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# From Pipe Dreams to Practical Reality

## The Electrification of District Heating in Greater Copenhagen

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## Abstract

This thesis examines the electrification of district heating in Greater Copenhagen, focusing on how key actors perceive the system's future and which constraints hinder the scaling of electrified district heating. It adopts a qualitative single-case study design, drawing on interviews, recordings, and reports. The analysis is informed by Large Technical Systems theory, particularly the concept of reverse salients, and supplemented by the Multi-Level Perspective to contextualize the broader transition dynamics surrounding electrified district heating. The findings suggest that electrification is widely expected to increase, though not as a full replacement of the existing system. Instead, a more electrified yet still hybrid district heating system emerges as the dominant vision. This transition is constrained by several interconnected barriers, particularly electricity grid capacity, geospatial limitations in dense urban areas, investment uncertainty, and organizational fragmentation. The thesis concludes that electrification should be understood primarily as a wider system integration challenge rather than a simple technological substitution. Its findings have practical implications for policymakers, utilities, and planners, highlighting the need for closer alignment between electricity and heat planning, as well as more coordinated infrastructure siting, permitting, and investment processes.



**Keywords:** District heating electrification; Greater Copenhagen; Large Technical Systems; Multi-Level Perspective

# Executive Summary

## Problem Definition and Context

District heating is a central component of Denmark's heat supply and plays a particularly important role in Greater Copenhagen, which is home to one of Europe's largest and most interconnected district heating systems. Historically, the expansion of biomass-based district heating helped reduce dependence on fossil fuels such as coal, oil, and gas. However, the sustainability of biomass has become increasingly contested, which has created growing interest in the next phase of the district heating transition: a system that relies less on combustion-based heat production and more on renewable electricity.

Electrification is thus increasingly presented as a key pathway for the future development of district heating. Large-scale heat pumps, electric boilers, and thermal storage can enable district heating systems to utilise renewable electricity, integrate diverse heat sources, provide flexibility to the electricity system, and support broader goals of decarbonisation and energy self-sufficiency. In Greater Copenhagen, this shift is already visible in strategic planning processes and investments in electrified heat technologies. However, while the technical and economic potential of electrified district heating has been widely modelled, less attention has been paid to how the electrification of district heating is unfolding in practice.

## Aim and Research Questions

This thesis addresses this gap by examining the electrification of district heating in Greater Copenhagen as a socio-technical system integration challenge. The aim is to provide empirically grounded insight into how the future of district heating is understood by key actors and which constraints are slowing the scaling of electricity-based district heating in practice.

The thesis is guided by two research questions:

**RQ1:** How do key actors view the future of district heating in Greater Copenhagen and what role does electrification play?

**RQ2:** Which constraints slow down the scaling of electricity-based district heating in Greater Copenhagen?

## Research Design, Materials and Methods

The study adopts a qualitative single-case study design focused on Greater Copenhagen. It draws on stakeholder mapping, semi-structured interviews, audiovisual material from Dansk Fjernvarme's annual general meetings in 2024 and 2025, and relevant policy and planning documents. These sources were combined in order to capture both detailed, region-specific insights and broader sector-level perspectives.

The analysis is informed primarily by Large Technical Systems theory, particularly the concept of reverse salients. This concept is used to identify components or problem areas that lag behind the development of the wider system and thereby constrain further transformation. The Multi-Level Perspective is used as a supplementary analytical lens to situate the findings within broader socio-technical transition dynamics, including landscape pressures, regime structures and emerging technology configurations. The empirical material was analysed through hybrid thematic analysis, combining deductive themes derived from the theoretical frameworks with inductive sub-themes emerging from the data.

## Main Findings

### A more diverse district heating system

The findings show that key actors broadly expect electrification to play an important role in the future district heating system in Greater Copenhagen. However, electrification is not generally understood as a complete replacement for existing heat sources given the intermittency of renewables such as wind and solar and the limited amounts of thermal storage that can be developed in dense urban settings. Rather, the dominant expectation is a more diverse system with greater amounts of electricity-based technologies but also some more traditional sources in order to provide system flexibility and dispatchable heat.

### Electrification as a system integration challenge

A central finding of the thesis is that the transition from combustion-based to electricity-based heat production is not simply a matter of installing new technologies. Instead, it requires alignment across multiple infrastructures, institutions and actors. Electricity grid capacity emerges as the most significant technical bottleneck. Large-scale heat pumps and electric boilers require substantial electricity connections, but the grid is already under pressure from wider electrification across transport, industry and other sectors. Grid expansion is slow, capital-intensive and dependent on lengthy planning, permitting and approval processes. This creates a structural mismatch between the pace at which district heating actors seek to electrify and the pace at which electricity infrastructure can be reinforced. In this sense, the electricity grid constitutes a key reverse salient in the transition.

### Technical and geospatial constraints

Other technical constraints relate to the existing district heating network itself. Much of the Greater Copenhagen system has historically been designed around high-temperature, combustion-based production, which is especially problematic as heat pumps operate most efficiently at lower temperatures. Older building stock further complicates the transition, as many buildings may require improvements to heating systems, control technologies or insulation before lower-temperature district heating can be implemented more widely. These challenges demonstrate that electrification strongly depends on distribution networks and end-use conditions. Geospatial constraints are also significant. Electrified heat production requires suitable sites for large-scale heat pumps, electric boilers and thermal storage. In a dense urban region such as Greater Copenhagen, available land is limited and subject to competing uses.

### Economic constraints and investment uncertainty

Economic conditions also affect how quickly district heating electrification can be scaled. Although electrified heat may be beneficial from a system perspective, utilities must assess whether individual investments are financially viable. This creates a possible gap between socio-economic potential and business-economic reality.

Large-scale heat pumps are especially sensitive to this issue because they require high upfront investment and depend on sufficient operating hours to become profitable. Their business case is shaped by electricity prices, tariffs, regulation and competition from alternative heat sources such as biomass, waste-based heat and individual household heat pumps.

Investment uncertainty is further reinforced by the long lifetimes of existing biomass and waste-based assets. Since many of these plants still represent sunk investments, replacing them too quickly may increase costs. Electrification is therefore not only a question of investing in new technologies, but also of managing the legacy of the existing district heating system.

### Political, regulatory and organisational constraints

Political and regulatory conditions also shape the transition. Electrification is supported by climate targets, energy security concerns and policy ambitions at EU, national and municipal levels. However, tariff structures, investment rules and approval procedures can slow down or complicate implementation. There is also a need for clearer political framing. Although electrified district heating can contribute to decarbonisation, energy self-sufficiency and resilience, these benefits have not always been clearly communicated.

Finally, organisational constraints arise from the complexity of the actor landscape. District heating electrification depends on coordination between district heating companies, electricity grid operators, municipalities, regulators, national authorities, technology providers and sector organisations. These actors operate according to different mandates, planning horizons and regulatory obligations. This increases the need for coordination across sectors, municipalities and governance levels. Fragmented responsibilities can slow implementation, especially when no single actor has authority over the full transition process.

## Conclusions and Practical Implications

The thesis concludes that district heating electrification in Greater Copenhagen should be understood less as a straightforward technological substitution and more as a system integration challenge. The central issue is not whether heat pumps, electric boilers and thermal storage technologies are available. Rather, the challenge lies in integrating these technologies into an existing urban energy system shaped by legacy infrastructure, spatial constraints, regulatory frameworks, market conditions and multiple interdependent actors.

One of the practical implications is that electrification strategies should focus on closer alignment between electricity grid planning and district heating planning, earlier identification of suitable sites for production and storage infrastructure, stronger coordination across permitting and investment processes, and regulatory frameworks that allow necessary infrastructure to be developed in time.

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# Abbreviations

CHP = Combined Heat and Power
$CO_2$ = Carbon Dioxide
CTR = Centralkommunernes Transmissionsselskab
DEA = Danish Energy Agency/Energistyrelsen
DH = District Heating
ETS2 = Emissions Trading Scheme 2
EU = European Union
FSC = Forest Stewardship Council
HOFOR = Hovedstadsområdets Forsyningsselskab
KEFM = Ministry of Climate, Energy and Utilities
LTS = Large Technical Systems
LULUCF = Land Use, Land-Use Change and Forestry
MLP = Multi-Level Perspective
MW = Megawatt
P2H = Power-to-Heat
PEFC = Programme for the Endorsement of Forest Certification
RED = Renewable Energy Directive
RQ = Research Question
SBP = Sustainable Biomass Program
TIS = Technological Innovation Systems
TWh = Terawatt-hour
VEKS = Vestegnens Kraftvarmeselskab
WtE = Waste-to-Energy

# 1 Introduction

Regulatory rollbacks and delays, including the recent weakening of corporate sustainability reporting requirements, alongside shifting political priorities among key actors such as the United States, illustrate the growing fragility of parts of the sustainability agenda. By contrast, at least in Europe, the renewable energy transition continues to advance in the background through structural changes that reshape how energy systems operate[1] (EEA, 2025; Eurostat, 2025). In 2025, for the first time, wind and solar generation combined accounted for a larger share of EU electricity production than fossil fuels (Petrovich, 2026).

One reason for this resilience is that energy transitions are driven both by long-term climate targets and by the pursuit of greater energy self-sufficiency in a context of geopolitical uncertainty (Erhvervslivets Tænketank, 2025; Green Power Denmark, 2025). In 2024, energy imports dependency rate in the EU was 57% (Eurostat, 2026), which makes the region highly vulnerable to "any disruption in output or transport, such as through the Strait of Hormuz" (Mathiesen et al., 2026). Such vulnerability adds an additional rationale for accelerating the transition. Moreover, energy systems are characterised by long-lived infrastructure and large capital investments that generate path-dependent dynamics once new technologies begin to scale[2] (Eitan & Hekkert, 2023). For such reasons, transforming energy systems may represent one of the most viable pathways for advancing broader green societal change, even as other sustainability initiatives face political backpedalling or dilution.

This perspective is echoed in the *Draghi Report on European Competitiveness* (European Commission, 2024), which explicitly links investment in clean energy technology and infrastructure as a foundation for future competitiveness. Rather than signalling retreat, the report emphasises that the energy sector is a strategic sector where the pace of change must accelerate (European Commission, 2024).

Within this broader energy sector transformation, the decarbonisation of heating remains a key challenge. According to the most recent Heat Roadmap Europe report, heat for buildings and hot water demand constitutes around a third of final energy demand and 75% of this still stems from burning fossil fuels (Mathiesen et al., 2026). The report suggests that a decarbonized heat market entails combining "increased electrification with a complete redesign of the heat markets including a utilisation of the vast amounts of renewable and waste heat sources" (Mathiesen et al, 2026: p. 6).

In Denmark, the decarbonisation of heating is closely tied to the future development of district heating (DH), which supplies approximately two-thirds of households (Johansen & Werner, 2022; Klimarådet, 2022). Electrification is increasingly recognised as a strategy for reducing emissions from heating by enabling renewable electricity to substitute combustion-based heat production (Klima-, Energi- og Forsyningsministeriet, 2021). Electrification in this sector is happening so rapidly that in the years 2019-2024, the DH sector was accountable for 61% of the overall increase in electrification in Denmark (Dansk Fjernvarme, 2026).

[1] This progress has not occurred uniformly and the fossil fuel economy has not been fundamentally displaced (Pavlenko & Cherp, 2026) but, there are tangible signs of forward movement.

[2] As Eitan and Hekkert illustrate, such lock-ins can be both positive and negative; it may render certain renewable energy investments more stable, but also block out better emerging alternatives, for example (Eitan & Hekkert, 2023).

This thesis focuses on the DH system in the Copenhagen region, which accounts for around 25% of Denmark's DH heat consumption (DBDH, 2023). The region hosts one of the largest and most densely interconnected DH systems in Europe and is currently undergoing a significant transformation, with investments underway in large-scale heat pumps, electric boilers and thermal storage (DBDH, 2023). Such investments and plans for electrification largely reflect a desire to move on from biomass-use in DH. Although historically it was an important step to use biomass in terms of transitioning away from fossil fuels such as oil and gas, the sustainability of biomass has become increasingly questioned (see discussion below in section 2.1) and now there is the desire and momentum to look ahead to the next step, namely the utilisation of green electricity.

However, as electrification projects begin to scale up across the region, a growing gap is emerging between the system-level potential of electrification and the ability to realise it in practice (Ea Energianalyse & PlanEnergi, 2025). Although a number of studies have examined the electrification of DH, much of the existing literature relies primarily on techno-economic modelling and optimisation approaches. Moreover, relatively limited attention has been given to the Greater Copenhagen context (see Literature Review in chapter 3). This creates a need for more research into how electrification is understood and implemented in this region in practice.

## 1.1 Aim and research questions

This thesis seeks to provide empirically grounded insights into how DH electrification is unfolding within the specific socio-technical system context of Greater Copenhagen. In doing so, the study aims to support more informed planning and decision-making by making the likely development and key barriers more visible and better understood. It thereby offers relevant insights for policymakers, utilities, and other stakeholders involved in the transition, particularly by highlighting factors that may influence the pace and direction of electrification. As Denmark is widely regarded as an international frontrunner in DH (Johansen & Werner, 2022), the electrification of its networks also provides an important case through which other countries may gain insights into the process of electrifying DH systems.

This leads us to the research questions that this thesis will seek to address:

**RQ1:** How do key actors view the future of district heating in Greater Copenhagen and what role does electrification play?
**RQ2:** Which constraints slow down the scaling of electricity-based district heating in Greater Copenhagen?

## 1.2 Scope & delimitations

This thesis examines the electrification of DH systems within the Greater Copenhagen region. The geographical scope follows the system boundaries defined in the recently published report *Elektrificering af varmesystemet i hovedstadsregionen* (Ea Energianalyse & PlanEnergi, 2025), ensuring consistency with recent policy and planning work while maintaining a coherent and manageable case study.

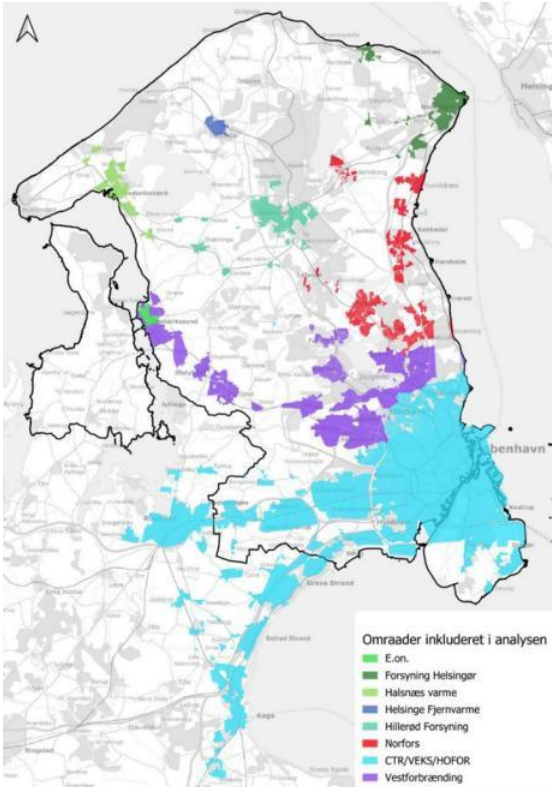


*Figure 1-1. Greater Copenhagen – the geographical region in scope. Source: Ea Energianalyse & PlanEnergi, 2025.*

This thesis focuses on the system integration of electricity-based heat production technologies, primarily large-scale heat pumps, electric boilers, and thermal storage, and the constraints affecting their deployment. It should be acknowledged that this development does form part of the broader transition towards fourth- and fifth-generation district heating and smart energy systems. However, these frameworks encompass a wider set of transformations, which are not examined in detail here.

Instead, the thesis focuses specifically on electrification as a central component of the transition. Electrification introduces distinct technical, economic, political, and organizational challenges, which warrant focused analysis. This narrower scope enables a more in-depth and empirically grounded understanding of how these challenges emerge in the Greater Copenhagen context. It also reflects current policy and sectoral priorities, where electrification is the primary focus of planning, investment, and debate in the capital region, and where the most immediate and significant system changes are taking place.

Finally, the study focuses on constraints and challenges, understood as reverse salients, and places less emphasis on solutions. This is a deliberate scoping choice in order to go more into detail on the existing issues. Since the electrification of DH in Greater Copenhagen remains relatively underexplored in academic literature, the first analytical step is to identify and understand the range of challenges shaping the transition. Before effective solutions can be proposed, the underlying problems must be clearly diagnosed.

## 1.1 Ethical considerations

### 1.1.1 Researcher honesty and personal integrity

The research design was assessed against Lund University's criteria for studies requiring ethical review and was determined not to require approval from the ethics committee. The study was conducted independently and was neither funded nor formally supported by any external organisation. No external stakeholder influenced the research process, analysis, or conclusions.

### 1.1.2 Ethical responsibilities to the subjects of the research

Participation in the interviews was entirely voluntary, and participants were informed of their right to withdraw from the study at any stage without consequence. Prior to participation, the purpose of the study and the intended use of the collected data were communicated clearly. Informed consent was obtained for both the recording of interviews and the inclusion of interview material in the thesis.

To protect participants' privacy, anonymity was offered to all interviewees. Consequently, only the general type of organisation is disclosed in the study. The only names that are mentioned in the analysis are those from publicly available recordings from the Annual General Meetings of Dansk Fjernvarme, where it can be assumed that the organizers obtained consent to share these recordings online.

The study primarily examined system-level dynamics rather than individual accountability, reducing the likelihood of personal or professional harm to participants. Furthermore, the anonymisation of interview data helped mitigate any potential reputational risks. Overall, there is no reason to believe that participation in the study exposed participants to disadvantage, harm, or negative consequences.

### 1.1.3 Data handling

The data collection did not entail collecting personal information beyond the name and role of the individual. All collected data was stored securely on password-protected devices accessible only to the researcher and was used exclusively for academic purposes. Data handling procedures complied with relevant data protection guidelines.

## 1.2 Audience

The intended audience for this thesis is the actors involved in shaping the future development of DH systems (presented in the stakeholder map in Chapter 6). This includes both those directly involved in planning and implementing energy infrastructure and those responsible for creating the wider framework conditions within which such decisions take place. The thesis is intended to be useful as a way of identifying where the electrification process may encounter practical constraints. Rather than treating electrification as a purely technical shift, the study highlights how its implementation depends on the interaction between infrastructure capacity, spatial planning, investment conditions, regulation and organizational coordination. In this way, the research can help inform discussions about how the transition can be made more coherent and practically feasible. While the thesis focuses on a specific regional case, its findings may also offer insights for other urban DH systems facing similar challenges in the transition towards more electrified and flexible heat supply.

## 1.3 Disposition

Chapter 1 (Introduction) introduces the research problem, aim and research questions, and situates the thesis within the green energy transition and the electrification of DH in Greater Copenhagen. It also presents the scope, delimitations, ethical considerations and the intended audience of the study.

Chapter 2 (Background) provides the contextual background. It discusses biomass and waste-based heat production, outlines relevant policy drivers and strategic planning, introduces key electrification technologies, and presents the current status and future scenarios for DH electrification in Denmark and Greater Copenhagen.

Chapter 3 (Literature review) reviews the academic literature on DH electrification and related socio-technical transitions. It then uses this review of the existing literature to understand the current research gap and where this thesis contributes.

Chapter 4 (Theory and justification) presents the theoretical framework and analytical justification. It draws primarily on Large Technical Systems theory and the concept of reverse salients, supplemented by the Multi-Level Perspective.

Chapter 5 (Research design, materials and methods) explains the qualitative single-case study design, stakeholder mapping, data sources, data collection and analysis methods, and reflects on the strengths, limitations, reliability and validity of the study.

Chapter 6 (Findings and analysis) begins with the stakeholder mapping, then analyses actor perspectives on the future of DH and the main technical and geospatial, economic, political and regulatory, and organisational constraints affecting electrification.

Chapter 7 (Discussion) discusses the findings in relation to the literature. It considers how the empirical findings support, nuance or extend existing research, reflects on the contribution of the thesis and discusses the limitations and generalizability of the study.

Chapter 8 (Conclusion) concludes the thesis by answering the research questions, discussing the broader implications of the findings and outlining areas for future research.

# 2 Background

This chapter provides the contextual basis for the thesis by explaining the development of district heating electrification in Denmark and Greater Copenhagen. It follows a progression from why electrification has become increasingly relevant, to what electrification means in practice, to where the system currently stands and where it may be heading. The chapter first discusses the contested role of biomass and waste-based heat production and outlines the policy and planning context that has strengthened interest in electricity-based heat. It then introduces the key technologies associated with electrified district heating, before presenting the current status of electrification in Denmark and Greater Copenhagen. Finally, it outlines future scenarios for the region's heat supply, with particular attention to the changing roles of biomass, waste-based heat, heat pumps, electric boilers and thermal storage.

## 2.1 A discussion on biomass and waste-based heating

Although climate-adjusted $CO_2$ emissions from DH have fallen significantly by 51% between 1990 and 2024 in the energy sector statistics according to Energistatistik (Dansk Fjernvarme, n.d.-a), part of this reduction reflects international greenhouse-gas accounting conventions. Under these rules, $CO_2$ released from the combustion of biomass is reported as zero in the energy sector and instead accounted for under the land use, land-use change and forestry (LULUCF) sector in the country where the biomass is harvested (Birch Sørensen et al., 2018; Danish Energy Agency, 2020; HOFOR A/S, 2025). It remains uncertain whether current rules ensure that producer countries adequately account for emissions in their own LULUCF inventories (Birch Sørensen et al., 2018)

The treatment of biomass as carbon neutral is based on the assumption that, over larger forest areas and over time, forest growth offsets harvesting. However, balance cannot always be guaranteed, particularly given that a substantial share of biomass used in Denmark is imported (almost 80% in 2017) and hence depends on the reliability of other countries' carbon accounting and forest management (Johansen & Werner, 2022; Birch Sørensen et al., 2018; Chatham House, 2022; HOFOR A/S, 2025).

Biomass combustion entails substantial $CO_2$ emissions at the point of use. Danish emissions from biomass combustion amounted to roughly 20 million tonnes of $CO_2$ in 2022, which would correspond to around one third of total energy-related emissions (Danmarks Statistik, 2023). There is often a significant time lag between the release of emissions and uptake of CO2 from the atmosphere (Birch Sørensen et al., 2018). Depending on the feedstock used, biomass burning can increase global warming for decades, known as the 'carbon payback period' (Chatham House, 2022).

In addition, biomass should be regarded as a limited resource (Birch Sørensen et al., 2018). Although global biomass availability appears large, the role of forests as long-term carbon stores places clear constraints on how much biomass can be sustainably utilised from a climate perspective. Current estimates suggest a sustainable global biomass potential of around 100 EJ per year, which is only modestly higher than present global consumption of approximately 63 EJ per year. This narrow margin, particularly when considered alongside projected global population growth, indicates that biomass cannot be relied upon indefinitely as a primary substitute for fossil fuels in an accelerating green transition (Birch Sørensen et al., 2018). As such, it may be of higher value to reserve it for other energy applications where alternatives are less readily available and entail higher costs (Ea Energianalyse & PlanEnergi, 2025).

On the other hand, proponents of biomass emphasise that its impact can at least be mitigated through improved governance and sourcing practices. Certification schemes such as FSC, PEFC and SBP, alongside regulatory initiatives like the EU Deforestation Regulation (EUDR), are intended to strengthen sustainability standards and increase transparency across biomass supply chains (Danish Energy Agency, 2020). In addition, it is often highlighted that a substantial share of biomass used for energy consists of residues and by-products from forestry and industrial processes rather than high-quality timber. These feedstocks are generally associated with lower climate impacts, as they would otherwise decompose and release $CO_2$ over relatively short timeframes (Danish Energy Agency, 2020).

Certified biomass represents a major improvement compared to fossil alternatives such as coal and gas (Danish Energy Agency, 2020; Ørsted, n.d.). In the Danish context, biomass has played a central role in the transition away from coal in the electricity and DH sector, where straw, wood pellets and wood chips have largely replaced coal in combined heat and power (CHP) production (Danish Energy Agency, 2020).

More broadly, recent analyses emphasise that energy policy objectives are not limited to decarbonisation alone, but must also account for security of supply and economic competitiveness (Erhvervslivets Tænketank, 2025). In this context, the need for reliable and cost-effective energy supply is stressed alongside climate goals. Biomass-based production is characterised by its ability to provide controllable and dispatchable heat, which is not dependent on weather conditions. This is highlighted as an advantage in systems with increasing shares of variable renewable energy, as it allows for heat production during periods when wind and solar generation are low (Ørsted, n.d.).

Although much of the recent debate has centred on biomass, waste-based combustion used in DH also raises a number of parallel concerns. Denmark was the first country to ban the landfilling of combustible waste in 1997, a policy that strongly encouraged the development of waste-to-energy (WtE) plants. However, their environmental performance remains contested, as a substantial share of municipal waste consists of fossil-derived materials such as plastics and synthetic textiles. As a result, waste incineration leads to significant $CO_2$ emissions per unit of energy produced, in addition to other pollutants. European analyses estimate that waste-to-energy plants emit approximately 580 g $CO_2$eq per kWh of electricity generated, roughly twice the average emissions intensity of the EU electricity grid (Vähk, 2021).

Recognising these concerns, Danish policy discussions have increasingly emphasised the need to reduce waste incineration and prioritise waste prevention, recycling and circular economy strategies (Johansen & Werner, 2022). However, alternatives such as landfilling raise concerns about methane emissions, itself a potent GHG, as well as space constraints (Dansk Fjernvarme, 2025). As a result, the debate has largely stagnated.

Overall, the growing scrutiny of biomass and, to a lesser extent, waste-based heat production has contributed to increasing interest in alternative forms of heat supply within the DH sector. This is reflected in a wider set of European, national and municipal policy initiatives shaping the future development of DH, as will be discussed next in section 2.2.

## 2.2 Policy drivers and strategic planning for DH electrification

One important driver of DH electrification at the EU level is the increasing political focus on simultaneously decarbonizing the heating sector and reducing dependence on imported fossil fuels. Heating is a particularly important area of intervention due to its substantial share of overall energy demand. In 2023, space and water heating represented 77.6% of final energy consumption in EU households (European Commission, n.d.-b). Following Russia's invasion of Ukraine, concerns surrounding climate change, imported fossil fuel dependence and strategic autonomy became more closely intertwined within EU energy policy. This development became particularly visible through the EU's REPowerEU plan, which aims both to accelerate the green transition and phase out Russian fossil fuels. Within this framework, heat pumps are identified as a key technology for reducing fossil fuel demand, with the plan calling for the installation of an additional 60 million heat pumps by 2030 (European Commission, 2022). Alongside this, the revised Renewable Energy Directive introduced stronger targets and measures for increasing renewable energy in heating and cooling (Directive (EU) 2023/2413, 2023). In addition, the Emissions Trading Scheme II (ETS2) was phased in from 2025 and is expected to become fully operational in 2028. By putting a carbon price on fossil fuels used for heating buildings, ETS2 is likely to make fossil-based heating more expensive and strengthen incentives for low-carbon alternatives (Elangovan et al., 2026; European Commission, n.d.-a).

At the national level, Denmark adopted a Climate Act in 2020 that legally commits the country to a 70% reduction in greenhouse gas emissions by 2030 compared with 1990 levels, and to achieving climate neutrality by 2050 (European Parliamentary Research Service (EPRS), 2024). This direction was further reinforced through the 2022 political agreement Klimaaftale om grøn strøm og varme, which supports the electrification of society with more renewable electricity. It also introduced the political ambition that no homes in Denmark should be heated with gas boilers from 2035 and calls for the faster roll-out of DH (Klima-, Energi- og Forsyningsministeriet, 2022). In the government's climate plans (KF25) there is the aim that over half of heat production in Denmark will be electricity based by 2035 (Klima-, Energi- og Forsyningsministeriet, 2025).

At the municipal level, Copenhagen's Climate Strategy 2035 aims to reduce biomass use in the Copenhagen heating network by at least one third by 2035 and up to half by 2050 (Københavns Kommune, 2025b). This ambition is further supported by the municipality's latest energy strategy, which does not establish fixed targets but sets guiding principles for areas such as electricity-based heat production, lower DH temperatures and the siting of new energy infrastructure (Københavns Kommune, 2025a).

These broader targets and ambitions do not in themselves determine how electrification will unfold in practice. The transition must instead be translated into concrete planning initiatives within the existing DH system. In the Greater Copenhagen context, this has increasingly taken place through joint strategic planning processes involving municipalities, utilities and other energy actors.

Among these, the 2025 report *Elektrificering af varmesystemet i hovedstadsregionen*, prepared by Ea Energianalyse and PlanEnergi on behalf of the strategic collaboration forum, Energi på Tværs, is particularly important. The analysis was developed in collaboration with a broad working group consisting of municipalities and utility companies from across the Greater Copenhagen

[3] The ETS2 will also cover other sectors such as road transport and small industry.

region, including actors such as ARC, CTR, HOFOR, VEKS, Vestforbrænding and Ørsted, alongside more than thirty municipalities. As one of the most comprehensive and recent assessments of district heating electrification in the region, the report provides an important contextual foundation for this thesis and illustrates a key example of the electrification pathways currently being considered within the Greater Copenhagen heat system. The report's future development scenarios for the regional heating system are presented later in this chapter in section 2.4.

## 2.3 Understanding DH electrification

The following section outlines how electrification of DH is defined and understood in this thesis.

Electrification of DH refers to a system-level transition in which heat production increasingly relies on electricity-based technologies, notably large-scale electric heat pumps and electric boilers, supported by thermal storage.

Large-scale heat pumps are envisaged primarily as baseload technologies within electrified DH systems, as the costs of acquiring and installing heat pumps are high, while the costs of ongoing operation are low (Dansk Fjernvarme, 2020). Heat pumps enable the utilisation of a wide range of low- and medium-temperature heat sources, including industrial excess heat, wastewater, ground- and seawater, ambient air, refrigeration systems, buildings and geothermal resources. Many of these renewable and residual heat sources are available at temperature levels that are insufficient for direct use in DH networks. Heat pumps are therefore required to upgrade these heat flows to a temperature level suitable for injection into the DH system (Dansk Fjernvarme, n.d.-a).

Electric boilers form another important component within an electrified DH system. They have relatively low investment costs, but relatively high costs for ongoing operation. This is because they are less electricity-efficient than heat pumps and thus there are higher electricity costs (Dansk Fjernvarme, 2020). In practice, electric boilers are primarily used when electricity prices are low or to perform grid balancing services. A key advantage of electric boilers is that they are characterized by fast response times and high operational controllability (Dansk Fjernvarme, n.d.-b).

Thermal storage constitutes a key enabling component in an electrified DH system by increasing operational flexibility. It is necessary to distinguish between short-term thermal storage in the form of large steel accumulation tanks and longer-term storage in the form of seasonal pit thermal storage, for example. Accumulation tanks are mainly used to balance short-term fluctuations in heat demand (1-3 three days in winter demand) and to optimise the operation of heat production units in response to electricity price variations. Seasonal pit thermal storage operates at a larger scale and can store heat over longer time horizons, but is more space- and capital-intensive (Dansk Fjernvarme, n.d.-a; Ea Energianalyse & PlanEnergi, 2025; Vad Mathiesen et al., 2026).

Thermal storage enables DH operators to produce heat in excess of immediate demand during periods of low electricity prices or when there is a need for balancing services in the power system (Dansk Fjernvarme, n.d.-b). The stored heat can subsequently be used during periods of lower renewable generation and higher electricity prices. The vision is that the DH sector can thus effectively function as a large thermal battery for the electricity system, enabling the effective use of surplus electricity from renewable electricity sources and thus contributing to system flexibility, balancing and overall security of supply (Dansk Fjernvarme, n.d.-b).

Taken together, these technologies point towards a broader transformation in the way district heating systems are designed and operated. Rather than functioning as a static heat supply system, the Heat Roadmap Europe envisions an "adaptive DH system", which is "designed to respond flexibly to varying conditions in heat demand, ambient temperature, and electricity prices" (Vad Mathiesen et al., 2026, p. 9). Within such an electrified DH system, smart control and demand response automation are important for orchestrating heat production, storage and consumption (Reda et al., 2021).

## 2.4 Past, present and future of the DH system

While the previous sections outlined the broader policy context, strategic planning initiatives and key technologies associated with DH electrification, this section now turns to the past, present and future development of the DH system. It first traces the historical development and current status of the system before outlining the future scenarios currently shaping expectations for the region's heat supply. Examining these developments together helps contextualise the scale, pace and direction of the transition currently underway.

### 2.4.1 Historical development and current status

This section first considers the development of Danish district heating, before narrowing the focus to Greater Copenhagen. It traces both the growth of electrified technologies, such as electric boilers and large-scale heat pumps, and the wider shift in heat sources within the DH sector, showing that electricity-based heat production is expanding but still represents a limited share of total heat output.

Electrification of DH in Denmark has progressed markedly in recent years, particularly in terms of installed capacity. The first collective electric boiler plant was commissioned in 2002, but deployment remained limited for many years. More recently, however, expansion has accelerated substantially. By 2024, 136 electric boiler facilities were in operation, providing a combined heat production capacity of just under 1,900 MW (Dansk Fjernvarme, n.d.-b). Figure 2-1 below illustrates the growth in heat production capacity (MW) from electric boilers in Danish DH in the years 2007-2024.

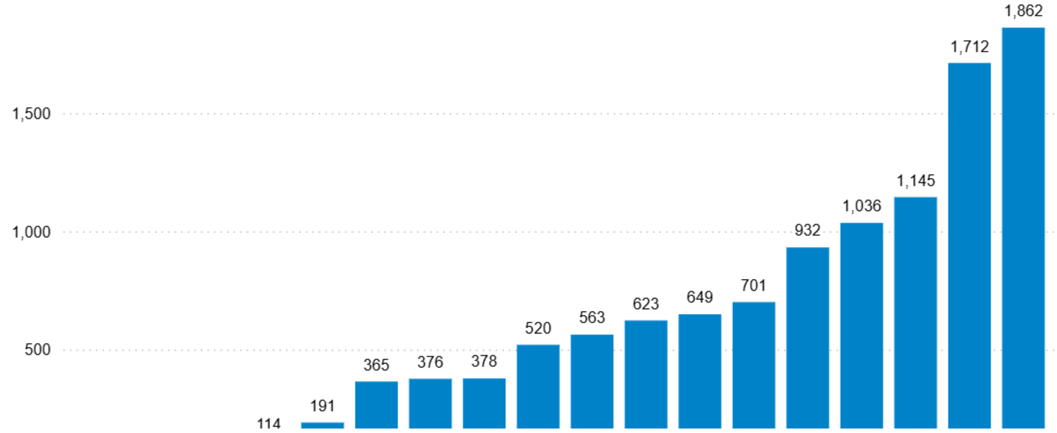


*Figure 2-1. Heat production capacity of electric boilers in Danish DH (MW). Source: Dansk Fjernvarme.*

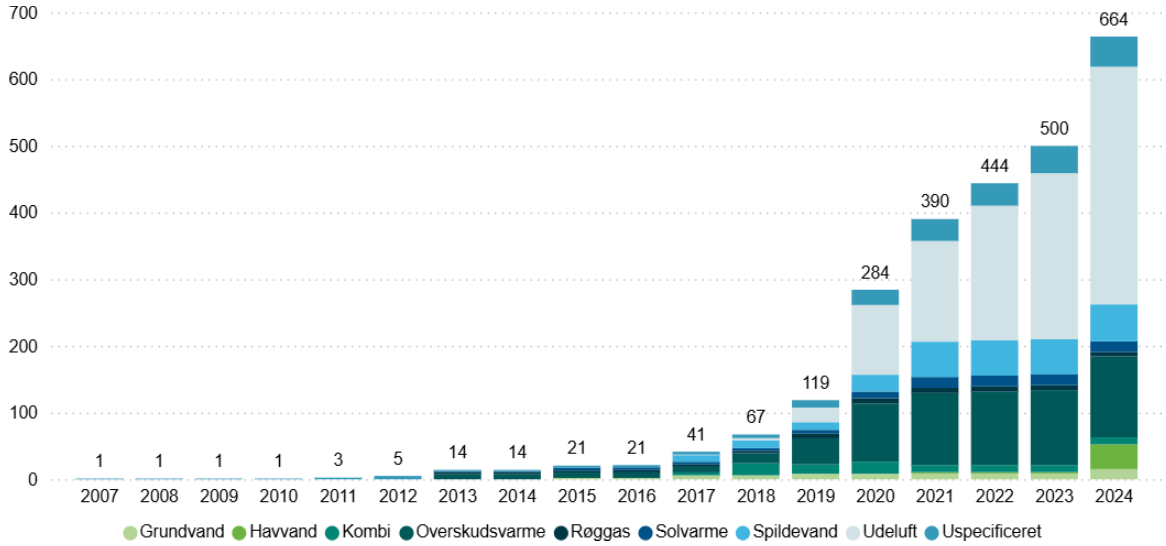


*Figure 2-2. Heat production capacity of large heat pumps in Danish DH (MW). Source: Dansk Fjernvarme.*

Large-scale heat pumps have followed a similar but even steeper growth trajectory. Figure 2-2 illustrates this trajectory in terms of the growth in large heat pump capacity in Danish DH between 2007 and 2024. The different colours represent the various heat sources[4] utilised by the heat pumps, which are upgraded to the temperature levels required for integration into the DH network. Between 2023 and 2024, the total installed capacity of large-scale heat pumps rose from 500 MW to 664 MW, corresponding to a 32.8% year-on-year increase (see figure 2-2 above) (Dansk Fjernvarme, n.d.-a). Viewed over a longer time horizon, this expansion is even more pronounced. Compared with a decade earlier, installed heat pump capacity has increased by a factor of approximately 46, highlighting the rapid scaling of electrified heat production technologies within the Danish DH sector (Dansk Fjernvarme, n.d.-a).

[4] The heat sources in figure 2-2 can be translated from left to right as: groundwater; seawater; combined / hybrid sources; excess heat; flue gases; solar thermal energy; wastewater; ambient air; unspecified.

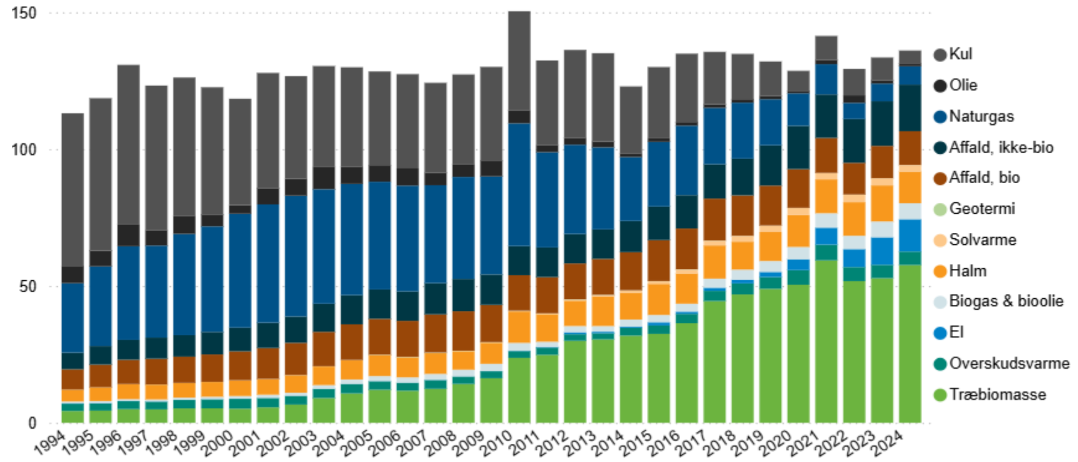


*Figure 2-3. DH production separated by sources from 1994 to 2024 (PJ). Source: Dansk Fjernvarme.*

Over the past two decades, Danish DH has undergone a significant structural transformation. This transformation can be seen in Figure 2-3 above, which shows how the shares of the different sources[5] of DH have changed over time from 1994 to 2024. The most prominent long-term trend has been the replacement of coal and natural gas with wood biomass, particularly from the mid-2000s onwards. This shift has enabled a substantial reduction in fossil fuel use but has also resulted in a system that remains heavily reliant on biomass. Other energy sources have exhibited relatively stable contributions over time, although the use of non-biogenic waste has increased slightly. From the early 2020s, a new transition phase becomes visible as electricity-based heat production starts to play a more prominent role (Dansk Fjernvarme, n.d.-b), indicating the beginning of a shift away from combined heat and power (CHP) to power-to-heat (P2H).

Despite this expansion in capacity, electricity-based heat production accounted for only around 9% of total DH output in Denmark in 2024. Fossil fuels including natural gas oil and coal together account for a similar share of approximately 9%, while biomass and waste continue to dominate heat supply (Dansk Fjernvarme, n.d.-b)

So far in this section, there has been a description of the national developments in the DH sector in order to present the broader picture, but we now turn to the regional level. In the Greater Copenhagen region, electrification has also begun but remains in early stage. In 2025, electric boiler capacity amounted to approximately 380 MW and heat pump capacity to less than 100 MW. It should be noted that these figures only refer to the capacity available and does not reflect actual use. Biomass and waste-based heat production continue to dominate at the regional level, with roughly 570 MW of waste-based heat capacity and a biomass-based capacity of 1800 MW (Ea Energianalyse & PlanEnergi, 2025). In terms of the DH energy mix, in 2025 around 88% was in practice still based on waste and biomass (32% waste and 56% biomass respectively) (Ea Energianalyse & PlanEnergi, 2025).

[5] These heat sources in figure 2-3 can be translated from the top-down as: coal; oil; natural gas; non-biogenic waste; biogenic waste; geothermal energy; solar thermal energy; straw; biogas and bio-oil; electricity; excess heat and woody biomass.

Electrification is currently underway in Greater Copenhagen through a series of concrete investments and pilot projects, most notably led by HOFOR. As part of its long-term strategy, HOFOR is currently investing approximately DKK 3–5 billion in large-scale electric heat pumps, electric boilers and thermal storage towards the end of the decade (Ea Energianalyse & PlanEnergi, 2025; Torp, 2026). A central element of this strategy is the planned deployment of up to ten large heat pumps across the city, with a combined capacity of roughly 300 MW, alongside approximately 550 MW of electric boiler capacity (Ea Energianalyse & PlanEnergi, 2025). Several projects have already progressed from planning to operation, including a 15 MW heat pump at Tietgensgade, commissioned in 2024, and a 29 MW wastewater-based heat pump at the Kløvermarken Pump Station, expected to be operational by 2028 and supplying heat to approximately 13,500 households (Torp, 2026).

### 2.4.2 Future scenarios

The following section now turns to the future development pathways currently being considered for the Greater Copenhagen heating system. In particular, it draws on the scenarios developed in the 2025 report *Elektrificering af varmesystemet i hovedstadsregionen*, introduced earlier in Section 2.2, as these constitute some of the most recent and influential strategic assessments of how electrification in the region may evolve over the coming decades (Ea Energianalyse & PlanEnergi, 2025).

The report examines three alternative development pathways: a reference scenario based on existing plans, a biomass reduction scenario with accelerated plant closures and an ambitious scenario aligned with CONCITO's recommendations to reduce biomass use by 50% by 2030 and 75% by 2040. These are not the only scenarios available, but they are the most recent, major plans to come from the collaboration of major DH stakeholders in Greater Copenhagen.

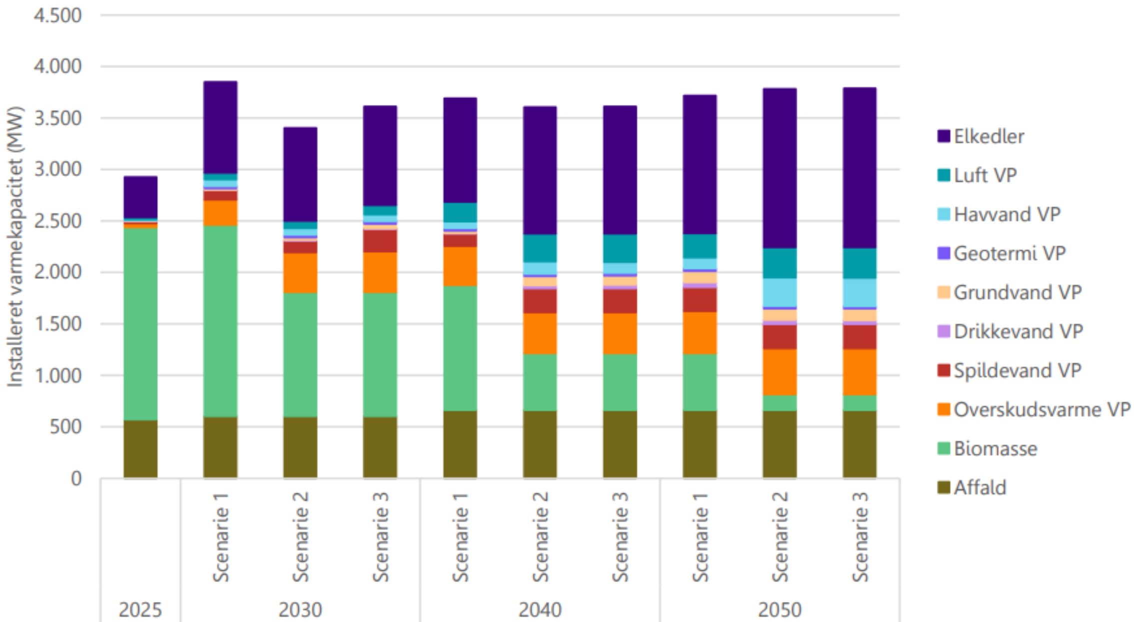


*Figure 2-4. Installed heat pump capacity by sources – current status and future scenarios. Source: Ea Energianalyse & PlanEnergi, 2025.*

The accompanying Figure 2-4 illustrates the modelled development of installed DH production capacity in the Greater Copenhagen area from 2025 to 2050 across the three scenarios. Across all scenarios, the system becomes progressively more diversified and increasingly electrified. Biomass-based baseload capacity is reduced, particularly under the more ambitious scenarios, and is replaced primarily by heat pump capacity and electric boilers. Waste-based heat production remains relatively stable throughout the period. Scenarios 2 and 3 exhibit faster and more extensive electrification than Scenario 1, reflecting the more stringent assumptions regarding biomass reduction. In scenario 1 for 2050, around 60% of heat capacity relies on electricity. Under the more ambitious pathways, installed large-scale heat pump capacity reaches up to approximately 1,300 MW by 2050, accompanied by a significant expansion of electric boilers, amounting to around 75% of installed heat capacity (scenario 2 & 3 in 2050). A more rapid phase-out of biomass leads to higher system costs in the short to medium term, partly because some biomass-fired plants are retired before the end of their technical lifetime, resulting in stranded assets (Ea Energianalyse & PlanEnergi, 2025).

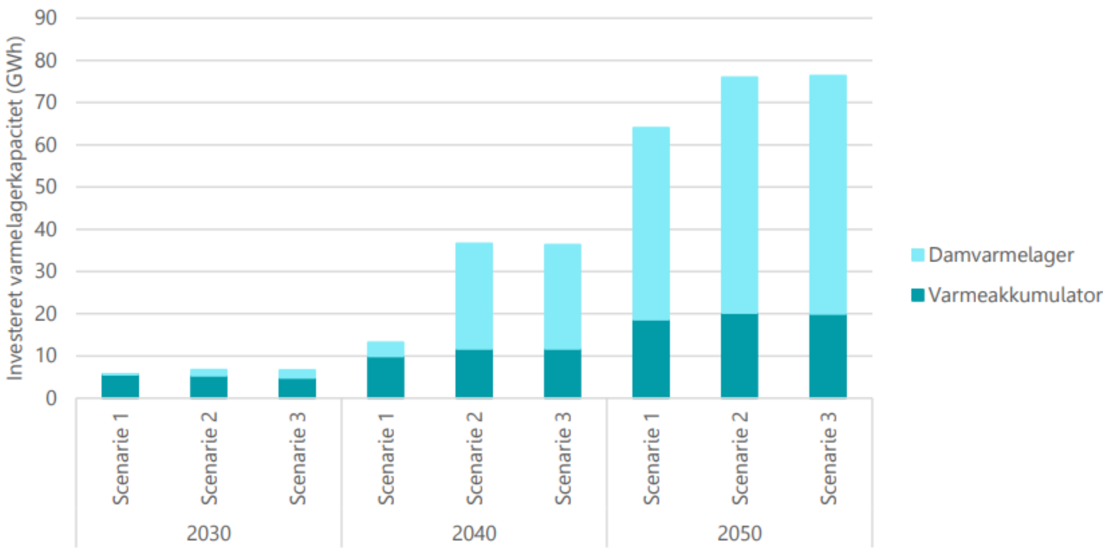


*Figure 2-5. Thermal storage future scenarios. Source: Ea Energianalyse & PlanEnergi, 2025.*

Thermal storage capacity, in the form of accumulator tanks and seasonal pit thermal energy storage, is also expected to expand significantly within these scenarios. Figure 2-5 depicts the scenarios for the expansion of thermal storage capacity (GWh) from 2030 to 2050. The lighter blue colour represents seasonal pit storage, whilst the darker colour represents accumulator tanks. While current storage capacity remains relatively limited, total capacity is projected to increase to between 60 and 80 GWh by 2050. Of this, around 20 GWh is expected to be provided by accumulator tanks, while seasonal pit thermal storage is projected to be between 45 and 55 GWh (see scenarios 1, 2 & 3 in 2050 in Figure 2-5) (Ea Energianalyse & PlanEnergi, 2025).

Having established the policy context, technological basis as well as the past, present and possible future of DH in the Danish and Greater Copenhagen context, the next chapter turns to the academic literature in order to assess how this transition has been studied and where further empirical insight is needed.

# 3 Literature review

This section reviews the existing literature on DH electrification and situates the thesis within current academic debates. It then uses this review of the existing literature to understand the current research gap and where this thesis can contribute to the literature.

## 3.1 Review of the current literature

The literature presents DH electrification as a potentially important pathway for heat decarbonisation, but the extent of its potential varies across studies depending on the system context and underlying analytical assumptions.

### 3.1.1 Techno-economic assessments of DH electrification

A large share of the literature adopts a techno-economic modelling perspective. These studies typically develop scenarios for electricity-based technology capacity, emissions reductions and broader environmental impacts, as well as system costs and pathways for economically optimising the heating system through different technology combinations.

Within this strand, several studies highlight substantial system-level benefits of electrification. Using a case study of a DH system in Beijing, Cheng et al. (2022) apply mathematical modelling and an optimisation approach to assess heat pump integration, finding that adding air-source heat pumps can reduce energy consumption by around 50% and carbon emissions by 10.8%, while improving economic performance (Cheng et al., 2022). Elangovan et al. suggest that if 60 million heat pumps were installed across the EU by 2030 in line with the REPowerEU Directive, it could facilitate reductions of 46% carbon emissions and 40% in nitrogen emissions in heating relative to 2022 levels. It should, however, be noted that this finding is not specific to heat pumps within DH alone (Elangovan et al., 2026).

Several studies particularly emphasise the potential scale and economic benefits associated with electrified DH. Lund et al., focusing on Denmark, estimate that the country could deploy 2-4 GW of heat pump capacity and achieve annual system cost savings of around €100 million by 2025 (Lund et al., 2016), although these figures should be questioned given that installed capacity was only around 0.6 GW by this date (Dansk Fjernvarme, n.d.-b). Dehghan et al. find that centralised electrified DH can reduce peak electricity demand and lower overall system costs compared to decentralised heating solutions. However, they emphasise that its applicability is limited to areas with high heat demand density, as network infrastructure becomes uneconomical in more dispersed settings (Dehghan et al., 2024). Pesola, analysing Nordic energy systems, suggests that adding heat pumps into existing DH systems can, if used optimally, reduce average operating expenditure by around 24%. In order to capture the full value of hybrid heating system, one needs to be able to utilize heat pumps to provide ancillary services in power market and receive compensation for feeding heat pump heat into the DH network (Pesola, 2023). Terreros et al., in the context of Austrian DH systems highlights that energy costs can be saved by taking advantage of low prices in the day-ahead market and additional revenues can be earned in the balancing market (Terreros et al., 2020).

However, these benefits are consistently shown to be highly context-dependent, highlighting the need to examine how these dynamics unfold in specific system contexts. Sorknæs, focusing on Denmark, emphasises that the value of electrification depends strongly on the broader energy system configuration, including the renewable electricity mix, the level of existing DH infrastructure, and the availability of alternative flexibility options (Sorknæs, 2021). Østergaard et al., also in a Danish context, introduce an important distinction between socioeconomic and business-economic feasibility, showing that while electrification may be beneficial at the system level, it is not always attractive for individual operators. In particular, profitability depends on electricity price variability and market conditions. Investments in flexibility such as heat storage or overcapacity do not necessarily pay off at the plant level (Østergaard et al., 2019). Rämä and Wahlroos, in the context of Helsinki, and Kontu et al., analysing Finnish DH systems more broadly, find that heat pumps perform well in terms of emissions reduction and energy efficiency, but that their economic viability varies across system types, particularly in systems with strong CHP competition (Kontu et al., 2019; Rämä & Wahlroos, 2018). Javanshir et al., analysing interconnected DH systems in Helsinki, Espoo, and Vantaa, show that electrification can reduce emissions and reliance on imported fuels but increases exposure to electricity price volatility and alters security-of-supply dynamics when fossil CHP is phased out (Javanshir et al., 2024).

Martin et al., in a European life-cycle assessment study, further demonstrate that while electrification and renewable-based DH can reduce greenhouse gas emissions by around 38% and significantly decrease fossil fuel use, they can also lead to substantial increases in other environmental impacts. In particular, increased reliance on wind and solar energy is associated with higher material demand, contributing to increases in metal depletion (around +110%), material supply risks (around +107%), and environmental impacts from material extraction (around +329%)[6] (Martin et al., 2024).

A few of the studies emphasize that technological performance is highly dependent on their placement and the operating conditions. Bach et al., in a modelling study of Greater Copenhagen using an optimisation model that dispatches technologies to meet heat demand at lowest cost, show that heat pumps connected to distribution networks are estimated to achieve around 3500 full load hours (out of a maximum of 8760 possible hours per year), indicating relatively high utilisation, although performance decreases by around 1000 full load hours when connected to higher-temperature transmission systems (Bach et al., 2016). Capone et al., in a case study context, further demonstrate that system integration is critical, showing that suboptimal placement of heat pumps can reduce emission benefits by up to 63%, where local temperature levels, flow conditions, return temperatures and network hydraulics reduce its efficiency and utilisation (Capone et al., 2023).

### 3.1.2 Next-generation district heating

Another strand of studies is concerned with broader system concepts, particularly fourth- and fifth-generation DH (4GDH and 5GDH). These frameworks conceptualise DH as part of a smart, integrated energy system. 4GDH is characterised by lower network temperatures, improved energy efficiency, and the integration of renewable and low-grade heat sources, while 5GDH extends this concept further by introducing very-low or ambient-temperature, bidirectional networks in which decentralised heat pumps upgrade heat locally and enable simultaneous heating and cooling. Importantly, these concepts are not presented as linear stages but as complementary system configurations that can coexist (H. Lund et al., 2021). Building on this conceptual foundation, studies such as Gjoka et al. and Sarbu et al., emphasise the importance of integrating diverse heat sources, improving system design, and enhancing

[6] Biogas also contributes somewhat to these effects, although wind and solar energy are the main drivers of the material impacts.

control and optimisation in order to enable these next-generation systems (Gjoka et al., 2025; Sarbu et al., 2022).

### 3.1.3 Historical, policy and systems perspectives

Several of the studies take a broader and more descriptive perspective on DH systems and their development. Johansen and Werner, focusing on Denmark, provide a comprehensive overview of the Danish DH sector, tracing its historical evolution, current structure, and briefly discussing future challenges. They highlight how coordinated planning, strong institutional frameworks, and CHP integration have enabled high efficiency and emissions reductions, while also identifying emerging challenges such as dependence on biomass and the need to transition towards non-combustion technologies (Johansen & Werner, 2022). Policy-oriented contributions such as Lowe et al., primarily focused on the UK context, outline key principles for electrifying heating systems, including prioritising energy efficiency, valuing heat as a flexible load, and designing regulatory frameworks that support decarbonisation (Lowes et al., 2020). At a European scale, David et al. highlight the large technical potential of DH, suggesting that it could supply up to 50% of heat demand by 2050, with around 25–30% of this supplied by large-scale heat pumps. Their work provides a detailed empirical survey of existing large-scale heat pumps across Europe, demonstrating their technological maturity, ability to utilise diverse heat sources, and potential to contribute to system flexibility by absorbing surplus electricity (David et al., 2017).

### 3.1.4 Challenges and barriers in the transition

Finally, a smaller but particularly relevant strand of literature focuses explicitly on the challenges and barriers associated with the transition. Reda et al., is a study of the transition towards low-carbon DH in Finland. As part of this it also considers the integration of more electricity-based technologies into the DH system, suggesting that they can support the "integration of the growing shares of intermittent renewable energy sources and balanc[e] fluctuating electricity prices" (Reda et al., 2021: p. 3). It is argued that it is possible to integrate heat pumps "without jeopardising the profitability of the current DH system", but that this is "especially in DH without combined heat and power (CHP) production" (Reda et al, 2021: p. 3). Through extensive stakeholder analysis the study identifies key barriers to the low-carbon transition such as institutional and regulatory constraints, lack of coordination across sectors, and insufficient system "smartness" in terms of data, control, and integration. These challenges are compounded by significant conflicts between stakeholder groups, with incumbents often favouring gradual change, while new entrants advocate for more rapid electrification. This creates misalignment across actors and slows the transition. A central concern is the risk of "biomass lock-in," where short-term reliance on biomass delays deeper decarbonisation (Reda et al., 2021).

These findings are complemented by Li and Nord who highlight the structural and technical complexity of transitioning towards fourth generation DH systems. They show that the transition requires simultaneous changes across infrastructure, buildings, and system operation. Lowering network temperatures involves both incremental improvements such as optimising existing systems and improving control and more fundamental redesign of components such as heat exchangers and substations, often requiring building-level adaptations. At the same time, integrating multiple heat sources and thermal storage increases operational complexity and demands advanced coordination, data systems, and optimisation capabilities (Li & Nord, 2018).

## 3.2 Research Gap

The literature shows that electrification of DH is generally recognised as technically feasible and potentially beneficial. However, much of the existing research remains dominated by techno-economic modelling approaches, broader next-generation DH frameworks, or studies situated in other geographical contexts.

While studies modelling system-level potential, cost efficiency and possible emissions reductions provide important insights, the transition to electricity-based DH is not solely a technical optimisation problem. It also involves a wide range of actors who must coordinate investments and operate within specific institutional, political and infrastructural conditions. As such, modelling approaches can only provide partial insight into how electrification unfolds in practice, and their findings remain highly dependent on underlying assumptions.

Although studies such as Reda et al. and Li and Nord examine challenges associated with transitioning towards next-generation, lower carbon DH systems, these contributions do not focus exclusively on electrification and are not grounded in the specific institutional, infrastructural and market conditions shaping DH systems in Greater Copenhagen.

In parallel, a range of grey literature reports address the electrification of DH in Denmark. While these provide important insights and will be drawn upon in the analysis section of this thesis, they tend to adopt a policy or planning perspective and do not offer a comprehensive, empirically grounded account of how the transition is unfolding in practice. Moreover, relevant information is often dispersed across different sources and tends to highlight a few select issues rather than providing an integrated understanding of the topic.

As a result, there is a lack of up-to-date, context-specific empirical research that captures all of the practical realities of electrifying DH in Greater Copenhagen. In particular, there is limited understanding of how technical, economic, political and organisational challenges are experienced by the actors involved in the transition. There is also a need to examine whether future scenarios presented in Section 2.4.2 are merely ambitions or whether they are actually deemed possible by a range of stakeholders currently working with the electrification of district heating in Greater Copenhagen. This thesis addresses this gap by providing an in-depth qualitative analysis of the electrification of DH in Greater Copenhagen, drawing on stakeholder interviews and sector-level material to examine how key actors view the future of DH (RQ1) and which constraints slow down the scaling of electrified DH in the region (RQ2).

# 4 Theory and justification

This chapter sets out the theoretical framework used to analyse the electrification of DH, justifying the selection of Large Technical Systems (LTS) theory combined with the Multi-Level Perspective (MLP).

## 4.1 Theory overview

This thesis primarily draws on the concept of "reverse salients" developed within the Large Technical Systems framework. This perspective is particularly well suited to analysing systemic bottlenecks and uneven development within complex socio-technical systems. In addition, the Multi-Level Perspective is employed as a supplementary analytical lens to situate these dynamics within a broader understanding of socio-technical transitions.

A range of alternative analytical frameworks commonly used in sustainability transitions research were also considered. For example, organizational and institutional theories were also considered as they provide valuable insights into how rules, norms, routines and organizational practices shape actor behaviour. Political economy approaches emphasise issues of power, vested interests and distributional conflicts, while multi-level governance frameworks highlight the role of policy coordination and authority across local, national and supranational levels. While these approaches offer valuable insights into organizational, institutional, and power dynamics, they were deemed less suitable for this study, which seeks to focus on the systemic challenges associated with integrating electricity-based technologies into an existing large-scale energy system.

Another framework that was strongly considered was the Technological Innovation Systems (TIS) framework, as it offers a fine-grained perspective on technological change, focusing on the development and diffusion of specific technologies. As such it would, at first glance, appear highly relevant to examining the spread of electricity-based technologies in DH.

Central to the TIS framework are a set of key system functions that influence technological development. These include entrepreneurial activities, knowledge development, knowledge diffusion through networks, guidance of the search through policy targets and expectations, market formation, resource mobilisation and the creation of legitimacy (Hekkert et al., 2007).

However, the analytical strengths of TIS are primarily oriented towards early-stage innovation dynamics, where emerging technologies struggle to gain traction, legitimacy and market shares. There is a strong focus on the learning and knowledge sharing processes and the mobilization of resources. In contrast, the core technologies examined in this study (heat pumps and electric boilers) are not fundamentally novel. Rather than representing radical innovations, they are relatively mature technologies that are being deployed in a new system context and on a larger scale.

## 4.2 Large Technical Systems

Large Technical Systems theory was selected as the primary theory for this thesis, as it allows for an analysis of systemic constraints and the uneven development of interconnected components within the broader socio-technical system. Large technical systems are defined as complex and heterogeneous systems of physical structures and machinery that are materially integrated, or coupled, over large spans of space and time (Ewertsson & Ingelstam, 2005).

They encompass not only technological components, but also the individuals and organisations involved in developing, operating and governing the system, as well as institutional elements such as ownership structures, organizational arrangements and regulatory frameworks. The components of an LTS, both material and immaterial, are functionally interdependent, and effective system performance depends on the coordination and alignment of these heterogeneous elements. LTS theory has a long tradition in the study of energy systems, to which it is particularly well suited given their scale, complexity and infrastructural character. It has also been applied specifically to DH systems, notably in Summerton's *DH Comes to Town*. The configuration of interests around this large technical system is described as a 'multiorganization' as many organizations participate to achieve a shared purpose (Ewertsson & Ingelstam, 2005).

Of particular relevance for this thesis is the concept of reverse salients, as introduced by Hughes in *Networks of Power* (1992). Within LTS thinking, reverse salients refer to components or subsystems that lag behind the overall development of the system and thereby constrain further expansion or transformation. Hughes defines a reverse salient as a "set of problems which when solved would remove the impediment" to the growth of the system (Hughes, 1992: 387). Importantly, he emphasises that the identification and articulation of such problems is itself a critical step in overcoming them, noting that "confidence that the reverse salient can be corrected increases dramatically once the problems are defined, because the articulation of a problem often implies its solution" (Hughes, 1992: 31). This idea is relevant for the present study, which seeks to diagnose the constraints and bottlenecks shaping the electrification of DH in Greater Copenhagen so that they can more effectively be addressed in future planning and decision-making.

Hughes emphasises that analysing the evolution of large technical systems requires attention to multiple domains of human activity. As he writes, the effort to explain system change involves consideration of "many fields of human activity, including the technical, the scientific, the economic, the political, and the organizational" (Hughes, 1992: 2). Reverse salients may therefore arise not only from technological shortcomings but also from economic conditions, regulatory frameworks, political decisions or organizational arrangements that constrain the further development of the system. This insight informed the analytical framework of the thesis, with these domains translated into overarching categories used to structure the data collection and coding process.

## 4.3 The Multi-Level Perspective

The Multi-Level Perspective (MLP) provides a framework for analysing how socio-technical transitions emerge and unfold over time. It conceptualises transitions as the outcome of interactions across three analytical levels: niche innovations, incumbent socio-technical regimes, and the broader exogenous landscape. Within this framework, socio-technical systems are understood as configurations that align multiple elements, including technologies, user practices, cultural meanings, institutional arrangements, business models, markets, and infrastructures (Geels, 2004).

Niche innovations typically face significant barriers when attempting to challenge established regimes. These barriers stem from various lock-in mechanisms that stabilise existing systems, including sunk investments in infrastructure and production assets, cost advantages derived from economies of scale, performance improvements accumulated over time, and entrenched routines, practices, and cognitive frames that reinforce the status quo. These are tied to the existing socio-technical regime. The exogenous landscape constitutes the wider context within which both niche and regime dynamics unfold. It influences transitions through both sudden disruptions, such as economic or geopolitical crises, and more gradual developments, including macroeconomic trends, societal changes, and long-term political shifts. These landscape pressures can destabilise incumbent regimes and create opportunities for niche innovations to gain traction (Geels, 2024).

Transitions are typically described as progressing through a series of phases. In the first phase, radical innovations emerge within protected niches at the margins of existing systems. These niches provide a space for experimentation and learning and allow innovations to develop relatively shielded from mainstream market competition. During this period, the incumbent regime continues to evolve along an established and relatively stable trajectory (Geels, 2026).

In the second phase, niche innovations gain a foothold in market niches where they can secure a more reliable flow of income. Learning processes within niches often lead to the emergence of a more dominant design. Despite these advances, niche innovations continue to struggle against the entrenched regime, which retains significant advantages due to existing lock-in mechanisms. At this stage, innovations typically remain more costly, and there is considerable uncertainty regarding their applications, performance, and scalability (Geels, 2026).

In the third phase, niche innovations begin to diffuse into mainstream markets and increasingly compete with incumbent technologies. This diffusion depends on improvements in cost-competitiveness and performance, as well as supportive developments at the landscape level that create "windows of opportunity" for broader adoption. This stage is often characterised by heightened contestation, including competition between new entrants and established actors, as well as political struggles over regulatory frameworks, policy targets, and incentive structures (Geels, 2026).

In the fourth phase, a successful transition results in the reconfiguration or replacement of the existing socio-technical regime. The new system becomes stabilised, widely adopted, and institutionalised, thereby establishing a new dominant configuration.

The above provides a brief overview of some of the key ideas in the classic formulation of MLP. In the present study, the MLP will be used primarily as a supplementary framework for contextualising the broader transition dynamics surrounding DH electrification, particularly the interaction between landscape pressures, existing regime structures and emerging electricity-based configurations. Figure 4-1 below presents a model of the analytical frameworks that will be used to analyze the empirical material in this thesis.

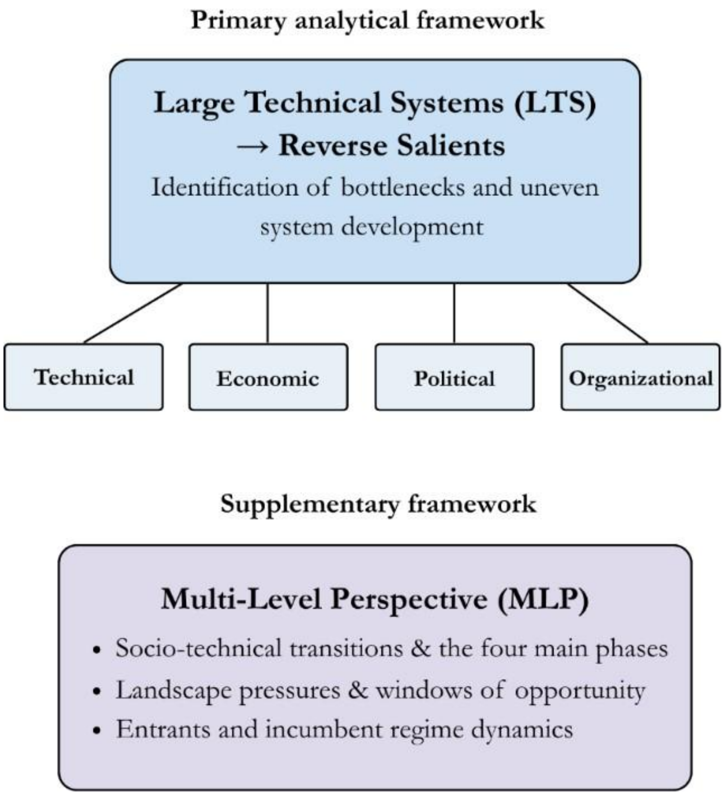


*Figure 4-1. Analytical frameworks based on LTS and MLP. Source: Author's own illustration.*

# 5 Research design, materials and methods

This chapter outlines the methodological approach used to examine the electrification of DH in Greater Copenhagen. The study is designed as a qualitative single-case study. Stakeholder mapping was conducted to identify relevant actors and thereby guide the sampling process. To address the research questions, the study draws on interviews, recordings and reports that provide insight into perspectives on the future of DH and the challenges associated with electrification.

Figure 5-1 below presents the overall research approach and process. This chapter first describes the study design, the stakeholder mapping, the data sources and the collection methods. It then explains how the material was processed and analysed, before reflecting on the strengths, limitations, reliability and validity of the study.

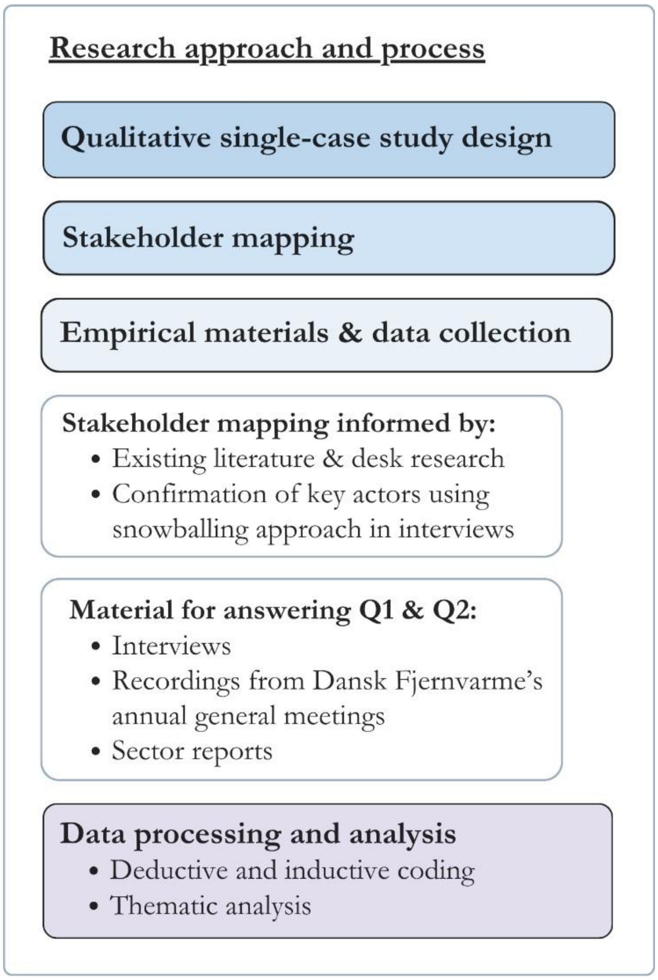


*Figure 5-1. Overview of research approach and process. Source: Author's own illustration.*

## 5.1 Qualitative single-case study design

This thesis adopts a qualitative, single-case study design to explore how key actors understand the electrification of DH and its associated challenges. This methodology is selected because the research questions require an in-depth and up-to-date insight into actor perspectives on the direction of change and the key issues, which are best accessed through direct engagement and qualitative explanations rather than through quantitative instruments.

According to Yin, case studies are particularly suitable for research that seeks to answer "how" and "why" questions, where the researcher has limited control over events, and where the focus is on a contemporary phenomenon embedded within a real-life context (Yin, 2018). These conditions are met in this thesis. The research questions aim to understand *how* electrification is unfolding in the existing DH system in Greater Copenhagen, rather than to measure causal relationships in a controlled experimental setting. Furthermore, the study examines an ongoing, real-world transformation over which the researcher has no control.

While a single-case design limits generalisability, the purpose of this study is analytical depth rather than statistical representativeness. Focusing on Greater Copenhagen enables a detailed examination of stakeholder interrelationships, institutional conditions and system dynamics within the electrification of DH. Although actor configurations may differ across regions, many of the underlying dynamics and constraints identified in this case are likely to recur in other urban European DH contexts, allowing for a degree of analytical transferability beyond the immediate case.

Alternative methodological approaches were considered, including survey-based research, and comparative case study design. A survey-based approach was considered, as it could have provided broader insight into how widespread different challenges are and given an indication of how strongly each issue affects actors (using Likert-scales, for example). However, this thesis is exploratory in nature and seeks first to identify and understand the key constraints shaping electrification in practice. An interview-based approach was therefore considered more appropriate at this stage, as it allows for more detailed insight into perspectives on the development of DH and the challenges as they are perceived by the stakeholders. In addition, practical limitations related to access to a wide enough range of contacts would make it difficult to gain a comprehensive picture.

A comparative multiple-case study design could also have been relevant, for example by comparing Greater Copenhagen with other Danish or European cities with DH systems undergoing electrification. Such an approach could have strengthened analytical comparison and helped distinguish between context-specific and more generalisable constraints. However, it would also have reduced the depth with which the Greater Copenhagen case could be examined within the limits of this thesis. Focusing on one region allows for closer attention to local actor relationships, institutional conditions, infrastructure constraints, and system-specific planning dynamics.

## 5.2 Stakeholder mapping

Since the first research question examines how key actors view the future of DH in Greater Copenhagen, it was important to identify the stakeholders. The study therefore began with a process of stakeholder mapping to establish an overview of the key actors involved in the Greater Copenhagen DH system and its ongoing electrification. The purpose of this mapping was both to identify the central organisations shaping the transition and to ensure that the subsequent data collection captured a broad range of relevant actor perspectives. The resulting stakeholder mapping is presented at the beginning of Chapter 6, 'Findings and Analysis'.

## 5.3 Empirical material and data collection methods

### 5.3.1 Material for stakeholder map

The stakeholder map draws on both existing literature and targeted desk research. It was to a large extent informed by the actor configuration outlined by Johansen and Werner (2022), supplemented by desk research into the relevant authorities, infrastructure operators, and organisations active in the Greater Copenhagen area. The sampling strategy was further refined during the interview process through a snowballing approach, whereby interviewees were asked to identify additional relevant stakeholders. This helped validate the initial mapping and ensured that key actors were included.

### 5.3.2 Interviews

In total, 11 semi-structured interviews were conducted with actors representing different positions within the system. The interviews lasted between 30 minutes and 1 hour 15 minutes, allowing for both focused and in-depth discussions depending on the participant's role and availability. Participants were initially contacted via email based on their relevance to the study. In addition, two interviewees were recruited through snowball sampling, where existing participants suggested further relevant contacts.

The sampling strategy prioritised actors with direct involvement in, or detailed knowledge of, ongoing electrification processes, particularly those engaged in the planning, operation or analysis of DH systems. At the same time, actors representing the incumbent regime were deliberately included to capture a broader range of perspectives and potential tensions within the transition. This included both DH companies that continue to rely on waste and biomass and a representative from the bioenergy sector.

The interviews were conducted one-on-one via online video conferencing. They were subsequently transcribed and checked for accuracy. The interviews followed a semi-structured format. This allowed for consistency across interviews while retaining flexibility to explore emerging themes in greater depth. Questions were designed to be open-ended, enabling participants to raise issues they considered important. The interviews were conducted in Danish as this was the most natural and allowed the interviewees to convey points clearly and precisely. Any material that is used in the analysis is translated by the author to English.

*Table 5-1. Overview of interviewees and their identifier codes*

| Identifiers | Interviewee classification |
|---|---|
| DH1 | DH company/utility |
| DH2 | DH company/utility |
| DH3 | DH company/utility |
| SA1 | DH sector association |
| SA2 | DH sector association |
| CN1 | Energy consultancy |
| CN2 | Energy consultancy |
| EN1 | Environmental NGO/Advocacy organization |
| EN2 | Environmental NGO/Advocacy organization |
| BI1 | Bioenergy industry association |
| EL1 | Electricity grid company |

### 5.3.3 Recordings

To complement the interview data, the study also draws on a broad selection of audiovisual recordings from Dansk Fjernvarme's annual general meetings (2024 and 2025), covering contributions from over 20 actors including industry representatives, policymakers, consultants, researchers and technology providers. Many of these actors would have been difficult to access through interviews due to their limited availability and senior roles. The use of recordings therefore enabled a broader representation of perspectives. The individual contributions typically take the form of talks lasting between 25 and 60 minutes. In some cases, multiple speakers contributed to the same session and are therefore grouped together in table 5-2 below.

*Table 5-2. Overview of speakers on the recordings from the Dansk Fjernvarme Annual General Meeting*

| Name | Organization/Known for | Codes | Classification |
|---|---|---|---|
| Mogens Rüdiger | Dr.phil. and lektor, Institut for Politik og Samfund, Aalborg University | AR1 | Academia & Research |
| Brian Vad Mathiesen | Professor at Aalborg University and Coordinator of Heat Roadmap Europe | AR2 | Academia & Research |
| Martin Kruse | Director of the Copenhagen Institute for Future Studies | AR3 | Academia & Research |
| Hans Henrik Lidboe | Founding Partner in Ea Energy Analysis | CN-R1 | Consultant |
| Lotte Hansen | CEO & Founder of Plan Earth | CN-R2 | Consultant |
| Louise Høst | Director of Fjernvarme Fyn | DH-R1 | DH company |
| Søren Søndergaard & Michael Schrøder | Chief Consultants in Dansk Fjernvarme | SA-R1 | DH sector association |
| Kim Mortensen | Director in Dansk Fjernvarme | SA-R2 | DH sector association |
| Jesper Frost Rasmussen | President of Dansk Fjernvarme | SA-R3 | DH sector association |
| Lars Trier Mogensen | Political commentator and radio host on 'Guld og grønne skove' | MD1 | Media |

| | | | |
|---|---|---|---|
| Stephanie Lose | Minister for Economic Affairs; Politician of Venstre | PL1 | Political actor |
| Jeppe Bruus Christensen | Minister for Green Transition; Politician of the Social Democrats | PL2 | Political actor |
| Svend Erik Hovmand & Poul Nielson | Former Energy Ministers | PL3 | Political actor |
| Marie Bjerre | Minister for European Affairs; Politician of Venstre | PL4 | Political actor |
| Lars Aagaard | Minister for Climate, Energy and Utilities; Politician in Moderaterne | PL5 | Political actor |
| Jonas Loholm Hamann | Sales Director at Danfoss | PT1 | Private companies and technology developers |
| Mads Lund | Head of Division at Grønbech | PT2 | Private companies and technology developers |
| Joachim Stenstrup | Global Head of External Affairs & Strategy at Eurowind Energy | PT3 | Private companies and technology developers |
| Samir Abboud | CEO of Innargi | PT4 | Private companies and technology developers (geothermal) |
| Rikke Juul Gram | Partner at Schønherr (landscape architect) | SI1 | Technical Planning & Spatial Integration Actor |
| Magnus Skovrind | Director in Tænketanken Brundtland | TT1 | Think Tank |
| Torsten Hasforth | Chief Economist in CONCITO's energy unit | TT2 | Think Tank |

Actors from all the categories defined in the stakeholder map (see Figure 6-1 below) were included. In total, across both interviews and recorded material, the sample comprises 4 speakers from DH companies, 9 from knowledge and advisory organisations, 8 representing interest and sector associations, 6 political actors within policy and regulation, and 5 actors from the technology and infrastructure domain. The empirical material therefore captures a broad cross-section of actors involved in the electrification of DH.

### 5.3.4 Reports

The reports selected for analysis include the *Copenhagen Energy Strategy 2025–2035*, the report *Elektrificering af varmesystemet i hovedstadsregionen*, and Dansk Fjernvarme's *Elektrificeringer i Fjernvarmen*. All reports were published from 2020 onwards, with the first two released as recently as 2025. The selection is based on their direct relevance to the research topic and their focus on the Danish context. The first two reports are considered particularly pertinent due to their specific emphasis on the Greater Copenhagen region and are therefore given greater weight in the analysis. Overall, this combination of interviews, recordings, and reports enables triangulation across data sources, strengthening the robustness and validity of the findings.

## 5.4 Strengths and limitations of the different data sources

These different forms of empirical material provide complementary perspectives on the electrification of DH in Greater Copenhagen. At the same time, each data source has distinct strengths and limitations that shape the type of insight it can provide.

The interviews enable an in-depth exploration of themes closely linked to the research questions and the specific Greater Copenhagen context, providing detailed insight into the practical challenges of implementation. In contrast, the recordings provide insight into broader sectoral dynamics and are more strategic in nature. They emphasise how electrification is framed at an industry level, including its links to energy security and geopolitics, as well as wider economic and political considerations such as questions linked to the financing large investments, maintaining affordable prices and ensuring predictable regulatory conditions. These recordings provide an unobtrusive source of data that is not shaped by the researcher's line of questioning. As such, they offer insight into how issues are discussed in a broader industry setting and help identify themes that may not emerge directly in interviews (Creswell & Creswell, 2022). The reports complement these perspectives by drawing on systematic analyses and providing more precise data and quantified insights.

At the same time, each data source has limitations. The interviews may be influenced by the presence of the researcher (Creswell & Creswell, 2022). Specifically, there is a potential risk of social desirability bias, particularly given the researcher's background in environmental studies, which may lead some participants to emphasise progress on the electrification agenda. To mitigate this, the interviews were designed to focus on concrete implementation challenges and practical constraints. A limitation of the recordings is that they may reflect strategic communication tailored to specific audiences and do not engage directly with the research questions. The reports are also limited in that they tend to focus on a relatively narrow set of challenges and emphasise scenario-based analyses, policy ambitions and guiding principles. Furthermore, while reports provide important insights, they do not always capture developments as they unfold in real time. As the transition is ongoing, there is limited up-to-date and synthesised documentation. It was therefore deemed valuable to complement the reports with first-hand accounts from actors actively engaged in the process through the interviews and recordings.

## 5.5 Data processing and analysis

After the empirical material had been collected and organised, the next step was to analyse it systematically in relation to the research questions and theoretical framework.

The material was analysed using a hybrid thematic analysis, combining deductive and inductive coding approaches (Fereday & Muir-Cochrane, 2006; Swain, 2018). Thematic analysis can be understood as a method for identifying and encoding patterns of meaning in qualitative data (Braun & Clarke, 2006). This approach was selected to ensure that the analysis remained grounded in the analytical frameworks, while also allowing for new, empirically grounded insights to emerge from the data.

The analysis began with a deductive, top-down coding process. A set of a priori themes was developed, operationalizaing the concept of reverse salients, as well as RQ1. The overarching categories therefore included technical, economic, political, and organizational challenges, alongside broader perspectives on the future of DH. These categories provided an initial analytical framework through which the interview material could be systematically examined, while remaining sufficiently broad to avoid overly constraining the analysis.

In addition, aspects of the empirical material were later interpreted in relation to selected elements of the Multi-Level Perspective (MLP). This included examining how the findings reflected dynamics associated with socio-technical transitions, such as regime lock-ins, landscape pressures, windows of opportunity and broader transition trajectories. The analysis considered the extent to which the development of electrified DH in Greater Copenhagen aligned with or diverged from more conventional MLP understandings of transition processes.

The analysis also incorporated an inductive, bottom-up component. The transcripts were read to identify recurring patterns, explanations and problem framings within and across interviews (Braun & Clarke, 2006; Swain, 2018). Through this process, more fine-grained sub-themes emerged within the broader categories. In addition, a new overarching theme related to geospatial considerations emerged from the data. This theme did not fit neatly within the initial coding structure but it was decided that these should be incorporated under a combined category of technical and geospatial challenges.

The coding process was conducted manually through hand-coding of the transcripts. The overarching themes were identified and organised using colour coding, while sub-themes were developed inductively through notes and annotations made during the coding process. The resulting themes and sub-themes were subsequently collated and organised under relevant headings to facilitate comparison across the empirical material. This approach supported a systematic analysis of recurring patterns while also allowing for more detailed and nuanced insights to emerge from the data.

## 5.6 Reliability

Reliability concerns the consistency and trustworthiness of the research process. To ensure reliability, transcriptions were carefully checked to avoid errors and coding procedures were applied consistently across the dataset (Creswell & Creswell, 2022). Due to the scope of a master's thesis and the large size of the dataset (11 interviews and 22 recordings), it was not feasible to involve a second coder and establish intercoder reliability. Instead, the researcher revisited and reviewed the coding multiple times to ensure internal consistency.

## 5.7 Validity

Validity refers to whether the findings are accurate and credible from the researcher's standpoint, the participants, or the readers of an account (Creswell & Miller, 2000).

Several strategies were used to enhance validity. Several strategies were used to enhance validity. First, data triangulation was applied by combining multiple data sources (interviews, recordings and reports) and by incorporating perspectives from a broad range of actors identified through the stakeholder mapping process. Furthermore, the study aimed to provide a rich and detailed account of the empirical material, which can strengthen the credibility and depth of the analysis (Creswell & Creswell, 2022).

Potential biases were addressed through careful research design. Interview questions were formulated in an open-ended and neutral manner to avoid leading participants, and both confirming and contradicting evidence were included in the analysis (Creswell & Creswell, 2022).

# 6 Findings & Analysis

This section analyses the empirical material in relation to the two research questions. It begins by presenting the findings from the stakeholder mapping. It then examines actor perspectives on the future of DH in Greater Copenhagen (RQ1), before turning to the key constraints shaping electrification in practice (RQ2). These constraints are analysed as reverse salients across technical & geospatial, economic, political, and organizational dimensions.

## 6.1 Stakeholder mapping

The purpose of the stakeholder map is not to provide a definitive categorisation of actors, but rather to offer an analytical overview of the main organisations and actor groups involved in the transition towards more electrified DH in Greater Copenhagen. This was important both for guiding the sampling process and for ensuring that the analysis incorporated perspectives from across the wider system.

It was decided not to present actor perspectives strictly according to stakeholder categories in the following section 6.2 (related to RQ1), as some categories contained relatively few representatives and considerable variation also existed within individual groups. Instead, perspectives are analysed more thematically across the material, while still ensuring representation from a broad range of actor positions within the system.

The stakeholder map is structured spatially, beginning with core system operators at the centre and moving outward to enabling actors and broader governance, legitimacy and framing actors that shape the institutional and political context. While some actors span categories and are not easily placed, this structure aims to illustrate the main functional roles within the transition. The blue circle constitutes the hands-on 'implementers' in this transition, while the purple rings on the map are the 'enablers'.

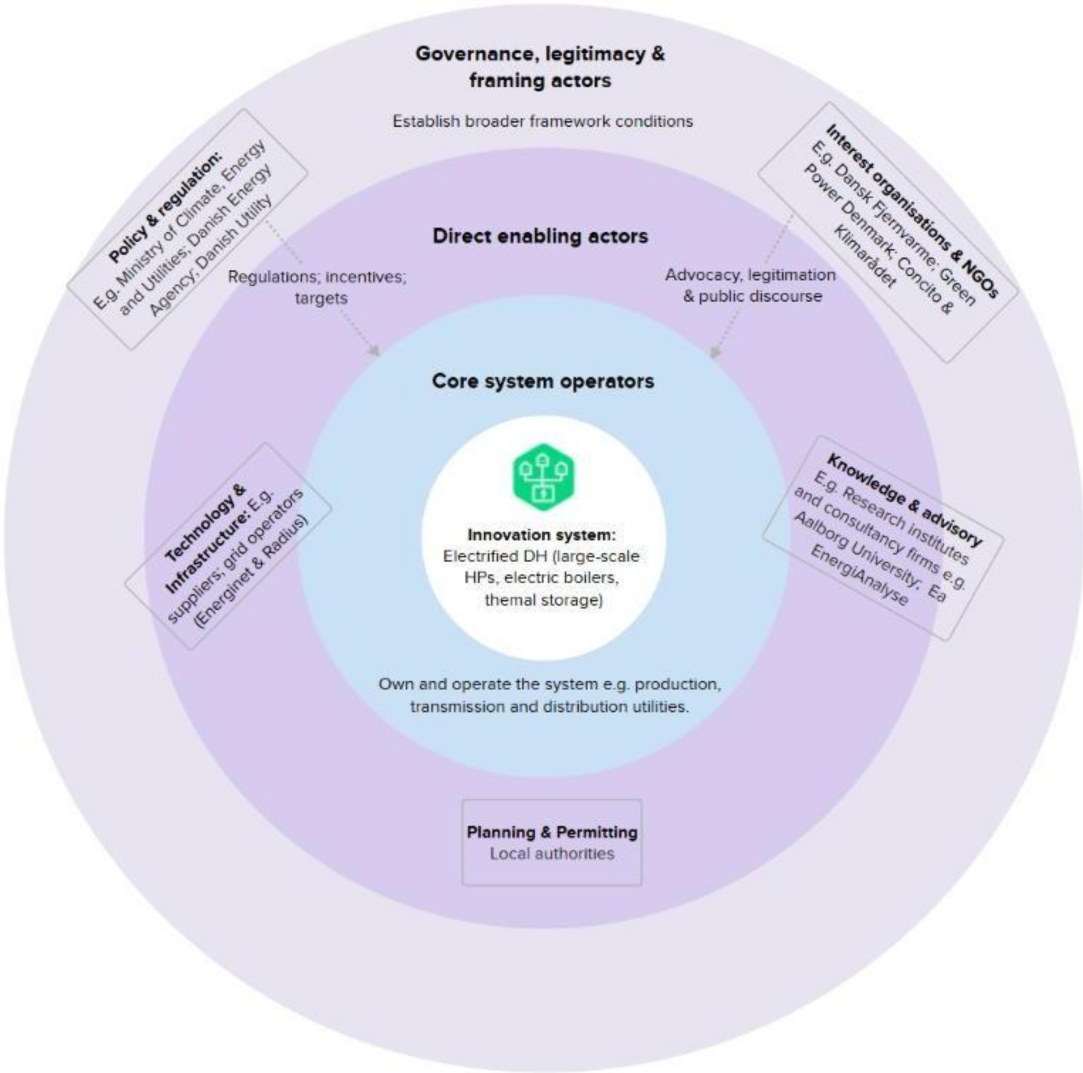


*Figure 6-1. Stakeholder Map. Source: Author's own illustration*

### 6.1.1 Core System Operators

Core system operators are the actors that own and operate DH infrastructure in Greater Copenhagen and are therefore central to electrification. The system is dominated by a small number of municipally owned utilities, most notably HOFOR, which operates major production facilities and leads investment in technologies such as large-scale heat pumps, electric boilers, and thermal storage. Transmission companies such as CTR and VEKS transport heat between large production plants and local distribution companies, while smaller municipal utilities primarily manage local distribution networks. The Danish DH companies are organised in two DH associations 1) Danish DH Association (DHA) and 2) Association of Danish CHP (Johansen & Werner, 2022).

### 6.1.2 Direct enabling actors

Direct enabling actors do not operate DH systems but provide the technologies, infrastructure, finance and expertise necessary for electrification. Technology providers supply key components such as heat pumps, electric boilers, thermal storage, digital control systems etc., while firms involved in electrical infrastructure enable grid integration. Electricity grid operators, including the distribution system operator Radius and the transmission system operator Energinet, play a critical role in ensuring capacity, stability and market access for large electric loads (Radius, n.d.; Energinet, n.d.).

Knowledge and advisory actors support decision-making through research, modelling, and technical analysis. Universities, research centres, and consultancies contribute to system design, scenario development, and feasibility assessments. Several universities have conducted research related to this topic including the Technical University of Denmark (DTU) with their CITIES research centre (CITIES, n.d.) and the Southern Danish University with the Centre for Energy Informatics (SDU, n.d.), as well as the Teknologisk Institut which contributes to testing, validation and demonstration of relevant technologies (Teknologisk Institut, n.d.). However, Aalborg University has been leading the field. Researchers at Aalborg University initiated and coordinated the Fourth Generation DH project (4GDH). In defining 4GDH, this research project produced the currently most cited paper in the world about DH (Johansen & Werner, 2022), Aalborg is also one of the founding universities of the Heat Roadmap Europe, which explores how European heating can be decarbonized at the lowest possible cost (Johanssen & Werner, 2022).

Local authorities act as key enabling actors through their role as heat planning authorities, responsible for preparing, assessing, and ultimately approving new collective heat supply infrastructure projects in line with ministerial criteria. In doing so, they evaluate the short- and long-term socio-economic and environmental impacts of proposed projects, including their contribution to the low-carbon transition, security of supply, resource efficiency, and broader system considerations, before granting approval or rejection (Johansen & Werner, 2022). DH projects are typically financed through long-term loans provided by the Municipal Credit Bank (Johansen & Werner, 2022) and repaid via tariff-based cost recovery mechanisms (København Kommune, 2024).

### 6.1.3 Governance, Legitimacy and Framing

Governance, legitimacy, and framing actors shape the broader institutional environment within which electrification unfolds.

Organisations such as CONCITO, Rådet for Grøn Omstilling and Green Power Denmark help shape debates around electrification, heating and biomass, but from different positions. CONCITO contributes as a green think tank (*CONCITO*, 2026), Rådet for Grøn Omstilling as an environmental advocacy organisation (Rådet for Grøn Omstilling, n.d.), and Green Power Denmark as an industry organisation representing actors across the green electricity value chain (Green Power Denmark, 2026). Their role is about framing problems, advancing policy proposals and influencing public and political debates. Sector associations such as Dansk Fjernvarme play a more directly system-specific role by representing DH companies, producing sector analyses and creating arenas for coordination and knowledge-sharing, for example through conferences, meetings and other sector events (Dansk Fjernvarme, n.d.-b).

Government bodies and regulatory authorities define framework conditions through legislation, policy design, and economic regulation, influencing investment incentives and market structures. Relevant national authorities include the Ministry of Climate, Energy and Utilities (KEFM) and the Danish Energy Agency (DEA). KEFM sets Denmark’s climate and energy policy direction, while the DEA develops, administers, and oversees these policies. The Economic regulation is overseen by the Danish Utility Regulator (Forsyningstilsynet), which supervises utilities, sets tariff frameworks, and seeks to ensure efficient, stable, and affordable energy services while promoting transparency and compliance with EU regulation (Johansen & Werner, 2022).

The legislative framework governing DH is primarily defined by the Heat Supply Act and the Executive Order on the Approval of Collective Heat Supply, which establish the conditions under which projects can be developed and approved (Johansen & Werner, 2022).

Having outlined the main actor groups involved in the electrification of DH in Greater Copenhagen, the analysis now moves to the main body of the chapter, which seeks to address RQ1 and RQ2 directly. Drawing on interviews, AGM recordings and sector reports, it first examines actor perspectives on the future of DH in Greater Copenhagen and the role electrification is expected to play within it.

## 6.2 The Future of DH (related to RQ1)

Across interviews, broader sector material, and Copenhagen's energy strategy, there is strong agreement that DH is moving towards a significantly more electricity-based and flexible system. This is expressed particularly clearly by Hans Henrik Lindboe, who argues that "if we want to be green, we need to be electric" (CN-R1). Similarly, Brian Vad Mathiesen frames the future role of DH as closely tied to the integration of renewable electricity into the wider energy system (AR2).

However, expectations regarding the extent of electrification vary considerably. Most estimates for the next few decades fall within a range from one third to two thirds (BI1; DH1; DH2; DH3; CN1; EN2; SA1; SA2; SA-R1, Københavns Kommune, 2025), although one or two also expressed hope for further electrification with only small reserves of other sources (EN1; CN2). Not all interviewees or speakers provided concrete estimates, but the empirical material suggests a somewhat more cautious outlook than the most ambitious scenarios presented in the report by Ea Energianalyse and PlanEnergi (2025), in which electrification reaches around 75% of district heating capacity by 2050 in Scenarios 2 and 3.

Rather than moving towards a fully electrified system, the dominant vision is one of a more electric but still fundamentally hybrid DH system. Jesper Frost Rasmussen explicitly cautions against treating electrification as an end goal in itself: "it is not a goal in itself to electrify all DH, because we should not once again make ourselves dependent on only one energy source" (SA-R3). There is emphasis on maintaining a diversified mix of technologies, including electricity-based heat production, biomass, waste-to-energy, geothermal energy, solar thermal and waste heat (CN1; DH1; DH2; SA1; BI1; SA-R1; PL5). While electrification is expected to play a growing role, several actors stress that controllable and more stable heat sources remain important for ensuring security of supply and supporting overall system stability (SA-R1; SA-R3; PL3).

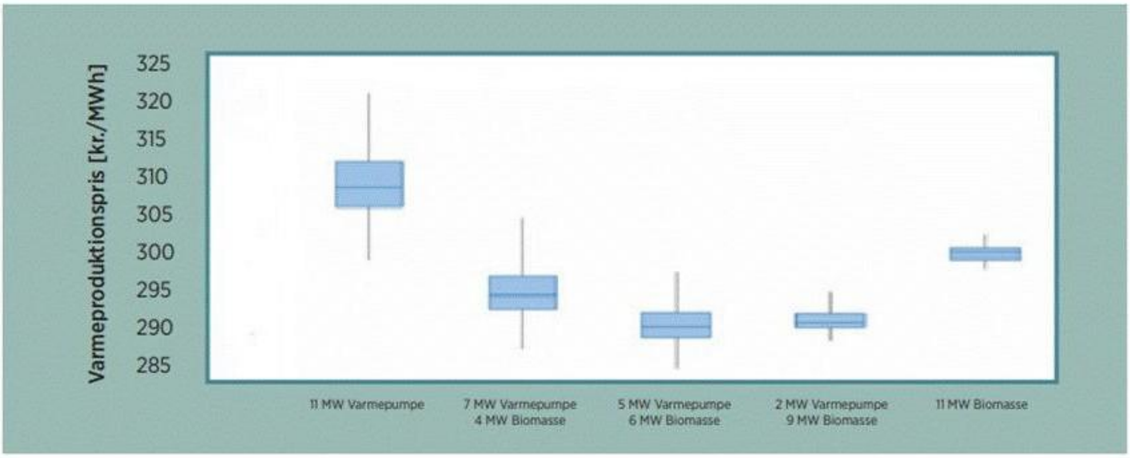


*Figure 6-2. Heat production cost ranges for different combinations of heat pumps and biomass boilers over a 20-year investment horizon. Source: Dansk Fjernvarme, 2020.*

This hybrid vision is closely linked to understandings of the economic performance of future DH systems. Rather than assuming that electrification alone will necessarily deliver the most efficient outcome, several perspectives emphasise the value of combining technologies. Modelling by Dansk Fjernvarme (2020), for example, suggests that systems combining heat pumps and biomass boilers can provide more stable and, on average, lower heat production costs over time than systems relying on a single technology (see Figure 6-2 above). This reflects the flexibility of hybrid systems: when electricity prices are low, heat pumps can be prioritised, while periods of high electricity prices may favour CHP-based production, which allows for simultaneous heat generation and electricity sales taking advantage of the high prices (Dansk Fjernvarme, 2020; Københavns Kommune, 2025).

This is contingent on the assumption that very large-scale thermal storage will remain limited in Greater Copenhagen. If substantial storage capacity were available, it could help smooth price and supply fluctuations and thereby strengthen the case for greater reliance on electricity-based heat production. Copenhagen's Energy Strategy 2025-2035 does not provide a clear estimate of how much thermal storage will be feasible in practice. There is hope of some accumulation tanks, but the report notes that seasonal pit heat storage is largely ruled out in Copenhagen because of the enormous space requirements involved (a 70,000 m3 tank) (Københavns Kommune, 2025).

Where views diverge more clearly is on the future role of biomass. Some actors view biomass as an important source of dispatchable capacity and system stability (CN1; SA2; SA-R3), while others argue that it is neither environmentally sustainable nor compatible with long-term energy independence. For example, Samir Abboud criticises continued reliance on imported wood pellets: "In Denmark, we must show the way, and it obviously makes no sense for us to be shipping in mountains of wood pellets from South America and the Baltics. That is not independence, and it is not green." (SA-R2). Kim Mortensen similarly suggests that shifting from gas to biomass simply means replacing one dependency with another (PT4). In contrast, other actors maintain that biomass may continue to play a role within a more diversified system, at least in the medium term (PL5). Copenhagen's Energy Strategy reflects a middle position, treating biomass as a transitional resource whose use should decline as electrification expands (Københavns Kommune, 2025).

Finally, existing infrastructure introduces important path dependencies. Large, relatively recent investments in biomass and waste-to-energy plants mean that these assets are expected to remain part of the system for decades, specifically the biomass plants Amagerværket Blok 4 (opened in 2019 with a contract ending in 2045) and Avedøreværket Blok 2 (opened in 2026 with a contract ending in 2040) (DH1; DH2; Københavns Kommune, 2025). The future system is therefore shaped not only by forward-looking visions, but also by existing asset lifetimes and investment decisions.

Overall, the material can be interpreted as pointing towards a coherent but nuanced vision: DH is expected to become more electrified and flexible, but not fully electrified.

## 6.3 Technical challenges (related to RQ2)

### 6.3.1 Electricity Grid Constraints

As electrification progresses, the DH system moves from being a net exporter of electricity to a net importer. Ea Energianalyse & PlanEnergi (2025) suggest that the system could shift from exporting just over 4 TWh of electricity in 2025 to importing approximately 3.5 TWh in 2050. With this background information and the parallel electrification in other sectors such as transport and industry, it becomes clear why the electricity grid emerges as the most significant technical bottleneck across the material with limited capacity and long connection times (BI1; DH1; DH2; DH3; EN1; EN2; SA1; SA2; Københavns Kommune, 2025; Ea Energianalyse & PlanEnergi, 2025). Projects are being delayed, resized, or pushed towards less green interim solutions because the grid cannot accommodate new demand at the required pace (SA-R1). "The grid has simply filled up faster than expected" (SA-R1). The issue is that in order to have greater grid capacity, significant reinforcements are also needed in the transmission network, where expansion timelines may stretch over more than a decade (EL1). Strengthening the high-voltage grid is therefore a prerequisite for large-scale electrification, yet major upgrades may not be completed until around 2035 at best (DH2).

Although connection with so-called 'limited grid access' ('*begrænset netadgang')* may be possible in the interim, this introduces risks of curtailment or temporary disconnection (DH2), creating uncertainty for DH companies. While occasional interruptions may be manageable, more frequent disruptions, especially during winter peak demand, would pose significant operational challenges (DH2).

Delays in grid expansion initially reflected the need for the system to respond to a sudden and unprecedented increase in demand. This required scaling up organizational capacity, including hiring more staff, building new competences, and securing components. Today, delays are increasingly driven by lengthy approval and permitting procedures. Grid expansion projects must pass through extensive administrative processes, including consultation, complaints procedures, expropriation, and environmental requirements, all of which can extend timelines by several years. At the same time, supply chain constraints remain for key components such as large transformers, with delivery times of up to six years (EL1). Together, these factors create a structural lag between the growing need for grid capacity and the pace at which it can be delivered. This suggests that grid constraints function as a classic reverse salient, where institutional, technical and supply-chain factors jointly slow system expansion.

### 6.3.2 Dependence on Renewable Electricity Supply

Electrification depends not only on grid capacity but also on the availability of sufficient green electricity. Several interviewees emphasise that the transition assumes parallel expansion of renewable generation, which cannot be taken for granted given delays and cancellations of renewable energy projects (BI1; CN1; Københavns Kommune, 2025). The Copenhagen Energy Strategy highlights that with the increased demand for electricity, "a significant expansion of green electricity production [will be required] to ensure that electricity is available and based on renewable energy sources". As one interviewee notes, "if we want people to electrify, then the state needs to show that there will also be more green energy available" (CN1).

### 6.3.3 Integration of Heat Pump Technologies

A second set of challenges concerns the integration of heat pump technologies into the existing DH system. While large heat pumps are relatively new in Danish DH, interviewees generally do not view the core technologies as fundamentally immature. Although there have been some "børnesygdomme" ("illnesses in infancy") many installations now operate reliably, and significant technological progress has been made since 2020 (DH1; DH3; CN2). The challenge is therefore less about individual technologies and more about system integration. As one respondent explains, "it is not so much the technology itself, but rather the need to adjust and manage the interaction within the system" (CN2).

### 6.3.4 Operational Uncertainties and Technology-Specific Challenges

Despite general technological maturity, there are some uncertainties that remain, particularly regarding large seawater heat pumps. Operational knowledge is still developing, especially concerning performance during winter when seawater temperatures fall (SA1; DH2). Access to deeper water layers could improve performance, but current projections of intake depths (3–5 metres) may limit efficiency compared to deeper sources (DH2). Air-source heat pumps are also seen as more vulnerable during transitional and very cold periods due to frost formation on the evaporators (CN1). This raises concerns about reliability of these large-scale heat pump solutions during peak demand "on the coldest days when you need them most" (CN1).

Further complexity arises in refrigerant choice. Ammonia is efficient but problematic in dense urban areas due to its toxicity, while $CO_2$ is constrained by high return temperatures in Copenhagen's system. Other refrigerants, such as HFOs and propane, involve additional technical and safety trade-offs, requiring context-specific evaluation (DH1; DH2). It will require careful weighing up of the different trade-offs when choosing refrigerants for the region's future large-scale heat pumps.

### 6.3.5 Temperature Mismatch and Legacy System Constraints

A particularly significant technical barrier concerns temperature levels in the DH network. Large-scale heat pumps operate most efficiently if there are lower supply temperatures (60-70 degrees) as the pressure and temperature can be lower in the heat pump condenser. Lower temperatures also have the advantage that heat loss in distribution is decreased. However, Copenhagen's system has historically been designed for high-temperature, combustion-based production (80 degrees plus) (Ea Energianalyse & PlanEnergi, 2025; Københavns Kommune, 2025). This creates a structural mismatch between legacy infrastructure and the ideal conditions of a more electricity-based system (EN2; SA2).

Both municipal and regional analyses highlight that lower temperatures are a technical precondition for efficient electrification, but achieving this depends on building-level optimisation and renovation (Københavns Kommune, 2025; Ea Energianalyse & PlanEnergi, 2025). A large share of Copenhagen's buildings are older and not well suited to lower-temperature heating (EN2; CN2). While technical solutions exist, respondents emphasise that deep temperature reductions quickly become "too expensive and difficult" (CN2).

More broadly, electrification alters the thermal and operational characteristics of the system. Traditional combustion plants provide stable, high-temperature output, whereas electricity-based and waste heat sources are often lower-temperature and more variable (DH3). This requires a more flexible and responsive system capable of managing fluctuations in both temperature and load (DH3).

### 6.3.6 Space, Siting, and Infrastructure Constraints

Finally, spatial constraints represent a major technical barrier. As one respondent notes, electrification "is to a large extent about finding a location" (CN1). Electricity-based heat production must be located close to both demand and infrastructure, but dense urban environments create significant limitations. Several actors highlight the "huge land requirement" associated with heat pumps, electric boilers, and storage facilities (SA1; SA2). As the joint report on electrification of DH in Greater Copenhagen suggests "there will be a significant task in all municipalities to find suitable locations for the new technical facilities […] and to ensure sufficient areas overall" (Ea Energianalyse & PlanEnergi, 2025). The number of suitable sites is limited by area conditions, proximity to DH and electricity networks, noise, physical limitations, etc (Ea Energianalyse & PlanEnergi, 2025).

Electrification depends on securing space not only for production technologies but also for substations, grid infrastructure, and storage, all while balancing competing urban land uses (Københavns Kommune, 2025; Ea Energianalyse & PlanEnergi, 2025).

Storage adds a further layer of complexity. While thermal storage is seen as important for balancing heat and electricity over time, large-scale thermal solutions are difficult to implement in Copenhagen. Thermal storage in the form of accumulation tanks can reach 20-40 metres in height and 14-16 m in diameter. Seasonal pit storage is considered particularly challenging due to its very large land requirements, requiring a 70,000 m3 tank and around 11,000 m2 in surface area (Københavns Kommune, 2025).

There is discussion about the decentralisation of heat production with potential to locate new facilities in municipalities surrounding Copenhagen where land is more available and less costly (Ea Energianalyse & PlanEnergi, 2025). However, one practitioner highlighted that for certain types of production units there can be clear advantages to maintaining production at or near existing central sites, such as former CHP plant locations. These sites benefit from established infrastructure, including high-capacity electricity connections, integration into the DH network, and existing planning permissions. In some cases, existing infrastructure such as seawater intake systems can also be reused (DH2). Of course, the appropriate location depends heavily on the specific technology, as seawater heat pumps require coastal access, while wastewater-based systems must be located near treatment facilities etc.

### 6.3.7 Synthesis: technical & geospatial reverse salients

Taken together, these technical challenges seem to reflect the need to integrate electricity-based heat production into a system historically designed around centralised, high-temperature combustion. Grid constraints, integration challenges, temperature requirements, building limitations, and spatial pressures all point to the same underlying issue: electrification is not simply a matter of replacing one heat source with another, but of reconfiguring the technical logic of the DH system as a whole.

## 6.4 Economic challenges (related to RQ2)

Electrification is increasingly seen as cost-competitive in principle (Københavns Kommune, 2025; EN2). The Energy Strategy for Copenhagen states: “If we succeed in establishing heat pumps in the right locations with good sources, it is expected to be able to outcompete some of the heat production from biomass” (Købenahavens Kommune, 2025: pg. 21). One interviewee highlighted electrification as one of the more cost-effective pathways for reducing $CO_2$ emissions in line with climate targets, considering the need also for carbon capture or offsetting costs with other approaches to meet the officially set targets (EN2).

However in practice, it would appear that there are still significant economic challenges, considering the scale of coordinated investment required, the fragility of project-level business cases under current system conditions, and governance frameworks that often favour caution over anticipatory investment.

### 6.4.1 Investment scale and coordination

A central challenge in the electrification of DH concerns both the scale and coordination of required investments. Even within Copenhagen alone, the transition implies very substantial capital commitments across multiple actors. Combined, HOFOR, CTR and Ørsted expect to invest roughly DKK 8.8–12.1 billion in heat pumps, electric boilers and thermal storage (Københavns Kommune, 2025). These investments in heat production are complemented by significant upgrades to electricity infrastructure, with Cerius/Radius Elnet expecting around DKK 6 billion in grid investments, as well as municipal investments of DKK 109 million to prepare buildings for lower-temperature DH (Københavns Kommune, 2025).

A further complication is the presence of existing capital stock in the current system. Accelerating the phase-out of biomass comes at a cost. Total system costs are estimated to increase by approximately DKK 450 million per year between 2030 and 2050 (Ea Energianalyse & PlanEnergi, 2025). A key reason for these additional costs is that the capital costs of existing biomass plants are treated as sunk costs, meaning that they must be borne regardless of whether the plants remain in operation. As a result, early closure does not eliminate these costs, but instead leads to a situation where new investments in electrification must be made while the financial burden of past investments persists. In addition, some of these plants generate significant revenues in the electricity market, including subsidies, which would be lost if they are phased out prematurely (Ea Energianalyse & PlanEnergi, 2025). This does not mean electrification cannot take place, but it can impact the ambitions for the heating sector in terms of the pace at which electrification is rolled out.

### 6.4.2 Project-level business cases under existing system conditions

These investment dynamics are further complicated by the conditions under which electricity-based heat production must compete. As multiple actors simultaneously scale up electrification projects, they are essentially “fishing in the same waters” for labour, equipment and technical expertise, driving up costs and slowing implementation (SA-R3). High land prices and urban density add further cost pressures, whether due to expensive excavation for laying pipes or the cost of large sites for heat pumps and thermal storage (DH1).

At the same time, DH must remain competitive with heat pumps for individual houses, which effectively set a benchmark for acceptable consumer prices. Estimates of around DKK 15,000 annually for individual house heat pumps therefore establish a demanding benchmark for DH pricing (CN-R1).

Heat dispatch adds another challenge to the economics of electrification. In the current system, waste heat is given explicit priority in order to make best use of existing investments in waste-incineration plants, meaning that newer electricity-based technologies such as heat pumps must compete for the remaining demand. This can reduce their operating hours and weaken their ability to recover high upfront capital costs, even where electrification may appear beneficial from a broader system perspective (DH1; DH2; Københavns Kommune, 2025). This applies particularly in the summertime, when there is most sun and thus opportunity to harness this form of renewable energy, but fewest operating hours available to utilities (DH2).

### 6.4.3 Long-term uncertainty and investment risk

A key cross-cutting issue is uncertainty. Electrification investments are long-term, often spanning 20–40 years, yet the conditions under which they will operate remain highly uncertain (DH2; AR2; AR3; PL1; SA-R1). Several respondents stress that the problem is not only current price levels, but the instability of the wider investment environment. Brian Vad Mathiesen and Martin Kruse, for instance, point to “stop-and-go” politics and shifting signals as factors that undermine investment stability (AR2; AR3). Stephanie Lose emphasises the need for stable and predictable framework conditions for long-term investments (PL1). In this context, the risk is that future changes in electricity prices, grid tariffs or regulation may weaken project economics, making final investment decisions more difficult. The Copenhagen Energy Strategy reflects a similar, but wider concern, highlighting how volatile electricity and fuel prices, construction costs, material and land costs, as well as broader macroeconomic and geopolitical conditions complicate investment planning and risk assessment (Københavns Kommune, 2025).

### 6.4.4 Institutional and regulatory constraints

Regulatory frameworks further shape these investment dynamics. The *hvile-i-sig-selv* (cost-recovery) principle limits the ability of DH companies to generate profits and requires that investments be justified in terms of cost efficiency for consumers (BI1). While this protects users from excessive costs, it can also weaken incentives to invest in new technologies. This is particularly the case because system-level efficiencies are often difficult to realise through incremental, project-by-project decision-making (CN2).

These economic and regulatory constraints are not limited to DH systems but extend to the electricity grid itself, which is a critical enabler of electrification in the heating sector. Grid expansion faces similar challenges related to investment uncertainty, cost allocation and regulatory oversight (EL1). A key challenge in grid expansion relates to the regulatory framework governing network companies, particularly the revenue cap. This model functions relatively well under conditions of stable and predictable demand but is less suited to the current context of rapidly increasing and uncertain electricity consumption. While grid operators can apply for adjustments to their cost allowances for specific projects, these requests are subject to approval by the Danish Utility Regulator (Forsyningstilsynet), which, according to the respondent, still operates with assumptions rooted in a more stable system. This can lead to scepticism on their side towards the necessity and scale of proposed investments. Although the regulator does not directly dictate which investments can be made, it can limit cost recovery by only approving part of the requested funding, thereby creating financial risk for grid companies (EL1).

This emphasis on cost control reflects a regulatory paradigm shaped by earlier policy priorities, particularly under former minister Lars Christian Lilleholt, where low electricity prices were prioritized given their role in safeguarding industrial competitiveness. However, in the current context, this approach may contribute to underinvestment, as it discourages proactive expansion. From a societal perspective, the interviewee argues that it is better to risk overbuilding rather than underbuilding, given the critical role of the electricity grid for wider goals in terms of powering our industry and society with higher amounts of green, domestic energy. This suggests that existing economic assessment frameworks may undervalue the broader system benefits of timely grid expansion (EL1).

### 6.4.5 Tariffs & guarantees

Finally, the material points to more specific misalignments in tariffs and financing structures. Electricity tariffs are not always aligned with the operational characteristics of electrified DH, meaning that companies may pay for capacity regardless of when electricity is consumed, even in periods where such consumption supports grid balancing (CN-R1). Another factor is the differences in municipal guarantee schemes which can create uneven financing conditions across projects (SA-R3).

### 6.4.6 Synthesis: economic reverse salients

Taken together, these findings can be interpreted as suggesting that while electrification is increasingly cost-competitive in principle, its realisation is far less straightforward in practice. The transition is shaped not only by technology costs, but by interdependent capital requirements, long-term uncertainty and governance frameworks that make it difficult for actors to invest proactively. The economics of electrification must therefore be understood not simply as a question of whether electric heat is cost-effective, but of whether existing institutions and market structures enable actors to build it at the scale and speed required.

## 6.5 Political and regulatory challenges (related to RQ2)

The political challenges of DH electrification are shaped by a growing overlap between climate policy, geopolitical instability and concerns over security of supply. While support for electrification is broad in principle, the transition struggles to generate sustained political momentum and public appeal. Electrification therefore emerges not only as a technical and economic project, but as a political one whose pace depends on how convincingly it is linked to security, everyday relevance and collective purpose. At the same time, several actors highlight that the necessary framework conditions remain insufficiently developed, pointing to a gap between technological readiness and the institutional and regulatory structures needed to support large-scale implementation. As Louise Høst puts it, "Teknologien er der, men rammerne halter" ("the technology is there, but the surrounding conditions are lacking") (DH-R1).

### 6.5.1 Crisis, security and the politics of urgency

The first political theme concerns the growing overlap between climate, crisis and security of supply (SA-R3, PL1, PL2). Jeppe Bruus Christensen formulates this most directly, arguing that "green transition and security are not opposites" and describing them as "two sides of the same coin" (PL2). Stephanie Lose likewise frames DH as critical infrastructure in an increasingly uncertain geopolitical context (PL1). In this reading, electrification is not simply about decarbonisation, but about strengthening resilience, autonomy and domestic security of supply.

At the same time, the material shows that crisis does not produce one clear political effect. For some actors, crisis creates urgency (AR1; PL4). Mogens Rüdiger, for example argues that "nothing drives change like crises" (AR1). For others, however, crises also compete with or complicate the climate agenda. Lotte Hansen argues that the green transition has become "not quite as attractive as it once was", while Louise Høst stresses that it is no longer an "fairy tale" but "hard, demanding work" that often generates more criticism rather than consensus (CN-R1; DI1). This ambivalence also appears in investment behaviour. As one actor puts it, ""perhaps not many are interested in investing in something when they do not know where it is heading… it makes one more inclined to maintain and develop what already exists" (PT2). Crisis can therefore justify acceleration, but it can also reinforce caution.

This ambiguity is expressed particularly clearly by Lars Trier Mogensen. He argues that DH ought to be central to the new agenda of resilience and security of supply, describing the sector as "Danmarks hjemmevarme" and "det sande hjemmeværn" ("Denmark's domestic heating" / "the true home guard") (MD1). His point is that DH offers the possibility of relying less on volatile global fuel markets, it can integrate diverse energy sources and is embedded in local networks that are less exposed to external shocks (MD1). Yet he also argues that the sector has not succeeded in connecting itself strategically to this heavier geopolitical agenda, and that the current climate of insecurity has in some ways slowed rather than strengthened momentum behind DH (MD1). More broadly, he suggests that parts of the green transition have been politically reframed in ways that foreground more visible and appealing elements, while "…the heavy, more cumbersome and not least costly transition has slipped into the background" (MD1). His point is not that the security case is absent, but that it has not been politically captured.

### 6.5.2 Weak direction, lagging framework conditions & past experiences

A central political challenge lies in the absence of coherent and credible long-term direction. Several actors emphasise that the core problem is not a lack of ambition in principle, but a lack of stable, clear and trusted political steering (AR2, CN-R1, TT2). Hans Henrik Lidboe questions whether a regulatory framework designed around careful socio-economic assessment and price verification is compatible with the need for rapid, large-scale investment. Brian Vad Mathiesen points to changing calculation models and shifting signals from the government as sources of uncertainty that cause projects to fall away (AR2; CN-R1). The lack of sufficient grid capacity is likewise seen by some respondents as a consequence of inadequate long-term planning and limited political attention (SA1).

There have been notable improvements in the framework conditions in some respects, including recent and substantial reductions in the electricity tax (*elafgift*), with a temporary reduction to the EU minimum level in 2026–2027 (it remains to be seen if this will be extended) (EN1). However, important challenges remain. Building regulations and energy labelling schemes have, since the introduction of the 2018 building code, imposed stricter energy requirements on buildings connected to DH than on those using heat pumps individually. In practice, this means that individual buildings with heat pumps can more easily achieve favourable energy ratings, while DH-connected buildings must meet more stringent standards. This contributes to an uneven playing field between individual and collective heating solutions (EN1; SA1).

Some interviewees also point to how past experiences shape current attitudes towards new investments in DH. Earlier transitions have, in some cases, led to unexpectedly high costs, which continue to influence how new projects are perceived (EN2; CN2). For example, one interviewee refers to a time where Dansk Fjernvarme invested in natural-gas based plants, where reliance on a single operator contributed to high costs. With electricity markets there is not the same problem with a single operator, but such past experiences still create a degree of caution towards new large-scale investments (EN2).

### 6.5.3 Legitimacy, visibility and local resistance

A third political theme concerns resistance, visibility and the difficulty of making both DH and electrification attractive. Several actors suggest that DH suffers from weak emotional and symbolic appeal. Louise Høst captures this succinctly when she notes that "DH may not be the sexiest topic in the world" (DI1), while Lotte Hansen contrasts it with individual heat pumps, which are easier to market and relate to at the household level (CN-R2). The broader push for electrification is also portrayed as a hard sell. Danish society has managed to romanticise highly industrialised agriculture, while struggling to do the same for energy infrastructure. Rikke Juul Gram's question, "Hvordan får vi solcellerne skrevet ind i Højskolesangbogen?" ("How do we get solar panels written into the Danish songbook?"), captures this point and highlights that electrification depends not only on technical feasibility, but on whether it can be made publicly resonant (SI1).

The next phase of electrification may become politically more difficult because the transition is moving into a phase where it affects more contested infrastructures, places and interests. Lars Trier Mogensen points to local opposition to long-distance high-voltage power lines and other energy infrastructure, arguing that many of the low-hanging fruits have already been taken and that what comes next will be both more expensive and more controversial (MD1). Martin Kruse notes that "if you accelerate on a motorcycle, you feel more headwind", suggesting that growing resistance may be an inevitable part of accelerating the transition rather than a sign that it has stalled (AR3). At the same time, he does not argue that opposition should simply be ignored. Rather, he stresses that politicians must take clearer responsibility and be better able to justify why pathways such as electrification are being pursued (AR3).

### 6.5.4 Synthesis: political reverse salients

Overall, the material can be interpreted as suggesting that the main political difficulty lies in how electrification is framed, prioritised and legitimised. Crises and geopolitics have made energy security and resilience more central, but they have not produced one clear political response. For some, they strengthen the case for DH; for others, they crowd out climate politics or make the transition less attractive and harder to sell (PL2; SA-R3; MD1; CN-R2). The material also suggests that the DH sector has not always been particularly effective at asserting its political relevance. Compared with louder and more visible interests, it has often operated more modestly in the background. If the sector is to secure a stronger place in future political priorities, it may need to become better at communicating the value of what it offers and at framing DH not only as a technical response to the climate crisis, but also as a contribution to resilience, domestic security of supply and strategic autonomy.

## 6.6 Organizational/Coordination Challenges (related to RQ2)

### 6.6.1 Interdependencies and the "chicken-and-egg" problem

A key challenge relates to the coordination between grid connection, site planning and project development. Electrification projects depend simultaneously on access to suitable land, timely permitting and sufficient grid capacity, yet these elements are interdependent and develop on different timelines (DH2). Grid expansion is typically driven by concrete connection requests, meaning that infrastructure is developed reactively in response to specific projects rather than through anticipatory planning. At the same time, project developers are often unable to secure sites or proceed with permitting without clarity on electricity access. This creates a 'chicken-and-egg' dynamic, where each actor would like the other to come first in order to reduce risk. Certain actors must commit to projects before key enabling conditions are in place, while others are reluctant to invest without firm and binding demand (DH1). The Copenhagen Energy Strategy captures the essence of the problem of timely and cost-effective grid expansion well in their statement:

*"A central challenge in the expansion of the electricity grid is to avoid building it everywhere without precise knowledge of the location of especially large consumption and production sites. There is a risk that costs escalate if all areas are covered simultaneously, while at the same time there is a risk of failing to cover areas with actual demand in a timely manner" (Københavns Kommune, 2025).*

As interviewee DH2 notes, "it is a large puzzle with many pieces that need to fall into place" (DH2). Heating projects are long-term and complex, often taking several years to plan, design and implement, during which key conditions may change. Utilities would ideally seek grid connection early to ensure electricity is available when projects come online, but this gives rise to a regulatory and economic dilemma: if they commit early and grid operators such as Energinet begin investing in infrastructure, these costs may not be recoverable from consumers under the Heat Supply Act if the project does not ultimately come to fruition. This makes early commitments financially risky, even though they are strategically necessary (DH2).

The result is a systemic coordination problem across multiple domains. Importantly, interviewees emphasise that these challenges do not stem from a lack of willingness to cooperate. Grid companies are described as open to collaboration, but constrained by regulatory frameworks, budgetary limits and the overwhelming pace and scale of the transition (SA1; DH2). Rather than reflecting conflict between actors, the difficulties arise from the tight interdependence between grid connection, land acquisition, permitting and investment decisions, where uncertainty or delay in one domain can stall progress in others (DH2). This reinforces the perception of electrification as a complex and uncertain "puzzle".

### 6.6.2 Grid capacity and prioritization of electricity demand

A further issue concerns how different electricity demands are prioritised. Several interviewees point to the growing number of actors requiring grid access, including electric vehicles, data centres, power-to-x projects and heating systems. Under the current regulatory framework, grid operators are not permitted to prioritise between different types of consumers (EL1). Access has largely been allocated been according to a "først til mølle" (first come, first served) principle. However, some interviewees question whether this is an appropriate approach, given the difference in strategic importance of the different uses of electricity. One interviewee suggests that there is a need for greater deliberation about how we prioritize, whether this is in terms of security of supply and the societal importance of certain infrastructures, the contribution to the green transition or market share considerations etc. (SA1).

Electricity grid companies are taking such suggestions seriously (EL1). The situation has triggered calls for urgent political intervention, as decisions on prioritisation cannot be resolved by grid operators alone. Interviewee EL1 pointed to the recent public statements from the CEO of Cerius and Radius, who declared the "need for outright emergency legislation". In an article, the CEO highlights a shift away from the traditional 'first come, first served' principle toward prioritising projects based on maturity and, increasingly, on societal value and flexibility (Plechinger, 2026). The main pressure on capacity comes from large-scale projects, such as data centres but also battery storage, which accounts for roughly one third of the capacity requested by those currently in the connection queue. Although batteries are often seen as part of the solution as they can offer greater energy system flexibility, they are currently exacerbating grid congestion (Plechinger, 2026).

### 6.6.3 Organizational adaptation and new forms of collaboration

The material points to a perceived lack of coordinating authority within an increasingly complex and diverse setting. As interviewee CN1 describes, "we are missing someone willing to take a seat at the head of the table and say: this is the kind of planning work we want to carry out" (CN1). As the energy mix expands to include electricity alongside traditional heat sources, responsibilities become more fragmented across utilities, grid operators, municipalities, and other stakeholders. As the Copenhagen Energy Strategy notes, "there will be more actors than today who are responsible for individual elements of the energy system, and no one is assigned an overall or coordinating role" (Københavns Kommune, 2025). This can make it difficult to align investment decisions, planning processes, and system development across actors with different responsibilities and time horizons. This challenge is particularly significant given the strong interdependencies between system components. Accordingly, the Copenhagen Energy Strategy emphasises that "coordination and knowledge sharing are essential for success" (Københavns Kommune, 2025), whilst Martin Kruse notes, "it is important that we do not think in silos", but instead engage across sectors, actors, and geographies (AR3).

Such coordination challenge are also visible in relation to emerging system opportunities. For example, the utilisation of waste heat from data centres, a form of indirect electrification, depends on coordination with these actors regarding site placement, ensuring that heat can be into the DH network and further upgraded through heat pumps (DH1).

These coordination challenges extend beyond individual actors to the regional scale. Energy planning in Copenhagen is closely tied to developments in surrounding municipalities, as "activities and priorities in the [capital's] energy strategy have effects beyond the Municipality of Copenhagen and are to a large extent also influenced by what happens in neighbouring municipalities" (Københavns Kommune, 2025). This creates a need for new forms of cross-municipal governance, reflected in the recognition that "a relevant task will be to explore how broader coordination and collaboration on energy planning can take place across municipalities" (Københavns Kommune, 2025). Coordination is therefore not only a matter of aligning actors within the capital, but also across administrative, geographical boundaries.

### 6.6.4 Synthesis: organizational reverse salients

Overall, these findings would appear to suggest that electrification is shaped by complex coordination challenges arising from strong interdependencies across infrastructure, planning, and investment decisions. The transition is not constrained by a lack of willingness among actors, but by misaligned timelines, fragmented responsibilities, and regulatory frameworks that make it difficult to coordinate action under uncertainty. The central challenge is that progress depends on multiple conditions being met simultaneously. From an LTS perspective, these challenges can be understood as organizational reverse salients, where coordination mechanisms and governance structures lag behind the technical potential for electrification.

## 6.7 Summary of key findings

The key findings from the above analysis are summarised in the table in the Appendix. The table brings together the findings from Research Question 1 on the future of DH and Research Question 2 on the constraints shaping electrification. It shows that while electrification is widely expected to increase, the transition is shaped by a set of interconnected reverse salients across technical and geospatial, economic, political/regulatory and organizational dimensions.

## 6.8 Multi-Level Pespective Framework

### 6.8.1 Alignment

The Multi-Level Perspective (MLP) provides a useful conceptual lens for analysing the electrification of DH within broader sustainability transitions. The shift towards electricity-based DH can be understood as a socio-technical transition involving changing relations between technologies, infrastructures, institutions, actors and operational practices that together fulfil the societal function of heat provision. In this sense, the MLP is valuable because it directs attention not only to technological change, but also to the wider socio-technical configuration in which that change is embedded.

The empirical material suggests that the fit with the classic MLP is only partial. While the framework helps illuminate important dynamics around innovation, regime stability and landscape pressure, it does not fully capture the specific form that this transition is taking in practice. Rather than a straightforward story of niche innovations replacing an incumbent regime, the case points to a more gradual restructuring of an existing heat system. Geels' later refinements to the MLP, particularly his emphasis on transformation, reconfiguration and incumbent reorientation, therefore appear especially relevant [JP1].

In the Danish context, heat provision has historically relied heavily on combustion-based technologies, including coal, natural gas, waste incineration and biomass-fired combined heat and power. These technologies form part of an established socio-technical regime characterised by a relatively stable alignment between infrastructure, market structures, regulatory arrangements and operational routines.

In terms of Geels' transition phases, the electrification of DH appears to be situated primarily in the diffusion stage. Electricity-based technologies such as large heat pumps and electric boilers have clearly moved beyond the experimental phase and are increasingly being deployed in mainstream DH systems. As Michael Skrøder notes, electric boilers have expanded rapidly in recent years and, when new heat production is planned, it is now primarily electric boilers and heat pumps that are being considered (SA-R1). At the same time, implementation still involves adaptation and learning. Although the technologies themselves are not entirely new, their application at large scale in DH, especially in complex metropolitan systems, has required continued learning-by-doing. Interviewee SA1, for example, describes the technologies as "more or less developed", while still pointing to incremental improvements, such as developments in refrigerants and optimisation for sources such as seawater (SA1).

However, the material also shows that diffusion is far from smooth. As Geels argues, socio-technical regimes are stabilised by techno-economic, social, cognitive and political lock-in mechanisms, which make them difficult to transform. This is clearly visible here. Electricity-based technologies are not entering an empty system but must expand within a heat system already structured around existing plants, infrastructures and operational logics. Several of the difficulties identified in the material can therefore be understood within the MLP framework as struggles associated with diffusion: competition with incumbent combustion-based assets, business struggles over profitability and operating hours, and broader tensions around how emerging technologies are incorporated into an established system. This is illustrated clearly by the continued weight of incumbent assets in Copenhagen. Amagerværket's Blok 4 and the Avedøreværket's Blok 2 (biomass CHP plants) were completed only a few years ago at very high cost and are therefore unlikely to be shut down in the near future given the 'sunk costs' that would be incurred (EN2). Similarly, the waste-to-energy plant, Copenhill, is 'oversized' and waste incineration continues to be prioritised in heat dispatch in Copenhagen (DH2). When waste heat is dispatched first, the operating hours available to heat pumps and other electricity-based technologies are reduced, thereby weakening their business case. Another key point is that the heat networks and building infrastructure in Copenhagen is not designed for lower temperatures in the supply and return temperatures where heat-pump technologies operate most efficiently. This also makes the transition to using certain types of heat pumps more difficult in practice. Together, these examples show that diffusion is not simply a matter of spreading new technology, but of trying to scale it within a system whose assets, cost structures and operating priorities were shaped under different conditions.

At the same time, the interviews and recordings point to constraints that are less clearly foregrounded in the classic MLP literature. While these barriers are not incompatible with the framework, they tend to be treated in a relatively abstract way, and the classic MLP can also place too much emphasis on incumbent resistance as the main cause of stalled transition processes. In this case, however, the picture is more complicated. Many incumbent DH actors are not primarily resisting electrification, but are themselves actively engaged in pursuing it. Yet progress is still slowed by concrete technical, physical and organizational constraints that shape implementation in practice, for example the long waiting times for connections to the grid and the difficulty of finding sites with both adequate space and strong electricity connections. These kinds of concrete constraints are evidently central to how the transition unfolds in practice, yet they are not always analysed in much depth in the classic MLP framework, hence why the use of the 'reverse salients' framework was used as the primary tool of elucidating the challenges in electrification.

### 6.8.2 Landscape pressures and the window of opportunity

Landscape pressures are clearly pushing the transition forward. In Geels, the socio-technical landscape refers to wider exogenous developments, such as war, macro-political shifts or societal priorities, that place pressure on existing systems and create more favourable conditions for emerging innovations. In this case, the climate crisis and the decarbonisation agenda form the broad background pressure, but more immediate geopolitical developments have also become highly significant. In the recorded material, both Stephanie Lose and Jeppe Bruus explicitly connect the green transition in DH to security, resilience and critical infrastructure, thereby broadening the rationale for electrification beyond climate mitigation alone (PL1; PL2). Electrification is therefore increasingly framed not only as a climate response, but also as part of a wider response to energy security concerns and geopolitical instability.

However, the material also shows that these landscape pressures do not push uniformly in one direction. Security concerns may strengthen the case for electrification, but they can also reinforce arguments for diversity, backup capacity and the continued role of multiple heat sources. Interviewee EN2, for example, argues that while the share of electric heat should increase substantially, a fully electric system is neither necessary nor necessarily desirable from a national energy security perspective, because periods of high electricity prices and low renewable generation make diversity valuable (EN2). This is significant because it suggests that the existing regime is not simply being displaced by one coherent alternative but is instead renegotiated through competing interpretations of what security, affordability and sustainability require. While the window of opportunity for electrification has to some extent opened, supported by strong national and regional policy and planning, countervailing dynamics remain present, both in the framing of the transition and in the form of concrete system constraints that shape what is feasible in practice.

The final phase of the four phases in the MLP framework, institutionalisation, would imply that the new system replaces the old and becomes the new normal. It becomes embedded in regulation, infrastructure, professional standards, user expectations and accepted ways of operating. The material suggests that electrification has not reached that point, at least not in the sense of full regime replacement. Electricity-based technologies are clearly spreading and becoming more central, but combustion-based assets still retain an important role, and many of the established actors, institutions and infrastructures remain in place. Indeed, full institutionalisation may never occur if the long-term aim is not a fully electric heat system, but a more diverse and flexible DH system.

### 6.8.3 Reconfiguration, transformation and elements of substitution

For these reasons, the case is better understood through Geels' later pathways of reconfiguration and transformation rather than the classical substitution model. Reconfiguration describes a process in which niche innovations are incorporated into an existing regime and gradually reshape its architecture through cumulative, knock-on effects (Geels, 2026). This characterisation fits well here. Large-scale heat pumps, electric boilers, thermal storage and new forms of interaction with the electricity system are not displacing DH as a socio-technical system; rather, they are being integrated into it, progressively altering how it operates. The pathway of transformation is also evident, as incumbent actors remain central to the process. It is primarily established DH companies that are driving the shift, rather than new entrants disrupting the regime from the outside.

Nevertheless, elements of substitution can still be observed, particularly in relation to bioenergy. As electrification technologies expand, they increasingly displace biomass-based heat production and the associated technologies and expertise, which particularly affects DH suppliers. This also points towards a gradual reconfiguration of competences within the sector. Future capabilities are likely to shift away from combustion-based operations towards skills related to electricity markets, system modelling, economic optimisation and smart, automated control of integrated energy systems (EN2).

Overall, then, the electrification of DH both aligns with and stretches the classic MLP theory. The framework remains valuable for highlighting the role of innovation, learning processes, regime stability, landscape pressure and socio-political struggle. However, the empirical material suggests that the classical image of niche breakthrough followed by regime replacement is not the best fit. What emerges more clearly is a gradual reconfiguration of DH through the incorporation of electricity-based technologies into an incumbent-led system. At the same time, the case also shows that some of the most important barriers to implementation are highly concrete and operational, and therefore less fully captured by the classic MLP's more aggregated account of transition dynamics. It would also appear that Geels' later concepts of reconfiguration, transformation, multi-system interaction and incumbent reorientation are more analytically useful than the simple four-phase substitution model for understanding the current electrification of DH.

# 7 Discussion

This discussion relates the findings to the most relevant literature, outlines the contribution of the thesis, and reflects on generalisability, limitations and avenues for further research.

## 7.1 Discussion in relation to the most relevant literature

Section 2.4.2 of the Background chapter presented future scenarios for DH electrification outlined in the report *Elektrificering af varmesystemet i hovedstadsregionen* (Ea Energianalyse & PlanEnergi, 2025). One reason for including RQ1, concerning actor perspectives on the future of DH, was to examine the extent to which these scenarios are regarded as realistic by actors involved in the transition. As noted in the analysis above, the interviewees and speakers who provided concrete estimates generally expressed somewhat more cautious expectations, most often envisioning electrification levels ranging from approximately one third to two thirds of DH production or capacity. By contrast, Scenarios 1-3 in the report, *Elektrificering af varmesystemet i hovedstadsregionen,* projected electrification levels of roughly 60-75% (Ea Energianalyse & PlanEnergi, 2025).

Several factors may help explain this difference. Firstly, the stakeholder composition differs somewhat between the two studies. Whereas the report primarily centred on DH companies and municipalities, this thesis also included a broader range of actors, including sector associations, consultants, academics and interest organizations etc. Secondly, the empirical material for this thesis was collected in spring 2026, by which point the gravity of several constraints may have become more apparent. For example, in March 2026 Energinet announced a temporary three-month pause on new grid connections while reassessing capacity constraints and revising its strategy for connection prioritisation (Energinet, 2026), highlighting the seriousness of grid-related bottlenecks. At the same time, these findings should not be overstated. The thesis is based on a relatively limited sample of 11 interviews, and not all interviewees were willing or able to provide concrete estimates regarding future electrification levels. The findings should therefore be understood as indicative actor perspectives rather than definitive forecasts and will need to be confirmed through further research.

The most relevant articles identified in the literature review were Li and Nord's (2018) article on the technical challenges of transitioning to 4GDH and Reda et al.'s (2021) paper on the socio-technical transition towards low-carbon DH in Finland. Li and Nord offer a technical account of the infrastructural and operational changes required for 4GDH, while Reda et al. situate the transition towards low-carbon DH within a broader socio-technical framework. Some of their findings directly support the results of this thesis, while others provide additional insights into aspects of the transition that this thesis was not able to examine in the same level of detail.

One important point of overlap concerns the challenge of lowering network temperatures. This thesis identified the high-temperature legacy of Copenhagen's district heating system as a significant barrier to the efficient integration of large-scale heat pumps. Similarly, Reda et al. (2021) emphasise the importance of lower-temperature systems for improving the utilisation of renewable and low-temperature heat sources. Li and Nord (2018) argue that most Danish district heating systems can still largely be characterised as third-generation systems and that substantial work remains before lower-temperature 4GDH systems can be fully realised.

This is closely linked to the existing building stock. Li and Nord note that older buildings are expected to account for around 85–90% of the Danish building stock in 2030 and that many existing older buildings have space-heating systems designed for supply temperatures of around 70°C or higher (Li & Nord, 2018). The prevalence of older buildings in Greater Copenhagen was also identified in this thesis as a constraint on the transition towards lower-temperature DH. However, Li and Nord add an important nuance by showing that older buildings should not be treated as an absolute obstacle. Retrofitting measures, such as window replacement and the installation of low-temperature radiators, can make it possible to heat even older buildings at lower supply temperatures (Li & Nord, 2018).

Li and Nord and Reda et al. help frame the transition to low-carbon DH as a process of whole-system reconfiguration rather than merely the substitution of heat production technologies. Reda et al. make this point explicitly by arguing that the unit of analysis should move beyond "single green technologies" towards changes in "entire provision systems", where the system architecture may be "stretched or reshaped" through "new linkages" between system modules (Reda et al., 2021, p. 3). This aligns closely with the findings of this thesis, where electrification emerged not as an isolated technological shift, but as a process that links heat production, electricity networks, storage, planning, regulation and market operation. Thus this transition can also helpfully be categorized as a 'whole-system reconfiguration'.

The articles also highlight a dimension that this thesis did not cover in detail, namely the enabling role of smart systems and ICT. Li and Nord argue that smart DH depends on a physical network, internet-of-things technologies and intelligent decision systems, while Reda et al. state that ICT is "fundamental" because smart control and automation are needed "to properly orchestrate the heat production, storage and consumption of energy flows" (Reda et al., 2021, p. 5; Li & Nord, 2018, p. 494). These insights highlight the digital capacity and mutually responsive systems needed to coordinate increasingly interdependent energy flows across sectors.

A further shared theme concerns flexibility, intermittency and back-up capacity. Reda et al. argue that "flexible back-up power and heat production capacity is needed during times of low wind and solar power production or high energy demand periods" (Reda et al., 2021, p. 5). Li and Nord suggest that intermittency can be managed through combinations of renewable energy technologies, thermal storage and dispatchable heat sources. These points are relevant to this thesis, where energy security and the need for some dispatchable capacity emerged as recurring concerns. However, the findings of this thesis also show that there is no clear agreement on what this back-up capacity should consist of. Reda et al. (2021) suggest renewable gases, such as biogas and hydrogen, as potential low-carbon back-up options. In this thesis, some actors argued in favour of continued reliance on biomass, particularly due to existing infrastructure and operational familiarity (CN1; SA1), while others emphasised the value of gas-based solutions given ease of dispatch and the ability to store it for longer than biomass, which can start to decompose (EN1).

Li and Nord (2018) primarily is useful for specifying the technical adjustments required to enable lower-temperature DH systems. However, because their analysis is primarily technical and engineering-oriented, they give less attention to how these adjustments are shaped by actor interests, regulatory frameworks, investment incentives and institutional responsibilities. Reda et al. (2021), by contrast, are more useful for situating these technical issues within a broader socio-technical, MLP transition perspective. The approach adopted in this thesis is more closely aligned with Reda et al.'s socio-technical framing, although this study identifies a wider range of constraints than Reda et al. and is situated within the Danish rather than Finnish context.

A notable difference that emerged when comparing the findings of this thesis with those of Reda et al. concerns the relationship between incumbent energy companies and new entrants.

Reda et al. identify a considerably more antagonistic relationship between these actor groups than the one observed in this thesis. In the Finnish case, stakeholder positions were strongly structured around distinct actor categories, leading them to conclude that "the positions of the new entrant and energy companies were diametrically opposed" (Reda et al., 2021, p. 8). Incumbent energy companies were associated with a preference for slowing down the transition. By contrast, new entrant firms, including companies working with renewable energy, excess heat recovery, ambient heat pump systems, energy efficiency, building automation and demand response, interpreted incumbents as resisting change due to vested interests and 'old mindsets' (Reda et al., 2021). This presents a relatively classical Multi-Level Perspective interpretation of niche-regime conflict, where emerging actors challenge an incumbent regime shaped by existing assets, infrastructures and routines.

The findings of this thesis suggest a somewhat different dynamic in Greater Copenhagen, where incumbent DH actors appear not simply as barriers to electrification, but as active participants in the transition. Several DH companies and sector associations demonstrate significant momentum towards greater use of large-scale heat pumps, electric boilers and thermal storage. There are several possible explanations for this difference. One is contextual and temporal: Reda et al.'s study examines the Finnish DH transition at an earlier stage, whereas this thesis analyses Greater Copenhagen at a point where electrification has become a more established planning and investment priority.

A second explanation concerns methodology and stakeholder framing. Reda et al.'s stakeholder approach is valuable because it shows how understandings of the transition are situated: different actors emphasise different barriers, opportunities and risks depending on their position within the system. At the same time, such an approach can risk overstating divisions between groups if actors are treated as representatives of relatively coherent stakeholder categories. Reda et al. themselves acknowledge this limitation when they note that actors are "not a homogenous group sharing a common set of values and business model innovation attitudes" (Reda et al., 2021, p. 9).

At the same time, the differences between the studies should not be overstated, as this thesis does also identify elements of tension between the 'old' and the 'new'. For example, competition can be observed between existing bioenergy suppliers and providers of new electricity-based technologies (and related services). Similar tensions also arise in the operation of the heat dispatch system, where waste-based heat is prioritised, thereby reducing the operating hours available for electric technologies. In this sense, the findings of this thesis do not reject Reda et al.'s more antagonistic interpretation but rather qualify it. They show that there can be broad support for greater electrification of DH, while power struggles can still emerge between particular sub-groups of incumbents and newcomers.

## 7.2 Contribution to the literature

This thesis contributes to the literature by shifting attention from the system-level potential of electrified DH to the practical conditions under which this potential can be realised. Techno-economic modelling and optimization studies are valuable because they can help to identify desirable pathways and can support decision-makers in assessing whether, and to what extent, electrification should be pursued. However, they often say less about how electrification unfolds in practice within a specific institutional, infrastructural and spatial context.

This thesis addresses that gap by providing an empirically grounded analysis of the constraints shaping electrification in Greater Copenhagen, making visible the gap between modelled transition pathways and the practical realities of system integration. It contributes by showing that electrification is not simply a matter of replacing combustion-based heat production with electricity-based technologies, but a broader process of system reconfiguration involving heat production, electricity networks, storage, spatial planning, regulation and market operation. By using the concept of reverse salients, the thesis identifies where this reconfiguration is slowed by uneven development across interdependent parts of the system. The contribution is therefore not primarily to demonstrate that electrified DH is desirable or technically possible, but to explain why implementation remains difficult even in a favourable and advanced DH context.

This thesis also contributes to the literature by being situated in the Danish context and by examining several issues that have so far received limited attention in academic studies. Li and Nord (2018) emphasise technical challenges related to lower network temperatures, building adaptations, heat source integration, thermal storage and smart system operation, while Reda et al. (2021) identify broader socio-technical barriers, including biomass lock-in, stakeholder disagreement, electricity taxation and the need for smarter energy systems. The findings of this thesis support many of these insights but show how they materialise within the specific context of Greater Copenhagen and it highlights a wider set of practical constraints. These include electricity grid capacity limitations, land-use pressures, storage feasibility, dispatch rules, sunk assets, tariff structures, cost-recovery regulation, municipal guarantees, competition with individual heating solutions, political uncertainty, *inter alia.*

The thesis also contributes theoretically by demonstrating the usefulness of the reverse salient concept for analysing DH electrification. Rather than identifying a single dominant barrier, the analysis shows that constraints emerge where different parts of the system develop unevenly. Electricity-based heat production technologies may be relatively mature, but their deployment is slowed by the wider system conditions. This supports the value of analysing electrification as part of a large technical system, where delays arise from interdependencies between components, actors and sectors.

## 7.3 Generalizability & limitations

### 7.3.1 Generalizability

This study adopts a single-case qualitative design focused on the Greater Copenhagen DH system. As such, the findings are not statistically generalisable in a positivist sense. The transferability of findings is conditioned by the specific institutional and infrastructural context of Copenhagen. The region benefits from a highly developed DH network, strong municipal ownership structures and long-standing planning traditions, which are not present in many other countries. The findings should therefore be interpreted as context-sensitive rather than universally applicable.

At the same time, the case has broader relevance because Denmark can be considered a "leading-edge" or "critical" case, understood as a case with strategic importance in relation to a broader problem (Flyvbjerg, 2006). The fact that these challenges emerge even under relatively favourable conditions suggests that many of these types of constraints are also likely to arise in other pursuing electrification of DH. Even if the specific manifestations differ across countries, broader challenges such as grid capacity limitations, coordination across actors, regulatory misalignments, and tensions between system-level and project-level economics are likely to arise in other urban European contexts pursuing electrification of their DH systems, although this of course remains more speculative.

### 7.3.2 Limitations

Several limitations affect this study. Firstly, the analysis reflects the perspectives of selected actors rather than the full population of stakeholders. Although efforts were made to include a diverse range of actor types and to triangulate data sources, some perspectives may still be underrepresented. While the empirical material includes contributions from more than 35 different stakeholders through interviews, recordings and reports, only 11 actors were interviewed directly in relation to the research questions. This limits the comprehensiveness and representativeness of the findings and means that the results should be interpreted as indicative rather than fully representative of the wider sector. The study did not include interviews with actors directly involved in building retrofits, although building-level adaptations are important for enabling lower-temperature DH. Nor did the study include interviews with staff in relevant municipalities or the energy ministry, which may have provided further insight into policy frameworks, political priorities and planning processes.

Second, while the thesis focuses on Greater Copenhagen, not all data sources were equally region-specific. Some recordings reflected a broader Danish DH perspective, and some interviewees spoke more generally about national conditions. This creates some uncertainty about which findings apply specifically to Greater Copenhagen. These insights are still relevant, as the region accounts for a significant share of Danish DH demand and is shaped by the same national regulatory and market context. However, the analysis would have been stronger if all empirical material had related directly to the chosen case.

Third, interview data may be subject to inaccurate recall, reflexivity and bias, as respondents may selectively remember events, provide imprecise accounts, or frame their responses in ways that reflect organizational interests or social desirability biases (Yin, 2018). While this was mitigated through triangulation and careful interview design, it cannot be fully eliminated. The use of recorded conference material introduces a bias towards more formal, strategic narratives that may not fully reflect day-to-day operational challenges.

Fourth, the study is temporally bounded and captures a transition that is still ongoing. Electrification of DH is evolving rapidly, and the findings should therefore be understood as a snapshot of a dynamic system rather than a definitive account.

Finally, the analytical framework itself introduces certain limitations. While the concept of reverse salients is useful for identifying system bottlenecks, it places analytical emphasis on constraints and may underrepresent areas of progress or positive system dynamics.

# 8 Conclusion

This thesis examined the electrification of DH in Greater Copenhagen through two research questions: how key actors view the future of DH in the region, and which constraints slow down the scaling of electrified DH. The study was motivated by the gap between the system-level potential of electrification and an understanding of its development in practice. While large-scale heat pumps, electric boilers and thermal storage are increasingly presented as central technologies in the next phase of DH decarbonisation and in terms of securing greater energy autonomy, the findings show that their deployment depends on much more than technological maturity or theoretical cost-efficiency. A central conclusion of this thesis is that DH electrification should be understood as a system integration challenge, in which progress depends on the alignment of electricity networks, heat infrastructure, spatial planning, regulation, investment conditions and actor coordination.

In relation to the first research question, the findings show that key actors broadly view electrification as an important part of the future DH system in Greater Copenhagen. Electrification is associated with the potential to reduce reliance on biomass, make greater use of renewable electricity and increase flexibility across the wider energy system. However, the findings do not point towards a simple transition from combustion-based heat to full electrification. Rather, the dominant vision is of a more electrified, but still diversified and hybrid, DH system. Security of supply, existing infrastructure and price competitiveness continue to shape expectations about the future heat mix.

In relation to the second research question, the thesis identifies a broad set of constraints that slow the scaling of electrified DH. Technical and geospatial barriers arise from electricity grid constraints; the high-temperature legacy of the existing district heating system, the condition of older building stock, and the difficulty of securing suitable sites for large-scale heat pumps, electric boilers and thermal storage in a dense urban region. Economic constraints relate to high upfront investment costs, uncertain operating hours, electricity price volatility, tariff structures and competition from existing biomass, waste-based heat and individual heat pumps. Political, regulatory and organisational constraints further affect implementation, as electrification depends on coordinated decision-making across utilities, grid operators, municipalities, regulators, national authorities and other sector actors. These interdependencies create sequencing problems, where actors are often uncertain about who should act first. The transition is therefore slowed not only by individual barriers, but by the difficulty of aligning technical, economic, regulatory and organizational processes in time.

The thesis helps to shift attention from modelled system potential to system realisation. Existing research has demonstrated that electrified DH can, under certain circumstances, be technically feasible and beneficial at the system level. This thesis does not challenge that conclusion but shows why implementation remains difficult even in a favourable and advanced DH context. By applying the concept of reverse salients, the study demonstrates how different parts of the system develop unevenly thereby slowing progress. Electricity-based heat production technologies may be relatively mature, but their deployment is constrained by lagging grid infrastructure, spatial limitations, investment uncertainty, dispatch arrangements and fragmented responsibilities. The thesis therefore contributes an empirically grounded account of electrification as a process of large technical system reconfiguration rather than as a discrete technological substitution.

## 8.4 Practical Implications and significance

The findings also have practical implications for policymakers, utilities and other stakeholders involved in the transition. Electrification strategies should focus not only on acquiring more electricity-based technologies, but also on the enabling conditions that determine whether these technologies can be integrated effectively. Securing more electrified DH is a complex puzzle and requires closer alignment between electricity grid planning and DH planning, earlier identification of suitable sites for production and storage infrastructure, and stronger coordination between permitting, investment decisions and regulatory approval processes. There is already notable collaboration through strategic forums, but this work must be continued, deepened and expanded to encompass more relevant actors.

As electricity grid capacity becomes an increasingly important constraint, the transition raises broader questions about how scarce capacity should be allocated. Moving beyond a purely first-come-first-served approach may require a more explicit discussion of the societal value of different projects, however sensitive this issue may be. This also implies a stronger role for policymakers in setting a strategic direction. While this debate has only begun to emerge, it will need to become more central as electrification accelerates across the heating, transport and industrial sectors, and as new electricity-demanding activities and project types, such as data centres and battery storage, place additional pressure on the grid.

A further practical implication concerns the allocation of operating hours within the district heating system. If Greater Copenhagen is serious about scaling electrified heat production, dispatch arrangements should consider not only short-term heat costs, but also long-term investment incentives. If waste-based combustion is routinely prioritised, it can reduce the operating hours available for large-scale heat pumps and weaken their business case. The profitability of electrification therefore depends on how production opportunities are allocated within the existing system. It is thus necessary for policy and planning actors in the heating sector to reflect on current dispatch principles in relation to whether they support or constrain the transition towards electricity-based heat.

In addition, the findings indicate that DH electrification requires a stronger political and public framing. As shown in the analysis, electrification is increasingly linked to climate goals, energy self-sufficiency and geopolitical resilience, but this connection has not always been effectively captured in the political debate. The transition thus depends on the ability of policymakers and sector actors to justify why these investments matter and build legitimacy around infrastructure decisions.

Although the findings are most directly relevant to the chosen system context, they arguably also have wider significance. Denmark is often regarded as a frontrunner in DH, and Greater Copenhagen represents a highly developed and institutionally mature heating system. The fact that substantial constraints emerge even in this context suggests that other urban regions pursuing DH electrification may encounter similar challenges, particularly in relation to grid capacity, spatial planning, actor coordination and the relationship between system-level and project-level economics. The specific form and severity of these constraints will vary across contexts, but the broader implication is likely to travel: electrification depends not only on selecting appropriate technologies, but on preparing the wider system around them.

## 8.5 Avenues for further research

Future research could build on this thesis in three main directions. First, further studies could move from identifying constraints towards evaluating potential solutions, particularly in relation to electricity grid expansion and coordination between heat and power planning. Second, more research is needed on building-level adaptation in the region, as lower-temperature DH and improved system efficiency depend partly on changes beyond the production side of the system. Third, survey-based research involving a wider range of DH actors could help assess how widely the constraints identified in this thesis are recognised across the sector and how severe different actors perceive them to be. This would complement the qualitative findings and support the development of more targeted strategies for different actor groups.

## 8.6 Concluding remarks

Overall, the thesis shows that the key question is not whether electricity-based technologies have a role to play in the future of DH in Greater Copenhagen, but whether the wider system can be developed quickly and coherently enough to allow them to fulfil that role. The transition from pipe dreams to practical implementation will therefore depend not only on the availability of relevant electricity-based technologies, but on the capacity to coordinate infrastructure, regulation, investment and planning across an increasingly interdependent and diverse energy system.

# Bibliography


Bach, B., Werling, J., Ommen, T., Münster, M., Morales, J. M., & Elmegaard, B. (2016). Integration of large-scale heat pumps in the district heating systems of Greater Copenhagen. *Energy, 107*, 321–334. https://doi.org/10.1016/j.energy.2016.04.029

Birch Sørensen, P., Elmeskov, J., Frederiksen, P., Bredahl Jacobsen, J., Buus Kristensten, N., Morthorst, P. E., & Richardson, K. (2018). *Biomassens betydning for grøn omstilling: Klimaperspektiver og anbefalinger til regulering af fast biomasse til energiformål*. Klimarådet.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Capone, M., Guelpa, E., & Verda, V. (2023). Optimal installation of heat pumps in large district heating networks. *Energies, 16*(3), Article 1448. https://doi.org/10.3390/en16031448

Chatham House. (2022, October 17). *Why burning biomass is not zero-carbon*. https://www.chathamhouse.org/2022/10/why-burning-biomass-not-zero-carbon

Cheng, L., Yu, Z., Xia, S., Li, S., Li, Y., Zhang, H., Li, B., Zhang, S., Liu, Z., & Zheng, W. (2022). Evaluation and optimization of heat pump combined district heating system: A case study of China. *Energies, 15*(20), Article 7622. https://doi.org/10.3390/en15207622

CONCITO. (n.d.). *Danmarks grønne tænketank*. Retrieved April 27, 2026, from https://concito.dk/

Danish Energy Agency. (2020). *Biomass analysis*. https://ens.dk/sites/default/files/media/documents/2024-11/biomasseanalyse_final_ren_eng.pdf

Danmarks Statistik. (2023). *NYT: CO2 fra biomasse udgør 31 pct. af drivhusgasser*. https://www.dst.dk/da/Statistik/udgivelser/NytHtml?cid=46703

Dansk Fjernvarme. (n.d.-a). *Analyser fra Dansk Fjernvarme*. Retrieved February 28, 2026, from https://danskfjernvarme.dk/viden-vaerktoejer/analyser

Dansk Fjernvarme. (n.d.-b). *Dansk Fjernvarme: Forsyningsselskabernes brancheforening*. Retrieved April 30, 2026, from https://danskfjernvarme.dk/

Dansk Fjernvarme. (2020). *Elektrificeringer i fjernvarmen*. https://danskfjernvarme.dk/media/cvjfg1b0/elektrificeringer_i_fjernvarmen_final_2020.pdf

Dansk Fjernvarme. (2025). *Eksperter advarer: Populært klimatiltag kan låse Danmark fast til forbrænding af biomasse*. https://danskfjernvarme.dk/aktuelt/presseklip/2025/250305-dagens-overblik

Dansk Fjernvarme. (2026, March 6). *Fjernvarmesektoren er blevet glemt, selvom sektoren har femdoblet forbrug af el*. https://danskfjernvarme.dk/aktuelt/nyheder/2026/fjernvarmesektoren-er-blevet-glemt-selvom-sektoren-har-femdoblet-sit-forbrug-af-el

David, A., Mathiesen, B. V., Averfalk, H., Werner, S., & Lund, H. (2017). Heat Roadmap Europe: Large-scale electric heat pumps in district heating systems. *Energies, 10*(4), Article 578. https://doi.org/10.3390/en10040578

Dehghan, S., Aunedi, M., Ameli, H., & Strbac, G. (2024). Whole-system value of electrified district heating networks in decarbonising heat sector in the UK. *Electric Power Systems Research, 229*, Article 110144. https://doi.org/10.1016/j.epsr.2024.110144

Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. (2023). *Official Journal of the European Union, L 2023/2413*. https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng

Ea Energianalyse & PlanEnergi. (2025). *Elektrificering af varmesystemet i hovedstadsregionen*. Energi på Tværs (Region Hovedstaden).

Eitan, A., & Hekkert, M. P. (2023). Locked in transition? Towards a conceptualization of path-dependence lock-ins in the renewable energy landscape. *Energy Research & Social Science, 106*, Article 103316. https://doi.org/10.1016/j.erss.2023.103316

Elangovan, E., Thuvander, L., Wallbaum, H., Audycka, B., & Szygulska, J. (2026, January). *Energy efficient renovation measures review* (EqualHouse Deliverable No. D8.1). Chalmers University of Technology.

Energinet. (2026, March 2). *Energinet indfører midlertidig pause i nye nettilslutninger og sætter turbo på akutpakke*. https://energinet.dk/om-nyheder/nyheder/2026/03/02/energinet-indforer-midlertidig-pause-i-nye-nettilslutninger-og-saetter-turbo-pa-akutpakke/.

Erhvervslivets Tænketank. (2025). *Energi og klima i 2025: Konkurrenceevne, forsyningssikkerhed og dekarbonisering*. DI. https://www.danskindustri.dk/arkiv/analyser/2025/5/energi-og-klima-i-2025-konkurrenceevne-forsyningssikkerhed-og-dekarbonisering/

European Commission. (n.d.-a). *ETS2: Buildings, road transport and additional sectors*. Retrieved May 13, 2026, from https://climate.ec.europa.eu/eu-action/carbon-markets/ets2-buildings-road-transport-and-additional-sectors_en

European Commission. (n.d.-b). *Heating and cooling*. Retrieved May 12, 2026, from https://energy.ec.europa.eu/topics/energy-efficiency/heating-and-cooling_en

European Commission. (2022, May 18). *REPowerEU*. https://commission.europa.eu/topics/energy/repowereu_en

European Parliamentary Research Service. (2024). *Roadmap to EU climate neutrality: Scrutiny of Member States: Denmark's climate action strategy* (PE 767.173). https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/767173/EPRS_BRI(2024)767173_EN.pdf

Eurostat. (2026, March 18). *Energy in Europe: Imports dependency*. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/wdn-20260318-1

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods, 5*(1), 80–92. https://doi.org/10.1177/160940690600500107

Geels, F. W. (2026). The multi-level perspective on sustainability transitions: Background, overview and current research topics. In J. Wesche & A. Hendriks (Eds.), *Introduction to sustainability transitions research* (pp. 15–33). Cambridge University Press. https://doi.org/10.1017/9781009437318

Gjoka, K., Rismanchi, B., & Crawford, R. H. (2025). Towards sustainable urban energy solutions: A multi-dimensional assessment framework for fifth-generation district heating and cooling systems. *Energy and Buildings, 326*, Article 115071. https://doi.org/10.1016/j.enbuild.2024.115071

Green Power Denmark. (n.d.). *Green Power Denmark*. Retrieved April 29, 2026, from https://greenpowerdenmark.dk/

Green Power Denmark. (2025). *Et elektrisk, selvforsynende og energiuafhængigt Danmark*. https://greenpowerdenmark.dk/files/media/document/Handout_GPD%20policyforslag_valgkamp_0.pdf

HOFOR A/S. (2025). *Miljødeklaration 2024 (200-metoden)*. https://www.hofor.dk/wp-content/uploads/2025/04/Miljoedeklaration-2024-200-metoden.pdf

Javanshir, N., Syri, S., & Hiltunen, P. (2024). The risks of electrified district heating in Finland's cold climate. *Renewable and Sustainable Energy Reviews, 202*, Article 114652. https://doi.org/10.1016/j.rser.2024.114652

Johansen, K., & Werner, S. (2022). Something is sustainable in the state of Denmark: A review of the Danish district heating sector. *Renewable and Sustainable Energy Reviews, 158*, Article 112117. https://doi.org/10.1016/j.rser.2022.112117

Klima-, Energi- og Forsyningsministeriet. (2022). *Klimaaftale om grøn strøm og varme 2022*. https://www.kefm.dk/Media/637920977082432693/Klimaaftale%20om%20gr%C3%B8n%20str%C3%B8m%20og%20varme%202022.pdf

Klima-, Energi- og Forsyningsministeriet. (2025). *Klimastatus og -fremskrivning 2025*. https://www.kefm.dk/klima/klimastatus-og-fremskrivning/klimastatus-og-fremskrivning-2025

Københavns Kommune. (2025a). *Energistrategi for København 2025–2035*. https://www.kk.dk/sites/default/files/agenda/f07aa7ac-84d1-4ac2-9767-9098f737cd7e/8383ecbc-d6c8-47af-ac62-d06322618eb2-bilag-4_0.pdf

Københavns Kommune. (2025b). *Klimastrategi 2035*. https://www.kk.dk/sites/default/files/2026-04/Klimastrategi_Redesign26_web.pdf

Kontu, K., Rinne, S., & Junnila, S. (2019). Introducing modern heat pumps to existing district heating systems: Global lessons from viable decarbonizing of district heating in Finland. *Energy, 166*, 862–870. https://doi.org/10.1016/j.energy.2018.10.077

Li, H., & Nord, N. (2018). Transition to the 4th generation district heating: Possibilities, bottlenecks, and challenges. *Energy Procedia, 149*, 483–498. https://doi.org/10.1016/j.egypro.2018.08.213

Lowes, R., Rosenow, J., Qadrdan, M., & Wu, J. (2020). Hot stuff: Research and policy principles for heat decarbonisation through smart electrification. *Energy Research & Social Science, 70*, Article 101735. https://doi.org/10.1016/j.erss.2020.101735

Lund, H., Østergaard, P. A., Nielsen, T. B., Werner, S., Thorsen, J. E., Gudmundsson, O., Arabkoohsar, A., & Mathiesen, B. V. (2021). Perspectives on fourth and fifth generation district heating. *Energy, 227*, Article 120520. https://doi.org/10.1016/j.energy.2021.120520

Lund, R., Ilic, D. D., & Trygg, L. (2016). Socioeconomic potential for introducing large-scale heat pumps in district heating in Denmark. *Journal of Cleaner Production, 139*, 219–229. https://doi.org/10.1016/j.jclepro.2016.07.135

Martin, N., Zinck Thellufsen, J., Chang, M., Talens-Peiró, L., & Madrid-López, C. (2024). The many faces of heating transitions: Deeper understandings of future systems in Sweden and beyond. *Energy, 290*, Article 130264. https://doi.org/10.1016/j.energy.2024.130264

Mathiesen, B. V., Gonzalo, E. G., Georgati, M., Nielsen, S., & Nikolic, J. (2026). *Heat Roadmap Europe: Towards a sustainable, resilient and competitive heating sector by 2050: Main report*. Aalborg University. https://vbn.aau.dk/da/publications/heat-roadmap-europe-towards-a-sustainable-resilient-and-competiti-2/

Ørsted. (n.d.). *Fremtiden for bioenergi i Danmark*. Retrieved April 20, 2026, from https://orsted.dk/bioenergi/fremtiden-for-bioenergi-i-danmark

Østergaard, P. A., Jantzen, J., Marczinkowski, H. M., & Kristensen, M. (2019). Business and socioeconomic assessment of introducing heat pumps with heat storage in small-scale district heating systems. *Renewable Energy, 139*, 904–914. https://doi.org/10.1016/j.renene.2019.02.140

Pavlenko, A., & Cherp, A. (2026). Do energy security crises accelerate decarbonisation? The case of REPowerEU. *Energies, 19*(1), Article 200. https://doi.org/10.3390/en19010200

Pesola, A. (2023). Cost-optimization model to design and operate hybrid heating systems: Case study of district heating system with decentralized heat pumps in Finland. *Energy, 281*, Article 128241. https://doi.org/10.1016/j.energy.2023.128241

Plechinger, M. (2026, March 26). Cerius kalder på hastelovgivning om elnettet. *Energiwatch*. https://energiwatch.dk/Energinyt/sol/article19108419.ece

Rådet for Grøn Omstilling. (n.d.). *Rådet for Grøn Omstilling*. Retrieved April 30, 2026, from https://rgo.dk/

Rämä, M., & Wahlroos, M. (2018). Introduction of new decentralised renewable heat supply in an existing district heating system. *Energy, 154*, 68–79. https://doi.org/10.1016/j.energy.2018.03.105

Reda, F., Ruggiero, S., Auvinen, K., & Temmes, A. (2021). Towards low-carbon district heating: Investigating the socio-technical challenges of the urban energy transition. *Smart Energy, 4*, Article 100054. https://doi.org/10.1016/j.segy.2021.100054

Sarbu, I., Mirza, M., & Muntean, D. (2022). Integration of renewable energy sources into low-temperature district heating systems: A review. *Energies, 15*(18), Article 6523. https://doi.org/10.3390/en15186523

Sorknæs, P. (2021). Hybrid energy networks and electrification of district heating under different energy system conditions. *Energy Reports, 7*, 222–236. https://doi.org/10.1016/j.egyr.2021.08.152

Swain, J. (2018). *A hybrid approach to thematic analysis in qualitative research: Using a practical example*. SAGE Publications. https://doi.org/10.4135/9781526435477

Terreros, O., Spreitzhofer, J., Basciotti, D., Schmidt, R. R., Esterl, T., Pober, M., Kerschbaumer, M., & Ziegler, M. (2020). Electricity market options for heat pumps in rural district heating networks in Austria. *Energy, 196*, Article 116875. https://doi.org/10.1016/j.energy.2019.116875

Torp, A. T. K. (2026, January 22). *Fjernvarmen gennemgår den største omstilling i 100 år*. Green Power Denmark. https://greenpowerdenmark.dk/nyheder/fjernvarmen-gennemgaar-stoerste-omstilling-100-aar

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). SAGE.

# Appendix

*Appendix A. Summary of key findings*

| Category | Subcategory | Key Findings / Insights |
|---|---|---|
| **Future of DH** | **Degree of electrification & biomass phase-out** | Electrification of DH expected to increase significantly in the next decades, but hybrid system remains dominant vision. Biomass will have a declining role but not fully eliminated in medium term. |
| **Technical & Geospatial** | **Electricity grid capacity** | Grid constraints are one of the most critical bottleneck, leading to delay or downscaling of electrification projects. Lengthy approval and permitting procedures create structural lag between demand and infrastructure readiness. |
| | **Renewable electricity availability** | Electrification depends on sufficient renewable electricity being available. Delays in expanding green power production could weaken the climate benefits of electricity-based heating. |
| | **Technology-specific uncertainties** | Seawater and air-source heat pumps face efficiency/reliability challenges in cold conditions. Refrigerant choices involve safety and performance trade-offs. |
| | **Temperature mismatch** | Copenhagen's DH system was designed for high-temperature combustion-based production. This creates challenges because heat pumps operate most efficiently at lower temperatures. |
| | **Geospatial constraints** | Urban density limits space for infrastructure. This applies for both heat pump and thermal storage sites. |
| **Economic** | **Investment scale and coordination** | Electrification requires major coordinated investments across heat production, electricity grids, and building adaptation. Existing biomass assets also create sunk-cost challenges. |
| | **Project-level business cases** | Individual projects face cost pressures from competition for labour and equipment, high urban land prices, and the need to remain competitive with individual heat pumps. Existing heat dispatch rules can also reduce heat pump operating hours, weakening their business cases. |
| | **Long-term uncertainty and investment risk** | Electrification projects require long-term investment decisions, but future electricity prices, tariffs, regulation, construction costs, and geopolitical conditions remain uncertain. This makes investors more cautious. |
| | **Institutional and regulatory constraints** | The cost-recovery principle protects consumers but can limit incentives for innovation and anticipatory investment. Similar constraints affect grid companies, where revenue-cap regulation may discourage proactive grid expansion. |

| | | |
|---|---|---|
| | **Tariffs and guarantees** | Current tariff structures do not always reward flexible electricity use by DH companies. Differences in municipal guarantee schemes can also create uneven financing conditions between projects. |
| **Political/ Regulatory** | **Crisis, security and urgency** | Energy security can strengthen the case for electrification, but crises can also create caution, uncertainty and competition with the climate agenda. |
| | **Weak direction and lagging frameworks** | Actors point to unstable political signals, insufficient long-term planning and regulatory frameworks that have not fully caught up with technological possibilities. |
| | **Uneven regulatory conditions** | Electricity tax reductions have improved conditions, but building regulations and energy labelling still create an uneven playing field between DH and individual heat pumps. |
| | **Past investment experiences** | Previous costly transitions in DH continue to shape caution towards new large-scale investments. |
| | **Legitimacy and visibility** | The benefits can be difficult to communicate publicly because DH lacks visibility and emotional appeal. As electrification requires more infrastructure that can change the landscape, such as transmission cables and production sites, local opposition may become more significant. |
| **Organizational and coordination challenges** | **Interdependencies and "chicken-and-egg" dynamics** | Projects require land, permits and grid capacity simultaneously, but each depends on the others. This creates uncertainty over who should be the first to commit. |
| | **Grid capacity prioritisation** | Many sectors compete for limited grid access, including heating, transport, data centres, batteries and Power-to-X. This raises questions about how socially important projects should be prioritised. Clearer political guidance may be needed to move beyond a simple first-come, first-served approach. |
| | **Fragmented responsibilities** | More actors become involved in the energy system and no single actor has overall responsibility for coordination. This makes planning and investment alignment difficult. |
| | **New forms of collaboration** | Electrification of DH requires closer cooperation between utilities, grid operators, municipalities and new actors such as data centres. This is needed to align project development, infrastructure planning and the use of new heat sources. |
| | **Cross-municipal coordination** | Copenhagen's energy planning is closely connected to developments in neighbouring municipalities. This makes regional coordination important for siting infrastructure, sharing resources and planning the wider energy system. |

# Declaration of Use of Generative AI (GAI) Tools

**1) Permitted Uses in This Course**

Students may use GAI tools for:

- Brainstorming and idea generation
- Planning and outlining
- Language support (grammar, clarity, tone)
- Translation of non-personal, non-sensitive content
- Drafting outlines (not full assignments)

Requirements:

- You must critically review, fact-check, and edit all AI outputs.
- Do not submit unedited AI-generated work.
- Do not input personal, sensitive, or confidential data into GAI tools.

**2) Student Declaration (to be completed)**

Project/Assignment title: Masters Thesis

Did you use GAI tools for this work? Yes

If Yes, complete the items below.

a) Tools used

List the tools and versions (e.g., "ChatGPT, Claude, DeepL"):

| |
|---|
| ChatGPT, DeepL |

b) What you used them for (check all that apply)

Brainstorming / idea generation

Planning / structuring

Language editing (grammar/clarity)

Translation

c) How you used the tools (be specific)

Describe prompts, steps taken, and how you revised the outputs:

| |
|---|
| To brainstorm topic ideas and think about the structure of the thesis<br><br>Later, mainly to improve the grammar and clarity of certain sections where I had the ideas but they were not reading well.<br><br>Also for some of the translations from Danish to English |

d) Your own contributions

What parts are entirely your original work?

| |
|---|
| This thesis is my own original work |

e) Verification and editing

How did you verify accuracy and edit AI output?

I mainly used it for structure and clarity, so just checking whether it made sense to put it that way.

Student signature: ________________ Date: 15-05-2026__________