and demonstrates the limited scope for information and feedback policies in affecting energy consumption, particularly in relation to energy poverty. The authors propose that, where countries have a high proportion of energy poverty (Bulgaria), consumers affected by energy poverty may not request or require as much information because they already tend to have information on maximising savings. Greater value is placed on the effort costs of implementing energy saving behaviours (Gerganov et al., 2019).

Regional differences and efficacy of policy design and implementation at regional (state) and municipal levels are important aspects of organisational community. These levels can be better able to acknowledge local context which in turn can be more effective implementing sustainability measures (Braun, 2010). However, in a multi-country survey of psychological factors in energy decision-making, Carrus et al. (2019) find that, irrespective of the policy level, whether at EU, MS or municipality level, and building type, consistent drivers of energy policy acceptance generally relate to pro-environmental attitudes of consumers. Therefore, policy measures should be framed in terms of relevance to the targeted public, and highlight policies that support sustainable energy choices by specific consumer groups from a psychological and social influence perspective, instead of solely or mainly relying on economic incentives and technological innovations (Carrus, Chokrai, et al., 2019). Decker and Menrad (2015) examine German house owners' perceptions and factors influencing the choice of heating systems. Particularly relevant for acceptance are specific consumer characteristics, which also include ecological attitude in addition to product experience, perceived purchase risk, and socio-demographic factors. Certain situational conditions can factor into acceptance as well, for the chosen heating system of neighbours and opinions the consumers’ social group. To address these characteristics and conditions, the authors recommend supportive policy instruments including target-oriented information campaigns by, for example, prioritising environmental considerations. To support uptake of HP, information campaigns should highlight the effect of the technology on comfort and convenience (Decker and Menrad, 2015). Lettmayer et al. (2018) provide a unique approach amongst the reviewed literature in terms of taking a historical perspective to the analysis of production and consumption behavior of citizens. The authors propose that the analysis of consumer behavior and energy transition, including consumer behavior towards heating technologies, cannot be reduced to just a cognitive task, social task or technological task. Their approach focuses on specific historical national and local contexts. As such, the research examines the extent to which past events (in terms of political, social, cultural and technological characteristics) influence current energy cultures to inform policy. This includes the experience of energy poverty at different points and intensities. For example in Bulgaria, there are strong memories relating to energy poverty and energy access. Using an energy memory approach can help with finding socially and politically sustainable (and acceptable) decisions that allow the successful implementation of sustainable energy goals (Lettmayer et al., 2018). The authors recommend that policy makers maintain an awareness of energy memories in MS, because these can have a strong influence on present energy cultures and potentially better likelihood of acceptance, but also in relation to rejecting unhelpful energy cultures (Lettmayer et al., 2018).

3.3.14.2 Authority, plant staff and incumbent utilities

Authority acceptance may also present a barrier to the adoption of DHC and HP technologies. The extent of regulation and the need for consent from various levels of policy makers and jurisdictions before a project may go ahead is an example of authority acceptance. As with bounded rationality, negative perceptions of DHC or HP, for example in relation to monopoly supply (for DHC) or reputation may restrict authority acceptance. Incumbent utilities may also pose a barrier to wider deployment of DHC and HP (incumbent acceptance), as such technologies introduce new actors into the existing system which impacts existing business models and structures and can introduce potential competition to existing suppliers. Incumbent businesses may act within outdated regulatory structures, or potentially prevent the entry of new actors deliberately by arguing lack of network capacity, excessive fees, slow down access through extended negotiations, litigation or price manipulation. Individual plant staff may also pose a barrier to acceptance, due to a lack of authority for decision-making relating to alternative technologies (Sneum, 2021). At a local authority or national level, Collier et al. (2018) also highlight the importance of available information and recommend that countries with no existing renewable heat policy should gather data for national and local heat production and consumption and map the potential for renewable and other low carbon heat sources at both national and local levels.

Pilot or demonstration projects are proposed as a means of addressing barriers relating to organisational community and plant staff to provide information and training. They can also play a particularly helpful role in encouraging sector coupling, for example in relation to PtH (Münster et al., 2020). To promote wider uptake or acceptance, such projects should exchange data, methodologies and results to accelerate learning, provide analysis of governance frameworks and markets for quicker implementation and engage stakeholders from different sectors to optimise planning coordination to harness potential synergies (Münster et al., 2020). The exchange of information and data can also enhance trust. Lack of transparency can contribute significantly to lack of trust, which according to Bouw (2017) is an issue for European district heating companies and therefore also links to incumbent utilities. Lack of transparency is often caused when the district heating company holds a monopolistic position in the market. This may create the perception of a worse deal in comparison to gas. This is an issue with incumbent utilities and it is the role of the relevant regulatory authority, for example, that price information must be clear and understandable. In order to make informed decisions on pricing, customers require information, which allows them to make such an informed decision on the fairness of pricing. In addition to the provision of clear information, prices should be monitored and benchmarked for customers comparing heating alternatives (Bouw, 2017). To overcome perceived and actual issues with trust in technology, provision of clear information on pricing and degree of TPA (FC4 - Ownership) is recommended (Bouw, 2017), subject to the ownership structures in place in a given Member State. This can support a level playing field in relation to incumbents and new entrants, thereby supporting the wider deployment of DHC. As with other FCs, for example with FC2 (Investment), FC3 (Permitting), the necessary regulatory framework relates to FC8 (Bounded rationality) and FC9 (Acceptance) in terms of the relevant authority.

3.3.15 Links between Framework Conditions and sector coupling

The links between the FCs have been highlighted throughout this section. Those observed repeatedly relate mainly to FC 2 (Investment), FC 4 (Ownership), FC9 (Acceptance). For example, any discriminatory entry requirements may negatively impact the flexibility that DHC technologies can provide. The barriers of unduly strict or insufficient regulation of TPA, costs of inspection in terms of operational standards and procedures, and ownership limitations under unbundling rules can be caused by immature markets and regulatory frameworks, or certain conflicts of interest in setting regulatory framework and restrictions on market participation for DHC. Examples of solutions include reducing the transaction costs of market access, particularly for small generators and TPA barriers relating to types of technology and capacities (Sneum, 2021).

Sector coupling is a particularly strong linking subject and is discussed in relation to several FCs, which the reviewed literature strongly suggests as a key means of improving the uptake and deployment of DHC and HP. As highlighted by Collier (2018), particularly countries with high shares and growth in renewables in electricity should place great priority on sector coupling, including the use of HP for demand response. This is because sector coupling refers to integration between demand and supply, which entails integration between final energy demand and supply chain options. This is also known under the broader term energy system integration (Münster et al., 2020).

The operation of flexible technologies is often driven by electricity market signals, in terms of efficient and stable regulatory market conditions dependent on input costs and prices, thereby linking FC1 (Operation) with sector coupling. For example, low electricity prices encourage the use of an EB, whilst HP can be attractive to operate over a broader electricity price range as a result of their efficiency (Münster et al., 2020). As flexibility is linked to sector coupling, this also creates a link to FC1 (Operation) in terms of the importance of market signals. Flexibility can be facilitated especially through coupling between heat and electricity systems, using the interplay between for example HP, EB, CHP and thermal energy storages (TES) and thermal mass for individual buildings. For example, HP combined with TES shifts the load and can achieve a reduction in net load and reduce the electricity surplus for intermittent renewable electricity supply. PtH can enhance flexibility both on a short term and on the long-term basis and can also facilitate the integration of renewable energy sources at scale. This would result in even greater coupling between sectors and enhance the flexibility of the power system, for example through the provision of energy storage solutions. Overall, sector coupling can improve the economic viability of, for example PtH, because the heat from conversion is attractive for sale to district heating networks (Münster et al., 2020).

Sector coupling may also be linked to FC2 (Investment), as in the medium-term greater revenue streams are dependent on availability of support mechanisms for emerging technologies, including subsidies such as feed-in-tariffs. In terms of prices, markets where the highest prices can be obtained for the main product and by-products need to be identified. For efficient markets to emerge from sector coupling, market prices must be consistent across the relevant sectors (Münster et al., 2020). Denmark is a leader in relation to DHC technologies, however in relation to sector coupling, heat has not yet been integrated with the Danish electricity system. Barriers relate to, for example, high taxes, a barrier identified in FC1 (Operational signalling), which prevented the integration of HP, due to the high taxes placed on the use of electricity for heat production (Hvelplund and Djørup, 2020). Due to the dominance of wind generation for electricity, infrastructure capable of managing the renewables' intermittency is required, which points to the need for integration or coupling of power and heat systems (coupling), otherwise these technologies compete or wind can undermine the case for decarbonised heating due to lower marginal costs. In such a scenario, CHP cannot significantly contribute towards system flexibility, for example during phases of less wind. Due to zero taxation on biomass for heat and high taxes on wind-generated heat, this may also incentivize the replacement of CHP plants with biomass-based district heating systems, which are less flexible (Hvelplund and Djørup, 2020). Lack of sector coupling can thereby create a barrier to heating technologies contributing towards decarbonisation.

Sector coupling is considered a means of addressing ownership (FC4) issues and for the efficient deployment of DHC but can require curtailment for capacity reasons. Sector coupling means linking sectors (usually network bound), such as electricity, gas and heat with their infrastructure. This results in a stronger link or coupling of grid-bound energy sources like electricity, heat and gas (Oberle et al., 2020). The continued reduction in heat generation from gas that is projected to occur to 2050 together with a parallel shift to heat generation from electricity creates an extent of competition between the sectors. As heat generation from gas decreases, gas distribution system operating costs increase and electricity network charges decrease (this may also encourage investment and link to FC2). Although gas condensing boilers are most efficient at present, Oberle et al (2020) suggest focusing on electricity and heat coupling rather than regulating and developing three sectors (gas, electricicty and heat) in parallel, especially for GHG reduction (Oberle et al., 2020). Hvelplund and Djørup (2020) recommend that in order to manage large volumes of intermittent renewables, an integrated energy system through the coupling of power generation with heat in DH systems with HP, solar heating or geothermal heating and heat storage is necessary (Hvelplund and Djørup, 2020).

3.4 Step 3: Identification of gaps in coverage

3.4.1 Gaps in geographic scope

Overall, Eastern European countries are less well-represented by the reviewed literature and mapping across the Framework Conditions and fewer studies on DHC and HP are dedicated to that geographic region. Büchele et al. (2018) focuses specifically on the policy framework for the future of DHC in Eastern European countries. For example, in relation to FC1 (Operational signalling), the paper assesses the policy settings and mechanisms both standalone and in combination, including long term loans, CO2 Tax, subsidy for DHC connection, renewable DHC connection subsidy, zoning, banning gas and a policy package which combines mechanisms and looks at the ability of different policies and policy combinations to generate favourable conditions for DH modernization was assessed (Büchele et al. 2018).

3.4.2 Gaps in policy coverage: considerations of gender in policy on heating technologies

Less consideration is given to gender aspects in heating policy and adoption of heating and cooling technologies within the reviewed literature. Studies by Correia et al. (2018) and Karytsas et al. (2019) examine gender in relation to heating and cooling policy. Karytsas et al. (2019) consider gender in relation to factors which impact consumer willingness to adopt and pay for residential hybrid systems that provide heating/cooling and domestic hot water. Magdalinski et al. (2017) also integrate gender into their analysis of the socio-economic and demographic facts that affect energy choices and behaviours, including in relation to heating technologies. Feenstra and Clancy (2020) examine gender and energy poverty in the EU more broadly, but factor in heating and cooling into their assessment of gender and energy poverty and heating demand.

According to Correia et al. (2018), who focus on cooling technology, gender considerations are neglected in nearly all energy transition indicator systems. Gender gaps exist in relation to many levels and areas of policy, including the energy sector, residential energy use and energy poverty despite evidence that women and men display varying attitudes towards energy transition and are motivated potentially by overlapping but differing priorities, for example in terms of importance of environmental issues and differences in energy consumption and demand patterns for energy services (Correia et al., 2021). This is supported by Karytsas et al. (2019), who show that the identified socioeconomic factors affect consumers' intentions in relation to adoption of heating systems. These factors include gender, income, educational level, occupation, past investments in thermal energy systems and percentage of income spent on household energy needs. Magdalinski et al. (2017) also highlight that gender perspectives are relevant to understanding differing energy practices and behaviour within and across households and the associated societies and the social, economic and environmental implications. As also pointed out by Feenstra and Clancy (2020), energy policies tend to be formulated in a gender-neutral way. Doing so not only conflates the perspectives, needs, experiences, values, resources and aspirations in relation to domestic energy access. This approach assumes that men and women respond to and benefit from heating and cooling policies in the same way, which is however not supported by Magdalinski et al.'s (2017) research. In fact, motivations for and barriers to the adoption of more efficient technologies, including heating, are gendered. Social acceptability and behavior towards energy saving policies and adoption of more environmentally sustainable energy investments is influenced by factors such as gender. The authors recommend that gender should represent a core concern for policy-makers considering the design and implementation of socially, economically and environmentally feasible and sustainable energy policies. The extent to which factors such as gender are integrated into policy formulation for efficiency measures and heating and cooling technologies can have implications for the level of equity, efficiency and effectiveness of such policies (Magdalinski et al., 2017).

The issue is compounded by the lower number of women represented in policy and decision-making bodies at all levels of governance in the EU and MS and the energy professions (Correia et al., 2021). In addition, a key aspect of gender inclusion is the recognition of the link between gender and energy poverty. The main indicators for energy poverty in the EU include home insulation levels, efficiency of appliances for heating, cooking or hot water, for example, and energy prices. As a result of lower average income, energy poverty is a greater risk to women than men. Factors include different energy use patterns and differential impact of energy poverty due income differences, housing conditions, age and care for dependents (Feenstra and Clancy, 2020). Correia et al. (2021) recommend the application of cross-cutting indicators, looking at gender or different aspects of gender which may provide better insights into gendered decision-making and general progress made towards clean energy transition. Due to the report's focus on cooling, a new energy poverty indicator integrating gender is proposed to track access to sufficient cooling. Overall, indicators should address the extent of gendered participation in energy transition in addition to energy poverty, as a result of the gendered nature of energy poverty (Correia et al., 2021). Hjorth et al. (2016) examine how to identify gender issues in DHC in terms of integrating gender considerations in district heating projects at different stages of the project cycle, from project preparation and implementation, through to monitoring and evaluation phases. The authors do so by focusing on both the demand and supply side of DHC projects. On the demand side gender looks at women as users of DHC services as also examined by Feenstra and Clancy (2020), Correia et al. (2021) and Magdalinski et al. (2017). The supply side of DHC relates to women as employees of DHC providers, including women's access to employment in the DHC sector (Hjorth et al., 2016). This analysis closely links gender to aspects of FC9 (Acceptance), including institutional capacity and training needs, authority in terms of training, representation and decision-making through management, and customer engagement. This includes equal access to training and awareness of the nexus between gender, energy efficiency and DHC at company level. The analysis also links to gender aspects of FC5 (DHC Technology conditions) in terms of procurement criteria (Hjorth et al., 2016). Proposed solutions to gender imbalances, and considerations on the supply side of the DHC sector include, female staff having equal access to training, promotion and awareness raising on the links between gender equality, energy efficiency and DHC within the company and management (Hjorth et al., 2016).

4 Overview of State Aid

4.1 Background

4.1.1 State Aid

EU rules on State Aid are set out in Articles 107-109 of the Treaty for the Functioning of the European Union (Consolidated Version of the Treaty on the Functioning of the European Union [2012] OJ C326/47). The European Commission has the authority to investigate potentially or allegedly illegally paid subsidies and may order MS governments to recover any financial support that creates a market distortion in favour of state-aided enterprises. DHC is of particular importance for energy markets, as discussed in relation to the FCs, but also since the EU's 2016 Heating and Cooling Strategy (Commission, 2016), part of the EU's plan to utilise DHC as a means of increasing renewable energy deployment in line with the Energy Union Strategy (Commission, 2015) and also more recently the Green Deal (Commission, 2019a).

State Aid is understood as an advantage of any type conferred by national public authorities to undertakings on a selective basis[2] and includes tax cuts or guaranteed prices, and the use of state resources even when not given directly from a government body (Art 107 TFEU) and where no allowed public interest can be demonstrated. State Aid rules apply to MS governments, local authorities, public sector or publicly funded bodies, including nationalised industries and state-derived funds paid by private sector bodies. Any such assistance provided by such entities must be notified to the Commission under Article 108(3) TFEU, unless subject to General Block Exemptions. State Aid rules are monitored and enforced by the Commission but decisions can be reviewed by the European Court of Justice. Aid is generally required to be in the interests of the EU and in line with EU objectives, and provide a benefit that could not otherwise be enabled (but must be proportionate). Several guidelines and notices on discretionary powers to approve aid under Art 107(3) TFEU set out categories of allowed aid in specific sectors including energy.

4.1.2 Guidelines on State Aid for environmental protection and energy 2014-2020

In 2014 the Commission published the Guidelines on State Aid for environmental protection and energy 2014-2020 (the Guidelines) (Commission, 2014). After a period of approving quite generous support schemes that qualified as State Aid, Member States were encouraged to reduce their reliance on price-based support mechanisms for renewables in exchange for a stronger application of market-based or quantity-based mechanisms. In the Guidelines, the Commission addresses support mechanisms that would be compatible with the internal market under Article 107 TFEU. The Guidelines are intended to help Member States reach their 2020 climate change targets, whilst addressing distortions to competition resulting from State Aid for renewable energy but also to encourage Member States to move towards market-based support mechanisms for RES, thereby gradually replacing Feed in Tariffs with Feed in Premiums, as the cost of renewable technologies had gone down sufficiently to allow them to be exposed to market prices (Commission, 2014).

Measures considered likely to be compatible with rules on State Aid, include forms of support for renewable energy and efficiency measures, such as cogeneration and district heating. No notification of

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[2] https://ec.europa.eu/competition-policy/state-aid/state-aid-overview_en (accessed 29 November 2021)

aid is required for measures that do not exceed certain thresholds or is granted pursuant to a competitive bidding process. Notifiable aid measures include operating aid for the production of renewable electricity and/or combined production of renewable heat, unless the aid is granted to renewable electricity installations at sites where the resulting renewable electricity generation capacity per site does not exceed 250 MW and 300 MW for plants generating from cogeneration plants. Aid for the production of heat from cogeneration will be assessed in the context of notification based on electricity capacity (Commission, 2014). In terms of compatibility with the objective of common interest, meaning that the aid in question contributes to a higher level of environmental protection, aid for DHC and cogeneration is only compatible with the internal market if granted for investment purposes, including upgrades, to high-efficient CHP and energy-efficient DHC.

Operating aid for high-energy-efficient cogeneration plants can be granted, subject to certain conditions applying to that operating aid. According to the Guidelines (Commission, 2014), these are:

a) the aid is granted in the form of a premium in addition to the market price at which the generator sells electricity in the market;
b) beneficiaries are subject to standard balancing responsibilities, unless no liquid intra-day markets exist; and
c) measures are put in place to ensure that generators have no incentive to generate electricity under negative prices.

Installations with an installed electricity capacity of less than 500 kW or demonstration projects, except for electricity from wind energy where an installed electricity capacity of 3 MW or 3 generation units applies, are not subject to these conditions. In terms of cogeneration specifically, aid may be granted under the Guidelines (Commission, 2014) to:

a) undertakings generating electric power and heat to the public where the costs of producing such electric power or heat exceed its market price; and
b) for the industrial use of CHP where it can be shown that the production cost of one unit of energy using that technique exceeds the market price of one unit of conventional energy.

4.1.3 Revision of State Aid Guidelines for environmental protection and energy

Although valid for the period 2014-2020, the Guidelines were formally extended until 31 December 2021 (Commission, 2020). The new Guidelines on State Aid for Climate, Energy and Environmental Protection and Energy 2022 (CEEAG) came into force in January 2022. A main driver for the revision is the expansion of the scope of the Guidelines to new areas and technologies, which help to deliver the Green Deal (Commission, 2019a) and to make compatibility with the rules more flexible. The scope of the CEEAG will be broader to include energy efficiency measures in buildings.

The revisions therefore also apply to support for the construction or upgrade of energy efficient DHC systems. These can include heating or cooling generation and storage plants or upgrade of the distribution network or both. Aid measures would usually cover the construction or upgrade of the generation unit for compatibility with renewable energy, waste heat, or highly-efficient cogeneration including thermal storage solutions (Commission, 2021k). To be compatible, district heat generation and networks must be efficient in line with the Energy Efficiency Directive 2012/27/EU (Energy Efficiency Directive). For example, under Article 24(1), Member States must analyse various indicators including electricity and heat generation from CHP, in their annual monitoring report to assess progress towards the energy efficiency target.

4.1.4 National Energy and Climate Plans

The National Energy and Climate Plans (NECPs) were introduced by the Regulation on the Governance of the Energy Union and Climate Action (2018/1999/EU), which was agreed as part of the Clean Energy for all Europeans package (CEP) of legislation (Commission, 2017), adopted in 2019. Under the CEP, MSs must set out the strategies and measures through which they plan to address energy efficiency, renewable energy, greenhouse gas emission reductions, interconnections, and research and innovation in their NECPs. Submission of final NECPs to the Commission was required by end of 2019. NECPs also exist for Norway, Switzerland and Iceland.

4.2 Subtask 3.2 Overview

Task 3.2 draws on the European Commission's database of State Aid cases. Searches were conducted for cases with reference to 'district' 'energy' and 'pump' to cover DHC and HP. The methodology involves several steps, which have been conducted simultaneously and included in this project's Task 3 database: Step 1 (case search), Step 2 (Review of NECP with clustering and classification of support scheme), and Step 3 (Review of NRRP with relevance to heating and cooling and alignment with NECP).

4.3 Step 1: Commission database of State Aid cases – overview of search results

A search for the term 'heat' yielded 86 results. The term 'district' yielded 23 results, which were also included in the results for 'heat. Two of the 'heat' and 'district' cases relate to the initiation of the Commission's formal investigation procedure, and one decision confirmed that the measure did not constitute State Aid. The term 'pump' did not yield any results in the Commission's database. In the majority of cases, no objections were raised by the Commission. Five cases were decided under the General Block Exemption Regulations with less detail reported. In the two cases where formal procedures were raised, these were based on the concern on the part of the Commission that an upgrade of the DHC would result in lock-in of carbon emitting plants and therefore would not be in the interest of environmental protection as required under State Aid rules because the updates to the DH system were based on existing fossil fuel plants. Poland – the country involved in both cases – had submitted that the upgrade was necessary to prevent losses and reduce CO2 and other particulates.

In the first case (SA.51987 District heating network - Tarnobrzeg (Poland)), the Commission initiated the investigative procedure under Article 108(2) TFEU rather than approving Poland's State Aid. Poland had proposed to support upgrades to the DH network in five municipalities in Podkarpackie. All projects involved existing DH systems based mainly on coal-fired boilers and some gas-fired boilers and in Ropczyce a small share of recycled waste heat. Poland submitted that the replacement of the old DHC networks would provide environmental benefits by mitigating heat transmission losses, and reducing emissions of CO2 and other pollutants, including fine particulates associated with coal-fired heat generation. The Commission notes that the argumentation in Poland's submission relies upon an assumption that the counterfactual situation is one in which the existing heating plant continues to operate and supply heat via an unmodernised network. However, the Commission emphasizes that upgrading DHC networks around continued use of fossil-fuel-based heating plants risks compounding a lock-in effect, as the upgrades to the DH network effectively prolong the operational lifetime of the fossil fuel based plants beyond what it would otherwise be. As such, there is a risk that although the network upgrades improve the economic viability of the DHC systems, they thereby perversely prolong the life of the mainly fossil fuel based power plants.

The Commission expressed doubts in its conclusion that the Polish DHC projects in the Podkarpackie region could be found compatible with the internal market on the basis of Article 107(3)(c) TFEU. Moreover, the Commission expressed further doubt as to whether the measures targeted an objective of common interest (environmental protection) because they involve support to district heating systems based on fossil fuels that do not meet the definition of efficient district heating in the Energy Efficiency Directive. The Commission raised objections, and instead of approving the aid invited interested parties to provide comments on the issues raised.

In case SA.52084 District heating network - Ropczyce (Poland), the Commission also initiated the investigation procedure under Article 108(2) TFEU. The record provided by the Commission reiterates the previous case, SA.51987. Cases SA.51987 and SA.52084 show that the Commission will object to State Aid for renewal or upgrade of DH infrastructure, where such activities would lead to a lock-in of or extended lease of life for existing fossil fuel based power plants as such effects are not compatible with the objective of environmental protection.

4.4 Step 2: Review of National Energy and Climate Plans (NECP)

The method for assessing the NECPs follows the criteria set out for Task 3.2. The geographical or spatial scope covers 16 countries: Sweden, Denmark, Germany, Netherlands, France, Italy, Poland, Lithuania, Spain, Bulgaria, Austria, Finland, Norway, Iceland and Switzerland. Altogether, the NECP review includes 16 countries.

The measures covered in the NECPs were divided into direct and indirect measures. Almost all countries within the geographical scope put in place both direct and indirect measures in their NECPs. 15 out of 16 countries (with the exception of the Netherlands) set out direct measures and 15 out of 16 countries (with the exception of Iceland) set out indirect measures. The measures were then clustered into two categories in terms of purpose: (i) increase energy efficiency and (ii) increase share of renewable energy production. The next step required a classification of measures in terms type: public funding (including subsidies), grants, soft loans, guarantees, tariffs and premiums.

Overall, more countries (14 out of 16) target the increase in share of renewable energy production. 11 out of 16 countries target the increase of energy efficiency. Figure 10 shows which countries address both energy efficiency and renewable energy as opposed to just one of those categories in the reviewed countries.

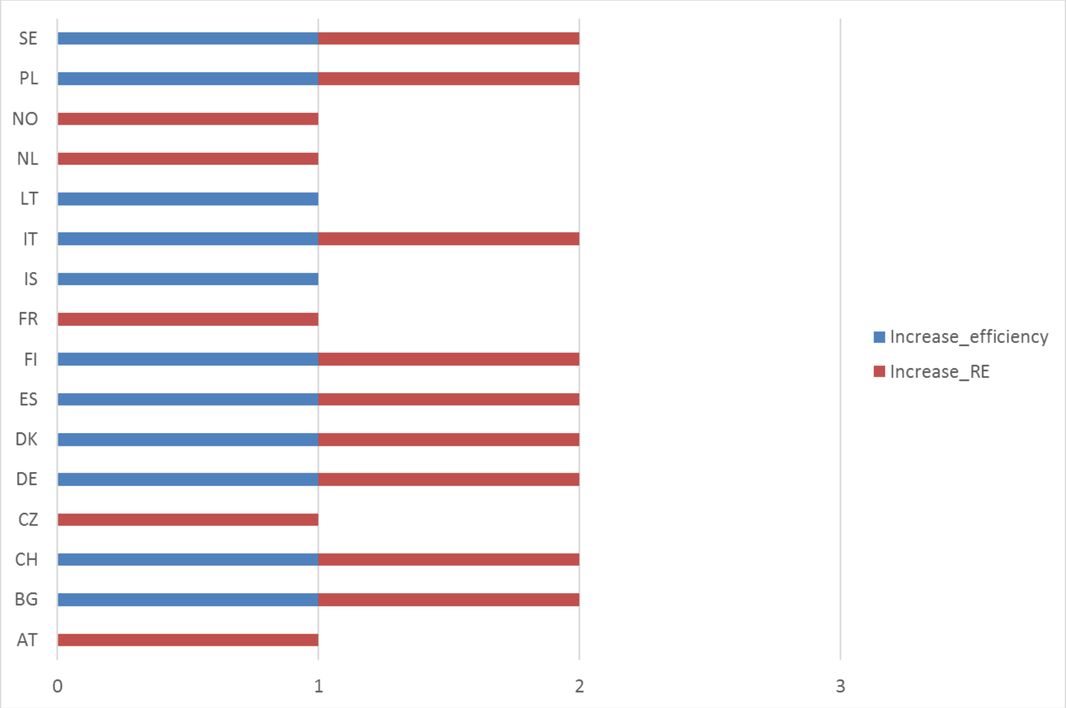

Figure 10: **Overview of NECPs relating to efficiency and renewable energy**

Classification of support schemes

Figure 11 below shows the spread of types of support schemes across the geographic scope. This reveals that the three most frequently occurring support schemes are (i) public funding and tax mechanisms, (ii) followed by tariffs and premiums, and (iii) grants. Soft loans and guarantees were least frequent. In relation to DHC and HP, public funding and tax mechanisms appear to be the most popular measures used to support heating technology both in terms of direct and indirect measures.

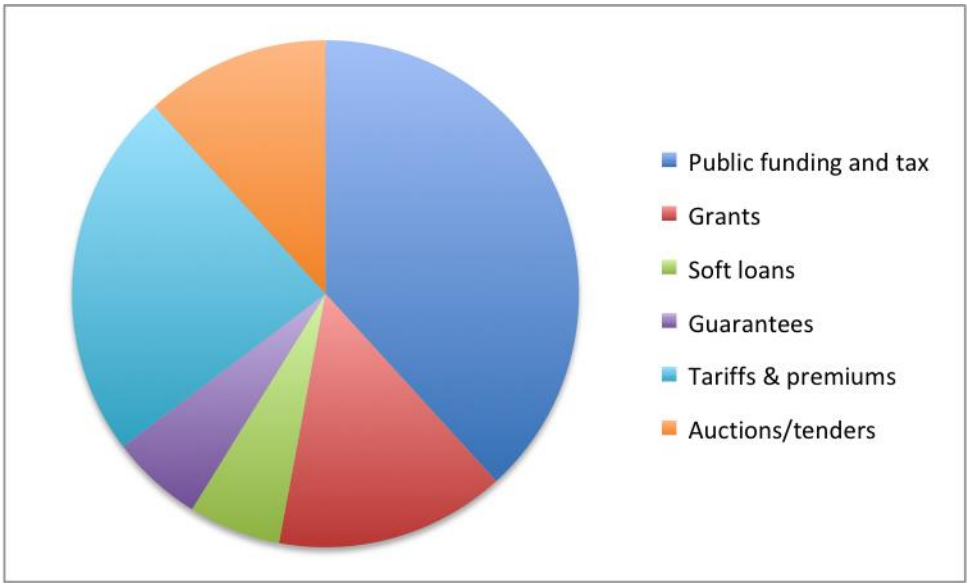

Figure 11: **Share of types of support schemes across reviewed countries**

A more detailed country breakdown in Figure 12 reveals the availability of support scheme type in each of the reviewed countries. Half of the countries (8 out of 16) use two types of measures, whilst Austria, Switzerland, Czech Republic, Iceland and Poland use three of the measures, all including at least public funding and tax with tariffs and premiums. Whilst Austria, Iceland and Poland combine these with grants, Switerland and the Czech Republic combine these with auctions or tenders.

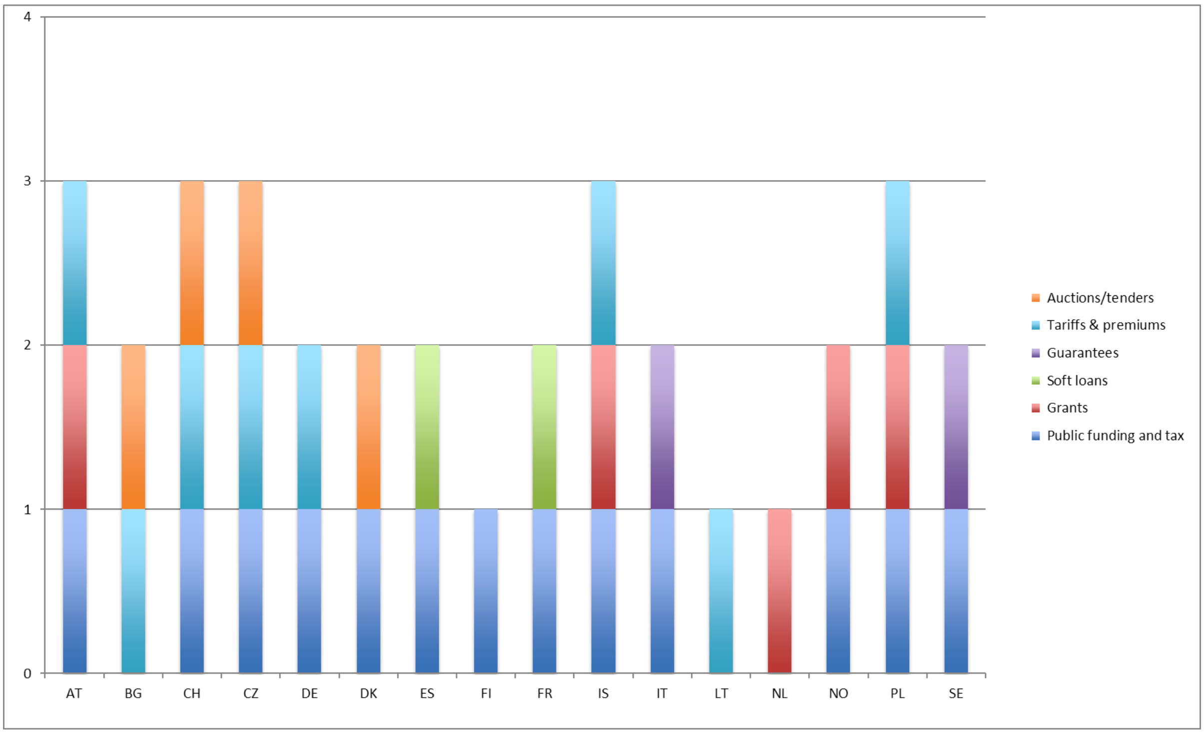

Figure 12: **Number of support scheme types by country**

In terms of technology, the focus in the NECPs is primarily on DHC systems overall. However, seven countries have provisions (directly or indirectly) for HP. The Netherlands, Italy and Czech Republic use indirect measures to support HP, whilst Denmark, Spain, Finland and Iceland use direct measures to support HP technology. Direct measures are in the form of tax reduction (Denmark and Finland) and loans or subsidies for installation (Spain and Iceland). Indirect measures, which specifically refer to HP are in the form of grants for sustainable installations generally (the Netherlands and Italy) or real estate tax exemption for certain technologies, including HP (Czech Republic).

The European Heat Pump Association (EHPA) has made additional data available on known available support for HP in their respective jurisdictions. Data is available from Austria, Czech Republic, Denmark, Finland, France, Germany, Italy, Norway, Poland, Spain and the Netherlands. EHPA members in these countries have categorised the information across different categories: (i) specifically mentioning HP or apply specific conditions to HP, (ii) for the replacement of Heating & Cooling (H&C) systems without mention of HP, (iii) for building renovation benefitting HP, (iv) for new buildings benefitting HP, and (v) for R&D, whether for HP or H&C in general.

As shown in Figure 13 below, EHPA member responses show that the Netherlands has funding schemes mentioning HP or applying specific conditions for HP but not the other categories of funding schemes. France has schemes under all of the categories. Germany and Norway display all the categories apart from other funding schemes affecting HP and Finland's data indicates the availability of all schemes except for those relating to new buildings benefitting HP.

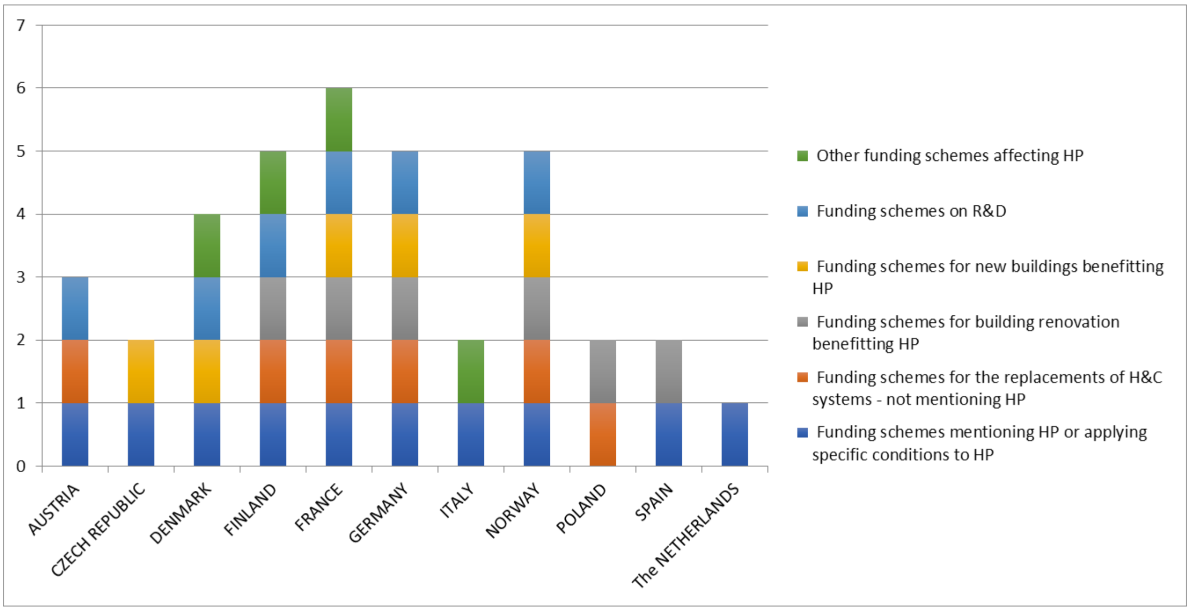

Figure 13: EHPA criteria of HP funding schemes by country, based on EHPA data

In addition, four of the countries (DK, FI, FR and IT) have other funding schemes affecting HP. This is highlighted here as Denmark is a leading country in the deployment of DHC technology. The EHPA member from Denmark highlights a scheme initiated by the Danish Energy Agency in 2017, under which Danish house owners operating an oil boiler as their heat source and who are located beyond the coverage of the DHC networks are able to order a HP on subscription without the need for significant upfront cost. The HP continues to be owned by an operating company. This programme was originally run under the Danish oil – but since 2020 also natural gas - boiler scrapping scheme, established by the Danish Government.[3] The operating companies enter into an agreement on payment for heat for a specified number of years. This payment covers the costs of purchasing and operating the HP. In practice, the business concept works as a form of subscription solution and provides many of the same benefits in terms of investment and convenience as access to a DHC system would.

Toleikyte and Carlsson (2021) provide an assessment of the heating and cooling related chapters of the NECPs. Several findings and conclusions are highlighted here:

- Not all countries meet the target set out in Article 23 of Renewable Energy Directive (2018/2001/EU) (RED 2018) of a 1.3 percentage point annual increase in renewables in the heating and cooling sector. Where countries did not meet their objectives, only a few countries provided details of the causes.
- National projections for heat supply from DHC were not usually provided. Increased DHC use is projected in three countries, including Lithuania and the Netherlands and a decline is expected in six countries, namely Czech Republic, Denmark, Estonia, Poland, Finland and Sweden. The decrease is the result of efficiency improvements in the building stock and DHC networks.
- Ambition to increase the share of renewables in the heating and cooling sector is frequently lower than that in the power sector. The objectives of Articles 23 and 24 of the RED 2018 in terms of targets including renewables for DHC are not met in many NECPs, without explanations in most cases about the constraints that caused the MS fall short of the targets.
- The potential use of waste heat and cold is often overlooked, with only 4 MS expressing an intention to increase its use.

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[3] https://ens.dk/en/our-responsibilities/heat

- Clarification is needed from the Commission on the definition of waste heat and cold and how to account for its contribution towards the heating and cooling targets in Articles 23 and 24 of the RED 2018.
- Limited detail is provided in most NECP on measures related to renewables and energy savings in the heating and cooling sector.
- Only six NECPs specifically address cooling technology, even though its importance in relation to decarbonisation and seasonal increase in temperature is expected to increase going forward.
- More alignment between legislation and NECPs is needed, for example, the timelines in some directives and those set out in the NECPs are not aligned, which leads MS to claim that there is insufficient information to rely on for their long-term strategy for buildings renovation and assessments under Article 14 of the Energy Efficiency Directive 2012/27/EU.

4.5 Step 3: Review of Commission Analysis of National Recovery and Resilience Plans (NRRP)

The Recovery and Resilience Facility (RRF) is part of the EU's facility for recovery from the coronavirus pandemic. The RRF will provide grants up to €338 bn, and loans up to €390 bn. EU MSs must submit NRRPs that describe the reforms and public investment projects they plan to implement with the support of the RRF. Officially, EU countries must submit their NRRPs by 30 April 2021 under paragraph 38 of the Preamble and Article 18(3) of the Recovery and Resilience Facility Regulation 2021 (Regulation (EU) 2021/241). However, this deadline is flexible and the Commission has accepted that countries may have up to mid-2022 to submit their plans. Member States set out in their recovery and resilience plan the reforms and investments that they aim to implement by 2026. Once submitted, the Commission assesses Member States' NRRPs within two months after submission and translates their content into legally binding acts. Based on a proposal by the Commission, the Council has as a rule four weeks to adopt the Commission proposal. Using the approach applied by the Commission's Joint Research Centre (JRC) when assessing the EU's COVID 19 Recovery Plan (Commission JRC, 2020), the Commission's analyses of the NRRPs for Denmark, Germany, the Netherlands, France, Italy, Lithuania, Spain, Austria, Finland and Czech Republic have been searched for references to DHC and HP technology. Bulgaria's NRRP was submitted on 15 October 2021. There is currently no English translation. Likewise, there are no translations for the submissions made by Poland and Sweden.

The Commission analysis highlights where countries have linked the NRRP to provisions set out in their respective NECPs. The countries reviewed are countries are Austria, Germany, France, Italy, Lithuania, Spain and Finland. Highlighted here are the Commission's comments on the links and compatibility between respective countries' NECP and NRRP in relation to heating technology. The Commission's analysis of a set of NRRP have been examined to show where the Commission has commented on the compatibility between the NECP and NRRP but also to highlight specific references to energy efficiency in buildings and/or heating. Each of the countries were found to show a degree of compatibility with their respective NECPs, however Lithuania and Spain were advised to either increase the ambition of efficiency targets and the scale of renovation for residential buildings which affects heating technologies (Lithuania) or to focus more on the promotion of renewable heating and cooling (Spain). For Finland, although found to show compatibility between its NECP and NRRP, and specifically including measures on waste heat, energy efficiency was not the primary aim of those measures. Austria and Germany showed compatibility between their NRRPs and NECPs. Austria addressed the decarbonisation of buildings, including the phasing out of coal and gas for heat to address the significant emissions which the building sector represents. Germany set out increased support for renewable heating. France focused more on the energy efficiency of buildings, whereas Italy set out efforts to increase the share of renewables and efficiency in heating but were assessed by the Commission to require more funding for those targets. In terms of coverage of heating technologies, eight of the 12 Commission’s NRRP analyses reviewed highlight specific references to ‘DHC’. These countries are Austria, Denmark, Germany, France, Italy, Spain, Finland and Czech Republic. Four countries refer to HP (France, Germany, Denmark and Austria). Some NRRP analyses refer more generally to ”heat”, for example Lithuania. A search for the term “cooling” did not reveal significant content and is only referred to once or twice if at all in conjunction with the phrase “heating and cooling”. Most of the NRRP analyses refer to cooling in the context of increasing shares of renewable energy in heating and cooling. These countries are Germany, France, Lithuania, Spain, Austria and Italy. According to the Commission analysis, the Czech Republic’s refers to heating and cooling specifically in relation to energy efficiency. The Danish NRRP analysis does not refer to cooling. Finland’s NRRP is singled out in the Commission’s analysis with a high share of renewable energy in energy consumption, with a major contribution from heating and cooling.

5 Summary and outlook

5.1 Summary of findings

The review of the literature relating to the **Framework Conditions** shows that, overall, *FC6 (Electricity grid access)*, *FC7 (Physical environment)* and *FC3 (Permitting)* are the least represented conditions, whilst *FC2 (Investment)*, *FC9 (Acceptance)* and *FC5 (DHC Technology Conditions)* are the three most represented conditions, as shown in Figure 5. In terms of geographic scope, Figure 6 shows that, with the exception of Bulgaria, most of the better-represented countries are in Northern and Western Europe. With the exception of Portugal and Bulgaria, most of the less well-represented countries are in Eastern and Southern Europe. This may be partly due to a focus on countries where the deployment of heating and cooling technologies has been relatively successful, such as Denmark, Sweden and Germany. The EU is measured as a separate category, as several items in the literature review refer to an overall EU-wide study, mostly still encompassing the former EU28 and therefore including the UK, but excluding Switzerland, Iceland and Norway. Where these countries are included, they are the least represented countries in the reviewed literature.

Sector coupling is a particularly strong thread between the FCs, which is a key means of improving the uptake and deployment of DHC and HP. Countries with rapid growth in renewables should place great priority on sector coupling, including the use of HP for demand response. Sector coupling can make market signals more effective but market prices must be consistent across the relevant sectors. Little consideration is given to gender aspects in heating and cooling policy in the reviewed literature. Gender as a factor can impact consumer willingness to adopt and pay for heating and cooling technologies. Policy indicators should address the extent of gendered participation in energy transition in addition to energy poverty, as a result of the gendered nature of decision-making on energy infrastructure.

The vast majority of cases relating to ‘district’ and ‘heat’ in the ECs database of **State Aid cases**[1] were not investigated further by the Commission. The cases in which further investigation was initiated suggest that the EC will object to state aid for renewal or upgrade of DHC infrastructure, where such activities would lead to a lock-in or extended lease of life for existing fossil fuel-based power plants. Cases SA.51987 and SA.52084 show that the Commission will object to State Aid for renewal or upgrade of DH infrastructure, where such activities would lead to a lock-in of or extended lease of life for existing fossil fuel-based power plants as such effects are not compatible with the objective of environmental protection. Overall, however, in the vast majority of cases relating to ‘district’ and ’heat’ the Commission did not investigate the matter further.

The review of NECPs shows that more countries (14 out of 16) target the increase in share of renewable energy production than energy efficiency (11 out of 16). The three most frequent support schemes are (i) public funding and tax mechanisms, (ii) tariffs and premiums, and (iii) grants. Soft loans and guarantees were least frequent. Where heating and cooling technologies are considered in the NECP, the focus is primarily on DHC systems overall. Although HP are mentioned in all NECPs, assessments of the heating and cooling chapters of the NECP recommend that all MS show trajectories of how HP will develop in future and provide more detailed analysis of how to increase the use of HP. In addition, the assessment of the heating and cooling chapters of the NECP show that not all countries meet the target for increasing renewables in the heating and cooling sector in accordance with the RED 2018 and only a few countries provided details of the causes. More alignment between legislation and NECPs is needed.

The **Commission's analyses of a set of NRRPs** have been examined to show where the EC has commented on not only the compatibility between the NECP and NRRP, but also to highlight specific references to energy efficiency in buildings and/or heating. The review highlights the extent that COVID recovery initiatives and funds in the NRRP also support countries' NECP objectives in particular where these target heating and cooling technology. All reviewed countries showed a degree of compatibility between their NRRPs and NECPs, however the EC highlights that countries tended to focus either on efficiency or decarbonisation. Where both decarbonisation and efficiency measures were prioritised, this leads in certain instances to issues with the extent of funding required to fulfil those targets. In terms of coverage of heating technologies, eight of the 12 Commission analyses of the NRRPs reviewed focus specifically to 'DHC'. These countries are Austria, Denmark, Germany, France, Italy, Spain, Finland and Czech Republic. Four countries refer to HP (France, Germany, Denmark and Austria). Some NRRP refer more generally to 'heat', for example Lithuania.

5.2 Outlook for future research

The literature review of the **Framework Conditions** shows that overall, *FC6 (Electricity grid access)*, *FC7 (Physical environment)* and *FC3 (Permitting)* are the least represented conditions. We therefore recommend further research to focus especially on these FCs. Whilst the FC taxonomy proposed by Sneum (2021) provides an important analytical framework with which to examine the barriers and incentives to DHC and HP, as highlighted in section 2.3.9 the FCs are very much linked and further research is needed to examine the relationships between the FCs and to consider additional aspects and perspectives. For example, the employed FCs do not reflect the nuances of complex and regionally-diverse electricity market frameworks that may strongly affect the uptake and degree of flexibility of DHC and HP systems. In terms of geographic scope, with the exception of Portugal and Bulgaria, most of the less well-represented countries are Eastern and Southern European countries. This may be partly due to a focus on countries where the deployment of heating and cooling technologies has been relatively successful, such as Denmark, Sweden and Germany. However, we also note that Iceland, for example, is not well-represented in the reviewed literature, despite successful DHC projects in municipalities like Reykjavik (Zuquim & Doorman, 2020). We would therefore recommend further research on DHC and HP uptake in countries that are less well represented in the literature review and further consideration of the correlation between the maturity of the heating market and availability of data and studies on DHC and HP in those markets.

In terms of FC3 (Permitting), an aspect for further research is the permitting framework at MS level relating to the placement of pipes for DHC and the extraction of (waste) heat from diverse sources. In relation to *FC4 (Ownership)*, we acknowledge that ownership regulation is not just associated with different degrees of unbundling. Ownership structures and models can be key enablers for certain heat sources, such as waste heat (Schmidt et al., 2020). Another aspect of *FC4 (Ownership)* is the ownership of physical assets, such as the substation in terms of responsibilities and maintenance, whether borne by the utility, customer or operator (or facility manager). Further research is also recommended on the impact of the revision of the RED II (draft REDIII) and revised EED on DHC and HP, on DHC and HP, in order to implement the provisions of the European Commission's proposed 'Fit for '55' legislative amendments, which are intended to keep the collective EU on course to reach the overall Net Zero emissions reduction target for 2050 (the 2050 Target). The 2050 Target was recently applied to the MS collectively under the EU's Climate Law.[4] At EU level, we acknowledge the potential broader relevance of the EU Taxonomy Regulations (2020/852/EU). Although not part of the FCs set out by Sneum (2021) for Subtask 3.1, we

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[4] https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/package-fit-for-55

recognise that there may be benefit in examining the relationship between the EU Taxonomy Regulations and DHC/HP uptake going forward.

The revision of the **Guidelines on State Aid** as now set out in the CEEAG 2022 will impact the availability of support for DHC and HP, in addition to the extent to which MS implement the proposals contained in their NRRP. These areas would therefore benefit from further research. We also note that support mechanisms can provide important incentives for building sites and refurbishment to integrate DHC and HP.

6 Heat planning, governance and regulatory frameworks

6.1 Introduction

Subtask 3.3 seeks to address governance factors which impact the uptake of District Heating Cooling (DHC). Previous subtasks for Task 3 identified regulatory and financial barriers and tools for the uptake of heating technologies. Subtask 3.3 now extends this to the energy and spatial planning frameworks for heat in light of proposed provisions for municipal level heat plans in the draft recast of the Energy Efficiency Directive. Task 1 of the project had already identified specific research gaps in relation to the perception of heating and cooling. As a result, it was determined to focus on mechanisms that are showing promise for the uptake of DH but are not as widely examined in the literature. An area of study that requires further analysis in this regard is the concept of heat planning. DH is of particular interest in relation to heat planning and spatial energy planning, as it requires the higher levels of organisation and planning which these mechanisms can provide (Djørup et al., 2019). For example, Zach et al. (2019) have shown that integrated spatial and energy planning strategies increase opportunities for DH. Denmark is considered a leading jurisdiction in terms of planning, distribution and maximising efficiency and production of heating and cooling using a heat planning approach (DEA. Danish Energy Agency, 2010. Danish Energy Policy 1970–2010. Copenhagen). More countries have now started to apply this approach, including Germany (Köhler et al., 2021) and Austria (Egger et al. 2017), but other jurisdictions also show signs of exploiting the characteristics of heat planning even if the term is not specifically used in that context (e.g. Scotland). Heat planning is in some jurisdictions still in its early development stages but is likely to increase with the provisions of the proposed recast Energy Efficiency Directive EED (Commission, 2021a). Part 1 of this report therefore focusses on jurisdictions that have started to plan or even implement regional or municipal heat plans, whether as part of a dedicated heat planning or a spatial energy planning approach to heat. Municipal heat planning has already proven highly effective in Denmark, which is recognised internationally for its heat planning approach to district heating (Johansen and Werner, 2022). Governance and regulation of the planning approach to heat is critical as heat infrastructure is relevant to different governance levels, both national and local. Thermal networks or DH are only economically viable in areas with high-density populations because thermal energy cannot be easily transported over long distances. Beyond urban or high-density areas, buildings generally require building-specific heating technologies. As such, heat infrastructure has developed according to these technical constraints and in accordance with available resources, national legislation and policies. However, a problem is that this has resulted in very different situations for heating supply across Europe (Djørup et al., 2019).

6.2 Methodology

Step 1 first provides an overview of the concept of heat planning and discusses it in relation to the broader concepts of integrated energy and spatial planning or spatial energy planning, including its relationship to acceptance and uptake of heating technologies. It should be noted that the concept of heat planning is not universally used and that forms of heat planning also fall within the wider category of spatial energy planning for heat. Once the core concepts are established, a review was conducted of the 27 National Energy and Climate Plans (NECP) to consider the extent of references by each MS to the provisions of the current EED requirement for comprehensive heat assessments under Article 14. In addition, the review considered whether the MS in question had gone further, either with plans to implement any form of heat planning, whether as part of its energy spatial planning strategy or as a dedicated heat plan, nationally or at regional or municipal level as required by the proposed recast EED. The review in relation to the coverage of heat planning and spatial energy planning was conducted with a view to the proposed provisions in the recast EED which, although still in draft form, will eventually amend the EED currently in force. The proposed new provisions require MS to encourage the implementation of municipal heat planning going forward. The review therefore involved a search of the NECPs for key words relating to heat planning or spatial energy planning for heat. NECPs were also reviewed for references to existing or planned heat strategies. This will provide a high-level overview of the countries in the EU27 which at the point of submission of their NECP refer (i) specifically to the concept of heat planning, (ii) to spatial planning in relation to energy, (iii) to spatial energy planning in relation to heat, (iv) have a national strategy or programme for heat (planned or implemented), including as part of a national energy strategy, (v) to the requirements of Article 14 EED 2012. Heat planning and spatial energy planning are explained in sections 2.3.1-2.3.2. It is acknowledged that many MSs discuss heat as part of a broader energy strategy, however the focus in this step is to determine to what extent countries see heat as part of energy spatial planning and/or are implementing or preparing for the implementation of municipal heat planning as set out in the proposals for the proposed recast EED.

Step 2 entails case studies of specific countries and the status of their heat planning or energy spatial planning framework for heat at (i) national and (ii) regional/municipal level. These case study countries are Austria, Denmark, Germany, Poland, Switzerland and Scotland (UK). This sample provides a broad range of approaches to heat planning and energy spatial planning for heat. Each jurisdiction has a unique energy policy and context, providing a range of planning approaches and stages of development. An examination of the national and regional/municipal level is conducted not only because the provisions of the proposed recast EED include heat planning for municipalities but also because the tools and powers given by national governments to municipalities (as displayed successfully in Denmark), can lead to expansion and sustainable investment in cost-efficient DH (Chittum and Østergaard, 2014). A case study approach supports the position that examining different experiences of heat planning can also support the implementation of solutions which support the phasing out fossil fuels (Djørup et al., 2019). Figure 14 below sets out the steps taken in relation to Part 1.

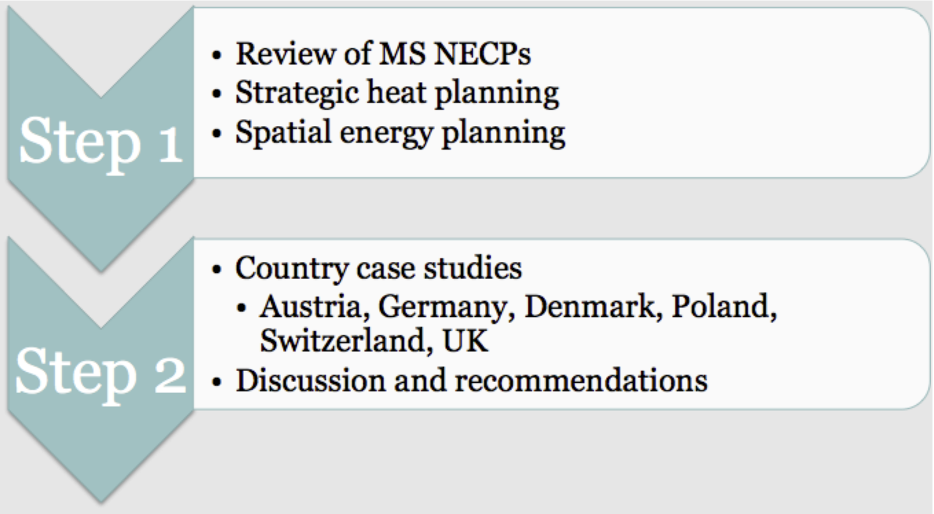

Figure 14: Steps for Subtask 3.3

6.3 Step 1: Overview of Heat Planning, Spatial Energy Planning and National Energy and Climate Plans (NECPs)

6.3.1 Heat planning

In the EU, the past 10 years have seen significant efforts towards deploying heating and cooling planning. Nonetheless, heat planning is at the very beginning of broader implementation in Europe, with only some countries, notably Denmark, leading the way (Aydemir et al., 2022). Aligning planning considerations with energy infrastructure, including heat is important for sustainable development, including in the urban context (Pol and Schmidt, 2016; Stoeglehner et al., 2020). Heat supply is a form of energy infrastructure that encompasses a variety of types and technologies. Even when focusing on heat networks, there is a range from centralised DH based on large fossil-fuel heat plants or waste heat to small local heat networks based on wood fired plants or waste heat (Schubert, 2014). It is necessary to understand the interaction between planning decisions and energy system integration. This is particularly so in relation to DH, where the relationship between energy needs and economic feasibility of DH networks must be fully understood to optimally plan for heat infrastructure (Pol and Schmidt, 2016). Heat planning is a means and importantly an iterative process of enabling municipalities to plan and decarbonise their heat supply within a defined geographic area. It takes into account the local characteristics and potential of heat supply, using an analysis of existing and potential heat supply, scenario modelling and heat strategy development. As such, heat planning is a key tool for implementing heat transition whilst incorporating local participation and local solutions. In fact, the engagement of relevant stakeholders is considered an essential way of ensuring the long-term success of heat planning (Köhler et al., 2021). Several authors understand heat planning as a tool for implementing sustainable urban planning (Köhler et al., 2021; Stoeglehner et al., 2020). In so doing, proponents of heat planning consider it to allow for the integration of both social and economic considerations in a structured and goal-oriented way (DEA, 2015; Köhler et al., 2021). The core concept underlying heat infrastructure, especially DH, is the use of local fuel and/or heat resources for use in the provision of heat to consumers (Johansen and Werner, 2022). Therefore, heating and cooling infrastructure is based locally from a spatial perspective. This requires implementation measures to be set up locally and in conjunction with local engagement (Aydemir et al. 2022). In order to develop heating and cooling infrastructure at a local level, heat planning has been recognised as an effective way to implement decarbonisation in a cost-effective way that is also appropriate to the local area (Chittum and Østergaard, 2014). In Denmark, a leader in this type of heating and cooling infrastructure planning, this approach is largely credited with great success in terms of planning, distribution and maximising efficiency and production of heating and cooling (DEA, 2015; Marriner, 2021).

6.3.2 Heat planning in the context of integrated energy and spatial planning

Heat planning is understood here to be a form of integrated approach to energy and spatial planning. This is shown in Austria, for example, where heat planning is a part of broader spatial energy planning (Köhler et al., 2021). Heat planning and energy planning more generally was a response in some countries to the oil crisis in the 1970s in order to lessen dependency on imported oil sources. Energy planning can be understood as a process of developing long-term policies to plan and guide the development of local, national, regional (and also global) energy systems. Energy planning can be implemented by governmental organisations or large energy companies and utilities. In particular, energy planning is supposed to engage different stakeholders across government agencies, local utilities and other groups in society. Energy planning consists of an integrated approach to consider energy supply and energy efficiency Importantly, energy planning can play a key role in setting the regulatory framework for the energy sector (Bhatia, 2014).

Heat planning is also considered to be a form of spatial energy planning and is defined as "action plans for realising long term visions of radical change in key parameters of the heat supply…[including] fuel demand, environmental factors and security of supply" (Djørup et al., 2019, 13). As such, it straddles both the spatial planning and energy planning dimensions, which together form spatial energy planning In more recent years, heat planning has increasingly become a tool for supporting climate targets in the heat and cooling sector (Aydemir et al., 2020). According to Chittum and Østergaard (2014), heat plans are developed locally in order to identify the current and future heat demand of the buildings within a specific area in addition to available and potential heat resources. This also involves the planning process which assesses the most cost-effective and appropriate heat supply options in a given area. Heat planning seeks to balance district heating, individual heating and heat savings in buildings to minimise fuel consumption within energy supply (Djørup et al., 2019, 15).

Spatial energy planning conceptualises the heat sector as part of overall energy supply and demand (Preiß and Schwaberger, 2021). Spatial energy planning involves the same steps and characteristics as for heat planning (i.e. analysis of existing and potential heat supply, scenario modelling and heat strategy development) (Köhler et al., 2021). The concept of spatial energy planning emerged around the same time as heat planning in response to the energy crises of the 1970s (Preiß and Schwaberger, 2021). Heat planning is often discussed in the context of energy planning rather than as a distinct area in and of itself (Aydemir et al., 2022). A study by Weinand (2020), which assessed municipal energy system plans, examining a large volume of literature (1235), showed that in countries like Germany, for example, DH is a central part of energy planning for municipalities. Weinand (2020) makes an important link therefore between energy system planning and heat planning as an important tool in energy transition. In relation to Denmark, DH planning as a key part of strategic energy planning is also highlighted by Chittum and Østergaard (2014). Taking a step further, Rehbogen et al. (2020) specifically link spatial energy planning with heat transition in Austria. According to the co-investigators of the Austrian Spatial Energy Planning for Heat Transition project, spatial energy planning represents a potential 'game changer' in facilitating heat sector decarbonisation in Europe (Heimrath et al., 2021). Spatial planning in contrast to more traditional land planning seeks to mediate between the spatial requirements of different actors in the categories of state, market and community. This mediation focuses on stakeholder engagement, integration of policy priorities and practical implementation (Bafarasat, 2015). In doing so, it links the local, regional and national levels. However, to be effective, spatial planning requires governance powers across sectors and levels to be effective (Taylor, 2010). The analysis below will show that in different jurisdictions, the alignment of sectors (planning/heat) and alignment of governance levels (national, regional and local) can prove challenging and continue to pose a barrier to effective implementation of heat planning as a form of spatial energy planning. Those countries which have sought to align their energy planning and spatial planning approaches through integrated spatial and energy planning or spatial energy planning in addition to alignment between different governance levels are showing more progress with heat planning. This is the case for Denmark, a leader in heat planning and Austria, which has integrated heat planning into its spatial energy planning. This approach seeks to impact policy on each level of governance from municipal to regional and national (Stoeglehner, 2020).

Maaß (2020) understands heat transition in terms of decarbonisation and efficiency as a task for the spatial planning regime. Schubert (2014) provides a good comprehensive overview of influential factors relevant to spatial considerations in heat supply and divides these into supply and demand side factors. Supply-side factors include (i) availability of local energy carriers, (ii) existing infrastructure, and (iii) regional availability of energy carriers and means of transport. On the demand side, relevant factors include (i) urban density, (ii) settlement structure/geography, (iii) energy (efficiency) status of buildings, (iv) ownership structure and (v) user characteristics. As a result, heat supply is closely linked to the spatial aspect of an (urban) area (Schubert, 2014). This shows that a holistic approach is key to energy system planning and spatial heat planning can contribute to this approach via mapping exercises, for example. As concluded by the Paardekooper et al. (2018a) under the Heat Roadmaps Europe final project report, energy mapping is key to energy planning. This is particularly important for the planning of relevant infrastructure. Heat sector information is very local and requires to be mapped as part of a heat planning exercise (Paardekooper et al., 2018, D6.4). One of the key findings is that certain tools and methodologies are specific to the heating sector and are required to coherently assess (model, analyse and design) the heating system as part of the overall energy system. This coherent assessment is a key part of developing strategic plans to decarbonise the energy system. One of the tools that contributes towards this assessment is a detailed spatial analysis to comprehend the local characteristic of heating (Paardekooper et al., 2018a, D6.4). Table 2 below shows the key descriptive element of each of the concepts and where heat planning sits within them (energy planning, spatial planning, energy spatial planning, heat planning).

Table 2: Descriptions of the key terms – energy planning, spatial planning, energy spatial planning and heat planning

Term	Description
Energy planning	• process of developing long-term policies to plan and guide the development of local, national, regional energy systems • can be implemented by governmental organisations or large energy companies and utilities • Engagement of different stakeholders across government agencies, local utilities and other groups in society • integrated approach to consider energy supply and energy efficiency • play a key role in setting the regulatory framework for the energy sector
Spatial planning	• spatial planning in contrast to more traditional land planning seeks to mediate between the spatial requirements and priorities of different actors for land use (e.g. government, the market and community) • mediation focuses on stakeholder engagement, integration of policy priorities and practical implementation • links the local, regional and national levels
Spatial energy planning	• conceptualises the heat sector as part of overall energy supply and demand • involves the same steps and characteristics as for heat planning (i.e. analysis of existing and potential heat supply, scenario modelling and heat strategy development but on a broader whole energy system basis
Heat planning	• combines spatial planning and energy planning approaches • means/process of enabling municipalities to plan and decarbonise their heat supply within a defined geographic area. • Integrates local characteristics using analysis of existing and potential heat supply, scenario modelling/heat mapping for heat strategy development

Term	Description
	• key tool for implementing heat transition whilst incorporating local participation and local solutions, relying on engagement of relevant stakeholders as an essential way of ensuring the long-term success of heat planning and acceptance/uptake of heat infrastructure

Figure 15 below shows the relationship between energy planning, spatial planning, spatial energy planning and heat planning.

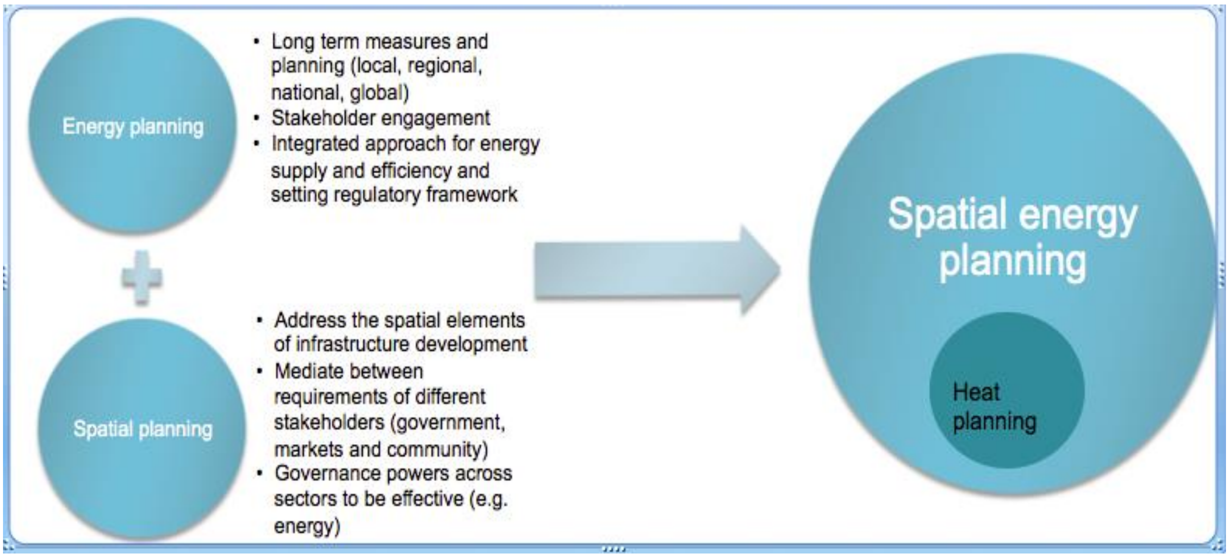

Figure 15: Relationship between energy planning, spatial planning and heat planning

6.3.3 Heat planning, spatial planning and infrastructure uptake andacceptance

It has been highlighted that the engagement of relevant stakeholders is considered an essential way of ensuring the long-term success of heat planning (Köhler et al., 2021). Rehbogen et al. (2020) explain also highlight the role of a spatial approach to infrastructure transition, which is particularly relevant in the context of heat system transition and uptake or acceptance of heat technologies. High transaction costs caused by planning processes, technology risk and upfront costs form barriers to a long-term and holistic understanding of optimal solutions. Existing infrastructure can block the integration of new systems, due to the priority of a primarily costs-based, economic approach. This is particularly so for network-based infrastructure, such as DH, which have an important role to play in harnessing and distributing renewable energy sources. Therefore, public intervention in the form of the planning process is required (Rehbogen, 2020). The importance of a spatial approach to DH uptake is particularly highlighted in Austria's comprehensive assessment for heat. The report maintains that '[t]he share of district heating depends above all on the connection rate that can be achieved in the district heating regions, which in turn is strongly related to the spatial energy planning framework conditions. Depending on the achievable connection rate, an economic potential for district heating is calculated from about 20% to over 50%' (Büchele et al., 2021, 'Potential for efficient heating and cooling'). This underscores the importance of a spatial approach to uptake and acceptance of DH. Heat planning goes even further in that it supports a spatial planning approach at a morelocalised level. Geissler et al. (2022) have reviewed of several NECPs, including Austria's, in terms of the link coverage ofto municipal spatial planning and support for investment in renewable technologies. The above-mentioned authors conclude that a stronger link needs to exist between goals set out in the NECPs and regional spatial planning laws or regulations. The authors call for a streamlining of provincial and municipal regulations relevant to the NECP. It is suggested that this proposal should be extended to heat planning and energy spatial planning for heat as between the various regional approaches and goals of the NECP but that also means setting out heat as an energy spatial planning matter across all the EU27 NECPs.

A local or municipal planning approach in relation to energy generally (and as proposed in relation to heat by the recast EED) is valuable because municipal planners are local experts in relation to the characteristics of the local energy system and the goals and strategies of the municipality as a whole. This expertise is particularly valuable to for energy (including heat) system modelling (Johansen et al., 2021). The role of municipalities and the spatial planning framework that empowers them is important because they can be seen, to some extent, as the intermediaries or links between the design and locally appropriate implementation of national and international climate strategies. In that way, municipalities intermediate between different scales of governance, whether local, national and international. Importantly, international and national strategies and goals are implemented with a view and often prioritisation of local circumstances. The efficacy of municipalities in this regard is however dependent on the degree of autonomy in implementation strategies (Gustafsson and Mignon, 2020). The case studies below support this, in that the autonomy (existing or planned) in Denmark, Austria and Scotland for example, is proving or already has been very positive in enabling heat planning. From an onshore renewable and power grid infrastructure perspective, Koecklin (2021) also supports the value of modelling for expansion planning for broader public acceptance of infrastructure, in Ireland for example, and that modelling must take into account public acceptance. A local municipal spatial energy planning approach to heat allows for the engagement of relevant stakeholders including the affected public. In particular, Koecklin (2021) highlights that the impact of public acceptance of additional energy infrastructure has a significant spatial dimension. As such, municipal heat planning could go towards addressing that spatial dimension for the uptake of heat infrastructure. This is further supported by Bouw et al. (2021) who argue that appropriate planning models must be capable of integrating local characteristics, for example stakeholder behaviour, resource availability and building characteristics. Regarding energy transition, this applies particularly to the built environment, building efficiency and renewable heating. Planning tools should support municipalities and local stakeholders with implementing national renewable energy and efficiency goals in a way that is suitable for the local scale (Bouw et al., 2021). Heat planning could help to address some of the gaps in current models identified by the authors, including stakeholder representation and participation and holistic modelling and viewing of the energy system, including heat, which leads to a lack of a full integrated systems approach with sufficient local detail. The disaggregated approach used in heat planning can help with these gaps.

Significance of governance processes for implementation of heat planning and spatial energy planning

Further support for energy spatial planning for heat or even heat planning is provided by Hemis (2017). The study of seven cities in relation to the integration of energy infrastructure, including heat, into urban planning processes shows that improved governance processes, in terms of responsibility for implementation via the regulatory framework, are needed to integrate grid infrastructure generally but also in relation to increasing renewable energy generation for heating. One of the ways to improve this is by providing cities with the responsibility for strategic energy planning for low carbon transition, including through the use of energy transition legislation or the integration of energy in planning legislation and regulation as distinct from the regulation of energy suppliers and network operators. Importantly though, it is recommended that these different instruments are integrated at the operative level, for example planning instruments at various spatial levels. Energy matters should be integrated into the entire planning process from the beginning (Hemis, 2017). In relation to onshore wind and solar PV, a study by McKenna et al. (2022) also highlights the importance of considering governance levels in relation to creating the right framework conditions for planning and policy. In turn this can support better uptake of technologies and stakeholder approval of new energy infrastructure, thereby overcoming issues relating to aesthetic impact and land use competition. Links to and insights for planning UK planning policy are made. Significantly, McKenna et al. (2022) rely on a spatially disaggregated dataset, which is also a feature of municipal heat planning. In addition, the authors apply a combined top-down and bottom-up method for national level solar PV potentials, however they specifically highlight that the methodology is suitable for regional and national analysis but does not represent a replacement for bottom-up studies for specific locations. Municipal heat planning, including the use of local data and heat mapping can provide such bottom-up data in municipal locations. It will be shown that some of the case studies below display such an approach more strongly (as shown in new provisions in Scotland but also existing ones in Denmark). It is clear that the more local and detailed the data, the more effective energy spatial energy planning is (Hemis, 2017). As a result, a municipal heat planning approach has the ability to provide a particularly effective way of supporting the uptake of heating technologies at local level. In light of emissions and renewable energy targets at EU and MS levels, a top-down coordinated approach to planning policy across jurisdictions is required in tandem to create a more positive enabling context for localised energy infrastructure development (McKenna et al., 2022), such as heat technologies. As argued in the context of variable renewable energy by McKenna et al., 2022), this requires the alignment of planning policy and energy policy at local and national levels for spatial energy planning relating to heat. The case studies in Step 2 will show that this is currently not the case in most jurisdictions, apart from Denmark to some extent. In fact, the design of the governance process, relevant actors for responsibility and implementation varies widely across jurisdictions. As such, no single approach is possible across jurisdictions, however Section 2.6 provide recommendations on best approaches, in terms of alignment between governance levels and sectors.

6.3.4 Overview of NECPs

EU countries are required to establish 10-year integrated National Energy and Climate Plans (NECPs) for the period from 2021 to 2030. The requirement for NECPs was introduced via the Regulation on the Governance of the Energy Union and Climate Action (EU/2018/1999) which entered into force on 24 December 2018. NECPs are policy instruments intended to ensure that the targets of the Energy Union are achieved by 2030 with a longer-term view to further improvement by 2050. The areas of reporting include decarbonisation, energy efficiency, energy security, the internal energy market, in addition to research, innovation and competitiveness (Commission, 2019). Decarbonisation and efficiency have dedicated sections in each NECP and relate to actions taken by MS on installations/infrastructure and systems that will achieve these aims. As such, these aims as set out in each NECP are relevant to land use and spatial planning (Geissler et al., 2022). These aspects are in turn important for heat planning. In parallel with the NECPs, all Parties to the Paris Agreement are invited to provide their long-term low greenhouse gas emission development strategies. In the EU, the Regulation on the Governance of the Energy Union and Climate Action (EU/2018/1999) sets out the procedure to prepare their Long-Term Strategies. These strategies should be consistent with MSs’ NECPs, including in relation to heat strategies. Under the EED 2012 and also a proposed recast EED, MSs must notify the Commision on their heating and cooling plans, as part of their NECPs. The NECPs of the 27 MS were therefore reviewed in relation to consideration of heat planning or aspects of energy spatial planning in relation to heat. In light of the proposals for heat planning at municipal level under Article 23 of the recast EED, it was decided to consider the extent to which MS have integrated heat planning as a form of energy spatial planning in these documents.

Article 14(1) of the EED already requires MS to carry out and notify to the Commission a comprehensive assessment of the potential for applying high-efficiency co-generation and efficient DH. MS have to develop national plans which need to assess the potential for heating infrastructure, including DH to meet the identified heating requirements. National heat plans can relate to a national plan overall or several municipal and regional plans, which cumulatively contribute towards the national plan. These plans tend to be primarily at an aggregated national level. The proposed recast EED, has now added a provision relating to municipalities. In detail, the European Commission has included proposals for municipal heat strategies or heat plans in its proposals for a recast EED. Under Article 23(1) of the proposed recast EED, MSs must still, as part of their integrated NECPs, notify to the Commission a comprehensive heating and cooling plans. However, a key new provision in the proposed Article 23 of the recast EED is the introduction of a provision for heat planning for cities over 50,000 inhabitants. The NECPs were reviewed, as part of the Methodology of this Subtask 3.3, for their coverage of or reference to (i) (municipal) heat planning, (ii) spatial planning in relation to energy, (iii) spatial energy planning in relation to heat, (iv) a national strategy or programme for heat (planned or implemented, including as part of a national energy strategy, and (v) reference to the requirements of Article 14 EED 2012. The following sets out the results of out review:

i. Heat planning:
   - no references specifically to the concept of heat planning in the NECPs.

ii. Spatial planning in relation to energy:
   - Flanders (Belgium), Croatia, Austria, Denmark, France, Luxembourg, Netherlands, Poland, Slovenia

iii. Energy spatial planning in relation to heat:
   - Austria, Denmark, France, Luxembourg, Netherlands, Poland, Slovenia

iv. National strategy or programme for heat (planned or implemented), including as part of national energy strategy:
   - Republic of Cyprus, Czech Republic, Germany, Hungary, Ireland, Lithuania, Slovenia, Austria

v. Reference to the requirements of EED 2012 Article 14:
   - Most MS refer to some extent to Article 14 EED 2012 or an aspect of Article 14, such as mapping of heat, demand studies or heat assessments more broadly. Malta does not have a dedicated heat plan or any existing DH networks.

None of the MS referred expressly to heat planning as a term. Several countries do specifically link spatial energy planning to heat. These countries are Austria, Denmark, France, Luxembourg, Netherlands, Poland and Slovenia. Several countries also indicated that they have implemented or are planning a national strategy or programme for heat. These countries are Republic of Cyprus, Czech Republic, Germany, Hungary, Ireland, Lithuania and Slovenia. Finally, most MSs refer to some aspect of the comprehensive assessment required under Article 14 EED 2012, such as heat mapping or assessing the potential of heat demand or more general heat studies. Malta does not have any dedicated heat plan or any existing DH network. The review of the NECP revealed that in most NECPs, mainly apart from Austria, Denmark, France, Luxembourg, Netherlands, Poland and Slovenia, spatial planning is mainly referred to in the context of maritime spatial planning and transport infrastructure but not in relation to heat. This is also supported by a review conducted by Geissler et al. (2022), who although not focusing specifically on heat, state that spatial planning is not an area of priority in the NECP in relation to renewable energy systems more broadly. Given the key role of spatial energy planning for a municipal level heat planning approach as now proposed in the recast EED, Task 3.3 sought to determine to what extent the concept had been integrated by MS. As will be shown in the case studies, the strong spatial energy planning approach taken by some countries in relation to heat, would also point to a spatial energy planning approach being highlighted in the NECPs. However, there is no specific reference to heat planning but some countries make a link between heat and spatial energy planning or specifically highlight an existing or planned heat strategy whether standalone or as part of a broader national energy strategy. This overview shows to what extent these countries specifically covered certain search terms in relation to 'heat planning', 'spatial planning + energy', 'spatial planning + heat' and 'heat strategy', for example, not whether they definitively have or are implementing a heat strategy or heat planning. For example, Denmark and Sweden do not refer to heat planning in the NECP but they do have heat planning (Denmark) or heat strategies in place. Only some countries make an express connection between spatial planning, energy and heat. As spatial energy planning is predominantly covered in the context of maritime spatial planning and transport, this represents an opportunity to highlight and encourage the use of spatial energy planning in relation to heat, due to its use of many of the tools of a heat planning approach, including heat mapping and zoning and a spatial planning approach from a regulatory perspective. Almost all countries refer to some extent to Article 14 EED 2012 or an aspect of Article 14, such as heat mapping or demand studies for heat. However, there is not always focus on the local/municipal level as now proposed in the recast EED.

A key distinction between the NECPs and Comprehensive Assessment required under Article 14 EED 2012 and heat planning or even the proposal for municipal level heat planning under a recast EED is the level of aggregation or disaggregation of data. The NECPs and Comprehensive Assessments focus primarily on the national, aggregated level. Municipal level heat planning, as contained in the proposals for the recast EED, is by its nature is local and requires disaggregated information and data to be effective, including local engagement and planning. In the Joint Research Centre's (JRC) overview of MS's comprehensive assessments of heating and cooling demand forecasts under Article 14(1) EED 2012, Jacubcionis et al. (2018) make several recommendations in assessments going forward, including the improvement of spatial resolution of available data, sufficient to identify the spatial relationship between heating areas and potential supply points. A key issue with the current Comprehensive Assessment requirement is the large variety in approach and methodology to estimating heating and cooling demand and the level of disaggregation. As such, the report finds that the estimated demand levels are incomparable. This makes the comparison comprehensive assessments very difficult. The report also comments positively in relation to some countries providing map layers for the distribution of renewable energy sources and the inclusion of maps with information on residual heat supply from industrial installations. This was considered to represent additional valuable information for energy planning and recommended for consideration as future mandatory information (Jacubcionis et al., 2018). A spatial heat planning approach which includes heat mapping and zoning would support the provision of such potentially mandatory information in future. Austria and the UK were singled out as examples of best practice in relation to the provision of a high-level of detailed disaggregation of building stock and using a high-level of spatial resolution (Austria) and determining heat consumption for each individual property (in the UK). As such, Part 2 of this report will focus on several jurisdictions that have or are implementing a spatial energy planning approach in relation to heat or heat planning specifically. The report also considers one jurisdiction (Poland) where there is currently no dedicated municipal heat planning approach, but which has been identified as having potential, not just in terms of studies for heat mapping, for example, but in terms of promising governance that might be used to implement heat planning.

6.4 Step 2: Case Studies

This section outlines six case studies examining heat planning and/or energy spatial planning related to heat.

6.4.1 Austria

National

An Austrian Heat Strategy is currently being agreed between the national government and the States (Federal Ministry for Sustainability and Tourism Republic of Austria, 2019). In Austria, heat (residential and industrial) currently represents approximately 50% of total energy demand. 44% of that is covered by fossil fuel sources, including DH and CHP (Adensam, 2021). The renewables share in DH is about 49%, out of this, the vast majority is biofuels. As of 2019, the renewables share in space heating overall is 33.8% but 35% of households in Austria still use fossil fuel based heat sources (Bundesministerium fur Klimaschutz, Energie, Mobilitat, Innovation und Technologie, 2021). The Austrian federal Minister of Economy and Minister of Environment presented the Austrian Energy Strategy in March 2010. The strategy focused on accelerating the refurbishment of buildings and the launch of an energy efficiency programme for the industrial and commercial sectors. Some of the central aims were the individual/residential sector and space heating appliances. The most recent strategy to 2030 ("Mission 2030") which sets out of target of reducing the CO2 equivalent of heat and hot water provision by 3 million tonnes (8million to 5 million) by 2050. Moving to renewables-based heat would save around 2 million tonnes of CO2 compared to the current status quo (Bundeskanzleramt, 2018). Key measures in the space heating sector are to continually replace fossil-based heating systems with renewable heating systems (IEA, 2020).

In Austria, heat planning is part of spatial energy planning (Köhler et al., 2021). To meet targets relating to decarbonisation, whilst accommodating the relationship between spatial structures and means of shaping the energy transition, Austria has sought over the past decade to develop and implement the concept of integrated spatial and energy planning. This concept has begun to influence policy making at different governance levels, including national, regional and local/municipal (Stoeglehner, 2020). Spatial energy planning is specifically mentioned as a key instrument in the Austrian NECP, yet there is no detail on specific measures that will be taken to achieve this (Federal Ministry for Sustainability and Tourism Republic of Austria, 2019). In relation to heat, under its NECP Austria seeks to reduce GHG emissions by 3m tonnes to 2030 in the building sector, phase out oil heating systems by 2035 and force renewable heat and DH (Adensam, 2020). In particular, Austria's NECP refers to measures and instruments as part of a 'Heating Strategy' agreed between the Austrian Federal Government and the provinces (Austrian NECP, 127). This strategy has been co-designed between the national government, regional states and local stakeholders, such as cities and municipalities (Adensam, 2020). As part of a renovation initiative in 2019, the Austrian Federal Government together with the provinces introduced a funding priority to phase out fossil-fuel powered heating systems in residential housing ('Oil Phase-Out Premium' [Raus aus dem Öl-Bonus]). Austria's NECP states that as part of its Spatial Planning Concept (Austrian Conference on Spatial Planning (Österreichische Raumordnungskonferenz – ÖROK), 2021), spatial planning is to have a role in achieving climate protection objectives and sustainable development goals (SDGs), using the motto 'Space for Change' (Raum für Wandel). This is to be implemented gradually by the partners of the Austrian Spatial Planning Conference, which include the Austrian Federal Government, the provinces, association of towns, cities and municipalities and interested parties during the period 2021-2030 (Federal Ministry for Sustainability and Tourism Republic of Austria, 2019). Austria's NECP specifically links spatial energy planning with heat by stating that energy spatial planning enables innovative energy concepts to be implemented by prioritising locally available and cheaper renewable energy, use of waste heat and integrated mobility systems. Energy spatial planning allows for the analysis and localisation of energy consumption, energy storage and transport, and the potential for energy-savings and recovery, offers vital insight into these areas from a spatial perspective with a view to sustainable planning. Energy spatial planning therefore is considered an integral part of spatial planning which comprehensively addresses the spatial side of energy consumption and energy supply (Austria NECP, 140). Spatial planning is specifically intended to identify areas with grid-bound energy infrastructure, such as DH areas, as soon as possible and by 2025 (Federal Ministry for Susatinability and Tourism Republic of Austria, 2019).

Austria has increasingly taken a spatial energy planning approach to heating. This is the case in leading regions such as Styria, Salzburg (Preiß and Schwaberger, 2021) and Vienna (Hemis and Erker, 2021). All of the Austrian regions or provinces have spatial planning laws which provide the framework for the form and content of any spatial development within the regions, including provisions for zoning plans and land use for building areas. Municipalities are responsible for this zoning and land use (Geissler et al., 2022). In Austria, heat planning is part of spatial energy planning, however this is not yet specifically implemented via national legislation or unified policy (Köhler, 2021). ÖROK is the Austrian Conference on Spatial Planning and is constituted by the federal provinces, the federal government and the municipalities. It has a coordinating role in relation to spatial planning, providing recommendations and guidelines to the provinces in addition to strategy setting at federal level. The provinces must adhere to these strategies in their provincial legislation. In terms of responsibility, ÖROK sits within the Ministry of Agriculture, Regions and Tourism rather than the Ministry of Climate Action, which is responsible for the implementation of the NECP. As such there is no hierarchical position or power of the Ministry of Climate over the spatial planning implementation. Instead, the provinces set up their own sectoral programmes in relation to renewable energy or heat, for example. Finally, it is the municipalities within the provinces that are responsible for zoning and land use planning at the local level (Geissler et al., 2022). Under energy spatial planning, heat is not treated as a separate area, but considered together with other areas of energy generation and supply (Preiß and Schwaberger, 2021). Energy spatial planning incorporates many of the same characteristics as heat planning but from a broader energy sector perspective, including analysis of demand and potential, scenario planning and strategic planning. The results of such energy spatial planning are taken into consideration and integrated into building and regional plans in order, amongst other things, to guarantee space for local renewable energy generation (Köhler, 2021). This is consistent with the measures and instruments being considered for the implementation of an Austrian Heat Strategy, which will include financial support, guidance and information provision, spatial planning tools at State level. Support measures for transition away from fossil fuels to renewables-based heating will be provided at national level and stands at EUR 650m for the years 2021 and 2022 (Adensam, 2021). It is clear that the Heat Strategy is broader than heat planning, unlike dedicated obligations in some German federal states (as shown below), but the Austrian Heat Strategy does incorporate elements of heat planning. In addition, the Austrian approach overcomes tensions between the limits to the powers of the national government and the powers of regional governments in relation to the heat and building sectors by creating a joint framework and mandate. This includes the creation of joint working groups, such as the working groups on DH, data collection and support mechanisms, staffed by representatives from both the national and regional administrations (Bundesministerium fur Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, 2020)

The Austrian Heat Strategy is currently still being agreed between the national government and the States (Federal Ministry for Sustainability and Tourism Republic of Austria, 2019). This joint mandate between the national government and Austrian States is particularly important because, as will be seen in Germany, the powers or competence in the building and heat sectors lie primarily with the States (Adensam, 2021). The Austrian Heat Strategy presents itself as a joint framework between the national government and Austrian States for the purpose of transition towards sustainable heat provision (Bundesministerium fur Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, 2020). The goals of the strategy are the shifting of heat supply in buildings to renewable sources, such as DH based on renewable energy sources, in addition to equivalent reductions in energy demand or increased energy efficiency to 2040 (Adensam, 2021). Currently, a draft Renewable Heat Law (Erneuerbare-Wärme-Gesetz) is also in progress with the aim of replacing existing oil-and coal-based heating with more sustainable heating systems based on DH, biomass or heat pumps by 2035 (Bundesministerium fur Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, 2020). Under the Austrian Federal Constitution, which defines the competencies between the national government and the regions, there is no direct federal competence in relation to regional spatial planning (Article 15(1)). Under Article 118(3), municipalities have specific jurisdiction over local planning matters. According to Geissler et al. (2022) this includes local development planning and therefore regional and local energy planning. Furthermore, municipalities are guaranteed responsibility in their own sphere of competence, including local development planning, under Article 118(3). To get around this, as we have seen in relation to spatial heat planning in Austria, the federal government and the provinces may under Article 15(1) make agreements in relation to their respective areas of competence (Bundes-Verfassungsgesetz (B-VG) Federal Constitutional Law StF: BGBl. Nr. 1/1930 (WV) idF BGBl. I Nr. 194/1999 (DFB); Nationalrat: Vienna, Austria, 1999).

Regional and Municipal

As in Germany, the Federal Government does not have the powers to implement heat planning obligations on the Austrian regions in relation to the heat and building sectors. Several Austrian States, such as Salzburg, Styria (Steiermark) and Vienna have taken the initiative on heat planning as part of energy spatial planning (Köhler, 2021). These three regions have joined forced to implement spatial energy planning via the project, 'Spatial Energy Planning for Heat Transition', which includes heat planning (Rehbogen et al., 2020). The broader aims are to address issues arising from heat infrastructure transition to meet climate change goals and speed up the redevelopment of heat supply infrastructure. More specifically, the use of spatial planning for heat transition seeks to lessen dependence on fossil fuel-based systems and lack of data or information for planners, policy makers and investors. The project will seek to implement spatial energy planning in practice. Heat mapping of renewable potential, energy supply infrastructure and heat demand via an online app is a particularly key feature of implementation, allowing planners, investors and authorities to make educated decisions (Rehbogen et al., 2020). Heat mapping is a key feature of heat planning.

For the federal states, the spatial planning law mandates that building areas are to be categorised. The energy supply category, including areas that are to be connected to the DH system must be visible in terms of zoning. This type of zoning plan is a requirement on all Austrian regions and divides municipal areas into defined and visible uses (Geissler et al., 2021). Spatial energy planning is to be rolled out incrementally via various regulations and administrative processes in order to support long term investment in heat infrastructure (Rehbogen et al., 2020). Between 2013 and 2016, the region of Styria took part in an EU project, which focused on spatial planning and energy for communities in all landscapes. The aim of this project was to integrate sustainable energy solutions into local spatial planning. This period marks the start of an energy spatial planning approach in the region and allows the region to create highly detailed and spatially mapped energy characteristics of local communities, taking into account an analysis of all the relevant data. This approach also allows for the spatial definition of priority areas in which communities can align energy and climate goals with the determination of long-term development potential of a given area. This has also allowed for the creation of a community energy and emissions database for all Styrian communities, which includes heat density and energy efficiency maps (Preiß and Schwaberger, 2021). The relevant legal basis for this approach emanates from the Styrian Spatial Planning Law, which also sets out the spatial planning principles and goals that are to be followed by local decision makers, allowing them to take spatial planning considerations into consideration and align these with climate policy. The term for this is a Municipal Development Plan or Concept, which has the legal status of a regulation. It represents a type of long-term municipal plan, containing the ability to introduce revisions under certain circumstances. The powers to implement these plans rest with the regions (Geissler et al., 2021). To take this approach forward and particularly relevant to network infrastructure and DH is the need to prioritise renewables-based DH and the prevention of infrastructure duplication. This is because there currently still exists a tension or competition between gas infrastructure and DH infrastructure, which is understood as a problem and barrier to the broader integration of renewables-based DH. Another key step in the implementation energy spatial planning relevant to heating is the improvement of access to the underlying data relating to the use and condition of existing building stock and connected energy infrastructure (Preiß and Schwaberger, 2021).

Another region taking a lead on spatial heat planning is Vienna. The focus of the energy spatial planning approach is the forward-looking and spatially coordinated development of energy supply, including heat. As an example, in Vienna under section 2(b) of the Vienna Building Regulation Code this approach aims to implement sustainable and efficient DH in addition to the integration of renewable energies and waste heat. Spatially, this approach takes a building to neighborhood to district to perspective, affecting both existing and new building stock and embedding the necessary and broad alignment with various planning and services processes within the city (Hemis and Erker, 2021). Energy spatial plans are regulations by the local council and decided at district level. However, the borders are drawn to a very high level of detail (by property) and are obligatory on building developers. These types of energy spatial planning regulations have allowed for the determination of climate protection zones (Klimaschutz-Gebiete)[5] which are digitally mapped. In those zones fossil fuel sources for heat and water in new builds are prohibited. Instead, a sustainable heat supply based on highly efficient systems is mandated. Connected to DH is possible, however it is not mandatory (in contrast to Denmark) (Hemis and Erker, 2021). Table 3 below shows an overview of heat and spatial energy planning in Austria.

Table 3: Overview table for Austria

Federal State/Region	Mandatory heat planning	Guidelines/policy for heat planning
National level	No dedicated heat planning legislation. However spatial planning law requires Federal States to visually zone building areas, e.g. areas to be connected to the DH system.	Yes, National Heat Strategy (still being agreed between the national government and the regions)
Vienna, Styria and Salzburg	Partially, spatial planning law requires building areas to be visually zoned, e.g. areas to be connected to the DH system.	Yes, 'Spatial Energy Planning for Heat Transition Project'

6.4.2 Germany

National

In Germany's NECP spatial planning is primarily referred to in relation to maritime spatial planning and air quality. The document does refer to a funding programme for 4th Generation Heating Networks (Heating Networks 4.0) and heat is part of Germany's overall Climate Action Plan 2030 (Government of the Federal Republic of Germany, 2020). Heating is not discussed in the context of Article 14(1) EED

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[5] https://www.wien.gv.at/stadtentwicklung/energie/erp/ (accessed 26 July 2022)

2012. Nonetheless, in Germany heat planning is seen as a means of meeting climate targets in the local heat sector (Köhler, 2021). Germany has submitted Comprehensive Assessments in accordance with Article 14 EED 2012. In its 2020 Comprehensive Assessment, Germany sets out municipal heat planning as one of its potential new strategies and policy measures. It sees municipal level heat planning as an accompanying measure to existing economic incentives. The Comprehensive Assessment highlights that heat planning allows for an integrated approach to be taken in relation to heat transition at a local level, made appropriate to local conditions. In turn, this allows for the identification of long-term, sustainable and cost-effective solutions for the relevant municipality in relation to heat. In particular, as part of a heat planning approach at local or municipal level, it is necessary to take into account local actors and citizen's interests (German Comprehensive Assessment, Federal Ministry for Economic Affairs and Energy, 2020). The Climate Protection Law 2019 is the basis for setting national climate protection goals and emissions targets for individual sectors of the economy. However, heat appears to cut across various sectors and so is not specifically addressed. To date, a coherent national legal framework specifically for heat planning in terms of efficiency and decarbonisation targets does not yet exist and only some local areas or regions have set up a heat plan (Köhler, 2021).

At federal level, Germany has sought to encourage municipal guidelines in relation to climate protection with a focus on heat, for example in its 2021 Municipal Guideline in Support of Climate Protection Projects (Bundesministerium fur Umwelt, Naturschutz und nukleare Sicherheit, 2021). However, unless the relevant State has formal heat planning regulation or legislation in place (e.g. Baden-Württemberg and Schleswig-Holstein), heat plans are currently drafted as planning instruments by municipalities. These aim to structure the long-term supply of heat, supported by the Local Authority Guideline. Within the Local Authority Guidelines, heat plans are categorised as climate protection concepts (German Comprehensive Assessment, Federal Ministry for Economic Affairs and Energy, 2020). Germany does have a federal Spatial Planning Law (2008 as amended) (Raumordnungsgesetz – ROG), however it is not directly linked to heat planning at state level. A directly equivalent implementation of a national obligation to implement heat planning as in Denmark, for example, does not currently exist, which may be due to some limits of the federal government's powers in relation to planning for heat under the German Constitution. However, this does not mean that the approach and methodology used in countries such as Denmark would be impossible to implement, as has already been initiated in Baden-Württemberg, which is discussed further in the next section (Köhler, 2021). Heat planning at national level in terms of a national framework is currently under discussion in the form of the "Sofortprogramm Gebäudesektor" proposed on 13 July 2022.[6]

Regional and municipal

Although Germany is a relative newcomer to the heat planning approach, several federal states have started to develop laws, policy documents and guidelines on heat planning (Peters et al., 2020). According to the various guidelines issued so far, heat planning should contain an analysis of the current state of the heat sector, assessment of its potential, the development of a heat development scenario and a strategy for transition of the heat sector. Relevant stakeholders should be involved in each of these stages. The process also involves data collection relating to heat planning, including current demand, GHG emissions, building stock and supply infrastructure information. Where possible, this data should be spatially recorded or mapped (Aydemir et al., 2022). As stated, the right to engage in community heat planning lies primarily within the powers of municipalities. There is no national obligation to implement community heat planning as yet. However, the State of Baden-Württemberg has implemented a new law, containing mandatory municipal heat planning. Under the Baden-Württemberg Climate Change Act larger municipalities, such as urban districts and major district towns must undertake heat planning. This

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[6] https://www.dstgb.de/themen/klimaschutz/aktuelles/sofortprogramm-gebaeude/#:~:text=Geb%C3%A4udesektor%20erh%C3%A4lt%20Sofortprogramm%20Klimaschutz,im%20Geb%C3%A4udesektor%20erreicht%20werden%20sollte. (accessed on 25 July 2022)

means that approximately 10% of the municipalities and 50% of the population of the federal state are captured by the heat planning obligation. The relevant municipalities must draw up their heat plans by the end of 2023 and publish them in a state database and online. In doing so, they receive a flat-rate payment and a grant, subject to population size. Municipal heat plans must be updated every 7 years. However, there is no requirement to implement the heat plans but there is an obligation to implement the measures if a heat plan is put in place (Energiezukunft, 2020; Köhler, 2021).

The City-State of Hamburg has also implemented a duty on the relevant authorities to conduct heat and cooling planning in its state Climate Law 2020 (Hamburgisches Klimaschutzgesetz vom 20.02.2020 HmbGVBI - KSG HH). There is a particular focus on identifying energy and cost efficiency measures and coordination with infrastructure development. The results of this process are integrated with building planning, thereby allowing heat and cooling planning to contribute towards future city planning. The relevant authorities here are entitled to require and assess the necessary data (Köhler, 2021). In the State of Schleswig-Holstein, there is as yet no express duty to engage in heat planning. However, under the State's Climate Protection and Energy Transition Law 2017 there is a requirement to make relevant data available which are necessary to conduct heat planning. More recently, in a revision to the Climate Protection and Energy Transition Law which came into force in January 2022, there is now a duty to implement community heat planning for larger communities (Schleswig-Holstein Ministerium fuer Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung et al., 2021). In the State of Bremen, there have been some guidelines for DH planning since 2015, which can be an important part of broader municipal heat planning. For example, there is a target to establish a heat map for the city. This is intended to help identify areas for expanding DH heat planning (Köhler, 2021). The other German states do not yet have heat planning integrated into their State Energy and Climate Protection legislation, but Rheinland-Pfalz for example has some aspects of energy or heat planning as part of its climate change policy which may lead to heat planning in future. Some States have additional guidelines and informational material in addition to support mechanisms to encourage the voluntary establishment of heat planning. In Bavaria, heat and electricity usage is covered in its energy use guidelines but not in any great detail (Köhler, 2021). Table 4 below shows an overview of heat and spatial energy planning in Germany.

Table 4: Overview table for Germany

National/Federal State	Mandatory Heat Planning	Guidelines on Heat Planning
National	No	No
Baden-Württemberg	Yes	Yes
Hamburg	Yes	Yes
Schleswig-Holstein	Yes	Yes
Bayern	No	Yes
Bremen	No	No (but aspects of DH planning integrated into overall energy policy approach)
Rheinland-Pfalz	No	No (but aspects of heat planning as part of State climate change policy)

6.4.3 Denmark

National

Danish heat planning is widely considered as one of the most effective approaches (IEA, 2011). The objectives of heat planning in Denmark are the promotion of heat forms which (i) provide the most net benefits to society, (ii) support the most sustainable types of heating, and (iii) reduce dependency on fossil fuels (DEA, 2015). Approximately two-thirds (Johansen & Werner, 2022) or at least 64% of private Danish households are connected to a DH system. There are six large central DH areas distributing a total heat production of approximately 67 petajoules (PJ) annually. These areas are geographically located near urban areas. About 400 smaller decentralized DH areas with an annual heat production of approximately 53 PJ are spread throughout the rest of Denmark (DEA, 2016). Consumption of DH constitutes approximately 44% of household energy consumption for heating (DEA, 2019). Heat policy in Denmark was greatly influenced by the oil crisis in the 1970s and lead to strong government support for DH and CHP (Kerr and Winskell, 2021). Denmark has fully taken on strategic energy planning, including in relation to heat (Sperling et al., 2011). In 2010, the concept of strategic energy planning was specifically rolled out as a desirable planning approach for planning local energy systems (Krog and Sperling, 2019). The translation of the Danish Energy Agency's definition of strategic energy planning is that '[a] strategic energy plan is a planning tool that gives municipalities the opportunity to plan local energy conditions for a more flexible and energy efficient system, in preparation for the potential transition to a more renewable energy... [sic]... Strategic energy planning includes all possible elements of municipalities' energy plans, and coordination with municipal plans, security of supply strategies and climate strategies. The municipalities should conduct energy planning to create an optimal interplay between the energy demands and energy supplies (heating, cooling and electricity) in such a way that the energy resources are optimally used' (Krog and Sperling, 2019).

Denmark delivered its comprehensive assessment of the potential for the application of high efficiency cogeneration and efficient district heating and cooling in Denmark in 2015 and in 2020 in accordance with Article 14 EED 2012. However, spatial planning is referred to in the NECP mainly in relation to maritime spatial planning but not in relation to heat. Nonetheless, DH in Denmark plays an important role in meeting EU targets and the national goals set out in the NECP (DEA, 2015). Energy (including energy spatial) planning is referred to only in relation to representations made by the regions and municipalities in the review of the NECP before submission. The Danish Government integrated comments from an organisation representing municipalities (Local Government Denmark), which was involved in the review of the NECP before it was presented to the Commission. In addition, comments were integrated from organisations representing the different regions of Denmark. The municipalities expressly view strategic energy planning as a key tool for transitioning to a renewable energy system and that strategic energy planning should be a mandatory responsibility of municipalities. In their view the Danish DH system secures a stable heating system for its citizens. In particular, the municipalities argue for the reintroduction of DH connection requirements, which have been relaxed over the years (Danish Ministry of Climate, Energy and Utilities, 2019). Danish heat planning is considered to satisfy the requirements of the EED 2012, especially as EU policies were in part modeled on the Danish approach to efficiency (Chittum and Østergaard, 2014).

At national level, the role of the Danish government is mainly to set out the regulatory framework and guidelines for heat planning, including tariffs, cost-effectiveness, converting buildings to DH and the proportion of renewable energy in heating supply (Sperling et al., 2011). The Danish Ministry of Climate, Energy and Building governs the national heat planning framework and oversees the Danish Energy Agency (DEA) and the Danish Regulatory Authority (DERA). The DEA is the national energy policy maker and regulatory body, whilst the DERA controls and reviews the prices of natural monopoly entities, such as DH providers and handles customer complaints (Chittum and Østergaard, 2014). The DEA is also responsible for the policy framework for local heat planning, including efficiency requirements (Danish Ministry of Climate Energy and Building, 2005. Executive Order No. 1295 of 13/12/2005). The role of the DEA is to set out the framework in which municipalities and regions can assess the cost-effectiveness of upcoming energy projects. (Chittum and Østergaard, 2014).

The most important piece of legislation in relation to heat planning and regulation in Denmark is the Heat Supply Law. The law was first passed in 1979 in direct response to the energy crisis at the time and subsequently amended. This legislation provided the initial framework for the form and content of heat planning, initiating a new approach to public heat planning that continues today (DEA, 2015). From the 1990s there was a shift in focus from security of supply to environmental compatibility and power expansion through the increased use of CHP technology. This shift was implemented via an amendment to the Heat Supply Law in 1990, thereby creating a new planning system. This system was based more on a project-based approach to promote the expansion of decentralised CHP, to target the reduction of CO2 emissions, whilst securing the economic viability of expanding the natural gas network by increasing sales of natural gas. This entails approval by the municipality of the project proposal for the DH unit or network. During this time renewables-based heating also became a priority (DEA, 2015). Although larger CHP plants are governed by electricity law, the heat supply from such infrastructure is regulated via the Heat Supply Law.

Regional and Municipal

Municipalities are the key actors in Danish heat supply planning, with specific responsibility for promoting the expansion of DH and ensuring that changes to the DH system are compatible with the Heat Supply Law (DEA, 2015). Under the Heat Supply Law, city councils, together with utility companies and other stakeholders take responsibility for implementing heat planning in a given municipal area. Denmark is at the forefront of DH development and has sought to maximise the benefits of this technology. Heat plays a key role in Danish energy planning generally and heat planning is expressly a form of energy planning in Denmark. Long term, stable heat plans in Denmark are credited with a strong long-term confidence in district heating systems, reducing actual and potential risks to all stakeholders, including customers, suppliers, municipalities and heat infrastructure owners (Chittum and Østergaard, 2014). Heat plans are initiated and developed by municipalities. These are empowered to guide local heat strategy at local level (DEA, 2012). Municipalities decide which new components for heat networks are built or reinforced and have the powers to direct heat suppliers to take on specific projects or specify which fuels or technologies are used (Danish Ministry of Climate Energy and Building, 2011 Consolidation Act. No. 1184 of 14/12/2011)

A characteristic of Danish energy policy therefore is the devolution or delegation of considerable autonomy and flexibility to the local level and actors so that they may address climate related challenges, including the reduction of Greenhouse Gas (GHG) emissions. For example, local authorities are largely responsible for system design in terms of the development and planning of DH systems (Chittum and Østergaard, 2014). Municipal heat plans were required by national law in Denmark from 1979 and are considered to be the reason why the policy and regulatory framework in Denmark has so successfully supported the grown of DH in that country (DEA, 2015). Since 2011, municipalities are no longer required to develop heat plans specifically, but are still responsible under the Heat Supply Act to engage in heat planning and approval of the activities of heat companies and heat projects (Danish Ministry of Climate Energy and Building, 2011 Consolidation Act. No. 1184 of 14/12/2011). As a result, municipalities take on a key role in the regulation of local DH companies' activities (Chittum and Østergaard, 2014).

A distinct feature of Danish DH companies is that they are independent companies but controlled by municipal agencies and local councils. This means that in larger urban areas, municipalities also retain some control in relation to any major decisions made by the DH company. In turn DH companies can act as a type of agency within the city government with staff from local heat planners. Even where heat companies are fully owned and controlled by consumers, city council representatives still sit on the heating company's board and have the power to approve or object to projects. Such representatives may require proposals for a new development, if identified as necessary by the local council or municipality (Chittum and Østergaard, 2014). The national government and municipalities are entitled to any information from private heat suppliers that might be required for heat planning activities (Ministry of Climate Energy and Building, 2011, Order No. 690 of 21/06/2011). This includes specifying certain projects, timelines, technology and having the final deciding power on location and means of placing new communal heat systems. Municipalities may also prohibit some types of technology in certain areas with the aim of supporting the existing heat plan (Chittum and Østergaard, 2014). Order No. 690 of 21/06/2011 also provides municipalities with the power to require both new and existing building to have a public DH or gas supply connection. The rationale is to provide investment certainty for DH infrastructure by limiting the ability of households to opt out, however the power is not frequently used as connection rates are very high already (DEA, 2015).

These structures show that municipal governments work in close collaboration with local DH companies in Denmark. Under Danish law, these companies are not allowed to generate profit in terms of directing these to private shareholders for example. Profits must be redistributed to consumers in the form of reduced rates to customers in following years (Ministry of Climate Energy and Building, Consolidation Act. No. 1184 of 14/12/2011). There are a variety of models, whether consumers, municipalities or commercial entities owned DH companies, such companies are nonetheless consumer controlled to some extent (Chittum and Østergaard, 2014). However, the two main models of DH ownership are cooperative and municipal ownership (Johansen and Werner, 2022). Consumers are entitled to choose the majority of the directors of companies that partake in heat supply or transmission activities (Danish Ministry of Climate Energy and Building, Consolidation Act No. 1184 of 14/12/2011). Various powers are granted to consumers through the right to be consulted on any obligation to connect to the heating system and to put forward arguments for exemption from mandatory connection for reasons of building demolition or existing low energy characteristics (DEA, 2015).

Significantly, heat planning and land use planning are highly integrated at municipal level (Chittum and Østergaard, 2014). This is achieved through the requirement for 12-year land use plans that address topics ranging from urban development, ecological protection and heat supply (Danish Ministry of Climate Energy and Building, 2005). As such, during the planning for a new development, municipalities will ask for the issuance of a proposal for heat supply from the local DH business and will decide whether that proposal is right for the local region or area (Chittum and Østergaard, 2014). The autonomy of local municipalities is also supported by their right to set up local frameworks for the content of a heat plan in addition to any guidelines. They may also make changes to local energy infrastructure to meet any regional targets (DEA, 2012). This allows for a great deal of flexibility and local autonomy during the planning process (Chittum and Østergaard, 2014). This local flexibility and autonomy is enabled by a top-down regulatory framework and is subject always to the legal requirement that the municipality will in exercising its powers follow the interests of the local area (Ministry of Climate Energy and Building, 2005).

6.4.4 Poland

National

Heating and cooling represent the largest proportion of final demand for energy in Poland at 56% (Paardekooper et al., 2018b). Poland also has Europe's second largest DH market, with approximately

400 DH networks supplying 16.5 million people (Szczecinska Energetyka Cieplna Sp. z o.o., 2021). According to Poland's NECP, "a low-carbon economy requires a spatial development approach that will ensure efficient use of land and infrastructure and reduce emissions from transport and individual heat sources while following the idea of a compact and cost-efficient city in the spatial planning process" (NECP Poland, 2019, 56). Amongst the larger European MS, Poland is one of the largest emitters due to pollution caused by continued large-scale fossil-fuel, particularly coal, reliance (Kurmayer, 2022). This is supported by a study on health-related social costs of air pollution due to residential heating and cooking in the EU27 and UK (Kortekand et al., 2022). However, Poland has only recently launched a "Ciepłownictwo Powiatowe" ('district heat') programme in order to speed up the decarbonisation of district heating. The programme is mainly aimed at funding the decarbonisation of heat for companies with a requirement for a stake held by local government of up to 50% (Szczecinska Energetyka Cieplna Sp. z o.o., 2021).

The development of DH and cogeneration is a specific objective of Poland's Energy Strategy to 2040 (Ministry of Climate and Environment, 2021). According to the strategy, 'the involvement of local authorities and local energy planning has a special role in the implementation of the state policy on district heating' (Ministry of Climate and Environment, 2021). The document reiterates that heat requirements need to be met close to the site of demand and that the nature of heat markets is local, but because, as of 2018, only 22% of municipalities had any planning document for the supply of heat, electricity or fuels, there is specifically a need to increase the participation of municipalities in local planning which enables cooperation between local governments and maximises local potential for energy supply. Data collection for a nationwide heat map is specifically identified as a useful tool for energy planning. However, this activity has only just commenced in 2021 (Ministry of Climate and Environment, 2021). Heat mapping is a particular tool used in heat planning. The Polish Energy Strategy acknowledges that the activities required to increase the deployment of efficient and decarbonised heat will not only necessitate financial and organisation support but adjustment of the legislative framework and public engagement (Ministry of Climate and Environment, 2021).

Although the focus is on impact of low-carbon heating across different heat technologies in Poland and not on governance or regulation of spatial energy planning or heat planning, the Heat Roadmap Europe project has produced a Heat Roadmaps Poland report (Paardekooper et al., 2018b). The report considers alternative scenarios and results that are intended to be technically feasible, economically viable and enable a deep decarbonisation of Poland's energy system. The Heat Roadmap project uses elements of a heat planning approach, with key features being the combination of mapping and energy system modelling to enhance the understanding of system effects of energy efficiency and the spatial dimension of heat. The Heat Roadmaps Europe approach therefore combines energy system analysis with spatial energy planning tools, which entails a detailed spatial mapping of heat demand and renewables-based heat sources (Paardekooper et al., 2018b). Spatial heat planning is an aspect of the Heat Roadmap Poland, in that a key feature of heat planning is to demonstrate the geographical nature of heating (Paardekooper et al., 2018b). The spatial element is important to heat as moving large volumes of thermal energy for greater distances (similar to electricity) is not possible without a certain percentage of transmission or distribution losses. As such, it is necessary to have accurate data on the geographic or spatial distribution of heat demand and potential sources when considering the potential of DH (Paardekooper et al., 2018a). This is a key purpose of heat planning.

Poland has a national Local Government and Energy Law under which in Article 18(1)(1), municipalities are responsible for the planning and organising of heat supply in addition to electricity and gas in a particular administrative area (Hemis, 2017). This legislation may provide a potential means of implementing heat planning from a national level. Despite the lack of dedicated heat planning guidelines or regulations in Poland, as of 1 January 2021 an obligation for households to declare the heating system they use came into force (Ancelle, 2021). There is also possible support for a spatial planning approach to decarbonised heat via the Polish Act on Spatial Planning and Development Act (2003) (Planowaniu i Zagospodarowaniu Przestrzennym). A study conducted by Solarek and Kubasinska (2022) examined local spatial plans as enabler of household renewable energy investment. These local development plans contain geographically specific planning arrangements under local legislation, including a graphic resolution or map of planning arrangements in individual areas (Solarek and Kubasinska, 2022). In relation to decarbonisation, the Spatial Planning and Development Act 2003 mandates that local zoning plans must set out the rules on investing in renewable energy sources. Solarek and Kubasinska (2022) reviewed these plans for their coverage and rules on renewable energy, including arrangements for heat supply to households. They found that the Polish local zoning plans contained the mandatory rules on heating of building. In relation to urban areas the rules covered the connection to the heating network but inconsistent rules on renewable energy sources for heating homes. It seems that there is a lack of effective local enforcement and frequent change in the regulatory framework, which leads to ineffective spatial planning tools. This seems to inhibit wider social acceptance of using renewable energy, including in heat. The authors recommend the urgent reform of local spatial plans that do not support the uptake of renewable energy, including for heat, through for example specific prohibition of fossil-fuel based sources (Solarek and Kubasinska, 2022).

Regional/Municipal

Warsaw as a city is seeking to integrate different energy systems, including gas, DH, electricity, local energy storage and electric mobility. Using data on urban development, emissions and socio-economic considerations, the city is developing assumptions for the supply of heat, electricity and gas. These assumptions are intended to help reveal energy demand, energy balancing and forecasts to 2035 (Hemis, 2017). Under the Local Government and Energy Law (Article 18), Warsaw as a municipality has the responsibility for energy planning. Under Warsaw’s energy planning procedure, the city can provide its own energy supply plans where the development plans of energy companies are insufficient (Hemis, 2017). From a regional or municipal perspective, local zoning plans mandated under the Spatial Planning and Development Act 2003, provide rules on investment in renewable energy sources at a local level. A review of these by Solarek and Kubasinska (2022) shows that these plans also contain rules in relation to heat supply for households and connection to heat networks in urban areas. A lack of effective enforcement and frequent regulatory change currently makes these plans less effective in terms of spatial energy planning but reform of these issues may turn these plans in to promising tools for heat planning.

6.4.5 Switzerland

National

Heat supply in Switzerland is to become entirely renewable and CO2 neutral by 2050 (Wärme Initiative Schweiz, 2022). As in Austria, heat sits within a broader energy strategy. In 2017, the Swiss people voted for the Swiss Energy Strategy 2050 and the national Parliament ratified the Swiss Climate Agreement (Jacob et al., 2020). The Swiss Energy Strategy 2050 aims at improving the energy efficiency in different demand sectors including heat and the further support for renewable energy. These will be implemented via regional energy laws and regulations – so called ‘Mustervorschriften’ which will usually focus on new builds but also more recently on renovations (Bundesamt für Umwelt BAFU, 2019). However, this takes place primarily at a regional level. Total CO2 emissions from the heat sector amount to approximately 18 million tonnes CO2 (including DH). This corresponds to approximately 40% of total emissions in Switzerland (Jacob et al., 2020). The deployment of renewable energy for heat supply in Switzerland is based on an analysis of potential, which is also characteristic of a heat planning approach (Köhler, 2021). Heat supply is considered to be a key aspect of spatial energy planning in Switzerland but is mainly established as a formal planning instrument in some Swiss cantons and municipalities. A spatial planning approach is used to integrate high volumes of renewable energy and waste heat but also to ensure coordination between energy supply and urban development (Schubert, 2014).

Regional/Municipal

Energy planning, including heat, is conducted at the level of the Swiss federal states or regions (Kantone) via regional laws. Responsibility for implementing energy planning lies primarily with municipalities. This means that to date, energy and heat planning has not seen a uniform approach across the country (Schubert, 2014). Not all regions have implemented energy planning. As of 2013, 15 of the 26 regions, especially those with large cities, implemented a form of energy planning more broadly in their legislation. Most regions integrated their energy planning in their energy laws (e.g. Zürich), whilst others, such as Bern integrated energy planning via spatial planning law. Although the term municipal or communal energy planning is used, there is often a focus on heat supply (Schubert, 2014). In the Kanton of Zurich, there is a link or integration between central actors, such as the city council, administration, and energy supply companies (Stadt Zürich, 2020). Energy planning, generally, is mandatory for municipalities and should be regularly updated (Jakob et al., 2020). Zürich has had a long-standing practice of municipal and regional energy planning in order to spatially coordinate heat supply (Hoesli and Gnehm, 2016). Under Zürich’s regional Energy Law, for example, municipalities are obligated to develop and implement communal energy planning. Energy supply planning is an integral part of that process. There is a particular focus on spatial determination of appropriate areas for network bound energy supply (Stadt Zürich, 2020). Municipal energy planning has the purpose of providing a long-term and sustainable energy supply plan for a particular community, which is in line with the concept of heat planning. Municipal energy plans are based on the analysis of demand and potential of available heat sources and existing infrastructure, which is a form of heat planning. The spatial approach is intended to allow for a holistic approach to using locally available and partially renewable heat sources in relation to their spatial distribution and concentration of demand (Schubert, 2014). The city council of Zurich started its energy planning approach in the 1990s and collects energy relevant data in a GIS-browser (Schubert, 2014). In Geneva, the Geneva Energy Act has, since 2010, required energy planning for any districts conducting renovations or new districts. The Hotmaps tool which maps the potential and demand for heating in a given area and seeks to develop open-source heating and cooling mapping and planning, revealed that the city should develop DH in certain specified areas, using only renewable sources (Energy Cities, 2020).

Regional energy plans are also to be coordinated and aligned with national energy strategy, in particular to implement the aims of national energy planning (Schubert, 2014). Traditionally, a large degree of variety existed in relation to the development and governance of municipal energy planning in the Swiss regions, in terms of implementing municipal energy planning via energy law or planning and building laws. However, in 2015, the Conference of Regional Energy Directors (Konferenzen Kantonaler Energiedirektoren) implemented a model regulation in order to try and harmonise regional energy planning. Municipalities can still implement their own energy planning for their area. The model regulation does contain a conditional obligation on property owners to connect to DH (Hoesli and Gnehm, 2016). In the region of St. Gallen, for example, the regional Energy Law (Article 2b, paragraph 1, Energiegesetz St. Gallen – EnG SG) contains an obligation on municipalities to with a minimum of 7,000 citizens to develop a municipal or regional energy plan in relation to heat. These plans must set out the current and future heat demand, usable sources, heat supply target and necessary measures for implementation (Hoesli and Gnehm, 2016). In the Canton of Thurgau, the regional masterplan (Kantonaler Richtplan) obliges the councils of key towns to develop a comprehensive municipal energy plan, which includes use of waste heat and renewable energy. The relevant council department decides on the target, method and scope of the plan (Kanton Thurgau Amt für Raumentwicklung, 2020). Luzern revised its regional masterplan in

2015, advising municipalities to develop energy plans, however revised energy law was rejected (Hoesli and Gnehm, 2016). Several stakeholders take part in the regional energy planning exercise, including the instruction of spatial planning consultants, municipal council departments, such as urban planning and forest management, energy (and district heat) providers. Similar to Denmark, but within certain limits, some of these actors are obliged to participate in energy planning. Also included in stakeholder participation are the building and landowners in addition to building developers. Energy plans are approved by the city or local council, but also need to be approved by the region before coming into force to ensure that the municipality or community has fulfilled all the conditions and ensured alignment with the regional requirements, including future requirements relating to heat supply. This ensures the accommodation of the regional level into the local planning process. On coming into force, the local energy plans are binding on the local authority or council and as relevant on land and building owners. There is also cooperation with the municipal utility, especially in relation to DH (Schubert, 2014). Table 5 below shows an overview of heat and spatial energy planning in Switzerland.

Table 5: Overview table for Switzerland

Federal State/ leading region	Mandatory heat planning	Guidelines/policy for heat planning
National level	No	No but Energy Strategy 2050 approved, containing provisions in relation to heat.
Zurich	No, but regions and municipalities are responsible for communal/municipal energy planning, using a spatial approach, including in relation to heat (Zurich Energy Law).	No but regional energy plans are coordinated and aligned with national energy strategy to implement the aims of national energy planning. Several stakeholders take part in the energy planning exercise, including the instruction of spatial planning consultants, municipal council departments, such as urban planning and forest management, energy (and district heat) providers.
Geneva	No, but Geneva Energy Act has, since 2010, required energy planning for any districts conducting renovations or new districts, including in relation to heat.	No but regional energy plans are coordinated and aligned with national energy strategy to implement the aims of national energy planning. Several stakeholders take part in the energy planning exercise, including the instruction of spatial planning consultants, municipal council departments, such as urban planning and forest management, energy (and district heat) providers.
St. Gallen	Yes, municipalities with a minimum of 7,000 inhabitants must	Yes, Guidelines for municipal energy planning for heat.

Federal State/ leading region	Mandatory heat planning	Guidelines/policy for heat planning
	develop a municipal or regional heat plan.	
Thurgau	No.	Yes, regional masterplan (Kantonaler Richtplan) obliges key towns to develop a comprehensive municipal energy plan, which includes use of waste heat and renewable energy.
Luzern	No	Yes, revised regional masterplan advises municipalities to develop energy plans

6.4.6 United Kingdom (Scotland)

The Scottish Parliament operates under a devolved system of government, under which certain powers are devolved to the Scottish Government by the Government of the United Kingdom (UK) and others are reserved to the UK Government. Under Schedule 5 of the Scotland Act 1998, most energy matters are reserved by the UK Government. Local government and planning matters are devolved. Devolution therefore allows for decisions on such matters to be taken by the Scottish Government. On 31 January 2020, the United Kingdom, and therefore Scotland, withdrew from the European Union. The UK submitted an NECP in 2019 but is no longer bound to follow through with and report on the plans for decarbonisation and efficiency, including in relation to heat, as set out in that document. The UK is also no longer required to provide updates on its NECP or Comprehensive Assessment for heat to the Commission. As such, the NECP for the UK has not been considered in this context, but the recent withdrawal from the European Kingdom and informative developments in relation to heat planning in Scotland mean that this jurisdiction still serves as a very useful and informative case study. Approximately 1/5th of total emissions in Scotland emanate from homes and workplaces (Scottish Government, 2021a). The Scottish Heat in Buildings Strategy states the intention of the Scottish Government to convert over 1 million homes and approximately 50,000 non-domestic buildings to zero emissions heat. Wider deployment of DH can achieve a more effective utilisation of heat from renewable sources, due to the availability of renewable sources and excess heat in Scotland (Connolly et al., 2015). In the UK generally, local governments can receive grants from the Heat Network Delivery Unit to perform feasibility studies and the related early stages of infrastructure development. This includes heat mapping, energy masterplans, techno-economic feasibility, and detailed project development (IRENA et al.,2018). Although not delineated specifically as heat planning, tools such as heat strategies, heat mapping and economic feasibility studies are aspects of heat planning. This type of information enables investor certainty, informing such actors as to the viability of projects in addition to long-term perspectives or planning. As highlighted in that report by IRENA, IEA and REN21, one of the main barriers to renewable heating and cooling uptake is the inadequate data and statistics on types and amounts of energy required to meet heating and cooling needs. Collecting data is also a way to favour the penetration of renewable energies in heating systems, as heat systems require long-term planning for urban development. Therefore, the more accurate the data, the easier to plan the decarbonisation (Ancelle, 2021). A recent development in the UK is the proposed Energy Security Bill 2022, which was introduced to the UK Parliament on 6 July 2022. As a UK wide measure and because energy policy is a reserved matter for the UK Government, this will have an impact on Scotland once it comes into force after its passage through Parliament. However, as at the time of writing, in relation to heat, the measures focus on a regulatory framework for heat networks and powers to enable heat network zoning in England (UK Government, 2022). The relevant measures for Scotland are in the Heat Networks (Scotland) Act 2021, as discussed below.

The Scottish Government is required under the Climate Change (Scotland) Act 2009 to provide annual progress reports on its Renewable Heat Action Plan, regarding progress towards its target for renewable heat generated in Scotland. Under section 60 of the Climate Change (Scotland) Act 2009, there is an obligation on Scottish Ministers to prepare and publish plans for promoting energy efficiency and improvement of energy efficiency in residential accommodation. Energy efficiency is defined as including the use of waste heat and DH. Under section 61, Scottish Ministers must publish a plan for the promotion of renewables-based heat. Heat is a significant, if not one of the largest elements of energy use in Scotland at approximately 51.5% of total energy consumption in 2020 (Scottish Renewables, 2021). DH is envisaged as a key means of meeting heat demand, whilst providing efficient heat at least cost to consumers from low carbon and renewable heat sources (Scottish Government, 2015). Although the Scottish Government is consulting on a revised National Planning Framework (NPF) 4 (Scottish Government, 2021b), the current one in place is the NPF3, in which spatial planning has a key role in supporting the development of combined heat and power and DH. The provisions in the NPF3 are supported by the Scottish Planning Policy (2014), which states that local development plans should use heat mapping to link the potential for co-locating developments with a high heat demand with heat supply sources. Local development plans should also facilitate the development of DH in as many locations as possible, even if these might rely on fossil-fuel based sources, provided that there is potential in future to convert these to renewable or low carbon heat sources. The mapping exercise should also identify the existing location of heat networks, storage and energy centres or their potential in addition to including policies that support their integration. In areas with existing or planned DH, or where an area has been identified as suitable for DH, local planning policies can include requirements for any new developments to establish infrastructure for connection and opportunity to heat DH (Scottish Government, 2014a). Scotland launched its own heat map in 2014 to help planning authorities support low carbon transition. The mapping exercise recognises that infrastructure and the co-location of supply and demand requirements have both spatial and policy implications. The use of the heat map allows for a focus on local requirements and strategy. Local development plans should specifically use heat maps to identify the existing and potential for new and extended DH and proceed to develop a spatial plan for heat with the development plan (Scottish Government, 2014).

The approach in Scotland to national planning, especially in relation to key infrastructure is considered to be distinctive and pioneering in the UK context, as it links national infrastructure priorities with the planning system from the very beginning of a project through its National Planning Frameworks (Morpeth, 2018). The planning system is used to determine the spatial pattern of heat supply, traditionally largely linked to gas network proximity (Scottish Government, 2021a). According to the 2014 Scottish Planning Policy, development plans must ensure that an area’s full potential for electricity and heat from renewable sources is achieved in accordance with national climate change targets, whilst giving due regard to environmental, community and cumulative impacts (Scottish Government, 2014b). The Scottish Planning Policy sits alongside the NPF, which sets out a statutory framework for Scotland's long-term spatial development, including the Scottish Government's spatial development priorities for the next 20 to 30 years. The Scottish Planning Policy specifically contains the policy that enables the delivery if the NPF objectives. According to the Scottish Government’s Consultation ‘Energy Efficient Scotland Improving energy efficiency in owner occupied homes’ most of these properties are intended to move to a form of electric heating through either individual heat pumps or a district heat network supplied by a heat pump. Any new homes approved for planning from 2024 will be required to apply a form of zero-carbon emissions heat (Scottish Government, 2019).

Regional/municipal

Under the Scottish Heat in Buildings Strategy (2021), Local Heat & Energy Efficiency Strategies (LHEES) are proposed as enabling a place based, locally-led and tailored approach to the heat transition. Such local strategies are data-driven and intended to facilitate an area-based approach to heat and energy efficiency planning and delivery in the form of strategic heat decarbonisation zones. LHEES strategies are to be accompanied by LHEES Delivery Plans. These Delivery Plan are developed in partnership with key stakeholders and provide a strong basis for action at local community, government, investor, developer and wider stakeholder levels. This type of early engagement allows for the identification of areas for targeted intervention and early, low regrets measures. The LHEES approach is intended as a platform for simultaneously addressing both local community and wider national infrastructure issues, thereby taking both a bottom-up and top-down approach. Both the Strategies and Delivery Plans are intended as a form of investment prospectus at national and local level, guiding implementation programmes and identifying potential areas of investment to market participants. The LHEES also support planning for all energy networks, in order to provide an evidence-base for the electricity Distribution Network Operators (DNOs) and Gas Distribution Network (GDN), by informing the Local Area Energy Planning approach already used by regulated network utilities (Scottish Government, 2021a).

The aim of the Heat Networks (Scotland) Act 2021 is to accelerate the deployment of heat networks in Scotland by implementing a regulatory system that strengthens consumer confidence provides greater investor certainty (Scottish Government, 2021c). The Heat Networks (Scotland) Act 2021 (the Act) received Royal Assent in February 2021 and sets statutory targets for the deployment of heat networks between 2027 and 2030, in order to contribute to Scotland's climate change targets. The Heat Networks (Scotland) Act 2021 specifically places an obligation on local authorities to assess areas likely to be especially suitable for heat networks development. The Scottish Government sees the LHEES as the means through which this assessment is conducted. The LHEES is to be the main vehicle for heat planning for all technologies on an area basis. The act makes provisions for the assessment duty to be exercised by the Scottish Ministers on behalf of local authorities to ensure broad identification of zones across the entire country (Scottish Government, 2021a). Several local authorities or municipalities in Scotland, including Aberdeen, Glasgow, and Orkney, have started completing the initial stages of such LHEES assessment. The Scottish Government intends for the LHEES to be published for all Scottish local authorities by the end of 2023 and to give the LHEES approach formal legislative status. The Scottish Government has consulted on the implementation measures for the Heat Networks (Scotland) Act 2021 and a regulatory framework for heat networks is set to come into force in 2024 (Scottish Government, 2021a).

Under the Planning etc. (Scotland) Act (2006), cities should have their own strategic planning arrangements, cutting across the local authorities of the city region, as a formal planning scale and use Spatial Development Plans (SDPs) to plan for them. The Heat Networks (Scotland) Act 2021 sets out targets for the amount of heat to be provided via DH. These are to reach 2.6 TWh of output by 2027 and 6 TWh by 2030. At the moment, DH supplies only 1.5% of heat in Scotland but has been identified as a key strategic technology for lowering heating emissions in homes and non-residential buildings. The Scottish Government is currently conducting its First Nationwide Assessment of potential heat network zones and is carrying out work to deliver a LHEES to inform its 2035 heat network target (Scottish Government, 2021a). To support this, the Heat Networks (Scotland) Act 2021 requires identification of suitable areas for DH development in co-called Heat Network Zones. The regulatory framework implementing the provisions of the Heat Networks (Scotland) Act 2021 is still being established but likely to be put in place in 2024 (Scottish Government, 2021a).

6.5 Discussion

A spatial approach can play a key role in the uptake and acceptance of DH. Energy transition can present challenges that require a spatial approach and planning for renewable and energy efficient infrastructure, which enables a localised participation and localised integration of such technologies (Stoeglehner, 2020). Heat planning specifically supports a spatial planning approach at a very localised level. In Denmark with its long-standing and stable heat planning frameworks, this localised spatial heat planning approach is enabled by a combined top-down and bottom-up approach. A degree of combined bottom-up and top-down governance is also occurring in countries with more recent heat planning or spatial energy planning approaches, such as Austria and Scotland. These jurisdictions are very different in terms of their constitutional structure, but they have both sought to either enable a form of very local heat planning or spatial energy planning relating to heat from the top-down (Scotland) or sought to bridge gaps in powers relating to spatial energy planning for heat by setting out joint mandates for cooperation and implementation of heat planning (Austria). In Germany, the powers relating to heat planning are still firmly based at state and regional level and there is as yet not the degree of cooperation between regional and national levels as seen in Austria’s joint mandate between the regional and the national government.

Heat planning has the potential to play an important role in the decarbonisation of heat in the coming decades and can contribute towards the collaboration of national/federal levels with regional and municipal governance of heat, whilst still observing local requirements in relation to decarbonisation and ensuring longer terms investment certainty, for example. This is made possible through the treatment of heat planning as a process that engages all relevant stakeholders (Köhler, 2021). Although heat supply strategies must be locally grounded, a top-down framework is needed which ensures the overall sustainability of the energy system. National authorities have an important responsibility in creating a framework for local planning which ensures that bottom-up activities do not aggregate into imbalances at the macro-level (Djørup et al., 2019). The implementation of heat planning and heat strategies at national level can as demonstrated through the examples of Denmark, German and Austria, be dependent upon the constitutional framework regarding powers or competencies in relation to planning and heat or energy more broadly. In Germany, the detailed design of a federal regulation of heat planning is still being drafted and requires consultation with the states. If implemented, the law would require states to introduce municipal heat planning several states have taken the initiative and introduced an obligation for heat planning for large municipalities. In Denmark, which does not have a federal governmental structure the obligation to implement heat planning emanates from national law but is reinforced by powers granted to municipalities and local actors to implement heat planning that is locally appropriate. In Austria, although also set up as a federal system, the Federal States and the national government have created a joint mandate via the new heat strategy, thereby overcoming the tensions between national and state level powers pertaining to the building and heat sectors.

Hoesli and Gnehm (2016) identify the issue that heat is often governed either in energy or energy efficiency frameworks and not in planning frameworks. However, municipal heat planning is by its nature spatial due to the characteristics of heat technology. As, such they require a more integrated planning-based approach and increased alignment between energy, efficiency and planning frameworks (Hoesli & Gnehm, 2016). The push for municipal heat planning in the proposed recast of the EED 2012 is an opportunity to support this integration. On the basis of the case studies examined here, is agreed with Sovacool and Martiskainen that a polycentric governance approach can help to facilitate a more rapid, effective and deep energy transformation, but also this kind of integrated spatial energy planning approach. A polycentric governance approach is able to integrate multiple levels from the local to the national (and beyond), whilst involving a wider range of stakeholders in the policymaking process, including municipalities and citizens. The authors consider the benefits of polycentric governance in heat transition in several jurisdictions more generally, including Denmark. The approach to heat planning in those case studies seen to be successful (Denmark) or innovative (Austria), shows that the argument in favour of a polycentric approach can also be applied more specifically to heat planning and strategic energy spatial planning for heat. This is because the polycentric governance approach seeks to integrate multiple scales and stakeholders together, thereby taking advantage of global, state/national and local actions at once (Ostrom, 2010). The work of Sovacool and Martiskainen (2020) shows using the example of Denmark that polycentric energy and governance is important in parallel with the design and transformation of heating systems. This is a reflection on why Denmark is considered to provide a best practice approach to heat planning. However, that conclusion is caveated by the observation in other case studies, that the governance or constitutional structure of a state matters for the efficacy of implementing heat planning and integrated spatial energy planning, as it will not always be from a national scale (as in Denmark) that the enabling framework will emanate from (as in Austria or Germany). These countries can still be examples of a multi-level approach but the impetus and power to act come from a regional level.

Table 6 shows an overview of the case studies, broken down further in the relevant sections for each jurisdiction.

Table 6: Overview table of case studies

Jurisdiction	EU	National Heat Strategy	Regional/Municipal Heat Planning or energy spatial planning for heat
Austria	EU - EED	Yes	Yes (Vienna, Styria, Salzburg)
Denmark	EU - EED	Yes	Yes
Germany	EU - EED		Yes (Baden-Württemberg, Schleswig-Holstein, Bremen, Bavaria)
Poland	EU - EED	Yes	No
UK (Scotland)	Non-EU	Yes	Yes
Switzerland	Non-EU	Yes	Yes (Zurich, Bern)

Case studies

To be effective, spatial planning requires governance powers across sectors and levels. Those countries which have sought to align their energy planning and spatial planning approaches through integrated spatial energy planning in addition to alignment between different governance levels are showing more progress with heat planning. This is particularly the case for Denmark, a leader in heat planning approach and Austria, which has integrated heat planning into its spatial energy planning. The case studies show that spatial energy planning initiatives relating to heat and heat planning benefit most from a combined top-down and bottom-up governance framework (as shown in the sections on Denmark but also seen more recently in Austria). A polycentric governance approach as taken in Denmark, is able to integrate multiple levels from the local to the national (and beyond), whilst involving a wider range of stakeholders in the policymaking process, including municipalities and citizens. A combined top-down and bottom-up approach has contributed to broad acceptance and uptake of heat technologies, especially DH systems in Denmark. However, it is important to understand that where integrated spatial energy planning for heat or heat planning are being implemented, these can originate from different governance levels, depending on the governance framework of the jurisdiction. In Germany and Austria, the powers for spatial energy planning and heat planning reside with the regions or states. In Denmark, although national legislation and policy has empowered municipalities to take on responsibility and autonomy in relation to heat planning activities, these powers originate from the national level. The key to the success of heat planning in Denmark is the local autonomy coupled with the strong support from top-down policies and government decisions issued over decades and regularly strengthened through legislation and policies.

The other jurisdictions examined here, such as Germany, Austria and Switzerland have implemented heat planning and spatial energy planning for heat more recently. Although Austria and Germany have initiated heat planning and spatial energy planning at a regional level due to the framework of competencies for planning activities relating to heat in those jurisdictions, Austria has made more progress in aligning national heat strategy with regional integrated spatial energy planning approaches by creating a joint mandate between the national level and the regions in relation to transitioning towards sustainable heat provision. In both Austria and Germany, although the regional approaches are very promising, they can lead to an uneven implementation across the country and continued difficulty with aligning planning approaches for heat between regional and national levels. As in Germany and Austria, energy planning, in relation to heat, is conducted at the level of the Swiss regions using regional laws. Similarly to Austria and Germany, there has therefore not been a uniform approach to energy and heat planning across Switzerland. Unlike Germany, although some Swiss regions take a lead on a spatial approach to heat as part of their energy spatial planning, it is not a dedicated heat planning approach. Apart from the obligation to align with national energy policy and strategy there is also not a top-down governance structure aligning with the bottom-up approach and responsibility of some of the regions as there is in Denmark and to some extent in Austria. In Switzerland as in Denmark and to some extent in Austria, a broad variety of stakeholders participate in this energy planning exercise, which includes spatial planning consultants, municipal council departments, such as urban planning and energy providers. Similar to Denmark, these actors are obliged to participate in energy planning, which can achieve broader acceptance of the proposed plans.

Scotland has similarities with Denmark in that strong national legislative and policy signals are being provided in relation to heat infrastructure. The approach in Scotland to national planning, especially relating to energy including heat, is considered to be distinctive and pioneering in the UK context, as it links national infrastructure priorities with the spatial energy planning system from the very beginning of a project through National Planning Frameworks. Scotland shows a particular strength in seeking to align its energy and spatial energy planning both at national (Scottish) level and at local level through the Scottish Planning Policy. As in Denmark, this combines a top-down and bottom-up approach in enabling cities or municipalities to take ownership of their spatial energy planning in relation to heat. It should be noted though that unlike Denmark, Scotland is a nation within the overall constitutional framework of the United Kingdom with certain devolved powers relating to energy infrastructure planning. Heat planning is not yet more developed in Poland, however there are some promising initiatives, for example Heat Roadmaps Europe has conducted a study for Poland primarily in relation to heat mapping, which can be a useful tool for initiating wider heat planning measures. Poland has also identified local authorities and local energy planning as a key role in the implementation of national policy for DH. There are some promising legislative tools in place, which might be used to support the wider implementation of heat planning.

6.6 Recommendations

- Heat planning, whether as a dedicated regulatory approach as in Denmark, or as part of energy spatial planning for heat (as in Austria) provides a framework for improving the uptake of heat infrastructure in a way that is appropriate to each local context by providing the data and coordination with relevant stakeholders. The approach should be used to strengthen acceptance and alignment with decarbonisation and efficiency goals.
- To be effective, the municipal level heat planning proposed by the draft recast EED must be implemented by MS in a manner that horizontally aligns or integrates energy planning and spatial planning, as has been demonstrated in Austria. However, it is also necessary to integrate vertical governance levels, as heat planning can link the local, regional and national levels but requires to be made effective. Combining a spatial planning and energy planning approach. The appropriate governance levels vary between jurisdictions, depending on the level at which heat planning is implemented (national or regional). A key issue that heat is that heat can be governed separate regulatory frameworks, such as energy or energy efficiency frameworks rather than in spatial planning frameworks, which helps to support a local perspective of heat infrastructure. The push for municipal heat planning in the proposed recast of the EED 2012 is an opportunity to support a more integrated approach between these frameworks. Austria is a good example of a country seeking to align its regional approach to heat planning due to spatial planning powers reserves to the regions with implementation of a spatial planning approach at national level in relation to heat via joint mandate. The integrated spatial planning approach to heat in Austria is thereby nearing both horizontal and vertical alignment of governance for effective implementation of heat planning and can serve as a good practice example for countries in which certain energy and spatial planning powers are spread among different governance levels.
- This report supports the position that polycentric energy governance approach to heat planning and integrated spatial energy planning is beneficial in parallel with the design and transformation of heating systems. This is why Denmark can be considered to provide a best practice example for successful heat planning for heat transition. However, it is important to note that constitutional structures differ across MS. Countries with federal structures such as Austria and Germany may not be able to replicate specific approaches, such as the Danish model, in each jurisdiction. The recommendation is therefore caveated by the observation in other case studies that the governance or constitutional structure of a state matters for the efficacy of implementing a polycentric approach to heat planning and integrated spatial energy planning. The enabling framework will not always originate from a national scale (as in Denmark) and may emanate from a more regional level (as in Austria or Germany). The differing constitutional and governance structures in each jurisdiction must be taken into account when considering how to effectively implement heat planning. It is necessary to align the approach to heat planning with governmental structure of the jurisdiction in question and give particular focus to where the powers to develop and implement heat planning and energy strategy emanate from, i.e. federal structures (Germany, Austria, Switzerland) as opposed to powers emanating from the national government (Denmark) or even as part of a devolved system as in Scotland.
- Conceptualising heat planning as part of an energy spatial planning framework (e.g. Austria, Scotland, Switzerland) supports a whole systems approach that integrates the local level with decarbonisation and emissions targets at national and international levels. Even in MS where heat planning is not yet implemented as a dedicated programme, there are windows of opportunity via national legislation for such implementation, via energy and planning legislation and regulation (e.g. Poland). However these must be effectively and consistently enforced and also be aligned with each other to avoid gaps in competencies for implementation.

7 Cost of Distribution and Transmission

7.1 Introduction and overview

This section of the report addresses Task 3.4 of the project. This task has the objective of analyzing the cost structures for supply, transmission and distribution in the context of District Heating and Cooling[7] (DHC) systems and networks. To this end, this section reviews the literature on cost assessment methods for DHC distribution and transmission. It presents the necessary background on the supply, transmission and distribution of heat or cold as well as different methods to determine the technical characteristics of the system and its costs. Top-down and bottom-up approaches are discussed and the development of a meta-level approach that combines the strengths of both is proposed. Furthermore, the available data on a European level is reported and a case study applying such an assessment method to Germany is presented.

DHC systems are mainly installed to take advantage of local fuels or waste heat in meeting local heating demand (Frederiksen & Werner, 2013). They consist of three main components, one or several heat and/or cold generation unit as well as a transmission grid linking the unit to separate settlements and a distribution grid to deliver the heat or cold[1] to individual houses within the settlement, see also 3 (Nielsen & Möller, 2013). Only larger DH networks require central substations to exchange heat between transmission and distribution grids whereas as such systems contain building-level substations, which are introduced in the task 4 report). The distinction between transmission and distribution grids is not a hard line but transmission grids use higher pressure and/or temperatures than distribution grids, which allows them to transport heat over larger distances. The different grids are linked through heat exchangers which transfer the heat from the typically larger transmission pipes to smaller distribution pipes while minimizing losses (Gamborg & Wolter, 2021) as shown in Figure 16. The viability of such systems depends to a large degree on the heat density of a given area, i.e. the heat demand per land area (Persson & Werner, 2011). This factor is not static over time and is for example reduced through energy efficiency improvements through building renovation measures (Andric et al. 2018). However, the demand-side is considered outside of the scope of this task as it is investigated in Task 4; instead this task focuses on the heat supply, transmission and distribution aspects. Regarding the heat supply, different technologies are characterized regarding their cost structure. In addition, the relevant technical and economic parameters for transmission and distribution networks and their data availability are introduced and methods to identify optimal technical configurations and derive the resulting costs are presented.

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[7] For simplicity's sake and due a larger focus on district heating systems than district cooling systems in the context of transmission and distribution, the chapter will refer to "heat" even if the same principles generally hold true for cold as well.

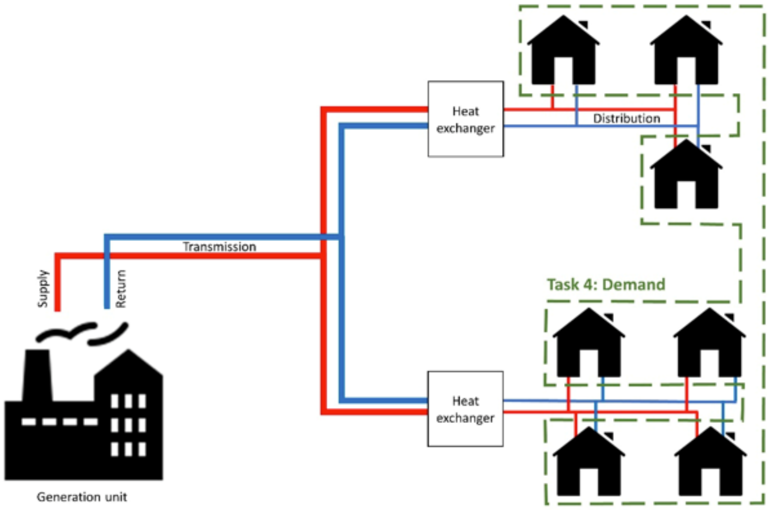

Figure 16 **Components of a typical DHC system (inspired by Gamborg & Wolter, 2021, not applicable for all systems)**

The heat supply for DHC networks can come from a number of different sources. Classical options that exploit waste heat supply include combined heat and power (CHP) plants, Waste-to-energy (WtE), or industrial excess heat, where the heat would otherwise be lost (Werner, 2017). Furthermore, fossil fuels can also be used in CHP or boilers and renewable heat supply can come from residual biomass, geothermal or solar thermal (Paardekooper et al. 2018c). Both heating and cooling are further possible using electricity in heat pumps or refrigeration cooling plants (Konstantin & Konstantin, 2022).

In contrast to individual heat generation at building or apartment levels, DHC requires transmission and distribution systems that lead to higher costs and additional losses during transmission. Their benefit is found in the economies of scale that they can exploit and the higher overall efficiencies due to a better utilization rate of the centralized plant. Indeed, district heating (DH) systems can be sized to meet about 60-70% of the sum of the individual heat demand peaks (Bordin et al. 2016). However, in purely residential areas, the co-incidence of heat demand peaks can rise up to between 80-95%, in which case this final benefit would be minimal (Konstantin & Konstantin, 2022). A similar situation is present for district cooling (DC), where the maximum capacity can be reduced to 80% of the individual peaks or even to 70% in the presence of thermal storage, which permits cost savings of between 10-50% compared to decentralized cold generation due to economies of scale (Dyrelund et al. 2021). These additional costs and savings need to be evaluated in order to identify if a DHC system is cost-competitive with individual heat supply.

The way DHC networks have been constructed has changed a lot over time. The first generations of DH networks were built at the end of the 19th century, using concrete ducts and relying on steam at very high temperatures above 200°C as a heat carrier (Lund et al. 2014). These networks still had very high heat losses and consequently low efficiencies as losses depend on the pipe diameter and the pipe insulation, but notably also on the temperature difference between the fluid inside the pipe and the outside environment (Persson & Werner, 2011). To minimize these losses, each consecutive generation of DH networks has used lower fluid temperatures as Figure 17 below indicates (Revesz et al. 2020).

Steam was replaced as the heat carrier by hot water in the second generation of DH networks and in the third generation, which represents the current state-of-the-art, prefabrication and pre-insulated pipes allowed to use even lower temperatures below 100°C (Werner, 2017). A fourth generation of district heating is currently emerging, which can be described by five main abilities according to Lund et al. (2014).

1. Ability to supply low-temperature district heating for space heating and hot water
2. Ability to distribute heat in networks with low grid losses
3. Ability to utilize renewable heat and recycled heat from low-temperature sources
4. Ability to be an integrated part of smart energy systems
5. Ability to ensure suitable planning, cost and motivation structures

A next, fifth, generation has already been demonstrated as well, which would use decentralized heat supply sources and an ambient loop to better exploit heat supply sources and further reduce distribution losses as well as customer site heat pumps for temperature boosting. Such a development would also allow for these networks to be used for cooling (Revesz et al. 2020). The development of DH networks over time is shown in Figure 15 below. This report only considers cost for the 4th generation DHC systems.

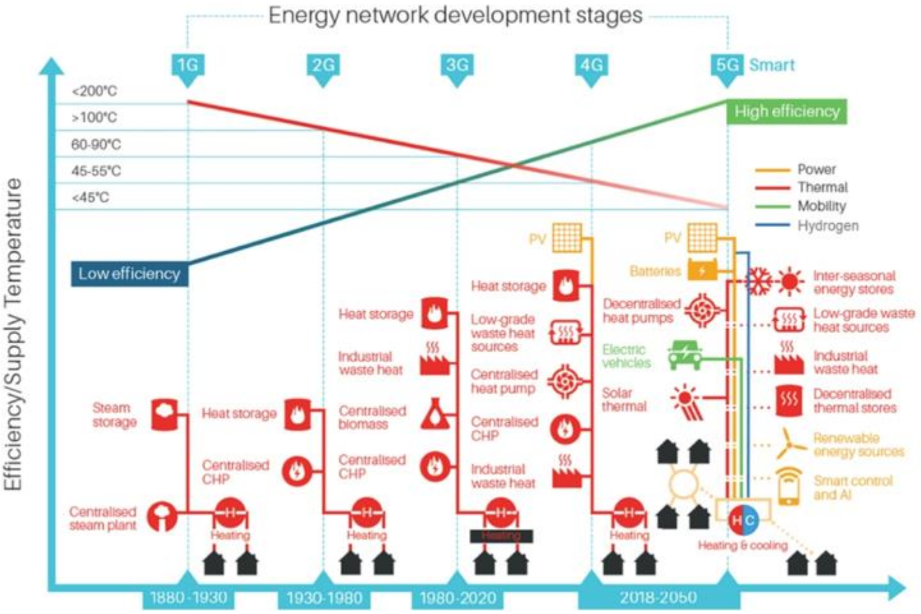

Figure 17: **Development of DH networks (Revesz et al. 2020)**

7.2 Fundamental techno-economic characteristics of DHC transmission and distribution

This section describes key concepts related to the supply of heating or cooling and the cost of transmission and distribution in DHC. This includes the relevant cost components as well as methods to determine whether a DHC network is economically viable. Furthermore, the available datasets that provide techno-economic parameters in a European context are described and finally some approaches to categorize different thermal supply technologies are stated.

7.2.1 Cost components

The costs of DHC networks can broadly be broken down into the cost for producing the heat, the transmission costs and the distribution costs (Nielsen & Möller, 2013). Since individual heat generation only includes a cost for the heat generation, a DHC system can only compete if at least one of two conditions is met as illustrates: either a source of cheap heat is available, usually waste heat from industrial processes, or the heat density is high enough that the heat source can be exploited with a high utilization rate due to a sufficiently high heat density (Spirito et al. 2021). The cost of the heat generation will be touched upon in section 3.2.7.

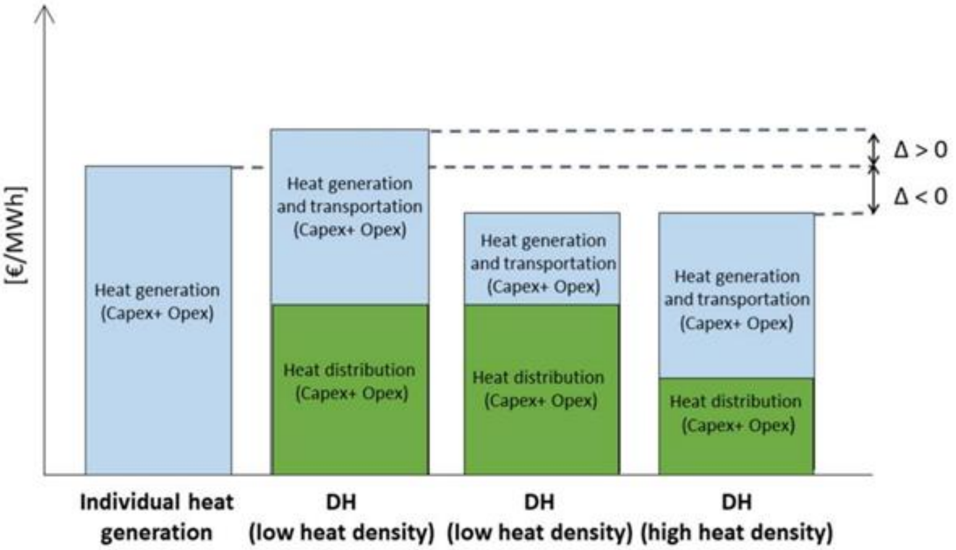

Figure 18: **Comparing individual heat generation with district heating (Spirito et al. 2021)**

The transmission costs depend mostly on the length of the network as well as its technical characteristics. Nielsen & Möller (2013) use information on the pipe diameter, flow rate limits, carrying capacity and cost of different network types to define the technical characteristics and then obtain the transmission cost by calculating the shortest distance between the heat supply source and the destination along the road network to determine the network length. Typically, transmission costs are considered in studies which connect heat sources to heat sinks (such as settlements) over distances of several kilometers (Weinand et al., 2019a; 2019b; 2019c). Further cost components that can be considered include the cost for pumping and the central substation cost to link the transmission and distribution network (Spirito et al. 2021).

To obtain the total cost of the distribution network, some additional cost components have to be considered according to Frederiksen et al. (2013). They argue that this cost depends on the distribution capital cost for laying down pipes, the annual cost necessary to cover distribution heat and pressure losses as well as service and maintenance costs. Persson & Werner (2011) argue that the first term is by far the most important component of the total distribution cost. The distribution capital cost depends on the network construction cost which in turn relies on the linear heat density, i.e. the transferred heat per length of pipeline, which also relates to the losses of the DH network (Fallahnejad et al. 2018). As the method developed by Persson & Werner (2011) can be used to model future distribution capital costs, even when no DH network exists, it has been adopted as the current state-of-the-art approach and is described in more detail in section 3.2.5.

7.2.2 Suitability assessment methods

There are two main approaches to calculate the costs of DHC transmission and distribution and thereby assess the feasibility of DHC systems. First, bottom-up approaches that consider individual heat sources and sinks (i.e. individual buildings). These require location-specific data and are computationally heavy, but provide more detailed and comprehensive results that can consider the existing infrastructure. However, due to the data requirements, the insights gained from such approaches have a limited generalizability. The second set of methods uses top-down approaches, which rely on spatially aggregated heat demand data (Paardekooper et al. 2018). These are more transparent and replicable as they require less and generally open data. For this reason, they are more commonly adopted even though they lack detail on aspects such as water flow, heat losses or ground elevation and are not well suited to layout planning of DHC networks (Fallahnejad et al. 2018). As another additional dimension of complexity, they require a filtering of the area that requires heating to exclude e.g. forests or bodies of water to obtain the effective heat density, which is critical to obtain the cost of transmission and distribution networks (Fallahnejad et al. 2022). It is critical for DHC planning to not only consider the heat demand, which is increasingly available in the form of geospatial datasets (e.g. AGFW, 2010; Persson & Werner, 2012; Persson et al. 2014), but also the relevant local conditions, such as the spatial distribution of demand or hot and cold sources. An approach combining the strengths of both of these methods is ideally required as top-down studies struggle with the latter (Werner, 2017). Hence an important remarkis that heating sector information is usually either analyzed highly locally or in an aggregated manner (Paardekooper et al. 2018c). However, explicit mapping of supply and demands is critical because the design and topology of DHC networks have significant impacts on their cost-effectiveness (Nussbaumer & Thalmann, 2016; Zvoleff et al. 2009). A further distinction needs to be made between brownfield projects that aim to extend or densify an existing DH network and greenfield projects that ought to construct a new DH network. Before such an approach can be developed, the relevant features of both bottom-up and top-down assessment methods need to be understood more in detail.

7.2.3 Bottom-up assessment

Bottom-up network planning allows incorporation of high-level spatial detail. Important parameters for the planning of DHC networks that can be incorporated in these types of models include (Dyrelund et al. 2021):

- The topology of the area
- The maximum supply temperature that needs to be ensured on the coldest day
- Alternatives for customers that need larger supply temperatures such as industries
- The expected return temperatures
- The length of the network and placement of pumping stations
- Capacity constraints in existing district heating pipes
- The possibility to install local peak boilers
- The maximal supply temperature of base load production units
- The potential benefit of heat storages

The most important tools for bottom-up assessments in Europe include Thermos (2021) and Hotmaps (2020). Thermos is an open-source mixed-integer linear programming optimization model that plans distribution networks at a building-level resolution while considering features such as the road pathways and the selection or exclusion of individual buildings. The tool can be used to plan the expansion of an existing DHC network or to plan new, greenfield, networks based on the available sources of energy supply and demand. Furthermore, it is also able to do performance assessments of potential DHC networks and compare them to non-DHC solutions (Thermos, 2021).

Similarly, Hotmaps is an open-source model that determines heat demand and the potential of renewable energy sources to meet that demand at a high spatial resolution. While a preliminary assessment can already be obtained using generic cost data and yearly energy consumption and production values, a detailed analysis requires even more information on the individual buildings such as their total energy consumption and demand profile, but also what type of heating they have and how well they are insulated. Furthermore, information on existing DHC networks can also be included, just like topographical information on rivers or roads and even policies (Hotmaps, 2020). However, Hotmaps does not perform the explicit network planning and is thus mainly useful as an input to such investigations.

DHMIN (Dorfner, 2016) is another tool that uses mixed integer linear programming to optimize local DH networks. It has been applied to a case study in Munich, where the resulting network was found to correspond well to the real plan (Dorfner & Hamacher, 2014). This tool requires building-level data on the total annual and peak heat demand, which is then aggregated along a street segment. Furthermore, the location of the possible heat sources and the maximum pipeline capacity for each street segment also need to be known to be able to apply this tool, as well as cost and technical parameters (Dorfner, 2016). A similar optimization model that permits the planning of DHC network expansions was developed by Bordin et al. (2016) and applied in an Italian case study. This tool also considers pressure losses in addition to the flow rate constraints, but also requires detailed information on existing networks.

While Finney et al. (2012) also used a bottom-up approach to map heat sources and sinks and quantify how much heat they supply or demand, respectively, Lumbreras et al. (2022) design a DHC network based on the existing excess heat from industry while using a routing algorithm for network planning and a Digital Surface Model and a Digital Terrain model to estimate the building-level energy demand for a case study in Spain. However, the former does not perform any economic evaluation while the latter uses the payback period to select the best network configuration.

Other examples of bottom-up assessment methods consider a range of different technical characteristics, from different pump types (Hagedorn, 2018) to the pressure drop (Gundmundsson et al. 2022).

With the increasing availability of GIS data, bottom-up approaches are less limited to a specific context and can more easily be transferred to another situation as the recent developments of Thermos and Hotmaps have demonstrated. Thus, the outlook for more widely applicable bottom-up assessment methods is promising. Nevertheless, their high computational complexity means they are not suited to large areas in the way that top-down methods are.

7.2.4 Top-down assessment

The top-down assessment of the viability of DH networks relies on the use of the concept of heat density, especially linear heat density, which is the ratio of the heat that is annually sold over the total length of the network (Andric et al. 2018). This approach requires two main points of information, first the total amount of heat that is demanded within an area and second the length of the network. Connolly et al. (2014) for example identify suitable areas based on the heat densities directly while Gils et al. (2013) use a range of statistical information and a population density map to first of all obtain the estimated network length and then based on that the distribution costs. Sandvall et al. (2017) and Hansen et al. (2019) also use a top-down approach to compare options for district heating with individual heat supply, both without optimizing the network endogenously but allowing the model to choose the heat supply unit based on its technical characteristics and cost.

A top-down approach does not preclude the inclusion of a high-level of technical detail as Kavvadias & Quoilin (2018) demonstrate. They assess the levelized cost of heating (LCOH) of CHP-based district heating transmission for all 28 EU countries while considering their variability of power and gas prices. To this end, they developed a technical model that determines the technical characteristics of the pipe and calculates the heat and pressure losses as well as the power loss of the CHP plant resulting from an increased heat production based on input data on the heat demand and pipe length as well as the ambient and soil temperature. The final configuration is then put into an economic model to calculate the capital costs as well as the operating costs, which are mainly a function of the pumping costs and the power penalty of the CHP plant.

The resulting model of Kavvadias & Quoilin (2018) also does not perform layout planning but instead optimizes how much heat can be supplied and how the DH network is configured. Four scenarios were analyzed with different distances and amounts of heat to be delivered, with the results showing that shorter distances and lower power prices yield a more competitive DH network. The impact of the most sensitive variables on the LCOH is shown in Figure 19 for all four of these scenarios. At high distances, the capacity factor of the plant is the most important variable but at lower distances, the cost of electricity and the required supply temperature, which in turn influences the extraction temperature and thus the power penalty, become more important variables. The discount rate also represents a critical assumption, which becomes more important for longer distances as longer DH networks are more capital intensive. Overall, smaller networks tend to be dominated by the operational costs and larger DH networks by their capital costs. However, this approach requires further improvements to incorporate GIS data on the heat demand and plant locations as this study considers a generic situation.

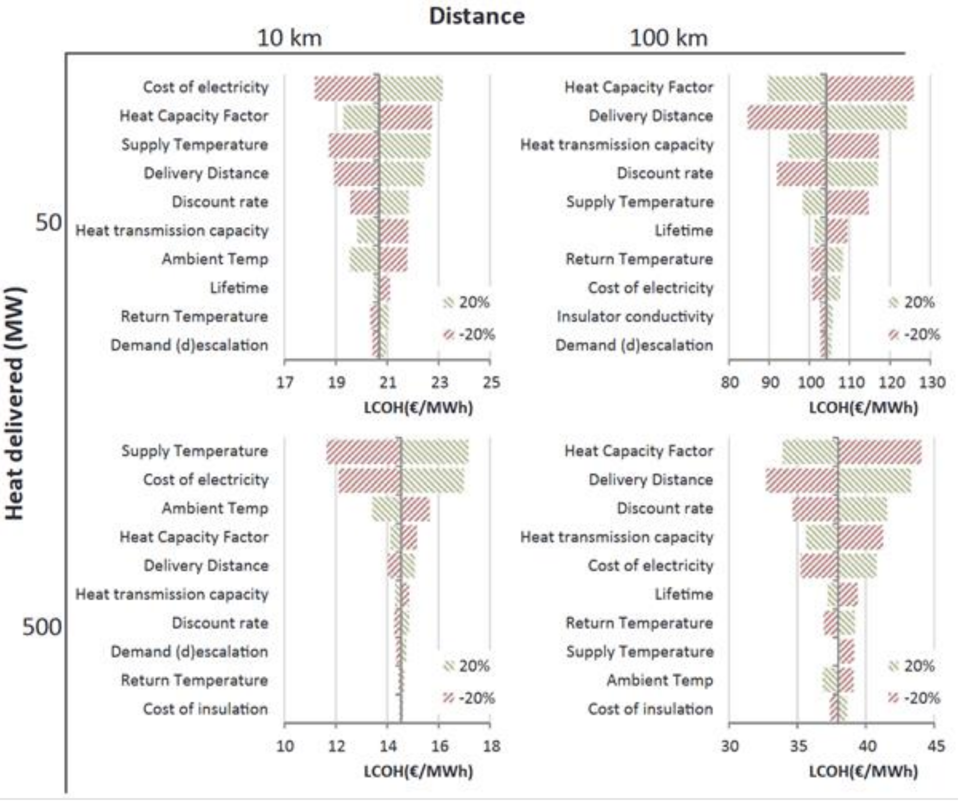

Figure 19: **The effect of the most sensitive variables on LCOH for different distances and amounts of heat (Kavvadias & Quoilin, 2018)**

A top-down approach that includes coarse network planning is used to determine the pipe network installation cost by Weinand et al. (2019a; 2019b; 2019c). The original studies use this method to place geothermal plants in a way such that they provide heat to different settlements at the lowest possible total cost. This is done using a heuristic that connects settlements iteratively based on their heat density until either all are connected, or the heat supply is exhausted. A minimal spanning tree network is then used to connect the different settlements once all possible geothermal plants are exploited according to their economic viability. This approach is adapted and generalized by Graf (2022) to introduce a component that adds technology choice for the heat supply. The module then contrasts the costs for the heat supply, transmission network between settlements and distribution networks within settlements with a pre-defined cost threshold to identify the viability of DHC on a hectare level. Each individual hectare is assigned one of three categories based on this cost:

1. It is excluded due to DHC not being viable for any technology
2. It can be connected to DHC given that existing plants can provide excess heat
3. It can be connected to DHC even with the cost to install a new, renewable, heat generation unit

If both the second and third category are the case for any single hectare, it is assigned to the third one since only a limited heat supply is available for squares in the second category. This approach, like the majority of those encountered in the literature, uses the method developed by Persson & Werner (2011) to calculate the costs of the distribution grid. This method is described in the next section.

7.2.5 Distribution capacity cost assessment method of Persson & Werner, 2011

In the absence of an existing DHC network, the linear heat density cannot be directly determined as neither the amount of heat annually sold, nor the total trench length of the network are knowable. For this reason, Persson & Werner (2011) reformulate the classic approach to calculate the distribution capital cost Cd and substitute the linear heat density by four related but more easily obtainable parameters (shown in equations (2)-(5)) according to equation (1).

$$C_d = \frac{a \cdot I}{Q_s} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{\left({}^{Q_s}/_{L}\right)} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w} (€/GJ) \tag{1}$$

$$p = P/A_L (number/m^2) \tag{2}$$

$$\alpha = A_B/P (m^2/capita) \tag{3}$$

$$q = Q_s/A_B (GJ/m^2a) \tag{4}$$

$$w = A_L/L (m) \tag{5}$$

where a is the annuity, from the chosen interest rate and the investment lifetime, I the total network investment (€), Q_s the heat annually sold (GJ/a), C_1 the construction cost constant (€/m), C_2 the construction cost coefficient (€/m2), d_a the average pipe diameter (m) and Q_s/L the linear heat density (GJ/m2a). In equations (2)-(5), P corresponds to the total population, A_L the total land area, A_B to the total building area, L the total trench length (m).

According to the approach developed by Persson & Werner (2011), the linear heat density can be derived based on 1) the population density, 2) the specific building space, 3) the specific heat demand, and 4) the effective width. The population density corresponds to the number of people living per area of land, the specific building space to the surface that has to be heated per person, the specific heat demand to the amount of heat required to provide space heating and domestic hot water and the effective width corresponds to the ratio between the area of land and the length of the network pipes. The last of these is used as a correction factor to avoid overestimating distribution costs and is usually estimated empirically based on the plot ratio as shown in equation (6) or described by Nielsen & Möller (2013) for Denmark.

$$e = p \cdot \alpha = \frac{P}{A_L} \cdot \frac{A_B}{P} (-) \tag{6}$$

The plot ratio corresponds to the product of the population density and the specific building space and is obtained by dividing the total building area within a given location by its land area (Fallahnejad et al. 2022). The concept of the plot ratio was adapted from Swedish city planning by Persson & Werner (2011). The higher the plot ratio is, the lower the distribution cost is, with values above 0.5 for the inner city whereas DHC can be economical in the Swedish context if the plot ratio is above 0.2 (Persson & Werner, 2011).

$$w = 61.8 \cdot e^{-0.15}\ (m) \tag{7}$$

Equation (7) allows for a further simplification of the calculation of the distribution capital cost as it provides an empirical relationship between the effective width and the plot ratio. Using this, the effective width can be calculated based on the plot ratio, which can also substitute the terms of the population density and the specific building space in equation (1). Then, the distribution capital cost can be calculated based on the approach developed by Persson & Werner using just a heat density map and a plot ratio map. Fallahnejad et al. (2018) applied exactly this approach to a case study in Vienna, where the linear heat density could be calculated based on these two inputs, followed by the pipe diameter is estimated empirically according to equation (8) and finally the distribution capital cost using equation (1). Fallahnejad et al. (2022) build on this work and compare its results to a bottom-up approach using DHMIN. While they find that the bottom-up approach leads to 20-30% higher network trench lengths, the normalized costs align well across both methods. They conclude by highlighting that an assessment based on the linear heat density using Persson & Werner's method of the effective width is well-suited for pre-feasibility stages and stating the importance of tuning cost components and input parameters to a given case study.

$$d_a = 0.0486 \cdot ln\frac{Q_s}{L} + 0.0007(m) \tag{8}$$

7.2.6 DHC pipes

Information on the technical characteristics and costs of DHC networks is provided by two principal sources, the IEA EBC Annex 73 (Dyrelund et al. 2021) and the DEA technology catalogue for transport of energy (Gamborg & Wolter, 2021). The former provides technical characteristics and costs for different types of DHC pipes as the excerpt in Table 7 shows. while, the latter only contains information on district heating but distinguishes between transmission and distribution networks while also providing technical and financial data as Table 8 illustrates. The data on heat supply sources/technologies is discussed in section 3.2.7.

The IEA EBC Annex 73 database includes technical characteristics such as the heat loss, flow rate and costs per meter among many others for district heating and cooling (Dyrelund et al. 2021). Data is provided for pre-insulated pipes with a diameter ranging from 15 mm to 1000 mm and Table 7 shows a sample of the type of information that is available from this source. They highlight that the cost per heat sale (€/MWh/a) in particular is a critical indicator to decide on the viability of DH networks. The database also contains pipe prices for different countries and based on the road type and the final three rows of the table show the most expensive pipe types for Denmark, the UK and Sweden. While this type of cost data is available for district heating pipes, this is not the case for district cooling.

In fact, the latter two columns on the technical characteristics of district cooling (DC) pipes show some stark differences to the equivalent DH pipes. They are able to carry significantly less thermal energy and while the costs per meter are equivalent or even cheaper, the costs per unit of heat are thus significantly higher. While no specific cost data is available, DC pipes can consist of plastic instead of steel, which allows them to be significantly cheaper at low diameters (e.g. 130 €/m instead of 237 €/m for the same type of pipe made out of plastic instead of steel at a 20mm diameter). However, the losses then get much larger and already at a diameter of 50 mm, plastic pipes are more expensive.

Table 7: DHC characteristics from IEA EBC Annex 73

	Unit	DN20 (DH)	DN1000 (DH)	DN20 (DC)	DN1000 (DC)
Inner diameter	mm	22.90	994.0	22.90	994.0
Velocity at 10 mm/m	m/s	0.36	3.5	0.36	3.50
Water flow	m3/h	0.53	9778.9	0.53	9778.9
Maximal supply temperature	oC	90	90	15	15
Return temperature	oC	50	50	6	6
Heat loss capacity	W/m	9.92	74.4	0.40	3.00
Heat loss energy per year	MWh/m/a	0.09	0.65	0.00	0.03
Capacity	MW	0.02	453.7	0.01	102.09
Annual max load hours	h	2000	2000	2000	2000
Annual heat transfer	MWh/a	49.54	907481	11.15	204183.20
Annual heat losses/km	%/km	0.64	0.00	0.24	0.00
Cost per meter	EUR/m	373.94	3156.9	373.94	1743.38
Cost per MWh/a per km	EUR/MWh/a/km	7548.09	3.5	33547.07	8.54
DH pipe prices DK – Large roads	EUR/m	374	3157	-	-
DH pipe prices GB – hard roads	EUR/m	893	2936	-	-
DH pipe prices SE – hard road	EUR/m	293	2376	-	-

The DEA technology catalogue only contains information on district heating but distinguishes between transmission and distribution networks and even between the degree of urbanization for distribution grids (Gamborg & Wolter, 2021). Distribution grid data is provided for rural, suburban, urban and greenfield areas – whereby the first three map to the categories used by Werner & Persson (2011). Table 8 reports the data for 2020 and shows that these distinctions are significant as the differences in energy losses and costs are large, even as transmission lines with a capacity above 20 MW have even smaller energy losses of 1% or less. The table shows that long-distance transmission has significantly smaller losses than local distribution grids and that a higher density helps to reduce both the costs and the losses of the distribution networks. Two additional cost factors are not reported in the table as they do not differ between type of distribution grid are the costs for the heat exchanger station (100’000 €/MW, 5% energy losses) and the pumping station (90’000 €/MW).

Table 8: DH characteristics from DEA technology catalogue

	Unit	Transmission	Distribution (rural)	Distribution (suburban)	Distribution (city)	Distribution (new area)
Energy losses, lines	%	3	15	14	5	18
Distribution network costs	€/MWh/a	-	720	655	150	655
Investment, single line, 0-50kW	€/m	-	280	280	280	180
Investment, single line, 50-100kW	€/m	-	355	355	355	235
Investment, single line, 100-250kW	€/m	-	370	370	370	250
Investment, single line, 250kW-1MW	€/m	-	460	460	460	320
Investment, single line, 1-5MW	€/m	-	640	640	640	455
Investment, single line, 5-25MW	€/m	-	1’185	1’185	1’185	900
Investment, single line, 0-50MW	€/MW/m	25	-	-	-	-
Investment, single line, 50-100MW	€/MW/m	12	-	-	-	-
Investment, single line, 100-250MW	€/MW/m	9	-	-	-	-
Investment, single line, 250-500	€/MW/m	6	-	-	-	-

7.2.7 Hot and cold sources

The Danish Energy Agency’s Technology Catalogue (Gamborg & Wolter, 2022) and the JRC Long term (2050) projections of techno-economic performance of large-scale heating and cooling in the EU (Grosse et al. 2017) provide information about different supply technologies. As the excerpts in Table 8 and 9 show, both contain data on the technical characteristics, the environmental impacts, and the costs associated with a given technology. This type of information is provided from 2015 to 2050 in both data sources and an uncertainty range is also given.

The JRC Long term (2050) projections of techno-economic performance of large-scale heating and cooling in the EU covers different types of boilers, geothermal and solar thermal as well as heat pumps and CHP to supply heat. Table 9 below shows the characteristics for a gas-fired boiler, both at the present state and projected to 2050. Furthermore, the dataset also includes information on cooling from heat pumps, namely the cooling generation capacity in addition to the thermal power output and the cooling COP in addition to the heating CHP as well as a cold start-up time of 0.5h. It also includes data on the substation and piping network but both at a coarser resolution than the two datasets described in section 3.2.6 (Grosse et al. 2017).

Table 9: Supply technology characteristics from the JRC Long term (2050) projections of techno-economic performance of large-scale heating and cooling in the EU (Grosse et al. 2017). The excerpt shows the available data for gas-fired boilers.

	Unit	2015	2050
Total degree of utilization, nominal load	%	95	95
Total degree of utilization, annual average	%	87	87
Electricity consumption	%	0.5	0.4
Technical lifetime	years	30	40
CO2	g/MJ_th	60	60
SO2	g/GJ_th	<	<
NOX	g/GJ_th	20	15
CH4	g/GJ_th	<	<
N2O	g/GJ_th	<	<
Particles	g/GJ_th	<	<
Nominal investment	M€/MW_th	0.1	0.1
- of which equipment	M€/MW_th	0.06	0.06
- of which installation	M€/MW_th	0.04	0.04
Fixed O&M	k€/MW_th/a	2	1.8
Variable O&M excl. Electricity costs	€/MWh_th	0.2	0.2

The DEA Technology Data Catalogue for Electricity and district heating production covers heat supply from fuel cells, waste-to-energy or biomass, either in dedicated heat-only plants or in combined heat and power facilities. Furthermore, it also considers boilers as well as geothermal and solar thermal heat supply. Table 10 shows the available data on gas fired boilers for district heating, both for the present day and projected to 2050. A comparison to the previous Table 9 shows that the dynamic plant capabilities, which are present here, are missing from the JRC database. While the database mentions that heat pumps could also be exploited for district heating or cooling, no specific technology data is provided (Gamborg & Wolter, 2022).

Table 10: Heat supply technology characteristics from the DEA Technology Data Catagloue for Electricity and district heating production (Gamborg & Wolter, 2022). The excerpt shows the available data for gas fired district heating boilers.

	Unit	2015	2050
Total efficiency, nominal load	%	105	106
Total efficiency, annual average	%	103	104
Electricity consumption	%	0.15	0.1
Forced outage	%	1	1

	Unit	2015	2050
Planned outage	weeks/year	0.4	0.4
Technical lifetime	years	25	25
Construction time	years	0.5	0.5
Space requirement	1000m2/MJ/s	0.005	0.005
Minimum load	% of full load	15	15
Warm start-up time	hours	0.1	0.1
Cold start-up time	hours	0.4	0.4
SO2	g/GJ_fuel	0.3	0.3
NOx	g/GJ_fuel	10	6
CH4	g/GJ_fuel	3	2
N2O	g/GJ_fuel	1	1
Nominal investment	M€/MJ/s	0.06	0.05
- of which equipment	M€/MJ/s	0.04	0.03
- of which installation	M€/MJ/s	0.02	0.02
Fixed O&M	€/MJ/s/year	2000	1700
Variable O&M	€/MWh	1.1	1.0
- of which electricity costs	€/MWh	0.1	0.1
- of which other O&M costs	€/MWh	1.0	0.9

As this scarcity of available data demonstrates, district cooling is still a small and specialised market. Indeed, it provided just 3.1 TWh, mainly to the service sector, in Europe in 2018, whereas district heating provided two orders of magnitude more energy at 445 TWh or 12% of the final heating energy consumption. The DH production in the EU-27 is dominated by combined heat and power plants (CHP) with a share of 63%. Two thirds of this supply comes from fossil fuels and another quarter from biomass, biofuels and renewable waste as Figure 20 shows. Meanwhile, other options such as excess heat, heat pumps or renewable heat from solar thermal or geothermal only have minimal shares in the current market (Directorate-General for Energy (European Commission) et al. 2022):

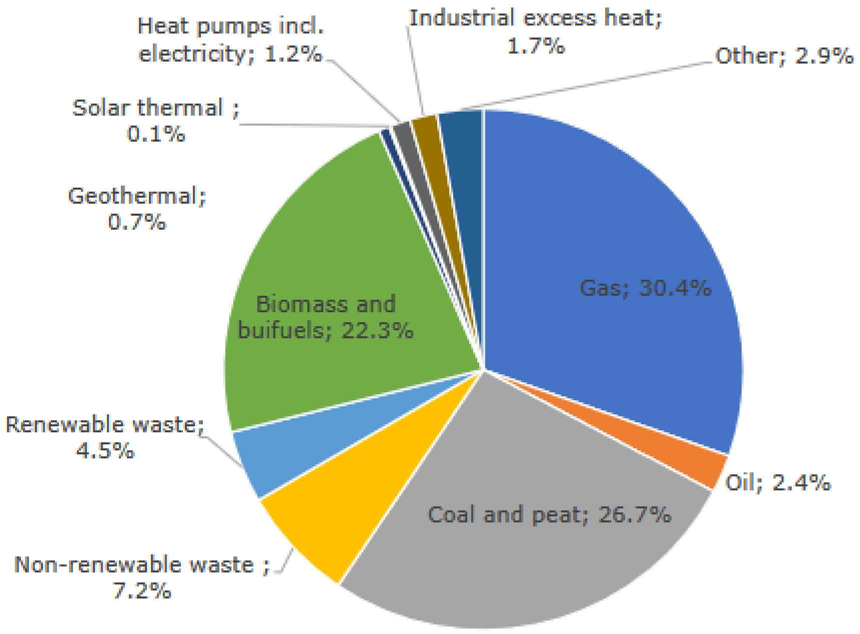

Figure 20: **EU-27 District heating supply fuel mix in 2018 (total 445 TWh)**

While excess heat can be considered to be virtually free, the cost of heat supply has to be considered if DH networks rely on new heat supply sources. Boilers, either based on fossil-fuels such as natural gas and oil or based on wood in the form of chips or pellets, are an example of a widely adopted heat supply source that is frequently used to cover demand peaks (Directorate-General for Energy (European Commission) et al. 2022). An increasingly important category is found in heat pumps that valorize either directly usable waste heat or else low temperature waste heat and ambient heat. Solar thermal energy in combination with thermal storage or geothermal energy constitute renewable sources of heat and combined heat and power generation can also be an example for such an option depending on the fuel that is used (Nussbaumer et al. 2020). Technical characteristics of different types of CHP, heat pumps and geothermal as well as natural gas boilers and solar thermal are presented by Gamborg & Wolter (2022) but due to their heterogeneity, these values are not directly comparable. A particularity to note on CHP is that since these plants produce both heat and power, an increase in the heat output will lead to a reduction in power generation, which is an additional trade-off that needs to be balanced (Kavvadias & Quoilin, 2018).

Each of these technologies differs in their capital and operating costs and these differences can be used to generate specific capacity cost curves such as the ones shown in Figure 21. These indicate the cost of different heat supply technologies based on for example the number of hours per year when they would be used and permit the identification of the suitable technology based on the expected full load hours, for the application to decentralized residential heating (Merkel et al. 2014). While this figure shows costs for individual heat generation units, the cost structure might change due to economies of scale at the district level. It is expected that a similar trend emerges when examining larger-scale plants for DHC, but the data from the DEA Technology Catalogue and the IEA Annex (Dyrelund et al. 2021; Gamborg & Wolter, 2021) are limited in terms of the range of capacities covered, so deriving such curves is challenging.

Technologies with a high fixed cost and low operational cost are well suited to be used as baseload generators that operate during a large number of hours. In fact, up to 90% of the annual heat demand can be met by technologies such as wood boilers or solar thermal plants. Waste heat is also exceptionally well suited to the purpose of baseload generation. Still, peaking plants with a low fixed cost but a relatively high operational cost remain necessary to meet demand peaks and typically, fossil fuel-based boilers have been used to this end (Nussbaumer et al. 2020).

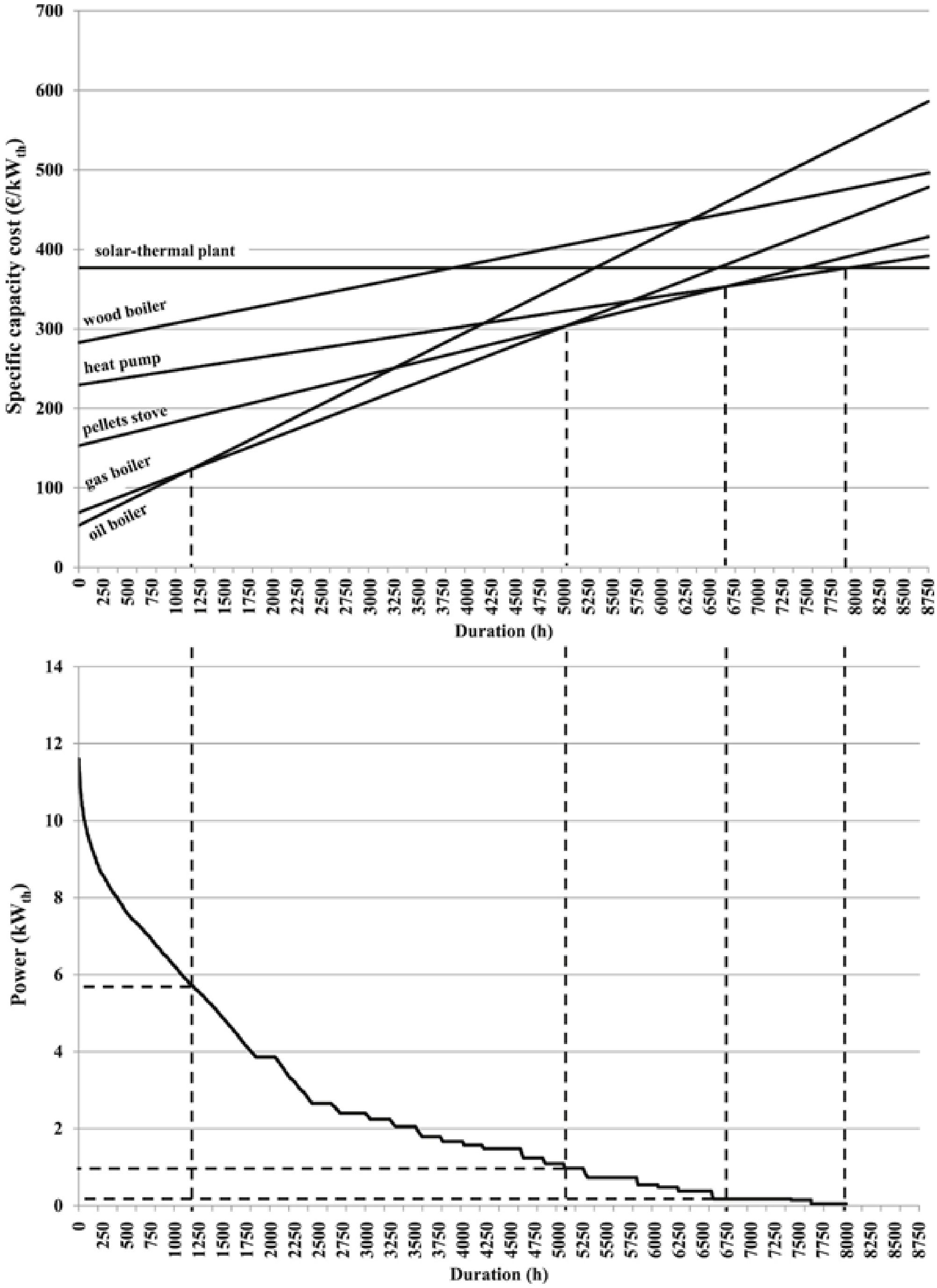

Figure 21: **Specific capacity cost of heat generating technologies and thermal load duration curve for a decentralized residential context (Merkel et al. 2014)**

The technology portfolio for district cooling looks quite different as cooling plants produce chilled water using either vapor compression refrigeration or absorption refrigeration, the former relying on power and the latter on heat. As an analogue to the previous comparison for district heating, absorption cooling has high upfront costs and requires sufficient waste heat from industrial processes, making it better suited as a baseload generator while vapor-compression refrigeration is especially well suited to peaks in cooling demand as such plants are quickly able to ramp up and down but require large amounts of power (Konstantin & Konstantin, 2022). The necessary cooling load can be determined based on the ambient temperature and the building insulation (see also task 4 report on “European end user costs for providing heating and cooling with heat pumps and district heating”). However, there has been significantly less research on district cooling than on district heating, which reflects the fact that demand for the former is vastly smaller than the demand for the latter (Joint Research Centre (European Commission) et al., 2018).

7.3 Application to the German context

Based on the background introduced in section 3.2, in particular the method developed by Persson & Werner (2011), this chapter introduces a case study that determines the distribution capital costs for 1711 districts in the 74 largest German cities (Schnellenpfeil, 2013). These cities were selected for their data availability and contain more than 30% of the total German population. Their average share of district heating is at 29% compared to 13% for Germany. The distribution capital cost was calculated for each of the 1711 districts with an average of 14’560 inhabitants in order to identify the economically feasible market share of district heating.

To be able to calculate the distribution capital cost for each city district, data was collected on the input factors required for the application of Persson & Werner’s approach described above. Namely, this includes the population density, the specific building area, and the specific heat demand as shown in Table 11. The specific building space only considers residential areas so it was multiplied by 1.4 according to Persson & Werner (2011) to obtain an estimate of the total including commercial buildings. The specific heat demand was only available on a state level and assigned to each district within a state. Additional data was required on the cost parameters C1 and C2 as shown in equation (1). In the absence of Germany-specific data, the data from Sweden was used, which in turn also led to the use of the district typology from Persson & Werner (2011) to select the suitable cost parameters, where districts are assigned to inner city areas (A), outer city areas (B) or park areas (C) based on their plot ratio. The input data was obtained from Eurostat and the Federal Statistical Office of Germany but also from regional and city-level statistical databases and direct inquiries to town halls or city departments.

Table 11: Input data to determine the distribution capital cost

	Unit	Average	Minimum	Maximum
Population density	inhabitants/km^2	3086.3	100	24996
Specific residential building space	m^2/inhabitant	56.8	25.3	438.6
Specific heat demand	GJ/m^2	0.512	0.48	0.56

The plot ratio was derived by combining the obtained data on the population density and the specific building space. Using the typology developed by Persson & Werner, only about 5% of the city districts were categorized as inner-city areas and just 10% as outer city areas with the remaining 85% qualifying as park areas even though these cover the largest cities by population in Germany.

Using the plot ratio, the cost parameters C1 and C2 are selected as well as the effective width based on equation (7). This in turn yields the linear heat density, which can be used to empirically estimate the average pipe diameter according to equation (8). Finally, all of these inputs can be combined to obtain the distribution capital cost according to equation (1) assuming an annuity of 0.051 based on a project lifetime of 30 years and an interest rate of 3%.

The calculated distribution capital cost as a function of the plot ratio is shown in Figure 22. It decreases with an increasing plot ratio, converging towards 0.815 €2013/GJ for higher plot ratios. The function is non-continuous due to the cost parameters, with jumps whenever the plot ratio indicated changing the cost parameters. Persson & Werner (2011) used 8 €2009/GJ as a threshold to exclude areas from DH exploitation and all but 114 districts are cheaper than that. Those 114 districts were then excluded from any further evaluations.

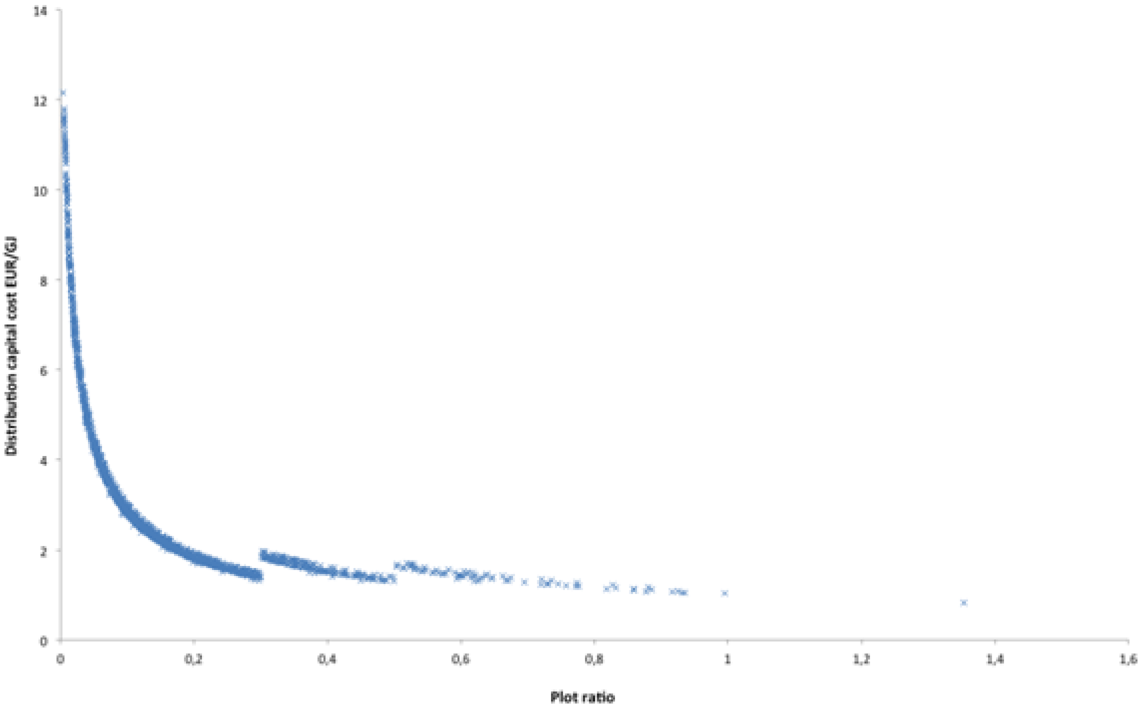

Figure 22: **Distribution capital cost and the corresponding plot ratio**

A similar pattern to the plot ratio was also identified for the population density where a higher population density reduces the distribution capital cost. The threshold for a distribution capital cost of 8 €2009/GJ is found at a population density of just 300 inhabitants per square kilometer and population densities of 2500 are already enough to find a distribution capital cost around 2€2013/GJ.

The threshold of 8 €2009/GJ was only used as an exclusion criterion but is set relatively high as the small number of exclusions demonstrate. Indeed, Persson & Werner do actually suggest a threshold plot ratio value between 0.15-0.20 for feasible district heating in the cities they studied, which translates to a marginal distribution capital cost of 2.1 €2009/GJ. For a similar assessment, the German city districts were sorted by their distribution capital cost as illustrated in Figure 23 where the x-axis demonstrates the share of the total heat market of the 74 cities combined when considering their populations. Based on this figure, a market share of 70% was identified as a threshold since the costs increase sharply thereafter.

This threshold leads to a marginal distribution capital cost threshold of 2.59 €2013/GJ for this case study, which is found in the 891 districts with a plot ratio equal or greater to 0.1095. While the required plot ratio is thus lower than in Sweden, the marginal cost is slightly higher. A 70% market share of district heating could thus be achieved without large increases in the distribution capital cost. This is significantly higher than both the 13% market share for all of Germany and the 29% share in the selected 74 cities and represents at least a doubling or even a quadrupling of the DH market share.

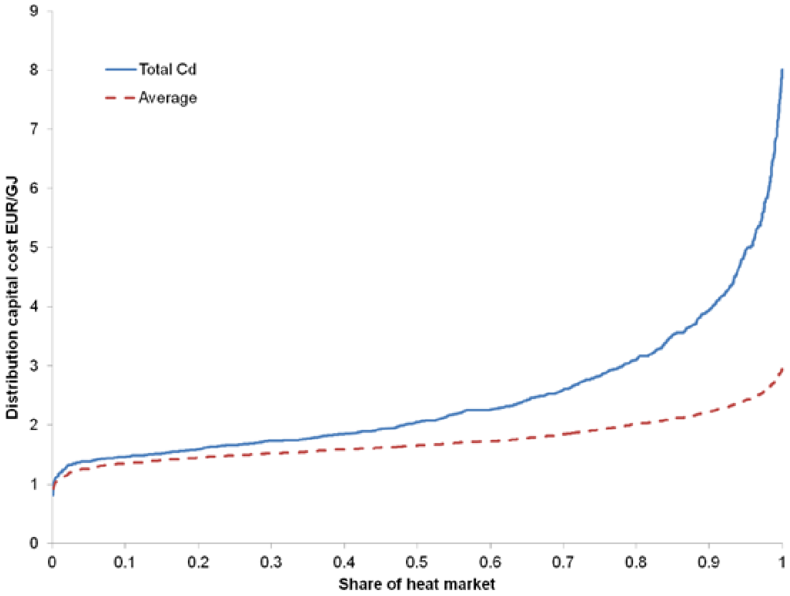

Figure 23: **Distribution capital cost over the share of the total considered heat marke Figure 21 shows the distribution capital cost against the heat market share but distinguishes between the three types of districts.**

It shows that a 100% heat market share would be possible for both inner city areas (A) and outer city areas (B) at a cost below 2 €2013/GJ while only about 60% of park areas (C) would be economically viable for district heating. This is again comparable to Persson & Werner, where a 100% district heat market share would be possible for A areas at a marginal cost of 2 €2013/GJ and for B areas and 2.2 €2013/GJ whereas park areas would only reach about a 30% market share since there is less of an emphasis on urban areas in that study. Large cities also have a lower capital distribution cost which would allow to reach cities with a population above 1 million inhabitants to reach a DH market share of 87% whereas cities with a population below 200,000 inhabitants would only see a share of 55%. Both of these patterns suggest that a higher population density, resulting in a higher heat demand density, is advantageous for the economic viability of district heating. Indeed, an interesting insight is that especially inner-city areas could achieve very large shares of district heating at competitive costs according to these assessments.

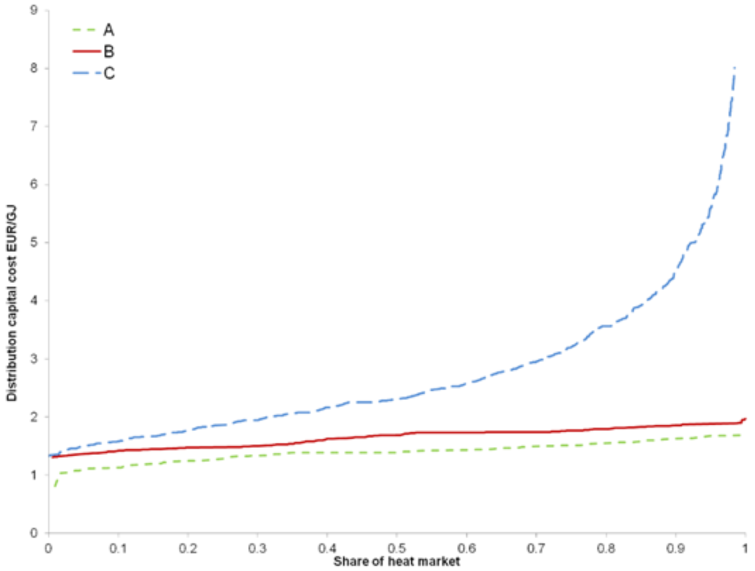

Figure 24: **Distribution capital cost over market share, grouped by district type**

A sensitivity analysis on the heat demand demonstrates that the distribution capital costs increase non-linearly with heat demand reductions as Figure 25 shows. The lower the heat demand is, the lower the viability of district heating. The non-linearity can be observed as the viable market share at the previously defined threshold of 2.59 €2013/GJ decreases from 70% at the original heat demand to 64% at 90% of the initial heat demand, but from 34% to 14% as the heat demand decreases from 60% to 50% of the original value. This again confirms the same insight as Figure 23 already illuminated, that the presence of a sufficiently high heat demand is indispensable for district heating.

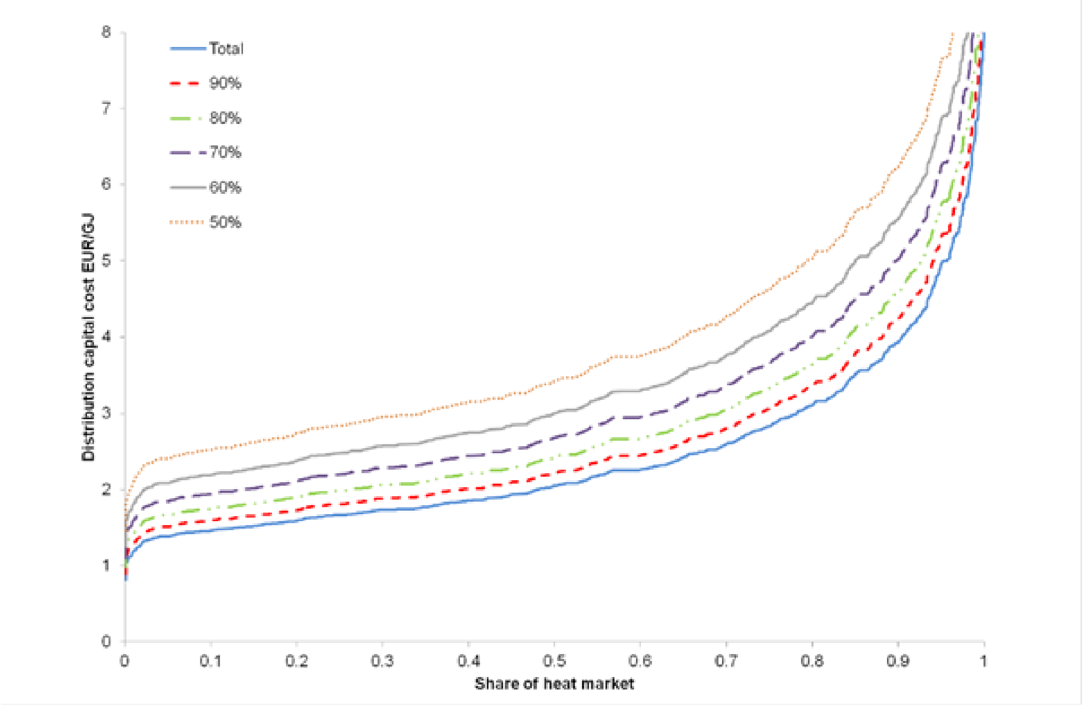

Figure 25: **Distribution capital cost over heat market share, heat demand reduction scenarios**

The work concludes that the distribution capital costs do not represent a significant barrier for the expansion of district heating in German cities as a potential heat market share of 70% is economically feasible at a cost limit of 2.59 €2013/GJ, which would represent more than a doubling of the market share in the considered areas. The heat supply was considered outside of the scope of this analysis but the identification of a competitive heat supply technology would thus represent a valuable extension to the presented model. Further limitations to the presented work also arise due to data limitations, both on the cost parameters but also on the heat demand projections, and the missing detail on the existing local heat supply and transmission system which has to be evaluated on a case-by-case basis, potentially using GIS data.

German customers however paid about 21.2 €2013/GJ in 2013, which would suggest that this is not an important barrier to the expansion of DH since the calculated distribution capital cost only represents about 12% of the total costs (Werner, 2016). However, such an analysis is a comparison of the final price with the cost for one part of the overall DHC system that overlooks several mitigating factors. First, the distribution capital cost represents a majority of the total distribution cost but both heat and pressure losses as well as O&M costs have to be considered as well. The distribution capital cost is a good indicator for the relative viability of different areas as the losses correlate with the linear heat density, which is incorporated in this cost, but should not be taken to provide a comprehensive picture of all costs

(Werner & Persson, 2011). Furthermore, it is important to highlight the difference between the cost of a DH system and the price that is charged. While the total project cost is a result of the expenses for heat generation, distribution and connecting households, the price also includes taxes, levies, and a profit margin. Indeed, about 40-50% of the total costs arise from the construction of distribution networks, a number that can be even higher in urban areas where laying down pipes is even more complex (Konstantin & Konstantin, 2022).

In summary, the following lessons can be learned from this German case study:

- While a large share of urban and even semi-urban areas can be supplied with DH, the costs rapidly increase in rural areas
- Increased energy efficiency harms the viability of DH by reducing the heat density
- The plot ratio is a good indicator for the cost/viability of DH networks

7.4 Generalization to the international context

This section consists of two parts. First, studies looking at the cost of heat supply, transmission and distribution in a European context are described in section 3.4.1 before section 3.4.2 introduces a new meta-level approach that combines the top-down and bottom-up assessment methods and outlines the necessary input data to adopt it.

7.4.1 European studies

The thresholds and criteria used to evaluate the viability of district heat networks vary between European countries. Table 12 below provides an overview of the type of thresholds that are present and the chosen values of different member states of the EU28 (Kavvadias & Quoilin, 2018). In the final column, Table 12 also shows the share of the population served by DH for each selected member state (Directorate-General for Energy et al., 2016). The numbers demonstrate a large heterogeneity in the way different countries approach district heating as both the indicators that are chosen and the threshold values differ a lot. Somewhat counter-intuitively, the higher the share of DH is, the more thresholds a country seems to have. Since the thresholds do not differ a lot between countries, there is no clear pattern to be observed. However, it is noteworthy that Germany with a very high minimum peak heat threshold has only connected half as many citizens to DH as Austria. Austria is also an example of a country with a low maximum distance that does not seem to have suffered for it, likely because, like Denmark, it has densely populated urban areas. While the minimum temperature requirements in both of these countries and Finland are set at a low enough level for the third generation of DH, enabling the advent of the 4th and 5th generation of DHC requires a lowering of this threshold. A commonality between member states is found in the minimum operating hours per year, which are set at the same value for every country that considers them. These constraints are justified by the pattern shown in Table 12 as the costs for a district heat system get exceedingly high if the number of operational hours is too small and they are unable to benefit from the high utilization rate which is important for their economic viability.

Table 12: Summary of thresholds defined by EU member states under Article 14.6 of the EED (based on Kavvadias & Quoilin, 2018 and Directorate-General for Energy et al., 2016)

	Maximum distance between supply and demand (km)	Minimum peak heat (MW)	Minimum heat supplied	Minimum temperature (°C)	Minimum operating hours per year (h)	Percentage of citizens served by DH in 2013 (%)
Austria	5	1.5	50 TJ/a	80	1500	24
Denmark	5			Surplus of +10	1500	63
Finland	5-20			80	1500	50
Germany		10				12
Greece			5.4 TJ/a/km			-
Ireland					1500	0
Italy					1500	6
Netherlands	3		2.5-25 TJ/a			4
Poland	20	10% of total heat supply				53
Slovenia			5.4 TJ/a/km			15
UK	2-15					2

Significant advancements in the assessment of transmission and distribution costs in Europe were made by Persson et al. (2019). They performed a hectare-level analysis for Europe looking at the physical and economic suitability of DH networks. Their results show that heat densities in European urban areas in particular are high and that at the lowest cost, district heating accounts for 50% of the heat market compared to just 12% in 2015. However, this study explicitly did not look at the cost of heat supply and mentions that the economic suitability has to be evaluated locally in more detail.

To determine the physical suitability of DHC networks, Persson et al. (2019) derive the hectare-level heat density. This process builds on georeferenced building data and aerial photos as well as building stock characteristics. The heat density is then obtained by combining the plot ratio, the product of the population density and the specific building space, with the specific heat demand of buildings. In their assessment, they differentiate between single-family homes, multi-family homes and non-residential buildings (excluding industry). For each category, they establish the residential heat densities by combining its floor area per hectare with census data on that grid cell and heat demand data by dwelling type. Finally, they thus obtain different heat density classes according to the Danish technology catalogue (Gamborg & Wolter, 2021), ranging from a very sparse heat density at below 20 MJ per m2 over a moderate heat demand between 50 and 120 MJ per m2 to a very dense one at above 300 MJ per m2.

Once the physical suitability is given, the economic suitability is assessed by determining the distribution capital cost of each hectare based on the method developed by Persson & Werner (2011). In addition to the previously calculated heat density, they thus require the annuity factor, the investment and the average system pipe diameter as well as the effective width to obtain the linear heat density according to equation (1). The latter three were determined empirically, with the investment cost differentiating between inner city areas, outer city areas and park areas using Swedish cost data for 2015. The effective width and the pipe diameter were again determined using the empirical relationships between them and the plot ratio and the linear heat density, respectively, as demonstrated in equations (7) and (8).

Their modeling results demonstrate that just 1.4% of the total European land with better than moderate conditions for DH includes nearly 70% of the total population and 78% of the total heat demand, making it well-suited physically for DH development. The economically optimal levels of district heating vary a lot by country, ranging from 26% in Croatia to 71% in Latvia. While the average country needs to expand its DHC network fourfold under this perspective, both Denmark and Lithuania already have a higher share of district heating in their total heat supply than the model deems cost-optimal.

Half of the total heat demand comes from (very) dense urban areas, which means that a significant proportion of the total heat demand can potentially be met by DHC networks. It is further interesting to note that the physical suitability depends not only on the heat demands, which are higher in Northern Europe, but also on the population density, which is typically higher in Southern Europe, so high-density areas in both are equally well-suited for district heating. Indeed, just eight states account for 90% of the necessary expansion in DHC with the biggest predicted increases being found not in the Northern European states of the UK, the Netherlands, France of Germany but rather in Spain and Italy, both of which would increase their DH heat market share in this scenario from below 5% to above 65% of the total heat demand.

Paardekooper et al. (2018c) provide some further analysis on the optimal share of DH heat supply, looking at 14 study countries that represent 90% of the EU heat market in more depth. While their optimal configuration also results in a 50% share for district heating, a 0.5% in the total system cost can already change the DH market share to between 32% and 68%. They further estimate that excess heat recovery could cover at least 25% of the district heat production needs. While they expect cooling demands to increase, they are still predicted to only represent about 20% of the thermal energy demand by 2050 and to be dominated by services and industry rather than by the residential sector. Their scenarios rely on 30% end demand energy savings which aligns with their main recommendations, one of which is to pursue energy efficiency wherever viable. Furthermore, they suggest to use district heating if sufficiently high heat density is present and to use electric heat pumps or renewable heat from solar thermal and biomass in rural areas where that is not the case.

An interesting study in the context of excess heat supply in Europe is conducted by Manz et al. (2021). They identify 1708 energy-intensive industrial sites across the EU28 that could provide excess heat using a georeferenced industrial database and approximate how much heat these could supply using a set of 29 different industrial processes. The available excess heat supply in Italy from a number of sources including waste heat from industrial processes, waste-to-energy, or waste water treatment and the renewable heat from biomass, geothermal, and solar thermal, has been mapped by Dénarié et al. (2021). While they do not consider the network side of the equation, this is addressed in an Austrian example by Zwickl-Bernhard et al. (2022), who downscale national heat demand scenarios to the 2095 areas at the community level (LAU) and evaluate the viability of district heating networks using a heat density threshold of 10 GWh/km2. For this, they require information on the population density, but also on the effective supplied area that remains once areas irrelevant to district heating such as forests or bodies of water are excluded. This is used analogue to a proxy for the effective width as both of these act as a correction factor to avoid overestimating the cost of distribution networks.

7.4.2 Meta-level approach

The meta level approach is, as of yet, still a theoretical concept that would combine the state-of-the-art top-down approach developed by Persson & Werner (2011) with context-specific conditions such as existing heat supply plants and DHC networks or an evaluation of the cost for different heat generation technologies. The top-down approach provides some level of spatial detail based on the resolution at which the heat demand density and plot ratio are determined. With the development of projects such as Hotmaps, the Danish Heat Atlas or the Austrian Heat Map, such data is increasingly publicly available at a high spatial resolution (Fallahnjead et al. 2022). Still, top-down methods are badly suited to explicit network layout planning or the identification of pumping or substation requirements as road networks or the topology are rarely considered. Furthermore, they also critically neglect the existing infrastructure for heat supply, transmission and distribution. This concerns not only existing plants with excess heat supply but also the costs of adding new heat supply units. Thus, the development of a meta-level approach requires further information to that included even in the most detailed top-down models that were discussed here, such as the elements in the following, non-exhaustive, list:

1. Potential heat sources, both pre-existing and new, how much heat they could supply for what costs
2. Existing DH networks
3. Current building-level demand characteristics and heating solutions
4. More geospatial data integration

An approximation of such a meta-level approach that incorporates the first, most critical, point of this list, was performed by Spirito et al. (2021). They use an Italian case study and estimate the distribution cost based on the network length while clustering settlements to obtain heat demands. However, they also identify and map existing waste heat supply sources such as industry, CHP, WtE, wastewater treatment plants and even data centers or metro stations and quantify how much heat they can provide based on the Pan-European Thermal Atlas (PETA) (Paardekooper et al. 2018c). For the evaluation of the economic viability, they consider not only the transmission and distribution cost but also that of the heat generation and the pumping and substation cost and compare their sum with an alternative individual heating solution. However, this approach still does not consider the existing DH network or additional renewable heat supply sources as these are not given by the Pan-European Thermal Atlas. While data on existing DH networks is still scarce, projects like the German District Heating Atlas aim to create bottom-up catalogues (Pelda et al. 2021). Furthermore, additional heat supply sources can be assessed according to methods such as the one developed by Merkel et al. (2014) or even mapped explicitly like Dénarié et al. (2021) did.

A meta-level approach would allow to obtain a more comprehensive insight into the costs of DH networks and their viability compared to individual heat supply. With more detailed results, this could then also be used for more than just the pre-feasibility stages of a project. However, it remains critical to tune input parameters and cost components to the case study that is analyzed to obtain reliable results (Fallahnejad et al. 2022). This is still an active research area with remaining gaps to address as several studies have mentioned that the optimization of DH networks and the economics of distribution networks have received little attention (Bordin et al. 2016; Persson et al. 2019).

7.5 Summary and conclusions

This section summarizes the results and draws some high-level conclusions relating to the cost structures for DHC supply/generation, transmission and distribution. For district cooling, the supply can come either from heat or from electricity whereas district heating has a much larger array of options. While CHP based on fossil fuels or bioenergy dominates the current fuel mix, alternatives such as geothermal, solar thermal or heat pumps allow for a cleaner heat supply. The generated heat is then carried to the site of demand, first through large transmission pipes that use higher pressures/temperatures to reduce losses and then through distribution grids to the destination, which have lower costs at the expense of higher losses.

The viability of DHC systems is only ensured if the combined cost of centralized heat supply and the transmission and distribution networks together is less than the cost of individual heat supply. For this to be the case, the heat demand has to be sufficiently concentrated, either due to population density or because of a concentration of energy-intense demands. Indeed, dense urban areas in Europe, which constitute less than 1% of the total land areas but nearly half of all heat demand, are ideal locations for the development of DH. However, predicted improvements in the building energy efficiency might harm the viability of DH by reducing the heat demand.

The viability of DH networks can be evaluated using top-down or bottom-up approaches. Bottom-up methods such as Thermos provide a detailed spatial planning of DHC for specific locations while tools like Hotmaps or the Pan-European Thermal Atlas have increasingly been used to generate inputs for top-down assessments. The state-of-the-art top-down approaches estimate the distribution capital costs using the method developed by Persson & Werner (2011). This approach requires information on the heat density, i.e. the heat demand per unit area, and on the plot ratio, i.e. the ratio of building area to land area, as well as the tuning of input parameters to the local context. The distribution capital cost only reflects a part of the total network cost which in turn does not constitute the total cost of the DH system.

The heat/cold supply is another critical component of DHC systems that is frequently neglected from bottom-up and top-down approaches. This can be justified if excess heat is exploited but DHC systems might even be viable with a completely new source of supply, in which case this represents an important cost component. Supply technologies can be characterized according to their investment and operational costs as well as the operational hours into baseloads and peakers. These cost components can be combined to cost functions, which in turn dictate the areas of operation of these plants in terms of capacity and full load hours for a given application.

This task recommends the development of a meta-level approach that combines the strengths of both top-down and bottom-up methods for integrated spatial heat planning. In theory, top-down methods could also be used for the pre-feasibility stages followed by a detailed bottom-up assessment but data availability remains an issue. Instead, the suggested meta-level approach adopts the distribution capital cost method but includes existing heat supply sources, which can cover up to 25% of the total heat demand, and DHC networks. In addition, new supply sources are evaluated based on how much heat they can supply, with what profile and at which cost for a more comprehensive picture of the cost structure. The incorporation of geospatial data allows to identify the needs for e.g. pumping and transfer substations based on the topology and road networks.

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List of abbreviations

CEP	Clean Energy for all Europeans Package
CHP	Combined Heat and Power
DHC/DH	District Heating and Cooling/District Heating
EB	Electric Boiler
EED	Energy Efficiency Directive 2012
FC	Framework Conditions
HP	Heat Pumps
MS	Member States
NECP	National Energy and Climate Plan
NRRP	National Resilience and Recovery Plan
PtH	Power to Heat
RED	Renewable Energy Directive 2018
TES	Thermal Energy Storage
TPA	Third Party Access

A.1 Overview of previous and on-going projects of the partners relevant to Task 3.1

Project name	**Relevant research outcome on**	**Region of interest**	**Project partner involved**
Flex4RES	Frameworks/Economics/Technical conditions	Nordics and Baltics	DTU
Heat Road Map Europe	Economic/Technical conditions	EU14	Fraunhofer
Hot Maps	Economic/Technical conditions	EU28	Fraunhofer
progRESsHEAT	Economics/Technical conditions	EU28	Fraunhofer, DTU
SET-NAV – Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation	Framework/Economics	EU28	Fraunhofer

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