Klimarådet.

December 2022

From gas to clean heating

Recommendations for an accelerated transition from natural gas to district heating and individual heat pumps

English summary

klimaraadet.dk

Introducing the Danish Council on Climate Change

The Danish Council on Climate Change is an independent body of experts who advise the Danish government on how to transition to a climate-neutral society, thereby ensuring that, in the future, we can live in a country with very low emissions of greenhouse gases while retaining our level of welfare and development. Each year, the Danish Council on Climate Change assesses whether the government's climate efforts have demonstrated that Danish climate targets are likely to be met. The Council also contributes to the public debate and regularly prepares analyses and recommendations for climate efforts.

From gas to clean heating
Recommendations for an accelerated transition from natural gas to district heating and individual heat pumps

Published 01 December 2022

Danish Council on Climate Change
Nikolaj Plads 26
1067 Copenhagen K, Denmark
+45 22 68 85 88
mail@klimaraadet.dk
klimaraadet.dk

Written by
Peter Mollgaard
Jette Bredahl Jacobsen
Niels Buus Kristensen
Jorgen Elmeskov
Bente Halkier
Per Heiselberg
Marie Trydeman Knudsen
Poul Erik Morthorst
Katherine Richardson

Klimarådet.

Table of contents

Abstract

The European energy crisis has accelerated the need to phase out oil and gas from heating systems. A broad majority in the Danish Parliament has agreed that the use of natural gas for heating must stop in 2030. On this background, in December 2022, the Danish Council on Climate Change (DCCC) published an analysis of the factors that should be considered in an accelerated transition from natural gas to individual heat pumps or district heating. While an accelerated phasing out of natural gas in the heating sector will have an immediate effect on greenhouse gas emissions and energy security in Europe, it is important that the decisions and plans we make today also make sense in the long run. In Denmark, suburban areas that predominantly comprise detached housing account for the biggest share of natural gas use for heating, while the Danish urban centres are typically supplied by district heating. Focussing on a model suburban area, the DCCC analysis investigates which factors an accelerated phasing out of natural gas should consider and how to ensure an optimal phasing out of gas both in the short and long run.

The main conclusion from the analysis is that low-temperature district heating based on large heat pumps is both the most energy- and cost-efficient heating solution. This is particularly true if there is access to geothermal energy or excess heat from industry. The costs of preparing Danish buildings for low-temperature heating are estimated to be fairly low, implying that the benefit of lower energy consumption in low-temperature district heating outweighs the costs of increasing the energy efficiency in buildings. Although low-temperature district heating potentially leads to the lowest costs for society, this low cost depends on a high connection rate to the system. If too few buildings connect to the district heating system, the total investment and running costs per building would be too high in areas with modest heat consumption density. District heating projects where it is uncertain if district heating or individual heat supply is the best option are very sensitive to district heating connection rates. With low connection rates, individual heat pumps are likely to be the cheapest heating solution for society. Finally, the analysis shows that district heating based on burning of biomass is the most expensive heating solution for society in most situations. Combined with the fact that biomass is a scarce resource, the DCCC recommends that phasing out natural gas should not lead to an increase in the use of biomass.

This Policy Brief provides an English summary of the DCCC analysis. The full report can be found (in Danish) here: https://klimaraadet.dk/da/analyse/fra-gas-til-groen-varme

1. Introduction

Many households in Europe and in Denmark depend on natural gas for heating and much of this gas has historically been supplied by Russia. The war in Ukraine has made this dependence even clearer. Politically, this has accelerated the decision to phase out oil and natural gas in the Danish heating supply. In June 2022, the Danish Parliament agreed to stop the use of natural gas for space heating in 2030 and to introduce a full stop for the use of other kinds of gas, typically biogas, for space heating in 2035.[1] The agreement in the Danish Parliament required Danish municipalities, in cooperation with district heating companies and gas distribution companies, to make a plan for phasing out natural gas as soon as possible, and to communicate the plan to all citizens whose homes are warmed with a gas boiler.

This Policy Brief summarises the Danish version of an analysis published in December 2022 by the Danish Council on Climate Change (DCCC) that investigated which factors an accelerated phasing out of natural gas for space heating should focus on. In the analysis, the DCCC estimated which heat supply systems are best from a socio-economic point of view in both the short and long run. Furthermore, the DCCC mapped the barriers to both an accelerated implementation of new heat supply and an optimal green transition of the heating system in the long run.

15 percent of buildings in Denmark are heated by natural gas

In 2020, around 400,000 or 15 percent of buildings in Denmark had natural gas heating systems. This is shown in Figure 1 below. The most common heating supply system in Denmark is district heating. Sixty-five percent of the buildings in Denmark's are connected to district heating. Denmark has a long history of district heating supply systems going back to the first half of the 1900s and the expansion of district heating rapidly increased during the oil crises in the 1970s.[2] Denmark has one of the highest shares of district heating in Europe. With only 15 percent of Danish households being heated by natural gas boilers, Denmark has experienced a relatively lower impact from higher natural gas prices than countries with a much higher share of gas in their heat supply.

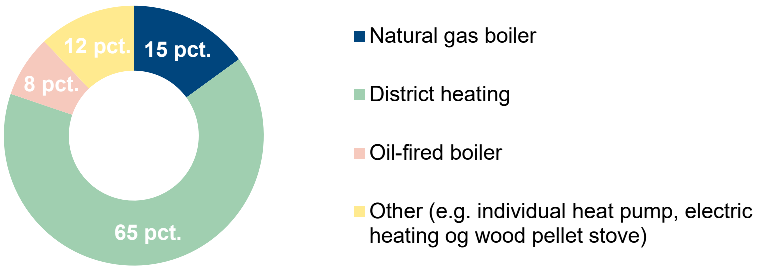

Figure 1 Danish heat system installations in 2020

Source: The Danish Energy Agency, 2021.

Individual heat pumps and district heating systems are alternatives to gas boilers
Individual heat pumps or district heating systems are considered as potential replacements for natural gas boilers. Both individual heat pumps and district heating can be fully based on renewable energy sources. District heating systems can use large heat pumps that use electricity, excess heat from industry, or other sources of energy. The DCCC has analysed, from a socio-economic point of view, whether heat-pump-based district heating, biomass-based district heating, or a solution that uses individual heat pumps is the optimal alternative to natural gas boilers. Furthermore, the DCCC analysis distinguishes between high-temperature and low-temperature district heating systems.

The DCCC has investigated five heating scenarios
The DCCC has analysed five alternative heating scenarios for transitioning from natural gas – one scenario with individual heat pumps, and four scenarios with different types of district heating. The analysis examines a model Danish suburban area of 1,000 single-family households that are heated by natural gas today. The model area is based on a dataset of all buildings heated by natural gas boilers in Denmark and has a representative distribution of age, size and energy consumption for all buildings supplied with natural gas in Denmark.

The economic viability of district heating systems depends on there being a sufficient heat demand within a certain area. The urban centres of most large Danish towns, which typically have a large share of multi-storey buildings and therefore high concentrations of heat demand, already have district heating. Therefore, current Danish heat planning focuses on whether district heating should be extended into suburban areas. This differs to heat planning in most other European countries, which tend to have a much lower share of district heating in their heat supply systems. District heating is, all other aspects being equal, more economically viable in urban centres. Many European countries still have urban centres with high concentrations of heat demand but without district heating. Introducing district heating in such urban centres is likely to be even more economically viable than reported for the model Danish suburban area analysed in this policy brief.

2. Danish heat supply in a European context

European countries rely on different fuels and infrastructures to supply their heat demands. Some countries primarily use natural gas through a centralised grid, some countries have a wide variety of heat sources, and some countries use district heating for densely populated areas. This section briefly compares Danish heat supply with that of other European countries and presents an overview of the Danish district heating regulation and governance. The results of the DCCC's analysis of heat supply should be seen in the context that Denmark already has a high share of district heating with a well-established regulatory framework supporting the sector.

In the 1980s, Denmark undertook detailed heat planning. This planning resulted in capital-intensive district heating schemes being developed in urban areas with high concentrations of heating demand (high heating density). Consequently, the central areas of most large Danish towns (typically with many multi-storey buildings) already have district heating. Urban areas with lower heating density levels were designated as areas that would rely on a natural gas distribution network and individual gas boilers in homes, due to the lower investment costs of the natural gas solution.

Heating systems vary across Europe and some countries are very dependent on gas for heating
Figure 2 shows that Denmark has a high share of buildings connected to district heating compared to most other European countries. District heating in Denmark is typically supplied by waste or biomass as the source of energy. The heating systems in most countries in Figure 2 rely on individual oil and gas boilers. Especially the Netherlands, the United Kingdom and Malta rely on gas for space heating. Electric space heating is less common in most of Europe, but is widely used in France and Malta. This variation in heating systems means that European countries must carry out their heating system transitions from vastly different starting points, and this will influence how they approach a transition towards a clean heat supply based on renewable energy.

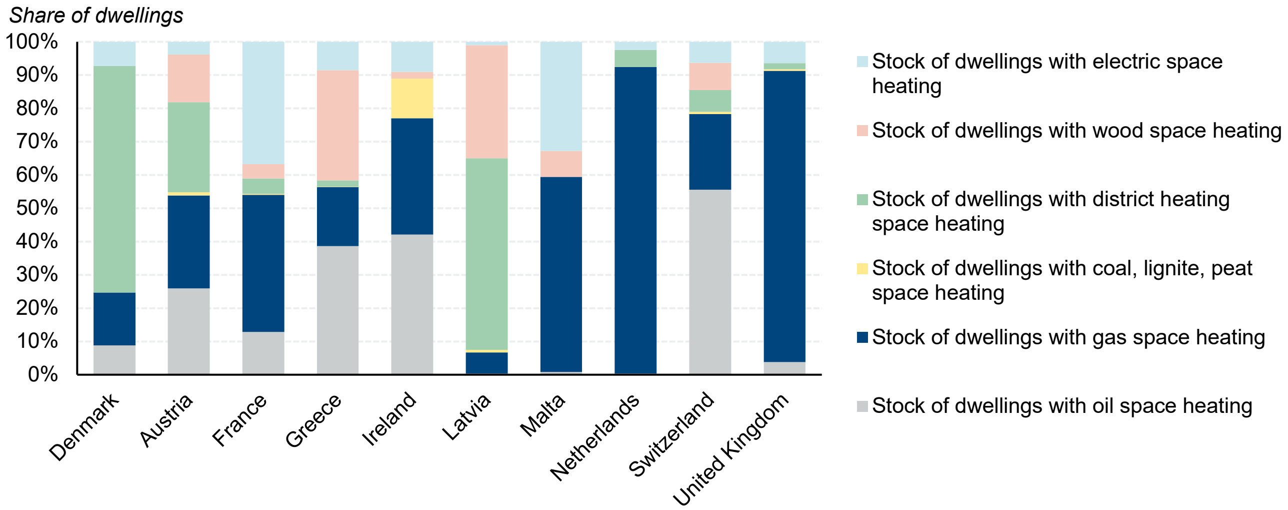

Figure 2 Permanently occupied dwellings by heat type in 2019 in a selection of European countries

Note 1: The countries in the figure are selected based on available data.

Source: Odyssee (Date of export: 2023-01-12).

Danish district heating regulative experience
Denmark has a high share of district heating as a result of a long historical development where technology, ownership and regulation have evolved together.[3] This has given Denmark a district heating governance regime that ensures fair consumer prices and long-term investment in heating infrastructure. Countries who are exploring the potential of district heating might seek inspiration in the Danish district heating model outlined below.

The main parts of Danish district heating governance consist of various regulations, price control and public ownership.[4,5] They have all been subject to change and it is often discussed whether elements should be renewed to accommodate new tasks, new technological options or changes in society. District heating is regulated in the *Heat Supply Act*, which defines district heating, stipulates which actors can plan and operate district heating systems, regulates heat planning in municipalities, and determines how to calculate district heating consumer prices. Important parts of this governance regime include:

- **The non-profit principle.** Danish district heating companies can only include necessary costs in their consumer price for heating. This means, in principle, that the consumer price for heating may only include investment, operating and maintenance costs, as well as other required expenses. However, exceptions to this principle have been made recently, as suppliers of renewable and excess heat are now allowed to include a profit in their consumer price for heating.

- **Public ownership**. Most district heating companies are owned either by the municipalities or the consumers directly. Very few are owned by private companies. Whether public ownership is beneficial or not is an ongoing debate in Denmark. Arguments for public ownership include the view that public ownership ensures low heating prices as the owners have no incentive to charge more, and it ensures long-term investments as there is no need for short-term profit. Arguments against public ownership mostly focus on a view that a lack of competition between private heating companies weakens the incentive to bring down costs.
- **Socio-economic calculations.** District heating companies have to prove that their investments provide a net benefit to society as well as showing they have a positive business case. There is a set of calculation rules and technology price estimates that have to be used for the socio-economic calculations, which are maintained and updated by the Danish Energy Agency. The existence of common calculation rules and cost estimations means that it is relatively easy to compare and evaluate different project proposals, compared to a situation without any common references.
- **Access to public finance.** Investments in district heating systems can be financed by public funds with low interest rates and long payback periods. This can decrease the cost of capital compared to alternatives on financial markets.

The Danish system should not be seen as the only viable governance regime, but as an example of how different elements come together to regulate a sector. District heating governance needs to adapt to local conditions and specific needs.

3. Technical alternatives to natural gas supply

A number of technical alternatives to heat supply based on natural gas exist. It is well established that electrification of heat consumption can integrate wind and solar energy in the heating sector.[6] Electricity can be used to produce heat through heat pumps. Heat pumps can either be used at an individual building level or as collective units in a district heating system. A district heating system can furthermore use excess heat resources, for example from industry, datacentres, or from power production. Heat can also be produced from a number of other sources, for example from biomass or using hydrogen. These solutions are generally not preferable compared to heat pumps, which is outlined in the section below.

3.1 Individual heat pumps and district heating as alternatives to gas-fired heating

Some areas are more suited to individual heat pump units being installed in buildings while others are better suited to collective heating supply (district heating). In this section we outline some pros and cons of individual heat pumps and district heating relative to each other.

Implementation speed is faster for individual heat pumps compared to district heating
Individual heat pumps can be installed in a fairly short amount of time as long as there is an available supply of units on the heat pump market. On the other hand, district heating systems often take years to plan, get approvals from the authorities and to tender, contract and build. The difference in implementation speed means that individual heat pumps may replace natural gas faster than district heating. This is good if individual heat pumps are the best solution for society. However, if district heating is the optimal solution for society in a specific locality, a fast roll-out of heat pumps can undermine the economic viability of a potential district heating project. Since there are large collective investments associated with district heating, it is important that as many of the building owners as possible agree on connecting to a new network. Low connection rates are a barrier to exploiting scale effects in what would otherwise be economically viable district heating projects.

Individual heat pumps are efficient but less flexible

Individual heat pumps use electricity to generate heat from a heat source, such as the outside air, and are typically fairly efficient. To some extent, individual heat pumps can operate in a flexible manner, such that they produce heat when the price of electricity is low. However, there are barriers to deploying this potential. Firstly, the buildings in which they are installed need to be well insulated, as heat storage is impractical or costly in small buildings. Secondly, the building owners either need to manually operate the heat pump or have a digital system to do so.

There are several system benefits related to district heating in a future energy system

One major advantage of district heating is that it can use heat from many different energy sources. Combined with large collective heat pumps, district heating systems can use excess heat from industry, datacentres and wastewater, as well as geothermal energy. In this way, heat pumps in district heating systems may need only limited electricity input. Furthermore, there are several system benefits related to district heating in a future energy system:

- **Flexibility.** District heating systems can produce heat when the price of electricity is low, as they typically have large heat storage systems. This flexibility will especially be beneficial in a future energy system that is mainly based on intermittent and non-dispatchable wind and solar energy. In an energy system with larger shares of intermittent production of electricity, district heating systems can also contribute to stabilising the power grid by shutting down or turning on electricity-based heat production at short notice.
- **Security of supply.** Utilising excess heat in district heating systems will lower electricity consumption for heating. Lower electricity consumption means that less electricity production is needed, which is an advantage, especially during energy crises. Furthermore, lower electricity consumption makes the economy more resilient to rising electricity prices in critical security of supply situations.
- **Fewer problems with noise and groundwater from vertical drilling.** Local noise problems are an issue in some areas with individual air-to-water heat pumps. Furthermore, vertical drilling when installing water-to-water heat pumps can cause problems for groundwater.

3.2 Direct electrification is preferable to biomass or hydrogen

One of the scenarios analysed by the DCCC looked at district heating that uses biomass. Using biomass for heat supply can, however, be problematic, as outlined below. Some countries are also considering using hydrogen for their heat supply. This is not being considered in Denmark, and was therefore not included in the DCCC's socio-economic analysis of heating scenarios. However, a short example of the energy efficiency of using hydrogen compared to a heat pump is also included below.

Biomass is a scarce resource that has been widely used in Danish district heating

Biomass such as wood, wood pellets, wood chips and other bioenergy products are incinerated to produce heat in many Danish district heating systems. The DCCC finds that the consumption of biomass in Denmark is too high. Reports published by the DCCC have shown that the Danish consumption of biomass for energy use per capita is much higher than a level that can be considered globally sustainable, and that Denmark has the highest import of biomass in the EU.[7,8] This means that other countries should not follow Denmark's example when it comes to biomass consumption.

There are also other reasons why increasing consumption of biomass is problematic. In the Danish emissions inventory, the use of biomass for energy is accounted for as carbon neutral. This follows the UN accounting principles, but ignores the fact that burning biomass has an impact on the climate. In a report from 2018, the DCCC shows that incineration of biomass increases the concentration of carbon dioxide in Earth's atmosphere for a period of time.[9] The reason for this is that carbon dioxide is emitted when burning the biomass. Over time, under natural circumstances, this carbon dioxide would have been part of a slower natural carbon cycle, where the carbon dioxide either would still have been stored in the forest or would have been emitted through natural decomposition over several years. However, incineration of biomass creates an instant emission of carbon dioxide to the atmosphere, which can only be recaptured by new trees over decades. The climate impact of burning biomass is particularly problematic if biomass is imported from countries where accounting emissions from the land use, land use change and forestry sector is not done in accordance with the UN's rules or if emissions reduction targets are not strict. The problems described above support the argument that new district heating systems should be based on electricity rather than biomass.

Hydrogen is not an appropriate alternative to natural gas heating
Hydrogen has been proposed as a low-carbon alternative to natural gas. Benefits include the fact that green hydrogen produced from renewable electricity with electrolysis is CO_2 neutral and that existing gas infrastructure potentially can be repurposed into transporting the carbon-free fuel.

However, green hydrogen for heating has some major drawbacks. A recent review of 32 journal articles explores whether hydrogen for heating is a viable alternative to fossil fuels.[10] The review concludes that hydrogen for heating would lead to higher energy system costs and high consumer costs, primarily due to high electricity consumption.

The electricity consumption for hydrogen production has significant energy losses. These are primarily due to the energy losses in the electrolysis process, but are also due to compound losses in transmission, transportation and energy conversion from electricity production to final energy delivery. Based on this, it has been estimated that a heat pump, either in a district heating system or in a building, is five times more efficient at delivering heat than a hydrogen-based system would be.[11]

3.3 Low-temperature district heating and excess heat utilisation

Most district heating systems in Denmark are operated at system supply temperatures of over 70°C. Experts on district heating systems have analysed the benefits of lowering the temperature in district heating.[12] Low-temperature district heating is also called fourth-generation district heating. The supply temperature in low-temperature district heating is between 50 and 70°C.[13] The main benefit of low-temperature district heating is that it provides increased efficiency that lowers energy consumption and costs. The reasons for increased efficiency are that heat pumps are most effective in low-temperature systems and that the benefits of utilising excess heat are higher. Furthermore, the heat loss in the district heating pipes is lower.

Low-temperature heating and excess heat increase the efficiency of large heat pumps in district heating
Large heat pumps can produce heat for district heating systems based on electricity. Heat pumps are very efficient at producing heat, and are even more efficient in low-temperature district heating. This is especially the case if excess-heat sources are utilised. The reason is that the efficiency of heat pumps depends on the temperature in the heating system and the temperature of the heat source. This is illustrated in Figure 3 below.

The efficiency of a heat pump is defined as units of heat produced using one unit of electricity. This is also called the coefficient of performance (COP). A high COP means high efficiency. A heat pump uses the heat from a heat source and raises the temperature using electricity. Heat sources can be outside air, geothermal energy, underground water or excess heat from industry, datacentres or wastewater treatment plants. Figure 3 shows that heat sources with high temperatures, such as excess heat from industry, provide increased efficiency of the heat pumps. The figure also shows that the efficiency increases if the temperature required in the heat system is low. Especially heat pumps in district heating systems can benefit from using high-temperature excess-heat sources. This is a big advantage compared to individual heat pumps where the heat sources are often outside air or groundwater. This means that their COP is limited to 3-4, while heat pumps in district heating systems can reach higher COPs, both by using excess heat or geothermal energy and by lowering the supply temperature in the district heating system.

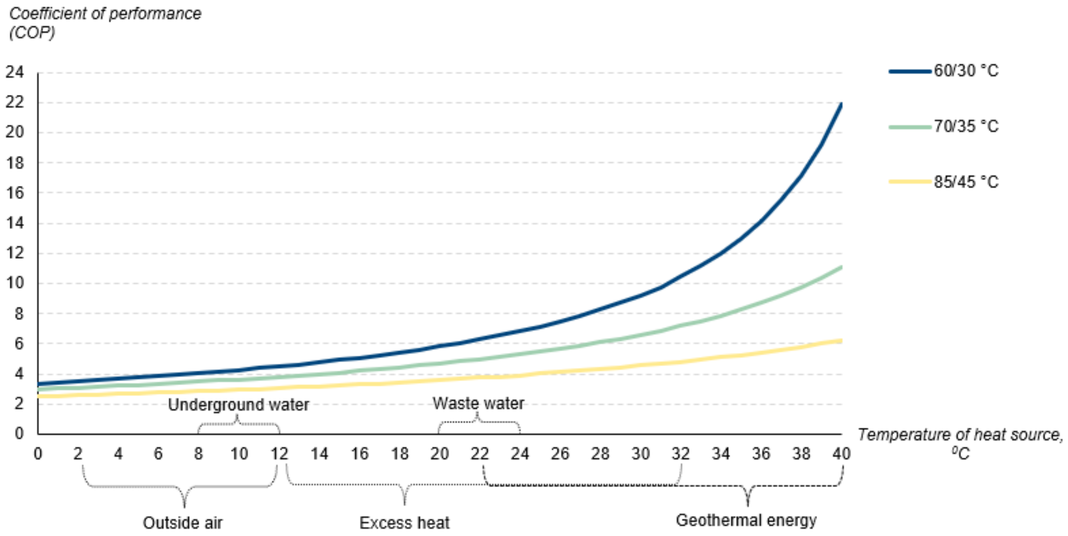

Figure 3 Coefficient of performance of heat pumps dependent on temperature of heat source at three different supply temperatures of district heat.

Note: The temperatures 85/45⁰C, 75/40⁰C and 60/30⁰C represent supply and return temperatures in district heating systems. Temperature levels of heat sources are indications and are not in absolute intervals.

Source: Danish Energy Agency and the Danish Council on Climate Change.

3.4 The relation between heat supply and the energy efficiency of buildings

When determining whether an individual heat pump solution or district heating is the optimal alternative to natural gas, one must consider the energy efficiency of the buildings in question. The energy efficiency and the state of the buildings have an impact on the overall efficiency of the heat supply system. Energy-efficient buildings require lower supply temperatures to deliver the heat demand. Lower temperatures lead to increased efficiency for heat pumps and district heating systems. Conversely, a few energy-inefficient buildings in a district can require that an entire district heating system must operate at high supply temperatures, just to meet the demands of those few buildings. If one energy-inefficient building requires high supply temperatures in the heating system, this building tends to dictate the supply temperature in the whole district heating system.

Old and energy-inefficient buildings are potentially a barrier for low-temperature district heating
In some old and energy-inefficient buildings preparatory measures need to be taken to allow the buildings to benefit from space heating based on low-temperature district heating. These measures can include installing larger radiators, adjusting the heating system inside the building, or implementing energy renovation initiatives to reduce heat loss. Examples of energy renovation initiatives include changing windows or improving insulation of walls or lofts. These initiatives lower the energy consumption for heating in the building. While it is often only economically beneficial to carry out substantial energy renovation initiatives in combination with other major renovations of a building, smaller initiatives such as changing radiators and adjusting a building’s heating system can be done efficiently at all times.

Limited energy efficiency measures are likely necessary to prepare buildings for low-temperature heating
In the Danish case, there is limited evidence on the extent to which initiatives are needed to prepare older energy-inefficient buildings for low-temperature district heating. For that reason, this aspect is uncertain. However, on the basis of existing studies and selected experiences, the DCCC draws two conclusions on energy efficiency measures:[14,15,16,17,18,19,20]

1. Most buildings in the studies could attain normal heat comfort levels with low supply temperatures in district heating with none or very few energy efficiency measures needing to be carried out in the buildings.
2. More evidence needs to be gathered on the implementation of low-temperature district heating in existing buildings.

The DCCC finds that low-energy-efficiency of some buildings most probably is not a major barrier to providing buildings with low-temperature district heating. The main barrier to implementing low-temperature district heating is that district heating companies do not have sufficient knowledge on 1) which buildings are unsuited to low-temperature district heating, 2) how they can identify unsuited buildings and 3) which energy efficiency measures are necessary in these buildings.

Energy-inefficient buildings require larger individual heat pumps
Individual heat pumps may also struggle to provide adequate heat comfort in energy-inefficient buildings. This can often be solved by installing an individual heat pump with a larger capacity.[21] If many owners of energy-inefficient buildings choose this solution rather than improving their buildings' insulation, it will lead to higher electricity consumption in general and will increase the peak load of the electricity network. For those reasons, it is important to energy renovate energy-inefficient buildings when it is economically beneficial.

4. Economic analysis of alternatives to gas-fired central heating

The DCCC has analysed five alternative heating scenarios to natural-gas-fired heating. The analysis examines a model Danish suburban area of 1000 buildings that are heated with natural gas boilers. The model area represents an area comprising mostly detached houses but also some terraced houses. The model area is based on a dataset of all buildings heated by natural gas boilers in Denmark and has a representative distribution of age, size and energy consumption for all buildings supplied with natural gas in Denmark. The analysis asks whether a district heating system or installing individual heat pumps would be the most socio-economically viable option for replacing the gas-fired central heating.

The model area has a relatively modest heat consumption density of around 10 kWh/m^2. This 10 kWh/m^2 density of heat consumption means it is uncertain whether district heating or individual heat pumps will be the best option from a socio-economic viewpoint. As a comparison, several European urban centres have heat consumption densities of 30 kWh/m^2 and upwards, which, for such centres, makes it more likely that investing in district heating would be a socio-economically viable option.

Five scenarios for heat supply
The five heating scenarios include one scenario with individual heat pumps and four scenarios with different types of district heating.

The heating scenarios are presented in Table 1 below. The district heating systems either operate with high supply temperatures of 75^{0}C, or lower supply temperatures of 60^{0}C. If supply temperatures are low, energy renovation measures are needed in some of the least-efficient buildings. The cost of installing larger radiators in some of these buildings is included as a proxy for energy renovation measures. In the district heating systems, the heat is either supplied from a biomass boiler or a large heat pump. In the last scenario, excess heat is used as a heat source for a large heat pump in a low-temperature district heating system.

In scenario 1, all buildings install individual heat pumps. In scenarios 2-5 all buildings are connected to a district heating system. A range of different sensitivity analyses explores the robustness of the results.

Table 1 Five scenarios for heat supply

Scenarios	Heating system	Assumptions
Scenario 1	Individual heat pumps	- No energy efficiency measures undertaken in buildings. Heat pumps dimensioned according to the heat consumption of each building.
Scenario 2	New high-temperature district heating system with biomass boiler	- Supply temperature of 75ºC - No energy efficiency measures needed in buildings
Scenario 3	New high-temperature district heating system with large heat pump	- Supply temperature of 75ºC - No energy efficiency measures needed in buildings
Scenario 4	New low-temperature district heating system with large heat pump	- Supply temperature of 60ºC - Energy efficiency measures needed in some of the buildings (proxy: cost of installing larger radiators)
Scenario 5	New low-temperature district heating system with large heat pump and access to excess heat	- Supply temperature of 60ºC - Energy efficiency measures needed in some of the buildings (proxy: cost of installing larger radiators)

Local conditions determine which heat solution is most cost effective

The economic analysis shows that the socio-economic costs of transitioning from natural gas are in the same order of magnitude in most of the scenarios. This implies that changes in assumptions and local conditions are important for the relative costs between scenarios, which is shown in the following sensitivity analyses. The results of the economic analysis are presented in Figure 4, and from these, the DCCC draws three overall conclusions:

1. District heating based on burning of biomass is the most costly heating solution for society
2. Low-temperature district heating scenarios are the most cost-effective alternatives
3. Low-temperature district heating with access to excess heat is particularly beneficial.

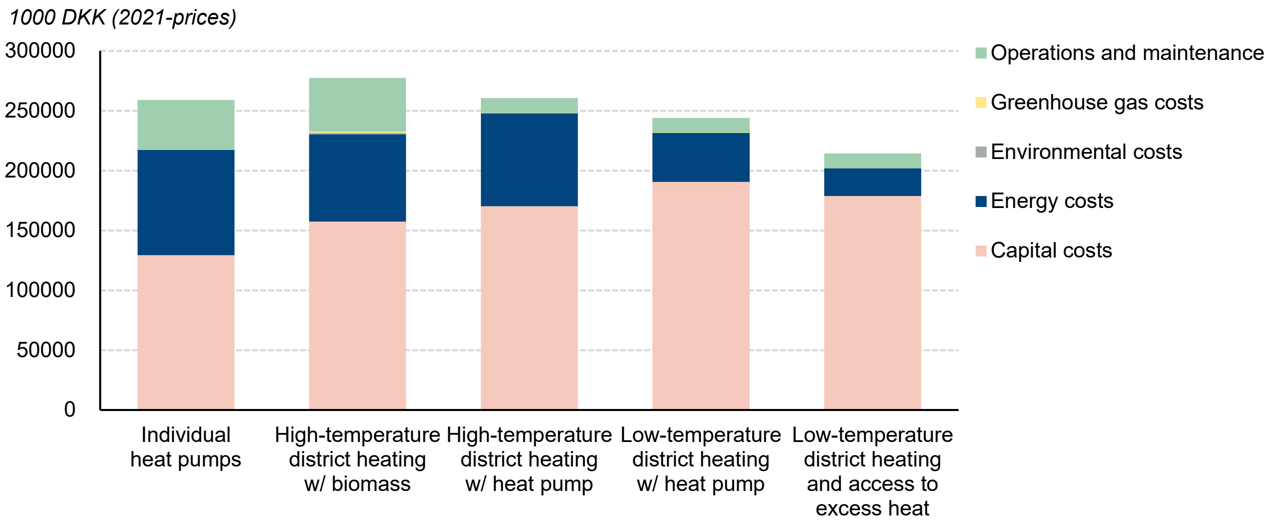

Figure 4 Total costs for society in heating scenarios

Note 1: The figure shows the present value of the total socio-economic costs for all 1,000 buildings in the DCCC model scenarios over the period 2023-2043. For district heating scenarios a connection rate of 100 percent is assumed.

Note 2: The costs of greenhouse gas emissions depicted in the high-temperature district heating with biomass relate to methane and nitrous oxide emissions. The carbon dioxide emissions from biomass burning are accounted as 0, since the burning of biomass is accounted as carbon neutral in Denmark's emissions inventory. The costs of emitting methane and nitrous oxide in all scenarios are valued based on the Danish Energy Agency's estimate of costs for CO_2-equivalent emissions outside the emissions trading sector.

Source: The Danish Council on Climate Change.

Low-temperature district heating has the lowest costs for society - in particular with access to excess heat

Scenarios with low-temperature district heating are the most cost-effective alternative. The main drivers of the cost-effectiveness are low energy consumption and low cost of operations and maintenance. These benefits outweigh the extra costs that would be incurred due to the energy efficiency measures that would need to be implemented in some of the energy-inefficient buildings, when compared with the other scenarios where such energy efficiency measures are unnecessary.

Low-temperature district heating with access to excess heat enables large energy savings. This is shown in Figure 5. Using excess heat as heat source increases the efficiency of the large heat pump, leading to lower electricity consumption and lower total energy costs.

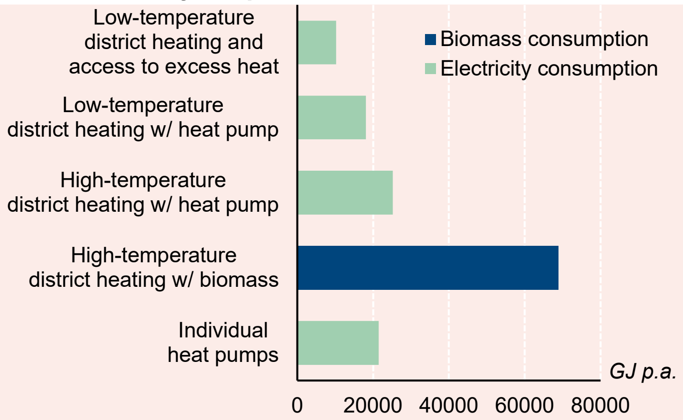

Figure 5 Average yearly energy consumption for all buildings in the scenarios

Source: The Danish Council on Climate Change.

Biomass should not be the energy source in new district heating systems
District heating based on biomass is the most costly heating solution for society. The main reasons for this are that biomass-based district heating uses more energy than alternatives based on electricity and that the operation and maintenance costs are high.

Changes in energy prices will especially affect the costs of less-energy-efficient heating systems. Figures 6.a and 6.b show how the total system costs change with changes in energy prices. It shows that low-temperature district heating is less sensitive to changes in electricity prices. Conversely, due to their higher energy consumption, high-temperature district heating and individual heat pumps are more sensitive to electricity price changes.

Biomass is a scarce resource and demand for biomass for many different purposes might increase. This means that biomass prices might increase in the future, also relatively more than electricity prices. Figure 6.b illustrates a situation with increasing biomass prices and stable electricity prices. Higher prices for biomass will make biomass-based district heating even more costly compared to heating systems based on electricity.

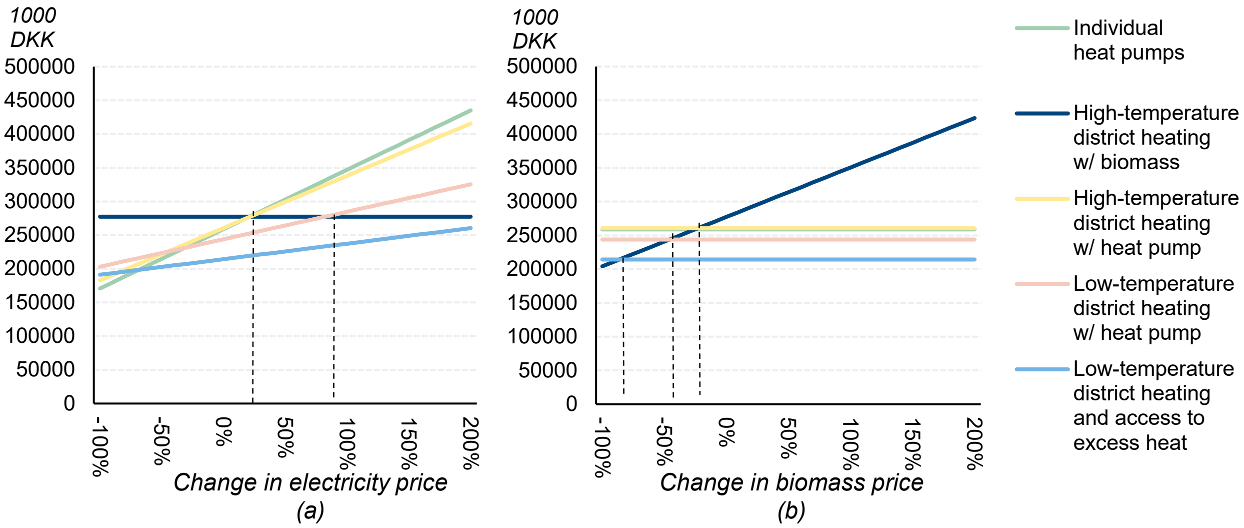

Figure 6 Total costs for society in heating scenarios at relative price changes in electricity and biomass prices

Note 1: The figure shows the present value of the total socio-economic costs for all 1,000 buildings in the DCCC model scenarios over the period 2023-2043. For district heating scenarios a connection rate of 100 percent is assumed.

Source: The Danish Council on Climate Change.

Share of buildings connecting to district heating is important for the economic viability of the projects
It is crucial for district heating projects that as many buildings in an area as possible connect to the district heating network. If too few buildings connect to the district heating system, the cost of heating each building with district heating becomes higher than heating each building with individual heat pumps. This is shown in Figure 7 below. If at least 90 percent of buildings in an area connect to low-temperature district heating, the district heating solution is cheaper per building than having individual heat pumps in every building. However, if low-temperature district heating is combined with access to excess heat sources, only 70 percent of the buildings need to connect to the district heating system for it to be more socio-economically beneficial than heating by individual heat pumps.

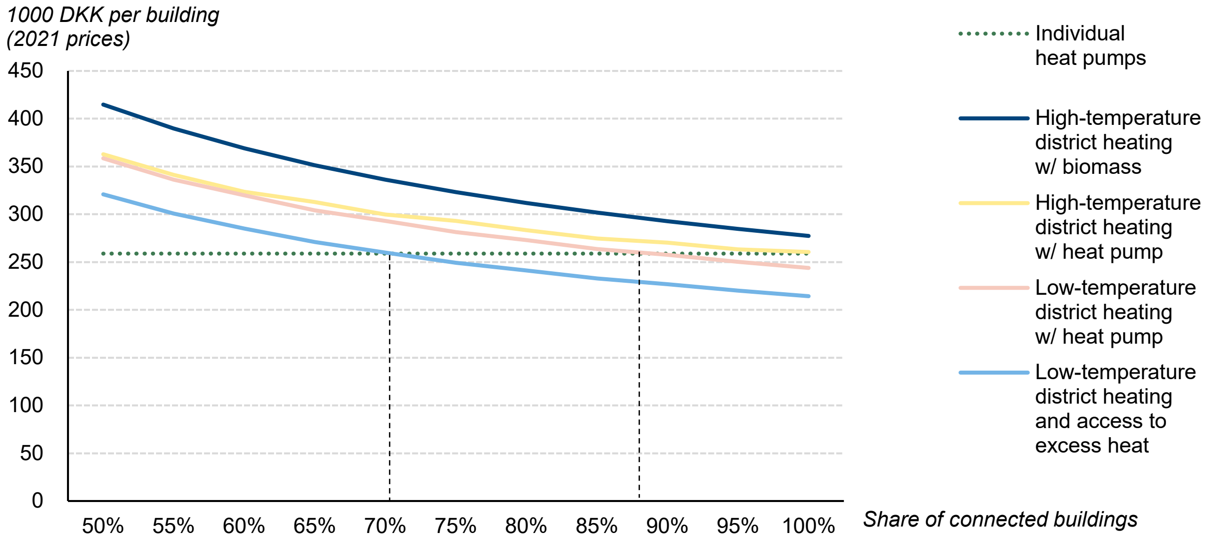

Figure 7 Total costs for society per building in heating scenarios depending on share of buildings connecting to district heating in an area

Note 1: The figure shows the present value of the total costs per building over the period 2023-2043.

Note 2: It is assumed that the share of buildings connected to district heating is unchanged over the period. This means that the calculation assumes a given share of buildings connected of 90 percent, for example, throughout the period and thus not increasing towards 100 percent.

Source: The Danish Council on Climate Change.

Temporary individual heat pumps can be substituted with district heating in the long run
Planning and constructing new district heating systems often takes more time than installing individual heat pumps. Schemes that enable the temporary installation of individual heat pumps during a period when district heating is being planned and constructed are a way of ensuring a faster phasing out of natural gas heating (compared to waiting for the completion of a new district heating network) and ensuring that enough buildings will connect to the district heating system. This could for instance be done by leasing a heat pump for five or ten years. An individual heat pump has a product life cycle of about 16 years. The DCCC has calculated the cost to society in a scenario where heat pumps are substituted by district heating after five or ten years, after which the heat pump is sold at scrap value. Replacing the heat pump when there are still some years of the product life cycle left means some of the pump's installation costs will not be offset by the energy savings that could have been gained had it operated through its whole potential service life (a so-called sunk installation cost).. However, replacing a temporarily installed heat pump with low-temperature district heating leads to energy savings and lower energy costs. The total costs after taking the sunk installation cost and the lower energy costs into account are of the same magnitude as keeping the individual heat pumps for their whole product service life.

5. Conclusions and policy recommendations

This section presents the main conclusions of the analysis and the DCCC's policy recommendations for Danish policy and decision makers. The conclusions of the analysis are based on the DCCC's socio-economic calculations and are likely applicable for other countries, although local conditions need to be considered, for example the quality of the building stock. Furthermore, while the DCCC's policy recommendations are formulated for a Danish context, the recommendations might also prove valuable for other countries in similar situations of an accelerated phasing out of natural gas from their heating supply.

Main conclusions

- **Low-temperature district heating based on large heat pumps is both the most energy- and cost-efficient heating solution in the model suburban area analysed.** The economic cost for society of low-temperature district heating based on large heat pumps is lower compared to other alternatives such as high-temperature district heating and individual heat pumps. This is especially the case when it is possible to use excess heat sources, for example from industry, in the district heating system. Furthermore, district heating has various system benefits compared to individual heat pumps. Energy-inefficient buildings will likely only require limited changes, such as the installation of new larger radiators, to be able to use low-temperature district heating for reaching comfortable indoor temperatures.

- **The benefit of lower energy consumption in low-temperature district heating outweighs the costs of increasing the energy efficiency in buildings.** Around 50 percent of Danish buildings have a relatively high consumption of energy per m^2 and might therefore require high temperatures from their heat supply source in order to heat the building to a comfortable standard. The majority of these buildings are located in areas where there is potential for district heating as an alternative to natural gas. Increasing the efficiency of these buildings or enlarging their radiator capacity might be necessary to enable low-temperature district heating. However, it is likely that the measures needed to improve the buildings are limited. This analysis assumes relatively low costs of preparing Danish buildings for low-temperature heating. The costs of preparing buildings for low temperature heating in general are uncertain and difficult to assess in Denmark.

- **It is crucial for district heating projects that a large majority of buildings in an area connect to the network.** If too few buildings connect to the district heating system, the total investment and running costs per building become too high in areas with modest heat consumption density. The feasibility of projects where it is uncertain whether district heating or individual heat supply is the best option is very sensitive to district heating connection rates. With low connection rates, individual heat pumps might be the cheapest heating solution for society.

- **District heating based on burning of biomass is the most expensive heating solution for society in most situations.** The main reasons for this are that biomass-based district heating is less energy efficient than electricity-based alternatives and that the operation and maintenance costs are high. Furthermore, biomass is a scarce resource and Denmark's use of biomass for energy purposes is already too high. Therefore, biomass consumption should not increase as a result of new district heating schemes in Denmark.

- **Short implementation time is key if district heating is to contribute to remedying the current energy crisis.** If the implementation time is too long, households will either continue heating with natural gas, which will be expensive and have consequences for the climate, or they will invest in individual heat pumps. Investing in heat pumps is not necessarily bad for society, but it can be a huge barrier to realising otherwise economically feasible district heating projects later on. To ensure adequate connection rates to future district heating projects, an option could be that households lease a heat pump until they can connect to the district heating system.

Main policy recommendations:

- **The phasing out of natural gas should not lead to increased biomass consumption, as biomass is a scarce resource that Denmark already draws heavily on.** Biomass should be prioritised for purposes where it creates the most value, which is not in the heating sector. The Danish government should therefore introduce regulations that ensure that the amount of biomass burning for energy purposes does not increase. The DCCC also recommends that district heating companies and municipalities minimise the establishment of new biomass capacity in the transition from natural gas boilers.

- **The government and municipalities should ensure overall prioritisation and coordination of the expansion of the district heating network.** The prioritisation should be based on how quickly the district heating projects can be established and which projects have a clear economic benefit for society relative to other alternatives. The most beneficial district heating projects will be those with a high socio-economic value and those that can be implemented fast. These projects should be prioritised and implemented quickly, preferably within the next three to five years. Prioritisation can give homeowners greater certainty about when they will get district heating and prevent them from buying an individual heat pump in the meantime. Prioritising and planning district heating projects can also help remedy any potential lack of labour and materials in the district heating sector and help avoid a situation where the green transition becomes unnecessarily expensive for society.

- **The government should give municipalities the authority to stipulate mandatory connection of buildings to district heating supply under certain conditions.** Mandatory connection to district heating once decided and planned can ensure a financially viable model for district heating and potentially lower heat supply costs for the consumers. Such regulation should be conditional on significant consumer protection. Consumer protection implies that the district heating company must guarantee cheaper heat supply than alternative heating solutions.

- **Municipalities and district heating companies in Denmark should investigate whether district heating can be established with a longer deployment rate** and lower initial connection rates, if this would enable higher connection rates over time. This means that buildings with newly established individual heat pumps can be connected on a continuous basis. Already today, district heating companies and municipalities can start working with prospective areas that can be connected in five to ten years, depending on the financial feasibility of the project. This gives time to continuously renovate the building stock in a given area, which would eventually mean that all buildings could be supplied with low-temperature district heating.

- **District heating companies should be given better opportunities to cooperate with owners of inefficient buildings** to ensure that the buildings can be supplied with low-temperature district heating. District heating companies should be able to provide targeted subsidies and help to increase the energy efficiency of critical individual buildings. This could include subsidies for improving heating systems or other relevant investments in buildings.

- **The Danish authorities should enforce the existing requirements in the Danish Building Code on making energy efficiency improvements in relation to major building renovations.** Enforcement can take place, for example, through random checks combined with fines or injunctions if the regulations are not complied with. In addition, help should be provided to optimise technical installations in buildings, for example through better information on energy saving potential and by offering free annual energy checks.

Klimarådet.

References

[1] Danish Parliament, *Climate Act on green electricity and heat 2022*, June 25, 2022.
[2] Danish Energy Agency, *Regulation and planning of district heating in Denmark*, 2017, https://ens.dk/sites/ens.dk/files/Globalcooperation/regulation_and_planning_of_district_heating_in_denmark.pdf
[3] Bertelsen, N., *Governing European Heat Transitions*, 2021, Aalborg University.
[4] State of Green, *District Energy Green Heating and Cooling for Urban Areas*, 2020, https://stateofgreen.com/en/wp-content/uploads/2018/08/SoG_WhitePaper_DistrictEnergy_210x297_V22_WEB.pdf
[5] Danish Energy Agency, *Regulation and planning of district heating in Denmark*, 2017, https://ens.dk/sites/ens.dk/files/Globalcooperation/regulation_and_planning_of_district_heating_in_denmark.pdf
[6] Lund, H., *Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems approach*, 2018, Energy 151, 94-102.
[7] The Danish Council on Climate Change, *Statusrapport 2022*, 2022.
[8] The Danish Council on Climate Change, *Biomassens betydning for grøn omstilling*, 2018.
[9] The Danish Council on Climate Change, *Biomassens betydning for grøn omstilling*, 2018.
[10] Rosenow, J., *Is heating homes with hydrogen all but a pipe dream? An evidence review*, 2022, Joule 6, 2219-2239, https://doi.org/10.1016/j.joule.2022.08.015.
[11] Rosenow, J., *Is heating homes with hydrogen all but a pipe dream? An evidence review*, 2022, Joule 6, 2219-2239, https://doi.org/10.1016/j.joule.2022.08.015.
[12] Sorknæs P. et. al., *The benefits of 4th generation district heating in a 100% renewable energy system, Energy*, 2020, Volume 213.
[13] Lund H. et. al., *4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems*, 2014.
[14] The Danish Council on Climate Change, personal correspondence with the local district heating company *Albertslund Forsyning*.
[15] The Danish Council on Climate Change, personal correspondence with the local district heating company *Viborg Fjernvarme*.
[16] Østergård, D.S. et. al., *Replacing critical radiators to increase the potential to use low-temperature district heating – A case study of 4 Danish single-family houses from the 1930s*, 2016
[17] Østergård, D.S. et. al., *Space hearting with ultra-low-temperature district heating – a case study of four single-family houses from the 1980s*, 2017
[18] Benakopoulos, T. et. al., *Improved control of Radiator Heating Systems with Thermostatic Radiator Valves without pre-setting Function*, 2019. https://www.mdpi.com/1996-1073/12/17/3215/htm
[19] Tunzi, M. et. al., *Digitization of the demand side: Use of heat cost allocators and energy meters to secure low-temperature operations in existing buildings*, 2022
[20] Østergård D.S. et. al., *Are radiators typically over dimensioned? An analysis of radiator dimensions in 1645 Danish houses*, 2018
[21] Teknologisk Institut, *Investeringer i varmepumper sammenlignet med investeringer i renovering af klimaskærmen for boliger*, 2020.