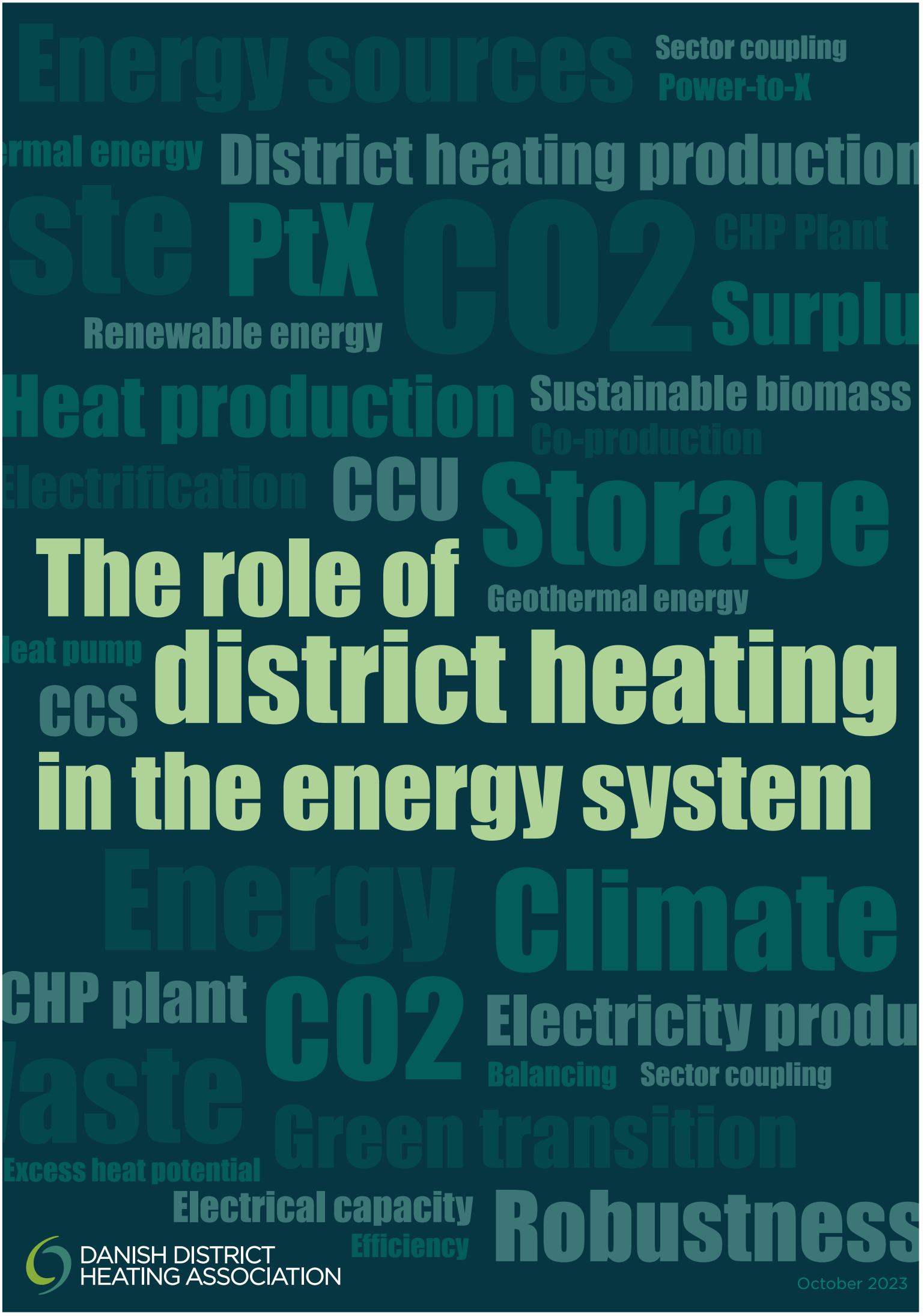


DANISH DISTRICT HEATING ASSOCIATION

October 2023

Value for you, me and the rest of society
The Danish district heating sector is characterised by providing green solutions for the benefit of Denmark.

We supply green heat to more than 1.8 million Danish homes and thus 3.7 million Danes. These are the same Danish homeowners who own the Danish district heating companies, either directly in a cooperative association or indirectly through the municipality. It is the same 3.7 million Danes who every day expect their district heating company always to deliver green heat. They have high expectations of the comfort we need to deliver.

Fortunately, Danish district heating companies do much more than that.

We help ensure security of supply in our electricity system, which is becoming increasingly green, but also increasingly volatile. Here, our combined heat and power plants provide the necessary balance so that we each have access to electricity when we need it.

We have been at the forefront of meeting our climate goals. Today, 76.9 percent of district heating comes from green renewable energy sources. By 2030, we expect the sector to be 100 percent green.

At the same time, a large number of companies, not least waste-to-energy plants, are involved in projects aiming to capture, store and utilise CO_2. It was not on the cards just a handful of years ago that the waste-to-energy sector would be one of the sectors responsible for some of the most forward-thinking technological development we have seen in Denmark in recent years.

We create value by utilising excess heat from industry, including the upcoming Power-to-X plants. Analyses show that selling excess heat to district heating can improve the competitiveness of PtX plants located in Denmark compared to neighbouring countries without widespread district heating.

I hope you will enjoy this publication, where we have compiled some of the contributions that the Danish district heating sector provides to us, to homeowners and to society.

Happy reading!

Jesper Frost Rasmussen

Chairman, Danish District Heating Association

Contents

Introduction

District heating really came into focus in 2022 when the Russian invasion of Ukraine sent energy prices skyrocketing. Since then, the country's district heating companies have been working hard to roll out district heating to as many people as possible as quickly as possible. More than 58,000 homes received district heating in 2022. This is the largest influx of new district heating consumers in 30 years. Many consumers have been (or still are) faced with the choice of a heat pump now or waiting for district heating to be rolled out to their area. Many choose to wait for district heating. This is probably mainly due to advantages such as stable and low prices compared to other forms of heating, and from a consumer's point of view, it can be of great value to avoid disadvantages such as noise nuisance, space requirements, responsibility and the costs of operating and maintaining an individual heat pump. However, district heating comes with a number of other benefits that are less obvious from a consumer perspective, but important from a societal perspective. District heating makes it possible to interconnect energy systems (called sector coupling) for the benefit of the parties involved and society.

A changing energy system

In the near future, large amounts of green energy will come from wind turbines, solar cells, biogas and soon also from Power-to-X plants. This requires strong cross-functional solutions. In return, the benefits are huge, both economically and for the climate. At the heart of the cross-cutting solutions, district heating can create societal benefits for the electricity system, for the necessary efforts to reduce greenhouse gas emissions and by benefiting the energy industry from export[1] to the development of new technologies such as geothermal energy, Power-to-X (PtX) and Carbon Capture Utilisation and Storage (CCUS).

This report aims to shed light on how district heating creates value for society through integration with the overall energy system.

The energy system is changing rapidly. An increasing share of fluctuating renewable energy needs to be integrated into the system, which can challenge the security of electricity supply. In the electricity system of the future, there is a much greater need for demand response to ensure simultaneity between consumption and production. At the same time, batteries and other forms of energy storage, along with sustainable biomass and green gases, are expected to play a greater role in ensuring resource adequacy and balancing electricity demand and supply (Energinet, 2022).

District heating can contribute to the integration of increasing amounts of renewable energy

Denmark has a number of strengths compared to other EU countries when it comes to integrating the increasing amounts of renewable energy, including the district heating sector. When there is a lot of solar and wind energy in the system and the electricity price is therefore low, the district heating sector's electric boilers and heat pumps can produce heat that can either be used immediately or directed to thermal storage and used for later heating. The district heating system can thus be seen as a huge energy storage system where "overproduction" of electricity can be stored. Conversely, when the electricity price is high, the district heating sector can turn off its electricity-consuming units in exchange for producing electricity at thermal CHP plants. In this way, district heating can contribute to solving the challenges in the electricity market, but district heating also creates value for other sectors, such as industry by utilising excess heat (often alternatively referred to as 'waste heat' or 'surplus heat', i.e. heat produced as a byproduct of other processes) that would otherwise go to waste.

Sections 2-6 explain the role of district heating in the energy system with a focus on a number of selected areas. It has not been the purpose of the report to account for the total socio-economic value creation of district heating, but rather to exemplify how district heating, in addition to its core task, also creates value in other sectors. Initially, in Section 2, the energy system of the future is characterised by summarising scenario reports from a number of key players in the Danish energy sector. Section 3 explains the fundamental advantages of district heating in terms of energy efficiency and flexibility, which translate into low and stable prices compared to other forms of heating. Section 4 describes the interaction of district heating with the electricity sector, while Section 5 has a special focus on sector coupling and the benefits of utilising excess heat, including excess heat

1) In 2022, a total of DKK 6.3 billion worth of district heating technology and services were exported. (The Confederation of Danish Industry (DI), Green Power Denmark, Danish Energy Agency and Danish District Heating Association, 2023).

from PtX, and the future potential of utilising excess heat. Finally, Section 6 explains the green transition of district heating production, the sector's ambitions for carbon neutrality and the potential for achieving CO_2 reductions in other sectors.

Summary

Energy Efficiency

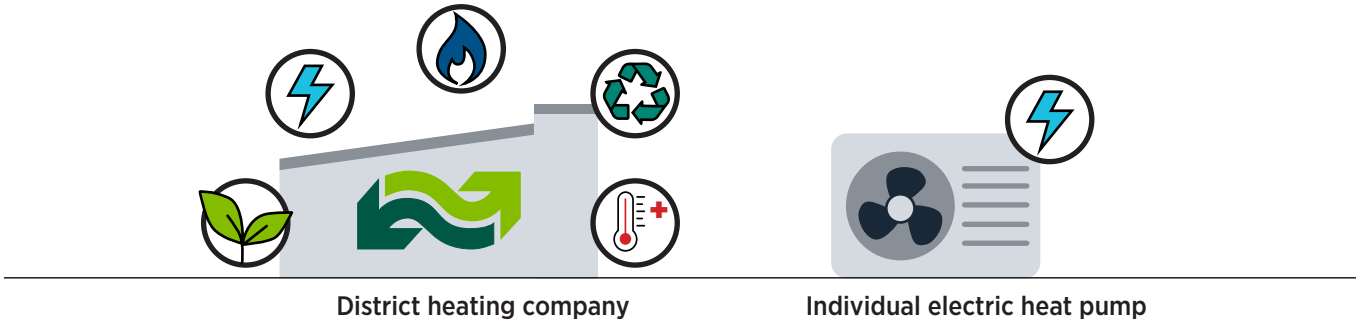
Denmark's first district heating plant was established 120 years ago to utilise the excess heat from waste incineration. Later, excess heat from electricity production was also utilised, and today district heating also utilises excess heat from industrial processes that generate heat, such as cooling, drying, evaporation, and melting. A large part of district heating is thus based on utilising energy sources that would otherwise be wasted, which increases the overall efficiency of the energy system.

In addition, a communal heating system makes it possible to utilise differences in the consumption patterns of heat consumers, which means that less total capacity is needed compared to individual heating. The reduced capacity requirement (typically down to about 62% of the sum of the corresponding individual heating requirements) is a significant factor in saving capital investments and operation costs.

Robustness

The ability of district heating companies to choose between several different fuel sources ensures high security of heat supply and makes the price of district heating less vulnerable to large fluctuations in the prices of individual technologies. This is one of the reasons why district heating companies have largely been able to keep prices stable during the recent energy crisis, where the price of other types of energy skyrocketed. The district heating sector's fuel flexibility and ability to utilise energy sources that would otherwise be wasted also contributes to reducing the consumption of fossil fuels and the resulting dependence on imported fuels.

Sector Coupling between Electricity and District Heating



District heating companies use multiple fuels and technologies that ensure stable heat prices and high security of supply. Individual heating, such as heat pumps, is more vulnerable to fluctuations in the prices of individual technologies

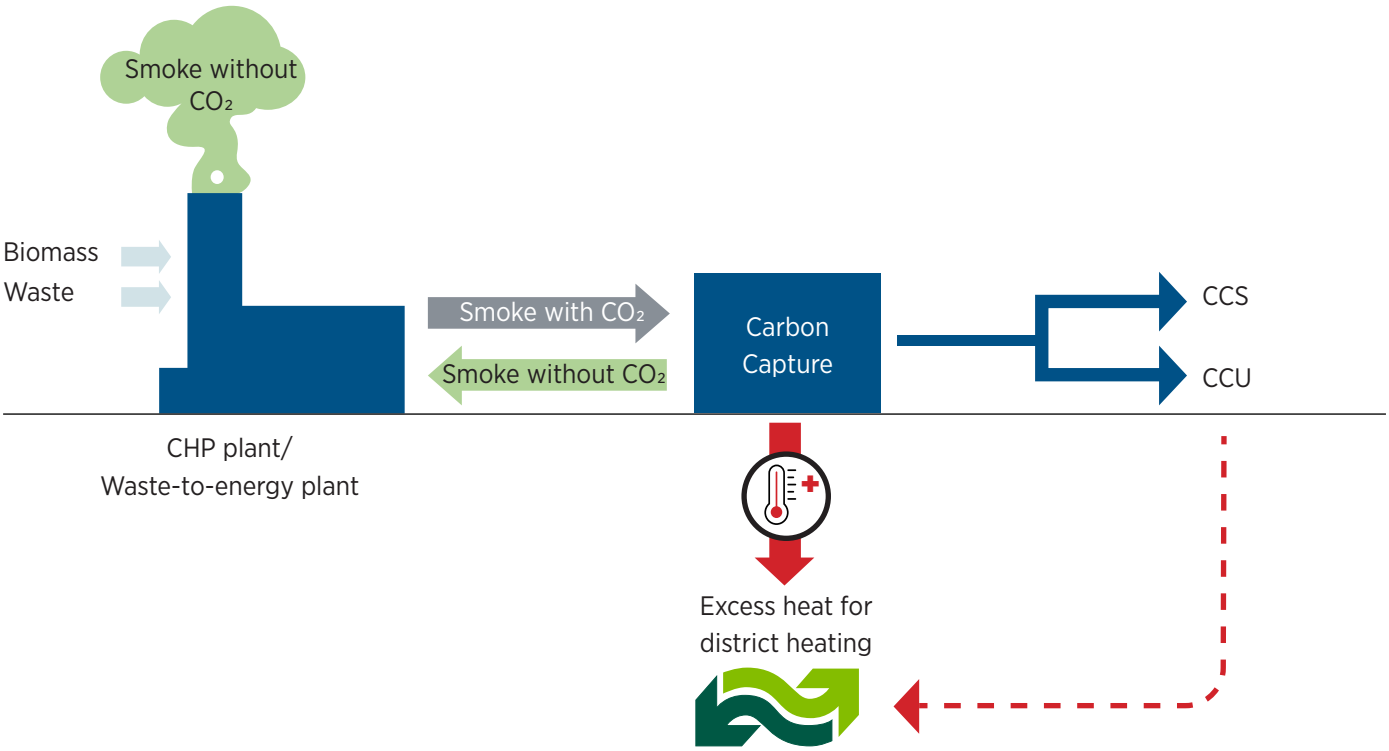
The electricity and heating sectors are naturally interconnected through the co-production of electricity and heat at CHP plants. The CHP plants ensure that Denmark has a significant capacity to produce electricity when solar or wind energy is not being produced. The plants can thus be used to balance imbalances between consumption and production in the electricity system, thereby contributing to the security of electricity supply. In the future, however, an increasing share of district heating is expected to be produced with electric heat pumps and electric boilers. The boilers have especially great potential when combined with thermal storage. This makes it possible to produce more than necessary on the boilers when there are relatively low electricity prices or demand for balancing services for the electricity system.

The heat produced is then stored in large-scale hot water tanks and used at later times when wind and sun are absent and electricity prices rise again. In this way, the district heating sector can act as a large battery for the electricity sector, where "excess power" from wind and solar can be utilised in a good way.

Sector Coupling between Industry and District Heating

The district heating sector's utilisation of excess heat from industry, including in the future from the PtX industry and the data centre industry, creates value for both the district heating sector and the new industries. District heating companies gain access to a carbon neutral heat source, and at the same time, the industry's gain from the sale of excess heat can help improve the competitiveness of PtX plants located in Denmark compared to neighbouring countries without widespread district heating. In addition, the district heating sector can create value for PtX plants by providing sustainable carbon from carbon capture for the PtX plants' production of green fuels and products that can replace fossil fuels in other sectors.

In addition, the district heating system can act as a link between excess heat from PtX and companies that need process heating in industrial processes.



Carbon capture can provide CO_2 reductions and the process generates large amounts of excess heat that can be utilised in district heating.

Green Transition

District heating production has undergone a massive green transition from historically being dominated by oil, coal and natural gas to today being dominated by sustainable biomass and other renewable energy sources. The district heating sector's ambition is to ensure 100% carbon neutral heating by 2030. In addition, district heating can contribute to CO_2 reductions by converting the majority of the approximately 500,000 homes and 40% of commercial buildings that are currently heated with fossil fuels. Furthermore, there is great potential for carbon capture in the district heating sector, which enables a reduction of unavoidable fossil emissions, such as the incineration of non-recyclable residual waste.

The district heating sector can also contribute to negative emissions by capturing and storing CO_2 from biogenic sources, such as biogenic waste or sustainable biomass, thereby removing CO_2 from the atmosphere.

Background

A number of key players have given their views on what will characterise the future energy system. This section briefly summarises a number of messages that have emerged in projections and analyses prepared by the Danish Energy Agency, Energinet, Aalborg University and Energy Modelling Lab, respectively.

- The Danish Energy Agency's Analysis Assumptions for Energinet 2022 provide an estimate of the development in electricity and gas consumption as well as in electricity and district heating production capacities in the period 2022-2050. The analysis assumptions take into account political objectives and are thus not based on "frozen policy".

- Energinet's System Perspective 2035 analyses the expected development of the energy system up to 2035 and focuses in particular on how the increasing amounts of electricity from wind and solar power can be integrated into the energy system.

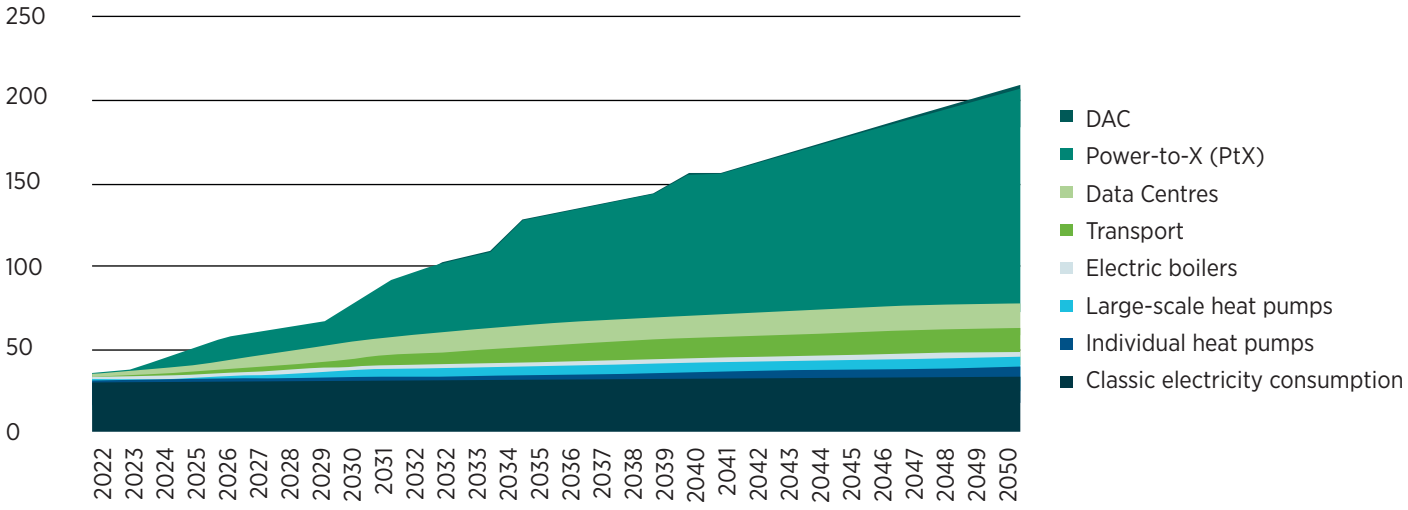
- The analysis prepared by Energy Modelling Lab for the Danish District Heating Association focuses on the development of the energy system in the period 2020-2040 with the purpose of projecting the thermal electricity production capacity towards 2040.

- Heat Plan Denmark 2021 has been prepared by a number of researchers at Aalborg University and analyses the heating system as an integrated part of the overall energy system in order to come up with a concrete proposal on how the district heating sector can best and most cost-effectively contribute to Denmark's climate goals.

Electrification

The key players paint a picture of the future energy system, which is characterised by a general electrification of society with rapidly increasing electricity consumption (approximately tripling by 2040) and massive expansion of renewable energy. The Danish Energy Agency's projection of total net electricity consumption shows a large increase in consumption, primarily driven by a sharp increase in electricity consumption for PtX (see Figure 1). Electricity consumption for heat pumps, both large-scale and individual, is also expected to increase as a result of the phasing out of natural gas for heating and a transition of district heating production away from fossil fuels. In addition, electricity consumption is also expected to increase due to the electrification of the transportation sector and an increasing number of data centres.

Figure 1: Total net electricity consumption (TWh)



Source: *Analysis assumptions for Energinet 2022 (Danish Energy Agency, 2022).*

The Danish District Heating Association's analysis also finds that future electricity consumption is expected to be more flexible than today and thus regulate itself in relation to electricity production from wind and solar power. In 2030, 37% of electricity consumption is estimated to be flexible, while in 2040 it is assumed to be 47%.[2]

Integration of increasing amounts of renewable energy

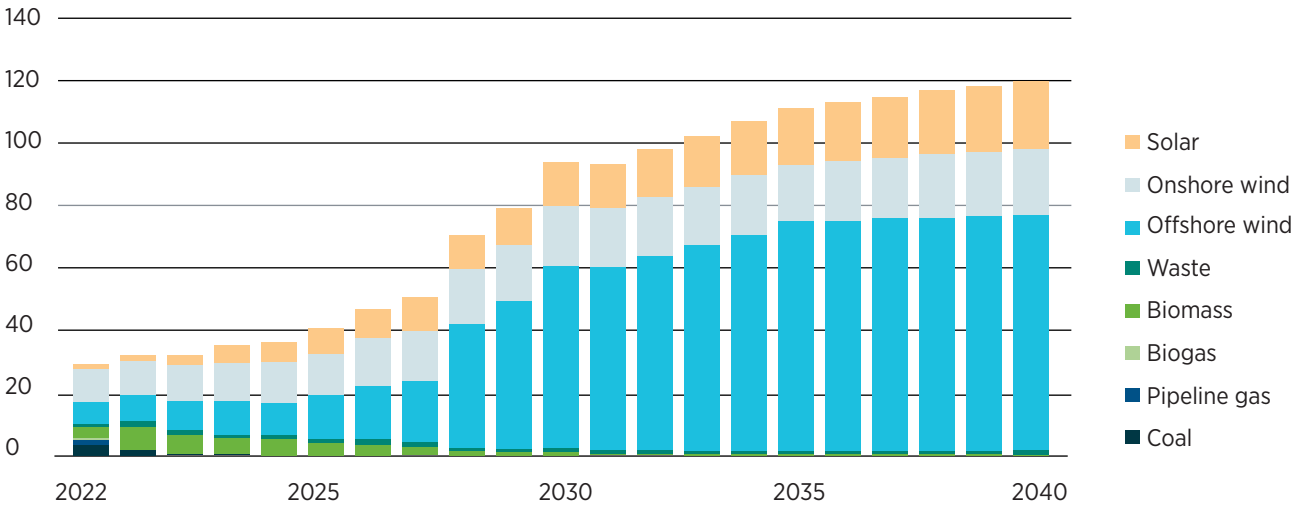
The increased electricity consumption towards 2040 is expected to be largely covered by renewable energy, especially from wind and solar, while a gradual reduction of biomass and a rapid phase-out of fossil energy sources for electricity generation in Denmark is expected (see Figure 2).

Both the Danish District Heating Association's analysis and the Danish Energy Agency's analysis assumptions indicate that the transition away from fossil fuels for electricity and district heating production means that a large part of the thermal electricity production capacity will be phased out by 2035. The Danish Energy Agency's analysis assumptions expect a decrease in thermal electricity capacity from approx. 5.8 GW in 2022 to 4.3 GW in 2030 and 2.8 GW in 2035, and the Danish District Heating Association's analysis indicates that the thermal capacity will be phased out faster than the Danish Energy Agency assumes.

Energinet's System Perspective 2035 concludes that a number of new initiatives are needed to integrate the increasing amounts of wind and solar power in the coming decades without compromising the security of electricity supply. In this context, the district heating sector is referred to as one of Denmark's comparative advantages compared to other EU countries, as the district heating sector can help address the challenge of large amounts of wind and solar in the North Sea region. For example, excess heat from PtX projects can be used as a heat source and thereby contribute positively to the profitability of PtX projects. This can help make it advantageous to locate such projects in Denmark. Heat pump technology and heat storage can also contribute to efficient use of electricity and good flexibility for fluctuating electricity production.

Energinet emphasises that an efficient sector coupling in general is crucial for the integration of the large amounts of renewable energy in the energy system and has the potential to deliver a large cost-effective CO_2 reduction towards 2035.

Figure 2: Electricity production towards 2040 (TWh)



Note: *The main reason for the reduction in electricity capacity at thermal power plants is that electricity production will be out-competed by large amounts of cheap electricity from wind and solar in the future. Coal and gas in electricity generation will be phased out in the first half of the 2020s.*

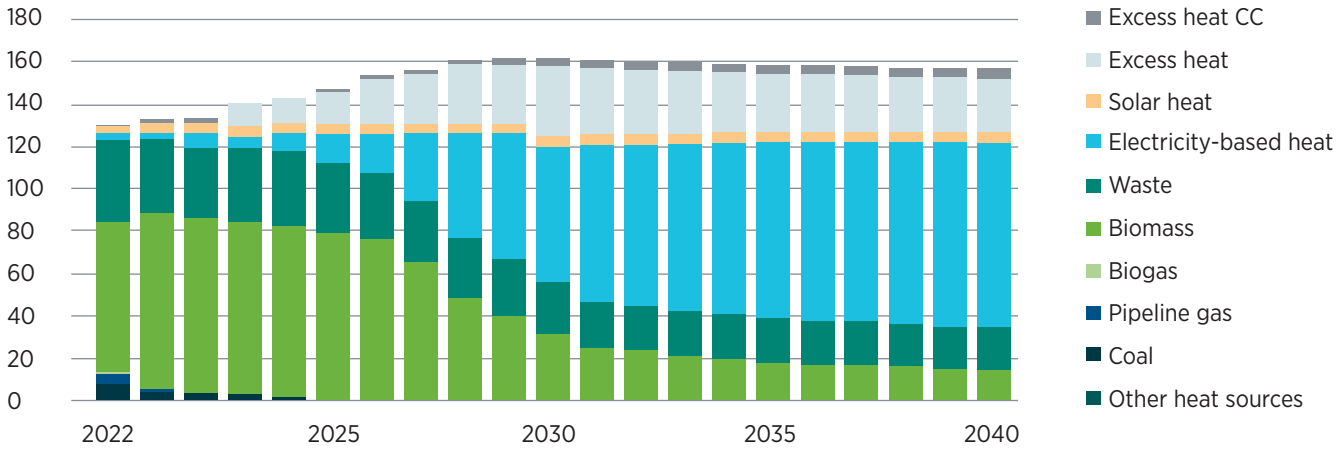
Source: *The development of thermal power plant capacity (Energy Modelling Lab, 2022).*

2) PtX, heat pumps and battery-powered transportation are assumed to be flexible with the possibility of flexibility in different time horizons depending on the technology. For example, battery-powered transportation can partially operate in the spot market on a daily basis.

The future of district heating production

Given the right, stable framework conditions, district heating could undergo a dramatic shift in supply structure. From supply being dominated by production from thermal plants (biomass, waste, gas, etc.) to a strong electrification (and thus a strong reduction of production from thermal plants) and much greater use of excess heat from existing and new industries.

Figure 3: District heating production towards 2040 (PJ)



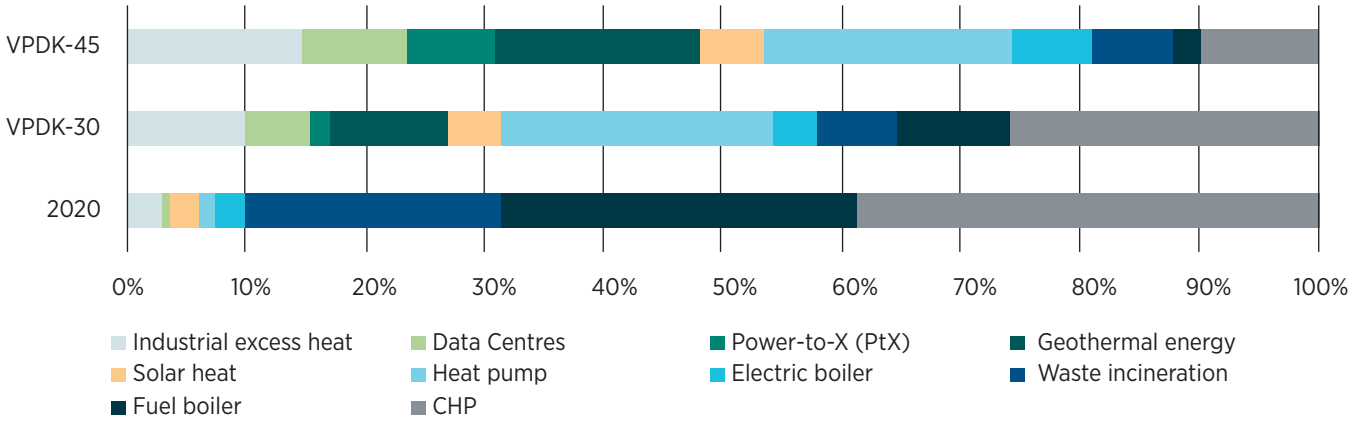
Note: *Heat pumps are taking over large parts of district heating production. Waste-to-energy and biomass plants will still play a role in the future district heating network, while fossil plants will be phased out already in the first half of the 2020s.*

Source: *The development of thermal power plant capacity (Energy Modelling Lab, 2022).*

The Danish District Heating Association's analysis concludes that district heating production towards 2040 will be dominated by heat pumps and excess heat (see Figure 3). This includes air source heat pumps, seawater heat pumps, heat pumps supplying geothermal heat and heat pumps that utilise excess heat from PtX plants, data centres and the like.

District heating production from biomass and waste will be significantly reduced by 2040. However, some heat will still be produced at waste and biomass plants.

Figure 4: Distribution of district heating production in 2020, 2030 and 2045



Note: *2020 figures are an estimate based on Heat Plan Denmark's own simulations.*

Source: *Heat Plan Denmark 2021 (Mathiesen, et al., 2021).*

Heat Plan Denmark also believes that excess heat will play a major role in future district heating production, but also sees great potential for utilising geothermal energy.

Figure 4 shows Heat Plan Denmark's estimated development in the district heating production mix towards 2045. CHP, boilers and waste incineration dominate the picture in 2020, but by 2030, excess heat and geothermal energy could account for around 27% of district heating production. By 2045, it is estimated that excess heat and geothermal energy could cover around 50% of district heating production. Solar heat is estimated to cover around 6% of heat consumption in 2045, while waste incineration is estimated to decrease from 21% of district heating production in 2020 to 7% from 2030 onwards due to increased recycling. The direct electrification of the district heating sector is also estimated to increase significantly. From a level of 2-4% of the district heating supply in 2020, Heat Plan Denmark assumes that heat pumps and electric boilers will eventually cover around one third of the total heat supply.

The Danish Energy Agency's analysis assumptions also provide an estimate of the composition of future district heating production. They assume that district heating production will be electrified with the expansion of large heat pumps, especially towards 2035, where the development is expected to be fastest. It is assumed that there will be an approximate fivefold increase in the electricity capacity of large heat pumps by 2050. For central areas, the development is driven by the expected closure of central CHP plants, where heat production is replaced by heat pumps with different heat sources such as air and seawater, as well as an expectation of greater utilisation of excess heat. The development is also due to technological development, targets for phasing out natural gas, and changing framework conditions.

Energinet's analysis shows that it is cost-effective to invest in electricity for heat (heat pumps) for district heating, industry and individual heating in all three analysed scenarios for the development of the European energy system.[3] In the two most ambitious green scenarios, it is also cost-effective to invest in PtX systems towards 2035.

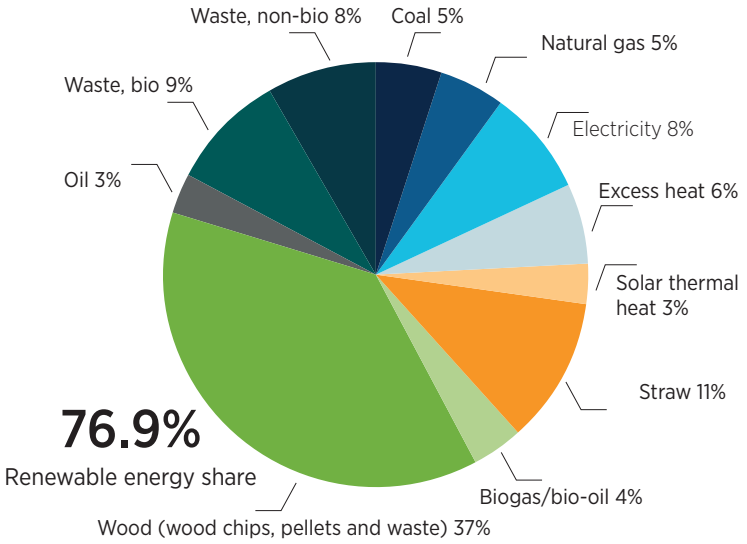
3) The starting point for Energinet's analysis is three European energy scenarios for 2030 and 2040 respectively, called TYNDP 2018 (Ten Year Network Development Plan), developed through a large collaboration under ENTSO-E and ENTSO-G.

Energy Efficiency

District heating was born out of a desire to utilise the excess heat from waste incineration and later from electricity generation and other industrial processes. The district heating sector was founded on the basis of providing competitive and secure heat to homes by utilising the advantages of economies of scale, high energy efficiency and access to cheap sources of supply such as excess heat, waste incineration/disposal, solar heat, etc. Although there is a heat loss in the transportation of heat to homes of 15-20%, the loss is more than offset by the aforementioned benefits. However, the energy efficiency of district heating is not only related to the production of heat, but also to the possibility of more efficient utilisation of the capacity of a communal heating system compared to individual systems.

Communal heating includes district heating and central natural gas heating, which today covers approx. 80% of the homes in Denmark, while the remaining approx. 20% are heated individually. Individual heating options include oil-fired boilers, individual heat pumps and biomass boilers. Communal heating consists mainly of district heating, which covers 66% of all households and approx. 3.7 million people, while central natural gas currently supplies approx. 14% of Denmark's homes (Statistics Denmark, 2023).

Figure 5: Energy sources in district heating 2022



Note: *Please note that this is a preliminary calculation, as the results from the Energy Producer Census 2022 are preliminary figures. Final figures will appear in Energy Statistics 2022, which will be published at the end of 2023. A renewable energy share of 72% is assumed for the electricity used, corresponding to the RE share in the Danish electricity supply (2021), and 33.6% for the share of biogas in the gas grid (2022). Excess heat is considered renewable energy.*

Source: *Energy Producer Census 2022 (Danish Energy Agency, 2023).*

Denmark's approx. 370 district heating companies produce heat themselves or buy heat from other production companies. Heat is produced in many different ways and with many different types of fuels. The majority of production takes place at CHP plants, where both electricity and heat are produced. This is done by utilising the energy from different fuels such as non-recyclable residual waste, gas, coal and sustainable biomass.

Some district heating companies only use natural gas at their production plants, while others combine several different technologies across multiple plants. The technologies also include CO_2-free heat sources such as solar heating and geothermal energy. In addition, industrial excess heat is often used for district heating, and heat pumps and electric boilers can be used to generate electricity from wind turbines.

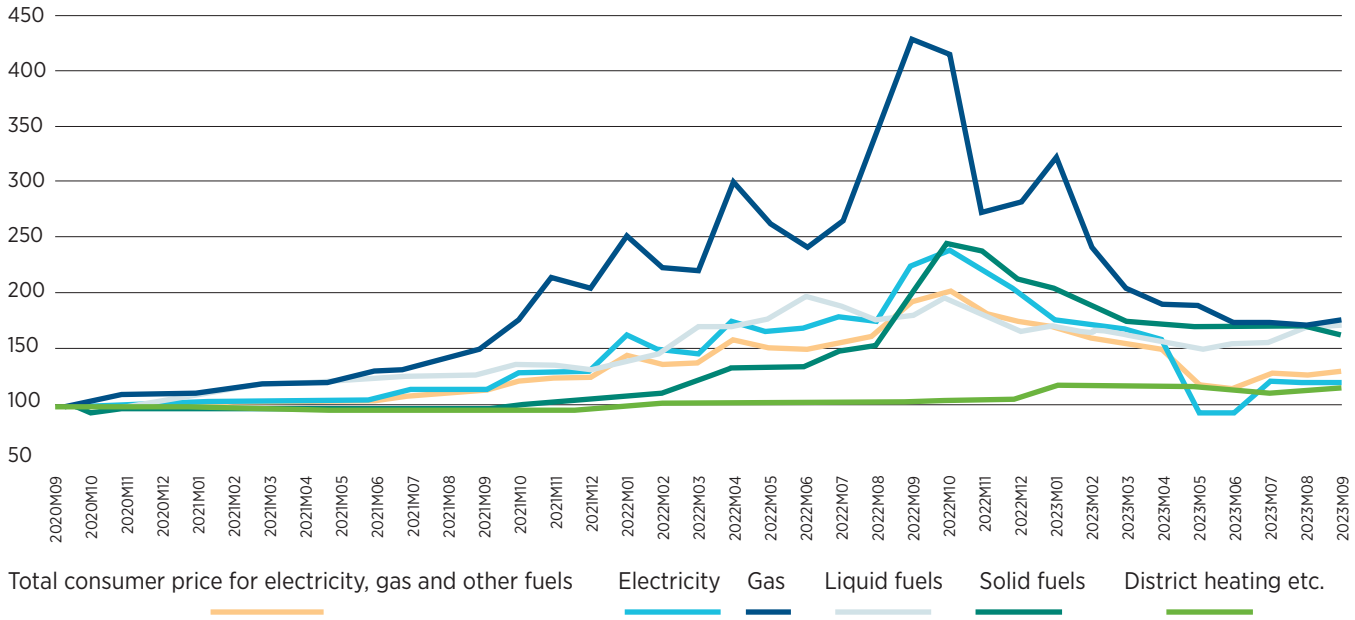
Figure 5 shows the composition of energy sources in the total district heating production in 2022.

The companies' ability to choose between several different energy sources contributes to high security of heat supply and makes the price of district heating less vulnerable to large fluctuations in the prices of individual technologies.

This is one of the reasons why district heating companies have largely been able to keep prices stable during the recent energy crisis, where the price of other types of energy skyrocketed. According to Statistics Denmark (2022), the price of district heating increased by 5.9% from August 2021 to August 2022, while the total consumer price for electricity, gas and other fuels increased 46.8% in the same period.

Figure 6 shows the development in energy prices from September 2020 through September 2023. It can be

Figure 6: Energy prices, September 2020 to September 2023, index September 2020=100



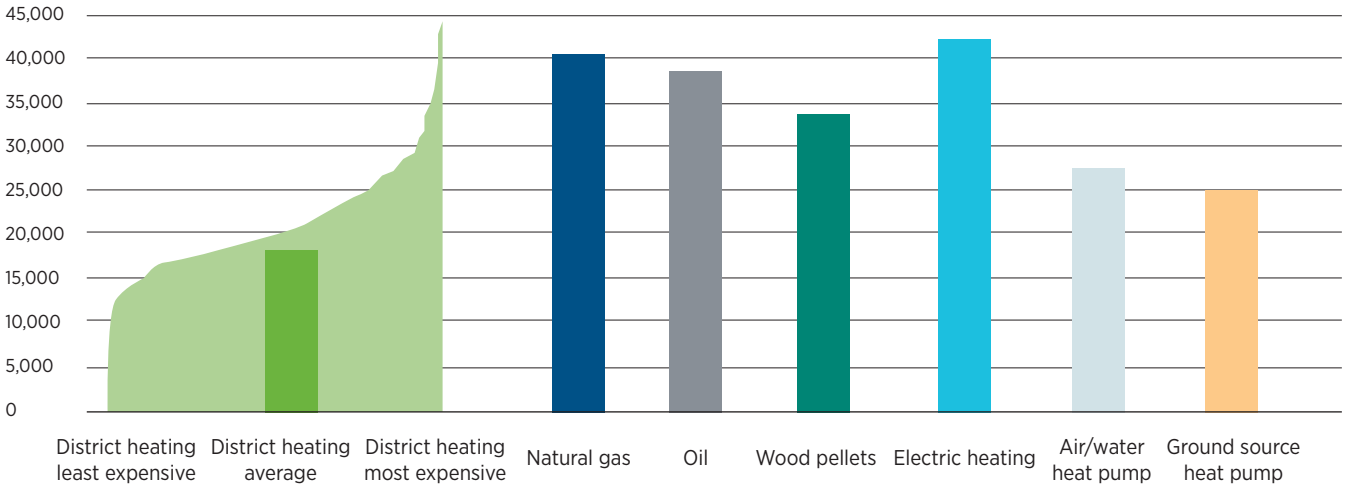
Source: *www.statistikbanken.dk/PRIS111, (Statistics Denmark, 2023).*

seen that the price of district heating has remained largely constant and lower throughout the period compared to the other energy forms.

However, the average price of district heating covers a large variation across companies, as illustrated in Figure 7. Figure 7 shows that the average price of district heating in 2022 was generally lower than alternative forms of heating, but with large variation between the different district heating companies.

District heating companies with more options and technologies have the lowest prices. Companies tied to mainly gas or mainly electricity have the highest prices.

Figure 7: Estimated annual cost of heating a standard house, based on prices as of 1 January 2023, including investment and maintenance (DKK)



Source: Data on district heating prices is based on the companies' reports to the Danish Utility Regulator's Heat Price Statistics. Data on electricity and gas prices comes from the Danish Utility Regulator's Electricity and Natural Gas price statistics. Data on oil and wood pellet prices is based on the Danish District Heating Association's own market surveys. Assumptions regarding investment costs are based on the Danish Energy Agency's Price and Lifetime Catalogue for Danish district heating companies. For an air/water heat pump, estimated investment costs prepared by EA Energy Analyses in 2022 are used.

Benefits of large-scale over individual heat pumps

Large heat pumps have some advantages over individual heat pumps in densely populated areas where it makes sense to establish district heating networks.[4] Investment costs for large-scale heat pumps are lower than those for individual heat pumps. This is because less total capacity is needed in a communal solution than when individual heat pumps are required to meet the full heating demand of each house.

Not all consumers demand maximum heat at the same time. Therefore, when summing up the individual consumers' required capacity, their total consumption must be multiplied by a simultaneity factor of less than or equal to 1. For residential areas, as a rule of thumb, the concurrency factor can be set at 0.62 (Andreasen, et al., 2021). The capacity requirement for large-scale heat pumps is thus estimated at 62% of the full individual requirement, which can reduce the need for electricity grid reinforcements. The reduced capacity requirement is a significant factor compared to the heat loss in the district heating network. In the district heating system, the net loss is on average 17-18% of the energy produced and is expected to decrease in the future as low-temperature district heating, better pipes and higher densification become more widespread.

Large-scale heat pumps and electric boilers can also help balance the fluctuating electricity production from wind turbines. Electricity consumption can be planned and regulated to a greater extent when it is done collectively through heat pumps and storage in the district heating system. The flexible electricity consumption of large-scale heat pumps helps to support the security of electricity supply. Large-scale heat pumps also tend to have a higher efficiency (COP factor) than individual heat pumps, which typically use outdoor air as a heat source, resulting in low efficiencies in winter.

The explanation is that heat pumps in district heating are able to use energy sources with higher temperatures, such as excess heat, geothermal energy or seawater, which results in higher efficiencies. In addition, district heating companies often have the option to supplement heat production from other technologies, which can further reduce costs. Finally, large-scale heat pumps are typically better regulated than individual heat pumps and have lower installation and service costs.

From a consumer point of view, it can also be of great value to avoid the responsibility and cost of operating and maintaining an individual heat pump. The consumer also avoids disadvantages such as noise nuisance, space requirements, maintenance, increased price sensitivity in relation to electricity prices, a worse appearance of the home and the need for more frequent reinvestments, etc.

Heat Plan Denmark recommends expansion of district heating coverage

Heat Plan Denmark 2021 has been prepared by a number of researchers at Aalborg University and includes a number of analyses of how much district heating and individual heat supply Denmark should aim for. The goal is to find out how the heat supply should be composed so that Denmark can implement the green transition in a technically, economically and environmentally suitable way (Mathiesen, et al., 2021).

In addition to focusing on energy renovation of the building stock and the transition to fourth-generation district heating, Heat Plan Denmark recommends aiming for an expansion of district heating. Specifically, an expansion from the current approx. 50% of the total heating need (on a building-by-building basis) to 63-70% in 2045 is recommended, depending on local conditions regarding geothermal energy and excess heat. An expansion of the district heating coverage of approx. 70% allows a greater utilisation of excess heat and thus does not lead to higher costs than an expansion of approx. 63%. However, an expansion of 70% has the additional advantage of reducing the pressure on biomass and wind, which is why Heat Plan Denmark specifically assesses an expansion to 70%.

The district heating expansions will primarily replace natural gas heating, but also oil, biomass and direct electric heating. Outside of district heating areas, heat should come from individual heat pumps supplemented by solar heating.

4) Regulation ensures that district heating is only established or expanded in areas where it is socio-economically more advantageous than individual supply, cf. Section 19(2) and 16(1)(10) in "Projektbekendtgørelsen" (BEK no. 697 of 6 June 2023).

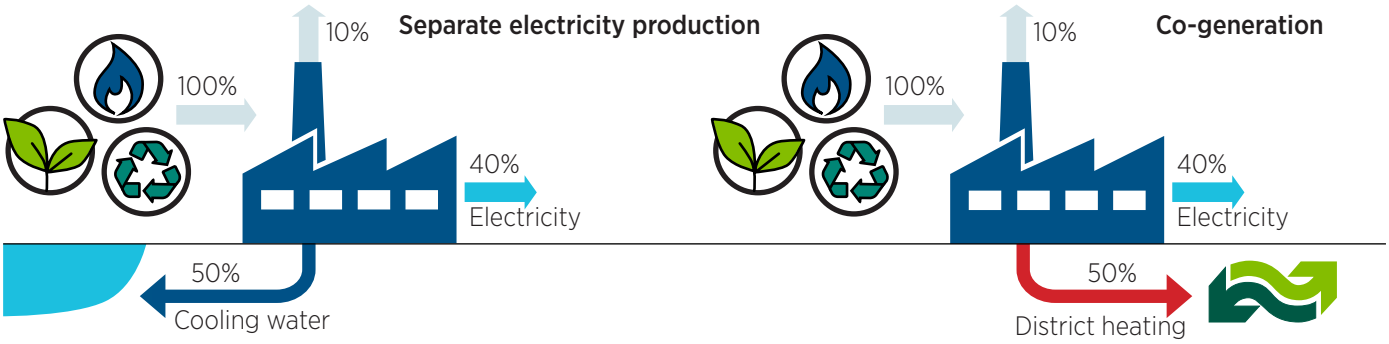
Interactions between district heating and the electricity sector

The electricity and heat sectors are historically linked through the co-production of electricity and heat at CHP plants. In the future, an increasing share of district heating is expected to be produced with electric heat pumps and electric boilers. The district heating sector will continue to be of great value to the electricity sector by providing system services, security of supply and by consuming green power.

Co-generation of electricity and heat

By co-generating electricity and district heating, it is possible to utilise the large amount of heat generated by thermal electricity production, as shown in Figure 8. The utilisation of excess heat from electricity production in district heating has for many years been the main argument for the political requirement for co-production of electricity and heat. Originally, the CHP requirement was based on co-generation being economically advantageous. The co-generation of electricity and heat at CHP plants has meant that both electricity and heat consumers have historically been better off than with separate production of electricity and heat.

Figure 8: Separate electricity production versus co-generation



Note: *In a traditional power plant, around 40% of the energy input is converted into electricity. The rest of the energy is not utilised and disappears with the cooling water into the sea and into thin air. A CHP plant works in the same way, but instead the steam is cooled with return water from the district heating network and the energy is utilised in the district heating system.*

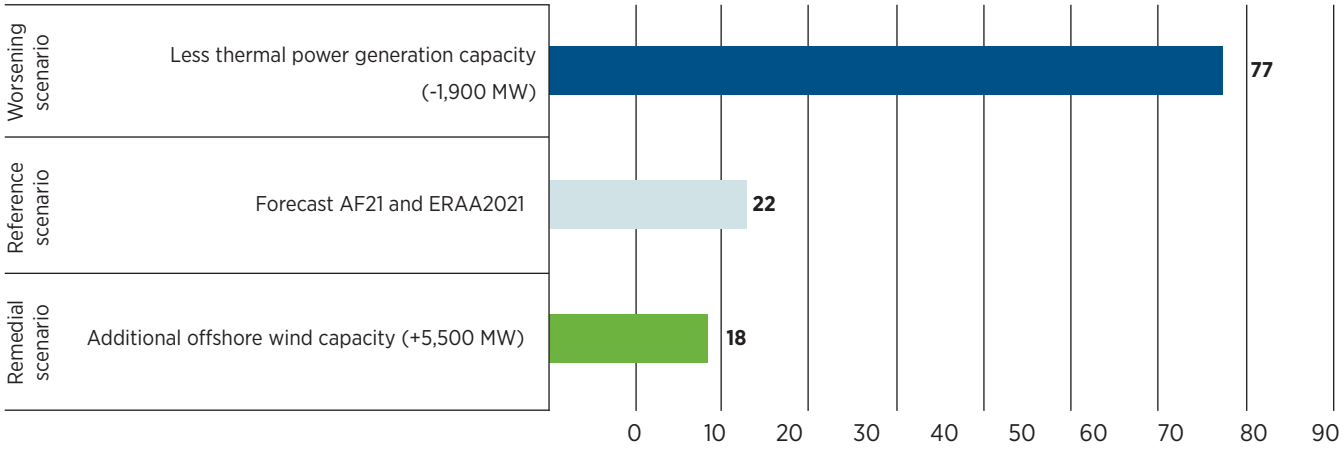
In 2021, 72.1% of thermal electricity generation was produced together with heat (Danish Energy Agency, 2022). Similarly, 65.8% of district heating was produced together with electricity. Co-generated electricity and district heating still represent a relatively high share of the total production of both services. The majority of CHP plants are owned by district heating companies, which are therefore net producers of electricity today. The CHP requirement has meant that in Denmark we have a significant capacity to produce electricity at CHP plants when solar and wind energy is not being produced. However, the development of lower electricity prices and the phasing out of electricity production subsidies has led to a decrease in the CHP plants' income from the electricity side, which means that there are no longer co-production benefits as before. It was therefore decided to repeal the CHP requirement with the energy agreement of 29 June 2018.

The value of CHP to the electricity sector

However, CHP plants continue to benefit the electricity sector as they allow for a controllable, weather independent electricity generation and can offer operational flexibility, i.e. both up and down regulation of electricity production. The plants can be used to offset imbalances in the electricity system, typically from wind or solar energy, when they do not produce as expected. In this way, CHP plants contribute to the security of electricity supply. In addition, the central thermal CHP plants provide system-supporting properties that enhance the power system's ability to withstand faults, typically short circuits. The central thermal plants thus reduce, all other things being equal, Energinet's need to procure system-supporting properties from other sources. In other words, they can avert or postpone investments in network components. The declining electricity production at CHP plants means that a large part of the capacity will be phased out over the coming years. The plants shut down when their lifespan ends or their heat contracts expire, since it is not economically viable to extend

their lifespan or invest in new plants. The Danish District Heating Association's analysis also shows that the thermal capacity risks being phased out faster than previously assumed by the authorities, which entails an increased risk of lack of resource adequacy and thus worsened security of electricity supply. Energinet's Report on Security of Electricity Supply 2022 shows that resource adequacy will deteriorate significantly if the domestic thermal electricity generation capacity is adjusted downwards compared to the Danish Energy Agency's Analysis Assumptions for Energinet 2021. A further phase-out of 1,900 MW of thermal capacity is thus expected to lead to an increase in outage minutes in 2032 of 55 min/year compared to the forecast of 22 min/year. In comparison, an upward adjustment of offshore wind capacity of 5,500 MW only leads to a limited improvement in estimated outage minutes of 4 min/year. Although the amount of added capacity from offshore wind is far greater than the amount of phased-out thermal capacity (5,500 MW versus 1,900 MW), the added offshore wind capacity is far from outweighing the phase-out of thermal power generation capacity. The flexibility from the dispatchable electricity generation capacity is therefore of great value to the electricity system, as shown in Figure 9.

Figure 9: Estimated outage minutes in 2032 for Denmark (min/year)



Source: *Own visualisation based on Energinet's Security of Electricity Supply Report 2022.*

Electrification of district heating

In the future, an increasing share of district heating is expected to be produced with electric heat pumps and electric boilers. The expected electrification of district heating will eventually lead to district heating companies moving from being net producers of electricity to net consumers of electricity. The majority of the investments that district heating companies will have to make in green conversion of medium, peak and reserve loads towards 2030 are expected to be in electric boilers combined with storage tanks or other forms of heat storage (Grøn Energi, 2022). This will provide a number of benefits for both district heating and the overall energy system. It will increase the district heating companies' mix of technologies, giving them more flexibility to optimise production for different input prices. In addition, both heat pumps and electric boilers are interruptible, so district heating companies can use electricity in heat production when there is high electricity production from solar and wind power and avoid using electricity when there is low electricity production.

The boilers have especially great potential when combined with storage tanks or other forms of heat storage. This makes it possible to produce more heat than necessary on the boilers when there are relatively low electricity prices or when there is demand for balancing services for the electricity system. The heat produced is then stored in the storage tanks and used at later times when electricity production from solar and wind power is low and electricity prices rise again. In this way, the district heating sector can act as a large battery for the electricity sector. The flexible consumption of district heating companies can thus help integrate the increasing amounts of fluctuating renewable energy of the future and improve the security of electricity supply. The district heating sector's ability to purchase electricity at times of high RE production and/or low demand can also benefit RE producers, as the produced electricity can then be sold at a higher price. This reduces the likelihood of negative electricity prices or the need to shut down generation plants during periods of very low prices.

Utilisation of excess heat

One of the district heating sector's great strengths is collecting and utilising excess energy. Denmark's first district heating plant was established 120 years ago in Frederiksberg, Denmark, based on a desire to utilise the excess heat from waste incineration. Later, the excess heat from the production of electricity at CHP plants was also utilised.

In addition, excess heat from industrial processes where heat is generated, such as drying, evaporation, melting and cooling, is utilised. What these processes have in common is that heat is an excess product that companies typically release into the air or waste water. However, it's far better to utilise the heat than to send it out as a loss where it's of no use. The heat can be utilised using a heat exchanger or a heat pump, which uses the collected heat to heat the water in the district heating network and send it to the district heating customers. Excess heat is thus an energy-efficient and environmentally friendly heat source.

There are several benefits to harnessing excess heat:

- Expressed in popular terms, the same energy can be harnessed twice. If the excess heat is not utilised, the residual energy from the industrial process is wasted and district heating must be produced with energy that could have been saved.

- A heat pump that utilises excess heat, e.g. from a data centre at 30 °C, is more energy efficient than a heat pump on outdoor air, where most of the annual production is at fairly low outdoor air temperatures. You get much more heat out of the amount of electricity needed to run the heat pump (higher efficiency/COP factor) when using excess heat.

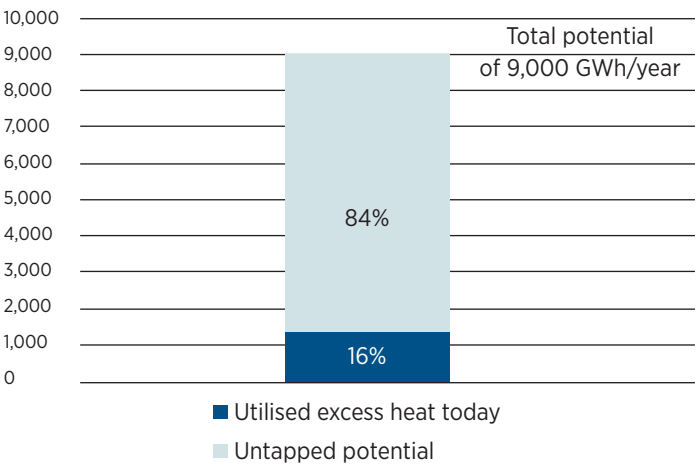
- Excess heat reduces the heating price for district heating customers. As the excess heat is a residual product, the district heating company's cost is typically lower than the cost of alternative heat production. Companies that supply excess heat to district heating companies can achieve a green profile and there may be an opportunity for financial income from selling the excess heat, which can increase competitiveness. Some excess heat is delivered free of charge, so the district heating company only needs to invest in facilities to utilise it.

- Excess heat is carbon neutral heat. It must be used at times when it is available. It will often be part of the district heating production base load, typically replacing fossil fuels or reducing the need to use biomass.

Today, 3.6% of district heating is produced from excess heat, which corresponds to approx. 1,400 GWh/year (Danish Energy Agency, 2022). However, there is a large untapped excess heat potential in Denmark totalling 9,000 GWh/year. (Rambøll, 2022), corresponding to approximately 500,000 homes (see Figure 10).

This potential is divided between the excess heat from comfort cooling, commercial and industrial businesses as well as waste water treatment plants and waterworks. Of the total excess heat potential in Denmark, only about 16% is utilised today. However, excess heat is expected to make up a larger share of future district heating production. Heat Plan Denmark's bid for 2030 is 16% excess heat from industry (excl. PtX) and data centres.

Figure 10: Excess heat potential (GWh/year)

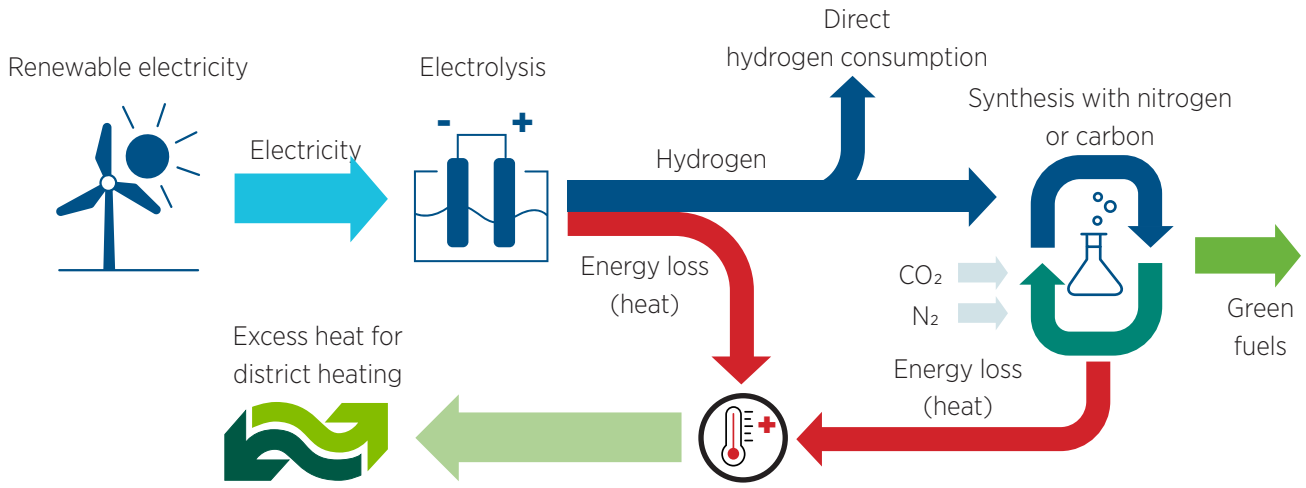


In 2045, excess heat from industry (excl. PtX) and data centres is expected to cover 23% of district heating production. For excess heat from PtX plants, Heat Plan Denmark 2021 uses a conservative estimate of just under 10% of district heating production in 2045. The potential is greater but associated with significant uncertainties, including the location of PtX plants in relation to the district heating network and the demand for the plants' end product.

Excess heat and PtX

All PtX processes have an energy loss in the form of heat, and capturing and utilising that heat requires infrastructure. This is exactly what district heating systems can do (see Figure 11). Heat infrastructure includes district heating pipes, heat storage and intelligent controls that connect district heating consumers with carbon neutral heat sources. The district heating infrastructure is the foundation for reusing PtX heat for home heating and green process heating in industry.

Figure 11: Utilising excess heat from PtX processes



Note: *Power-to-X (PtX) converts electricity (power) into Xs, such as hydrogen, methanol or jet fuel. The excess heat can potentially be used for district heating.*

Integrating PtX and district heating can create value on multiple fronts:

- **District heating can improve the economics of PtX systems:** Selling excess heat for reuse in district heating can improve the competitiveness of PtX plants located in Denmark compared to neighbouring countries without widespread district heating. Professional assessments indicate that the price of hydrogen can be reduced by 5-10% by integration with district heating, and that this will be sufficient to give a competitive advantage in establishing more hydrogen plants in Denmark (the Danish District Heating Association, Grøn Energi, COWI and TVIS, 2021). The improved economics of PtX plants can contribute to faster deployment and larger plants in Denmark.

- **PtX can provide carbon neutral district heating:** The excess heat from PtX is suitable for integration into district heating as part of a carbon neutral district heating supply. PtX systems are expected to operate for many hours and thus provide a stable, high-quality heat source (high temperature and high energy density).

- **District heating plants can supply biogenic CO_2 to PtX plants:** Waste-to-energy and biomass plants are also suitable for carbon capture (CC). In addition to storing CO_2 and removing it from the atmosphere, the biogenic CO_2 can be reused in the PtX production of green fuels. CO_2 sources that are available in the local

area are a competitive advantage because concentrated CO_2 sources can become a limiting factor for PtX. The carbon capture process also generates large amounts of excess heat, which can be utilised in district heating.

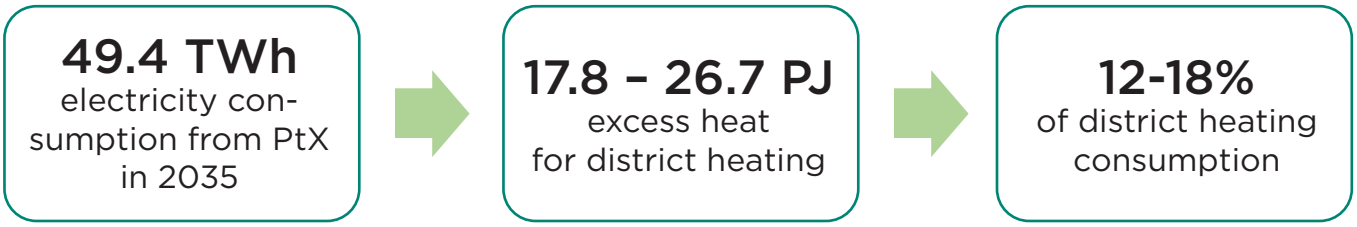
- **Increased sector coupling and energy efficiency:** Utilising excess heat from PtX for district heating enhances integration across sectors such as electricity, heat, transport, waste, industry and agriculture. This increases energy efficiency, which contributes to a better economy.

- **Increased green exports:** A Danish PtX expansion can be combined with Danish strengths such as wind power and district heating, thereby increasing Danish exports.

An analysis from Grøn Energi, TVIS and COWI has made an initial estimate of the effect on the operating economy of an electrolysis plant if the sale of excess heat to the district heating network is included. The analysis shows an improved competitiveness for the electrolysis plant when selling heat for use in district heating. The electrolyser can achieve higher revenues both as a result of the direct revenues from the sale of heat and as a result of more operating hours, as the sale of heat increases the number of operating hours during which the variable costs of the electrolyser can be covered.[5] No firm conclusions can be drawn about the magnitude of the financial benefit that integration with district heating brings. This requires a specific analysis of individual projects. However, the calculations indicate that integration with district heating can improve the economics of PtX systems.

Expansion of PtX and electrolysis plants will result in large point sources of excess heat. It can therefore make economic sense to utilise the large amount of excess heat in district heating. In Analysis Assumptions for Energinet 2022, the Danish Energy Agency estimates the expected development of PtX electricity capacity and electricity consumption in 2035 to 9.9 GW and 49.4 TWh, respectively, excl. the North Sea Energy Island. Based on this development, the Danish District Heating Association estimates that the potential for utilising excess heat in district heating is between 17.8 and 26.7 PJ in 2035. This means that up to 18% of Danish district heating consumption can be covered by excess heat from PtX systems. The estimate is based on the assumption that 10 to 15% (low and high estimate) of the electricity consumption for electrolysis and PtX can be converted into usable excess heat (the Danish District Heating Association, Grøn Energi, COWI and TVIS, 2021). The interval should reflect the fact that not all excess heat can be utilised depending on technology choice, operational profile, geographical location, etc.

Figure 12: PtX generates large amounts of excess heat



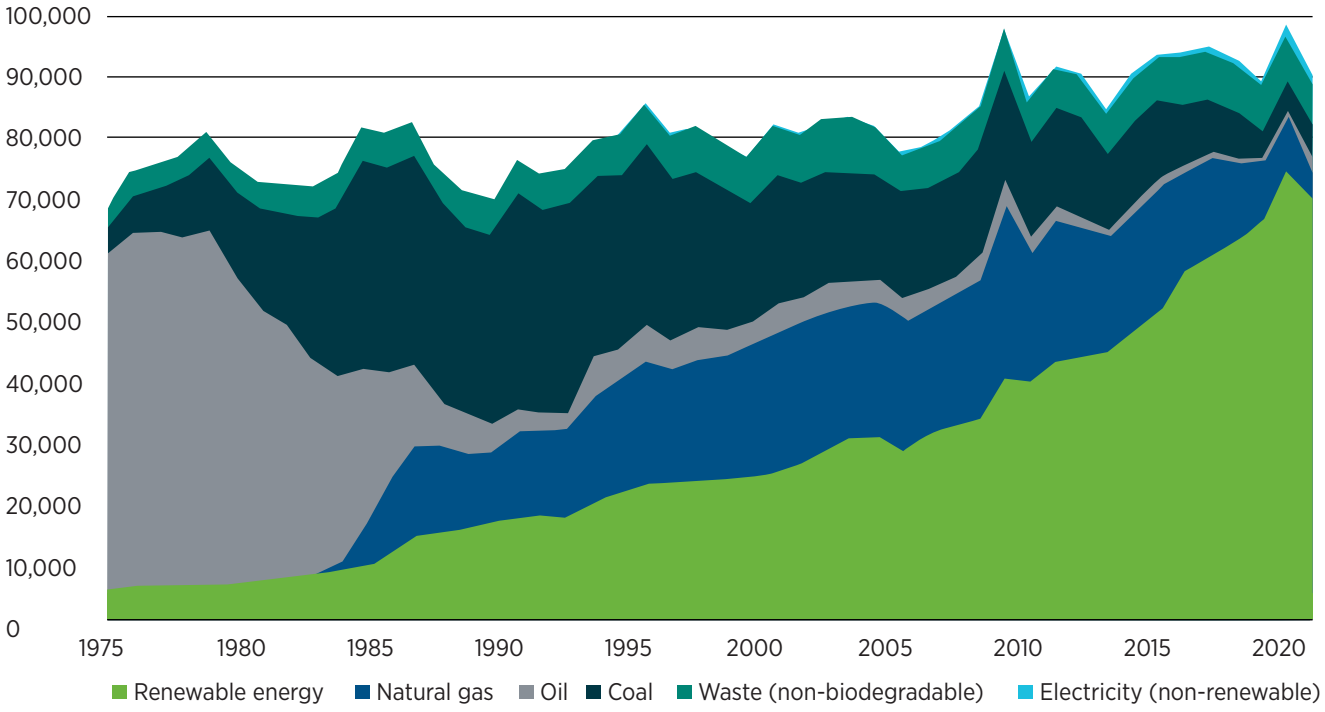
Integrating excess heat from PtX with process heating for industry leads to both increased heat production and heat offtake, which improves overall efficiency, and PtX plants can sell more excess heat, probably at a higher price. Part of the explanation for this is that the need for process heating is more evenly distributed throughout the year compared to space heating for buildings. The need for process heating increases the demand for heating during the summer months, when less heat is usually allocated. This increases the value of the heat and thus the integration of PtX into the district heating system.

5) For the two cases analysed in the report, an increase in the electrolysis plant's revenue of 27% and 20%, respectively, is achieved. However, the calculations should be viewed with the caveat that there are generally many uncertainties in the calculation of the economics of a PtX system.

Green Transition

District heating production has undergone a massive green transition from historically being dominated by oil, coal and natural gas to today being dominated by biomass and other renewable energy sources. Figure 13 shows the development of the fuel mix in district heating production from 1975 to today. Oil and coal dominated production until around 1990, after which natural gas and renewable energy sources began to take over district heating production more significantly. Today, district heating production is largely based on renewable energy (76.9%) and to a lesser extent on natural gas (5.2%), fossil waste (7.6%) and coal (5.4%).

Figure 13: Development in fuel consumption for district heating production 1975-2022 (TJ)



Source: "Energistatistik" 2021 (Danish Energy Agency, 2022) and the "Energiproducenttællingen" for 2022 (Danish Energy Agency, 2023). Please note that the figures for 2022 are preliminary and that the final figures will appear in "Energistatistik" 2022, which will be published at the end of 2023.

Today, sustainable biomass accounts for approx. 48% of district heating's total fuel consumption and is one of the main reasons why district heating overall consists of approx. 77% renewable energy.[6] The increasing use of biomass is mainly due to a political desire to phase out coal and the CHP requirement, which, however, was repealed with the energy agreement of 29 June 2018. The historical transition of the district heating production, from oil to coal to natural gas and most recently to biomass, illustrates one of the strengths of district heating: the ability to adapt and adjust to framework conditions. The district heating sector has thus been an important instrument for achieving political goals for green transition and reducing dependence on imports of fossil fuels from other countries.

Today, coal is almost completely phased out of district heating production in the small and medium-sized Danish towns, and in the large Danish towns and cities that have phased out coal, sustainable biomass has taken its place. The consumption of sustainable biomass is expected to decrease in the coming years due to investments in other technologies, but can still play an important role in our electricity and district heating production. Sustainable biomass can produce electricity and heat in the absence of solar and wind production, thereby contributing to a high security of supply and competitive consumer prices.

6) Renewable energy sources include renewable non-fossil energy sources in the form of wind power, solar energy, geothermal energy, ambient energy, tidal and wave energy and other forms of ocean energy, hydropower, biomass, landfill gas, gas from waste water treatment plants and biogas, cf. Section 2(2) of the RE Act.

Biogas also plays an important role in ensuring the security of both heat and electricity supply and contributes to the phasing out of natural gas in heat production. Biogas can be used directly for heat and CHP, or as upgraded biogas for biomethane. As district heating production converts to heat pumps and other technologies based on a fluctuating electricity production, the need for balancing heat production will increase. Biogas and biomethane are a green alternative to natural gas that can be used in gas turbines and engines to help quickly ramp up both electricity and heat production and maintain a high security of supply level.

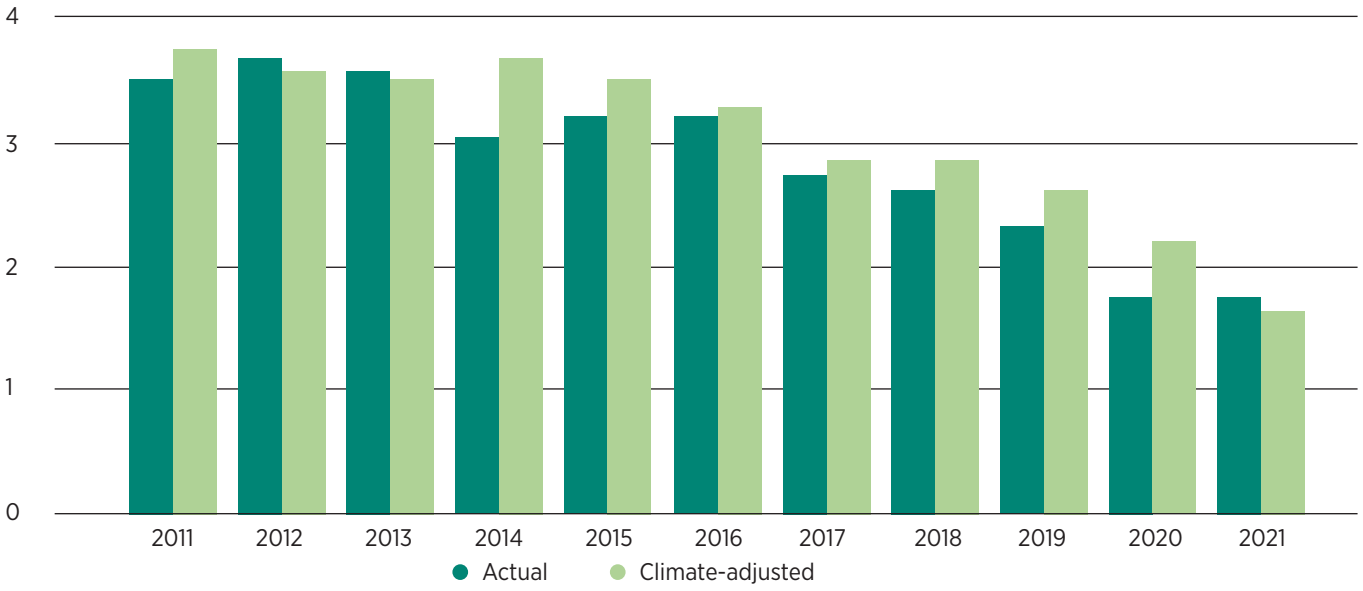
Although an increasing proportion of waste in Denmark is recycled, there will continue to be residual waste that cannot be recycled. The best and most efficient solution for handling this residual waste is energy recovery. Waste-to-energy plants in Denmark displace fossil fuels by utilising the residual waste that cannot be reused or recycled to produce electricity and heat at competitive prices for consumers. This is a sensible use of residual waste that would otherwise be landfilled to the detriment of the climate and environment.

Carbon neutral district heating by 2030

Figure 14 shows the development in district heating CO_2 emissions since 2011. Since 2011, district heating's climate-adjusted CO_2 emissions have been reduced from 3.8 million tonnes to 1.6 million tonnes of CO_2, corresponding to a reduction of 56.2%. The reduction should be seen in light of the fact that district heating production has increased by 7% in the same period. The ambition of the district heating sector is to ensure 100 percent carbon neutral heating by 2030. A green conversion of district heating also ensures that electricity in co-production with heating at the CHP plants will also be carbon neutral.

At the same time, the district heating sector can help convert the majority of the approximately 500,000 Danish homes and 40% of commercial buildings that are currently heated with fossil fuels. There is also potential for increasing the use of district heating as process heating in industry. In addition to ensuring reductions in the district heating sector's own CO_2 emissions, the district heating sector can also contribute significantly to CO_2 reductions in other sectors.

Figure 14: District heating CO_2 emissions (million tonnes CO_2)



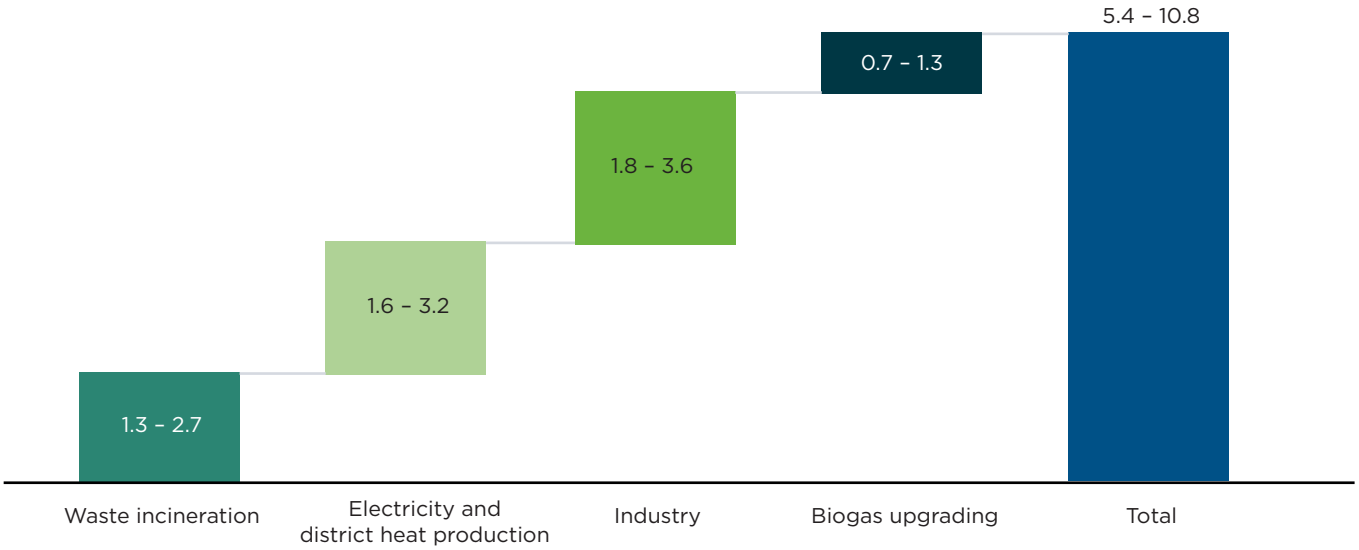
Note: *The Danish Energy Agency defines the climate-adjusted energy consumption for heating purposes as the consumption you would have had if the year had been a normal year in terms of the outside air temperature.*

Source: *Energistatistik 2021 (Danish Energy Agency, 2022).*

Carbon capture, storage and utilisation

The Danish District Heating Association represents both waste-to-energy companies and CHP companies and thus a large part of the sector where carbon capture can play a crucial role in achieving Denmark's climate goals. The Danish Energy Agency has estimated the possible capture potential in 2040 at 5.4-10.8 million

Figure 15: Estimated capture potentials by sector (million tonnes of CO_2 per year)



Source: *Point sources of CO_2 potentials for CCS and CCU – 2022 update (Danish Energy Agency, 2023).*

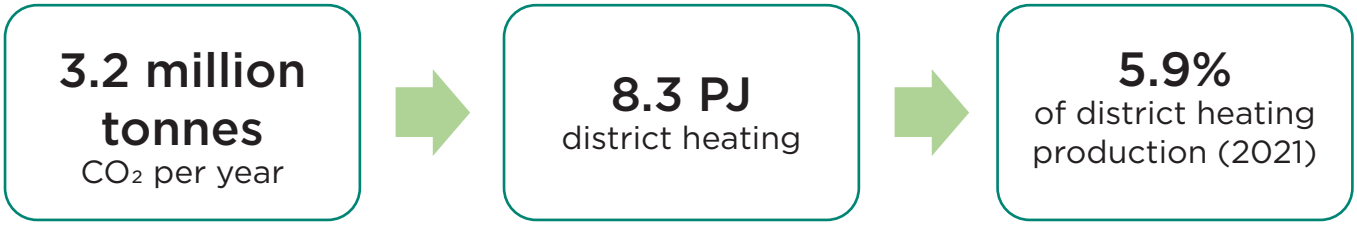
tonnes of CO_2 per year (see Figure 15), of which waste-to-energy companies and CHP companies are expected to contribute to more than half of the potential (2.9-5.9 tonnes of CO_2 per year). Carbon capture enables greenhouse gas emissions to be reduced in sectors where it is currently difficult or impossible to reduce emissions. When we capture and store CO_2 from biogenic sources, such as biogenic waste or sustainable biomass, we remove CO_2 from the atmosphere. This is called negative emissions. According to the Intergovernmental Panel on Climate Change (IPCC), enough greenhouse gases have already been emitted into the atmosphere that it will be impossible to limit global temperature increases to the Paris Agreement targets without removing CO_2 from the atmosphere through, for example, capture and storage of CO_2 from biogenic sources. Specifically, the IPCC has calculated that 740 billion tonnes of CO_2 will need to be stored globally by 2100 if we are to meet the goals of the Paris Agreement.

There will also be a need for the use of biogenic CO_2 for the production of green fuels. By capturing CO_2 at Danish CHP and waste-to-energy plants, the district heating sector can reduce unavoidable fossil fuel emissions and provide sustainable carbon for the production of green fuels and products that can replace fossil fuels in other sectors. For example, carbon from sustainable sources will be necessary if we are to fly sustainably or produce sustainable plastic.

CCUS provides large amounts of excess heat that can be utilised in district heating

In addition to the large CO_2 reductions that can be achieved through carbon capture, the process also generates large amounts of excess heat that can be utilised in district heating. This makes it possible to displace more fossil fuels in district heating production. A potential for carbon capture at the Danish CHP and waste-to-energy plants in the district heating sector of 3.2 million tonnes of CO_2 per year[7] corresponds to an excess heat potential of 8.3 PJ of district heating, which corresponds to 5.9% of the district heating production in Denmark or approx. 100,000 households.

Figure 16: Carbon capture leads to large amounts of excess heat



7) There is a political expectation of CO_2 reductions of 3.2 million tonnes by 2030.

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