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Industrial Heat Pumps, Second Phase IEA Heat Pump Technology (HPT) Programme Annex 48 Task 1: Danish Report

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Industrial Heat Pumps, Second Phase

IEA Heat Pump Technology (HPT) Programme Annex 48

Task 1:
Danish Report

Final Report

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Contents

1 Introduction

This report summarizes the activities of the Danish consortium related to task 1 of the Annex 48 about industrial heat pumps. Task 1 consisted of an analysis of the realized heat pump installations in an industrial context, including district heating.

The task comprised a collection of existing heat pump installations in Denmark, including several information about the specific application, such as heat source, heat sink as well as about the heat pump system, for instance the cycle configuration and the working fluid. The list is available on a separate homepage of Annex 48, while an analysis of the collected data can be found in Chapter 2.

The analysis of the current situation is substantiated with an analysis of the industrial heat demand and available excess heat in Chapter 3. Based on this, the potential for industrial heat pumps in Denmark is derived in Chapter 4. The analysis of the current situation and the technical potential is substantiated with an analysis of the economic boundary conditions for industrial heat pumps in Chapter 5.

2   Existing industrial heat pump installations

Task 1 comprised an analysis of the existing heat pump installations in industry and district heating. As a basis for this analysis, various data was collected for existing installations. This data comprised information about the application, such as heat source and heat sink, as well as about the system such as the layout and the working fluid. In addition, many of the cases were supplemented with a detailed description of the application from different perspectives, such as the manufacturer or the customer. The collection of cases will be published on a separate homepage for Annex 48 and include more detailed descriptions for selected cases.

The collection of the cases comprised the installation of industrial heat pumps and was conducted in 2018. An overview of the collection is given in Table 2-1. In total, 69 cases could be found, of which 47 installations with an accumulated capacity of around 100 MW were supplying heat to a district heating network. The remaining 22 installations were used by industrial customers to supply process or space heating and had an accumulated capacity of 19 MW.

Table 2-1: Overview of collected cases by 2018

	Cases	Capacity
District heating supply	47	100 MW
Industrial heat supply	22	19 MW
Total	69	119 MW

An overview of the number of installations in industry and district heating in the different capacity ranges is given in Figure 2-1 in terms of number of installations, while the accumulated installed capacity is shown in Figure 2-2. The number of installations for the supply of district heating accumulates in and around the category of 1 MW to 2.5 MW. The distribution for installations in industry is more even and has a similar number of installations in the categories from 250 kW to 2.5 MW. The largest installation supplies heat to district heating and has a design capacity of heat supply of 10 MW.

The weighting by the capacities, as shown in Figure 2-2, underlines the large contribution of the few large installations in district heating.

In Figure 2-3 the supply temperatures of the installed heat pumps are shown. The number of installations for both district heating and industry accumulates for a supply temperature between 60 °C and 80 °C. This temperature range is the most common supply temperature in the district heating distribution networks in Denmark and indicates that most heat pumps are designed for direct supply. For the industry, the heat pumps are used for different purposes, and the trend in supply temperature may reflect both direct use of the supply temperature as well as preheating of streams. The maximum observed supply temperatures for heat pumps installed in the industry also indicate the current industrial development of heat pumps utilizing ammonia as refrigerant, in terms of supply temperatures.

The dominating distribution of installations for the supply of district heating may be associated with different aspects. Such aspects may be the economic boundary conditions or different investment strategies. The district heating operators are typically considering longer investment horizons and are legally obliged to consider the socioeconomic cost in their investment decisions (Danish District Heating Association, 2015). In industrial applications, the focus lies more often on low payback times and thereby on low investment costs, even though this may result in lower operating performance throughout the plants lifetime. In addition, it may be noted that the ratio

of electricity to alternative fuels is more favorable when supplying heat to district heating compared to heat supply for industrial processes. An analysis of the economic boundary conditions is presented in Chapter 5.

Furthermore, the more widespread distribution of installations may be associated with the lower complexity of the systems into which the heat pumps have to be integrated. In district heating applications, the heat pump is used for supplying heat to the network and the location and the heat source are chosen accordingly. During operation, the heat pump is driven to cover a certain heating demand. In industrial applications, the heat pumps are to be integrated into more complex systems, which often involves comprehensive integration studies. In addition, the heat pumps are often used to supply both heating and cooling. This results in an increased economic performance but also implies higher complexity.
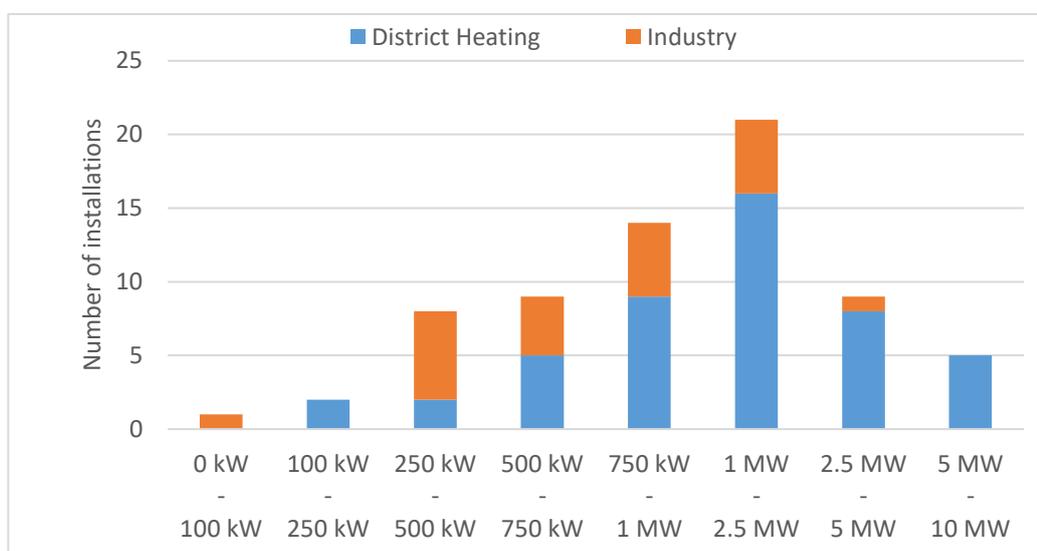

Figure 2-1: Overview of heat pump installations for industry and district heating by number of installations
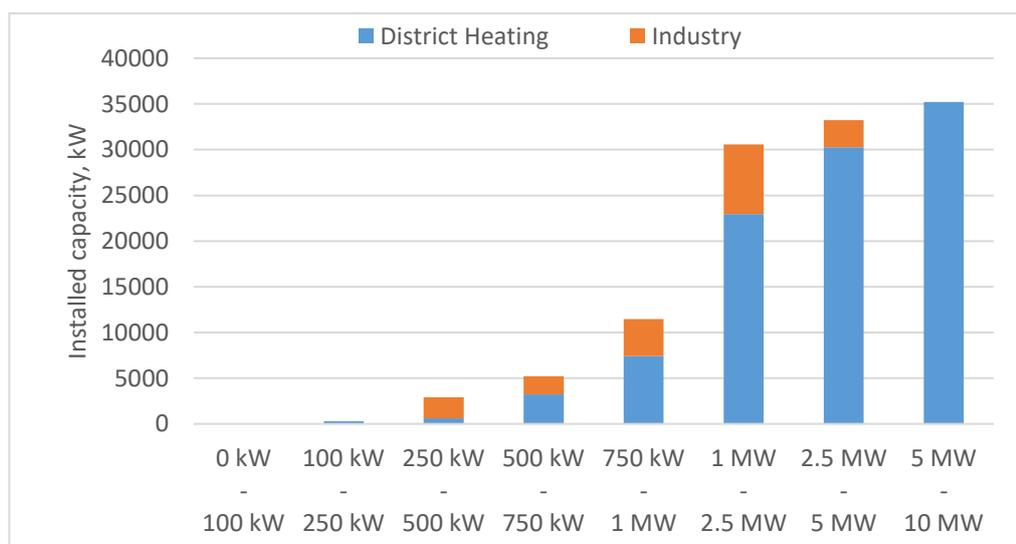

Figure 2-2: Overview of heat pump installations for industry and district heating by installed capacity
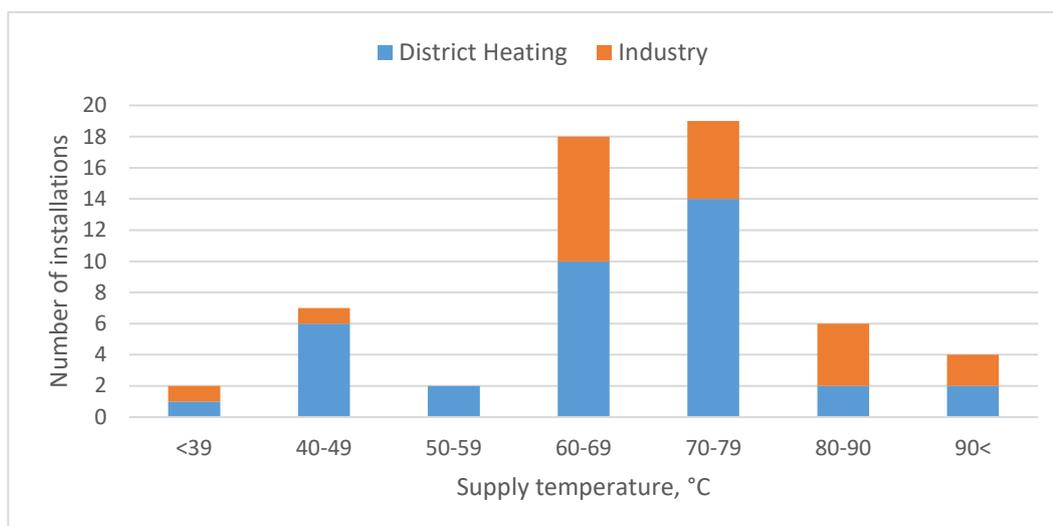
Figure 2-3: Overview of the supply temperature by number of heat pump installations in district heating networks and industry.

Figure 2-4 shows an overview of the refrigerants according to their installed capacity. It shows that the majority of plants is using R717 (Ammonia), due to high COP and moderate investment costs. The remaining plants use R744 (CO_2), hydrocarbons or a mixture of R717 and R718 (ammonia and water) in hybrid vapor absorption compression heat pumps. The use of synthetic refrigerants was limited to one application using R134a with a capacity of 25 kW for industrial washing applications.

Cases for which no information about the refrigerant was available, were omitted from the figure.
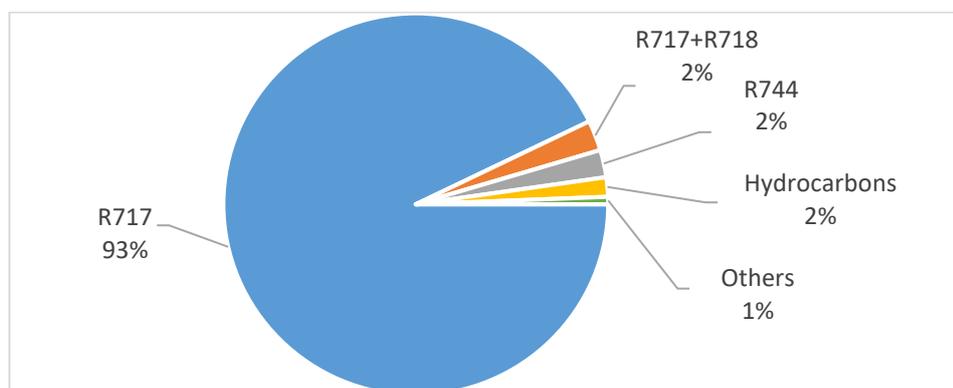

Figure 2-4: Installed capacity of heat pump installations for industry and district heating by refrigerant type

In Figure 2-5 the specific investment cost are shown for 29 heat pump installations. All of the considered installations were installed with a district heating network as heat sink. The investment cost included all related costs to the project, such as cost of equipment, construction, connection to both electricity and heating networks and the heat source. For the considered installations the specific investment cost varied between 0.27 €/MW and 2.58 €/MW. The most expensive heat pump is a test and demonstration heat pump and should be omitted for a general trend. In (Pieper et al., 2018) the investment cost for large-scale heat pumps was further analyzed and initial cost correlations was derived. The work is further presented in Report 2, Chapter 3 (Jørgensen et al., 2019).
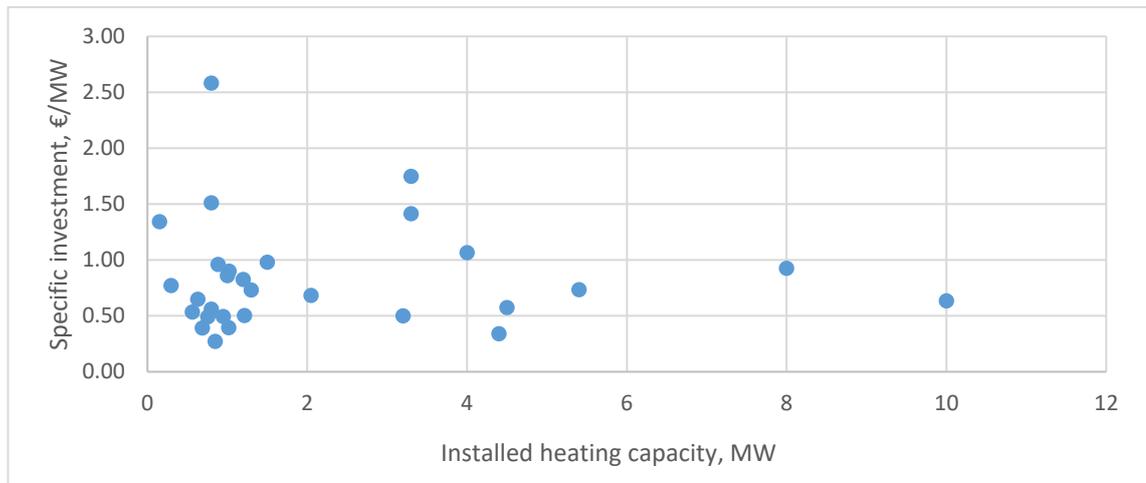
Figure 2-5: The specific investment cost of 29 heat pump installations for district heating.

The collection was based on publicly available information and supplemented with information from manufacturers, consultancy companies and end-users. The main purpose of the collection was an analysis of the applications of heat pumps in different sectors rather than an analysis of the performance. The collected information regarding COP and operating conditions may stem from the design phase or operating experiences. No standard was defined for the collection of the data. In addition, it may be noted that the list may be incomplete, due to lack of data.

3 Industrial energy demand and excess heat

This chapter presents an analysis of the industrial heat demand as well as the available excess heat. It serves as the basis for an estimation of the application potential of industrial heat pumps following in Chapter 4.

The gross energy consumption of the agricultural and industry sector of Denmark was 166.3 PJ in 2017. This corresponds to 22 % of the country's total gross energy use. The household sector accounted for 28 % and the transport sector for an additional 28 % of the gross energy use. Within the industry sector the manufacturing industry accounted for 70 % of the final energy use while the agricultural sector accounted for 20 % (Danish Energy Agency, 2018).

Figure 3-1 shows the distribution of final energy use by industrial sectors. It can be seen that the food & beverages industry is in energy terms the most significant one, followed by the manufacturing of plastic, glass and concrete products. All industries, except the wood & paper industry rely heavily on the direct use fossil fuels. The manufacturing industry with the highest turnover was also the food & beverages industry, followed by machinery, pharmaceutical and chemicals (Statistics Denmark, 2019). The ten largest enterprises of the Danish manufacturing industry account for 37 % of the total turnover.
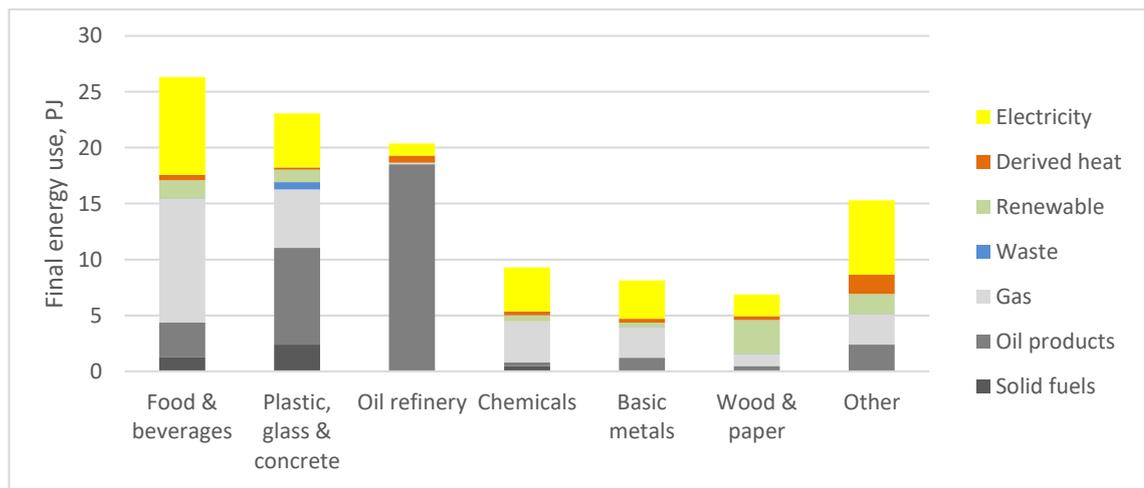
Figure 3-1: Final energy use by energy carrier and industry sector for the manufacturing industry in Denmark (2016). Based on data from Statistics Denmark (Statistics Denmark, 2017).

The use of fuels in the manufacturing industry is shown in more detail in Figure 3-2. It can be seen that the highest share of fuels is required for process heating and drying operation. In total 86 % of the fuel is used for thermal operations, while 14 % is used for transport.
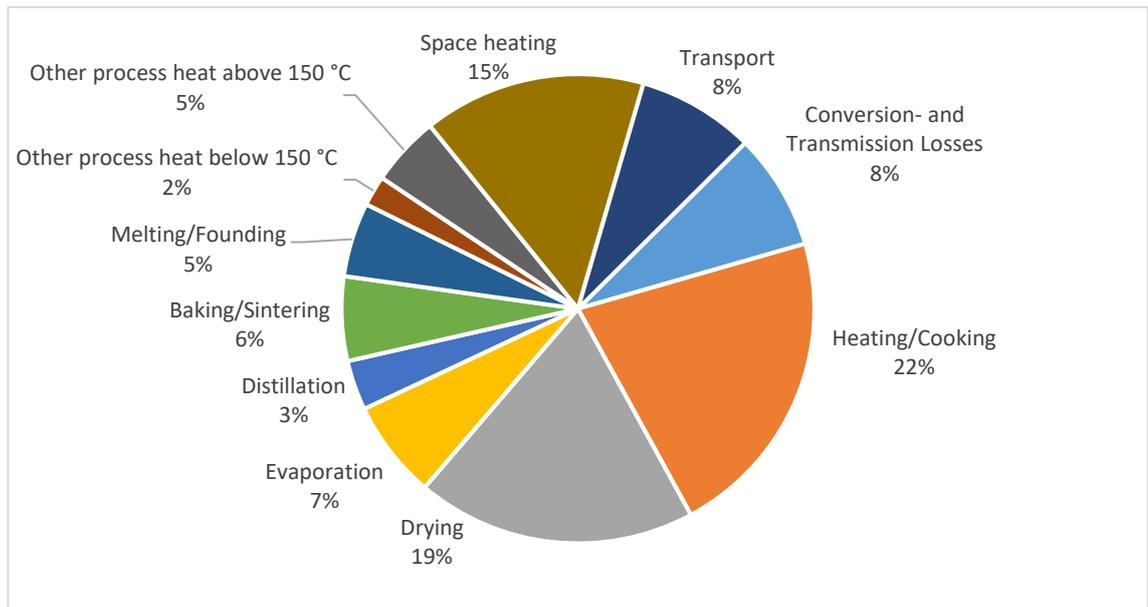
Figure 3-2: Distribution of fuel use in the manufacturing industry by final energy user in Denmark. Based on data from (Sørensen et al., 2015) using the 2012 final energy use from (Statistics Denmark, 2017).

The available excess heat for the main processes in the manufacturing industry are shown in Figure 3-3 based on an analysis conducted in (Huang et al., 2015). Using a top-down approach based on expert assessments, industry experience and case studies, typical excess heat temperatures and amounts for different processes were obtained. It can be seen that excess heat from refrigeration, evaporation and drying has the highest potential, though temperature of the excess heat is relatively low (< 100 °C). On the other hand, high temperature excess heat is available from furnaces and melting operations but is limited in quantity.
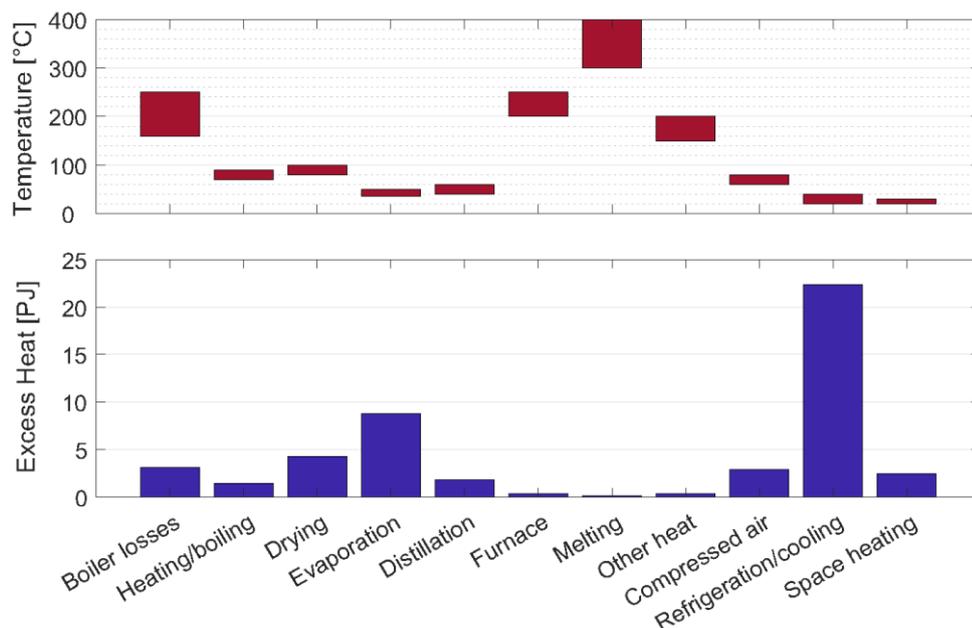

Figure 3-3: Quantification of excess heat from the manufacturing industry in Denmark by process and with temperature level of the excess heat sources. Based on data from (Huang et al., 2015).

It was estimated that there is a total excess heat potential of 220 PJ per year across all sectors, including road and sea transport, buildings and service sectors. The total excess heat potential corresponds to approximately 13 % of the net energy input to the sectors. The manufacturing industry had a total excess heat potential of 22.58 PJ, which corresponds to 21 % of its final energy use. Other major sectors with excess heat are transport utility and households.

Another analysis focused on industrial excess heat from thermal processes in the largest manufacturing industries in Denmark (Bühler et al., 2016). In this analysis the process categories were analyzed for each industry sector, leading to a higher level of detail than in the previous study. However, only thermal heating processes were considered, which excluded refrigeration and compressed air. For each industry sector energy-end use models were created for typical production processes, which included typical process temperatures and efficiencies. The work found a total available excess heat potential of 12.6 PJ. The distribution of this excess heat potential by temperature and industry is given in Figure 3-4. Excess heat from energy-intensive industries, in particular oil refineries and cement production are responsible for a large share of the excess heat at low and high temperatures. Some of the excess in the temperature bands 140 °C to 180 °C and 220 °C to 260 °C originates from conversion and transmission losses of the utility system and is not fully useable.
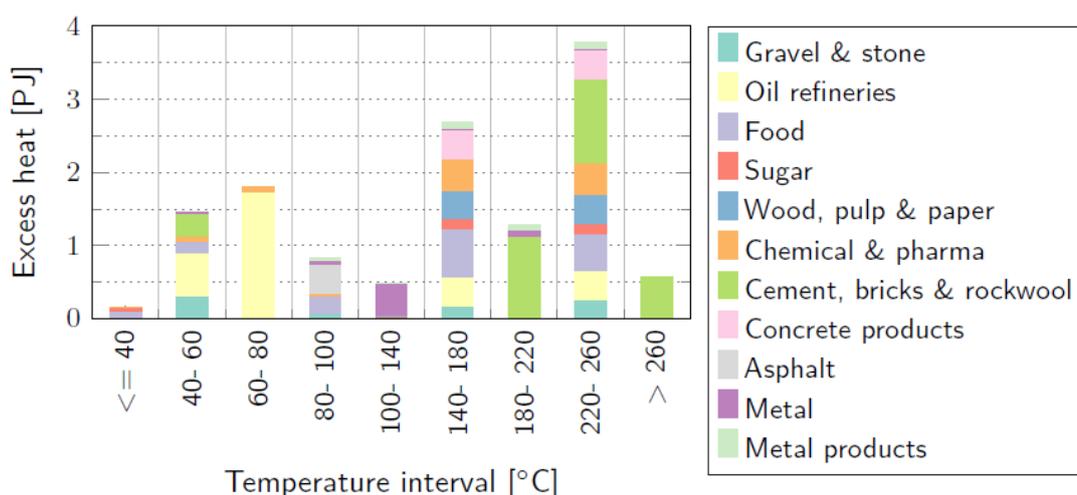
Figure 3-4: Excess heat potential in Denmark from thermal processes in the manufacturing industry. Based on data from (Bühler et al., 2017).

The assessment of excess heat from thermal processes in the manufacturing industry was further expanded by distributing the excess heat spatially (Bühler et al., 2017) and temporally (Bühler et al., 2018). Figure 3-5 shows the geographical location of industrial production sites in Denmark and the spatial distribution of industrial excess heat in Denmark. Several locations with a high density of excess heat can be found. These locations have a high concentration of energy intense industries (e.g. processing of metal and non-metallic minerals, oil refineries).
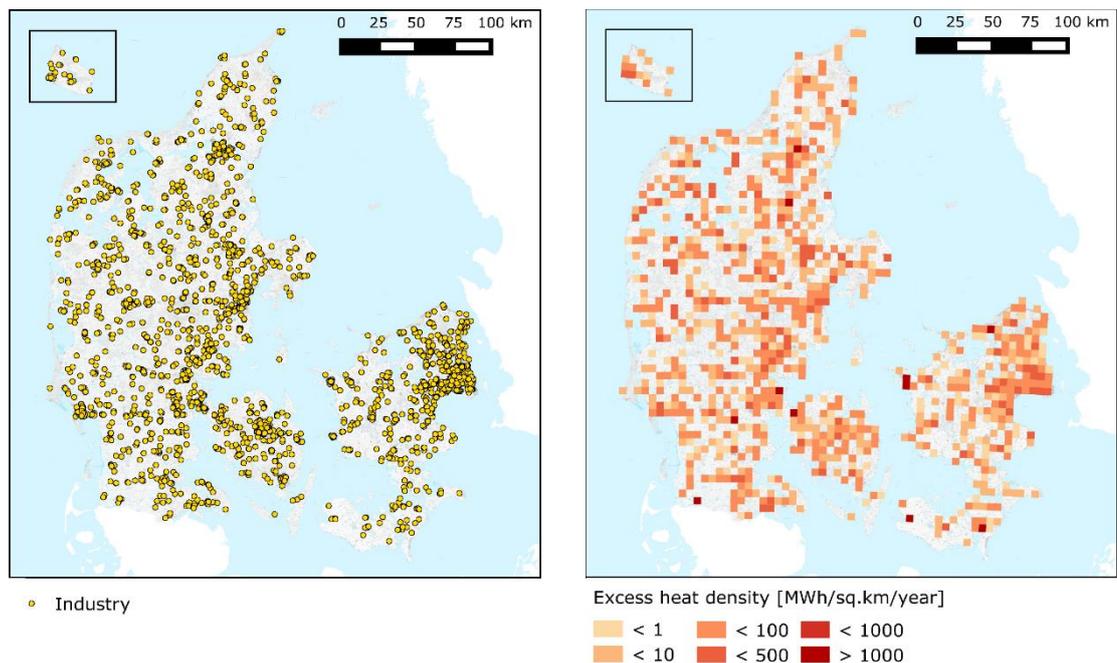
Figure 3-5: Location of industrial sites in Denmark (left map) and density of excess heat from the thermal processes. Based on data from (Bühler et al., 2017).

Based on typical operation profiles created for industrial sectors, which took the size of production sites into account, the average capacity of excess heat sources was established for each excess heat source (Bühler et al., 2019b). Figure 3-6 shows the distribution by number of sources, where it can be seen that the vast majority of sources is below 100 kW and is in the main sector of "Metal" in particular metal processing. Figure 3-7 shows that largest share of excess heat is emitted by sources above 1 MW, primarily from the production of e.g. cement, bricks, asphalt but also oil refineries and to smaller numbers in the food and chemical industry. It has to be noted that several excess heat sources may be combined to a single one in practice and that the distribution is very country specific.
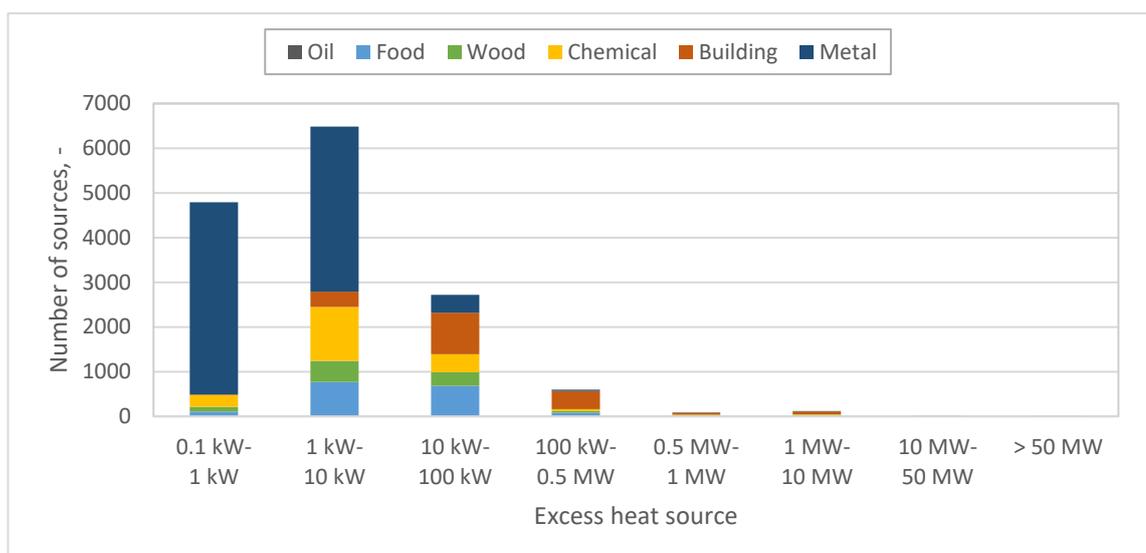

Figure 3-6: Distribution of industrial excess heat sources by capacity and industry sector, (Bühler et al., 2019b).
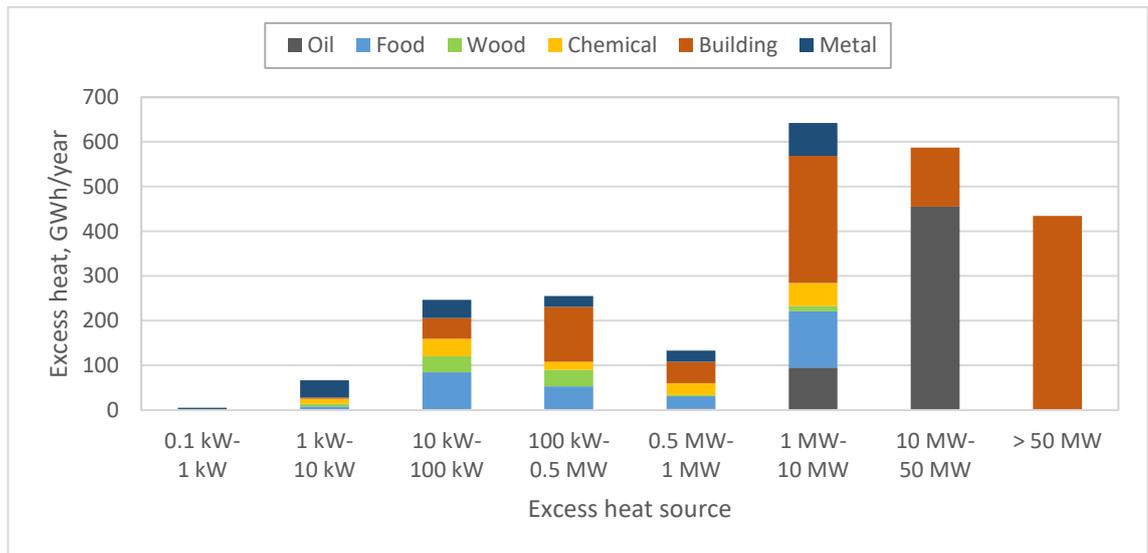
Figure 3-7: Distribution of industrial excess heat potentials by capacity and industry sector, (Bühler et al., 2019b).

4 Potential for industrial heat pumps

Following the analysis of the heat demand and availability of excess heat in the Danish industry, this chapter presents an analysis of the potential of industrial heat pumps.

4.1 Potential for heat pumps in district heating

The use of excess heat for district heating is an important topic in Denmark since approximately 64 % of all households are connected to district heating (Danish District Heating Association, 2019). Several of the district heating companies are reducing the share of fuel fired heating and combined heat and power plants in their heat supply while increasing the share of heat pump-based solutions. This increases the installation of large-scale heat pump systems for supply of district heating and accordingly the demand for heat sources.

An analysis of potential heat sources for heat pumps in district heating applications was conducted by (Lund and Persson, 2016). Within a 500 m radius around district heating areas, there was found a national potential for some sources including

- 3.4 TWh of industrial excess heat
- 0.4 TWh from supermarkets
- 2.9 TWh from wastewater treatment
- 0.8 TWh from drinking water
- 6.9 TWh from ground water
- 3.2 TWh from rivers
- 0.7 TWh from lakes

Additionally, it is expected that a substantial share may be covered by sea water.
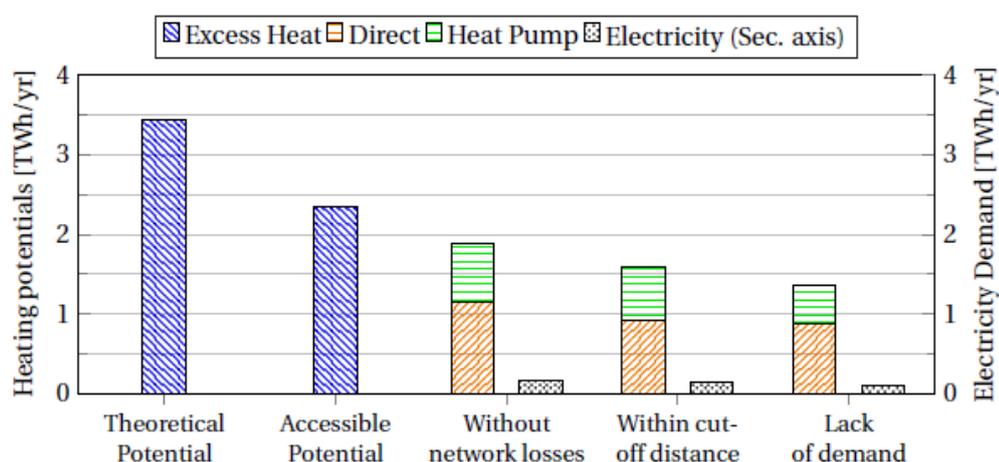
Figure 4-1: Utilization potential of industrial excess heat from thermal processes for district heating in Denmark (Bühler et al., 2017).

A more detailed analysis of the geographic distribution and utilization potential of industrial excess heat sources in Denmark was done in (Bühler et al., 2018, 2017). It showed that the majority of excess heat sources found in the industry are relatively small (< 100 MWh per year), while

there are a few large sources primarily found in the main industrial areas of Denmark (Ka-lundborg, Fredericia, Aalborg). On a national perspective the potential for utilizing the industrial excess heat for district heating is shown in Figure 4-1.

The energy outlook from the Danish Energy Agency (Danish Energy Agency (Energistyrelsen), 2019) projects approximately 10 % of the expected complete district heating supply in 2030 (135 PJ) to be covered by heat pumps and electric boilers (14 PJ). This corresponds to an installed capacity of large-scale heat pumps in district heating between 600 MW to 1000 MW in 2030.

4.2   Potential for heat pumps in industry

While the use of heat pumps for district heating is important, heat pumps are expected to also play a major role in the future process heat supply. The Danish industry is characterized by a high demand of low to medium temperature heat in the food, chemical and pharmaceutical industry (see the previous section). With an increase of renewable electricity generation, more of the process heat will be covered by heat pumps. (Bühler et al., 2019a) analyzed different electrification scenarios of the Danish industry, where it was investigated how much of the pro-cess heat demand can be supplied by electric technologies. Figure 4-2 summarizes the results of an electrification scenario with a high technological development, meaning amongst others high temperature heat pumps are available. A large share of the fuel use could be electrified in the food, oil and chemical industry with heat pumps. Using natural sources and excess heat, the heat pumps would considerably reduce the final energy use of most industrial sectors compared to the business as usual (BAU) scenario.
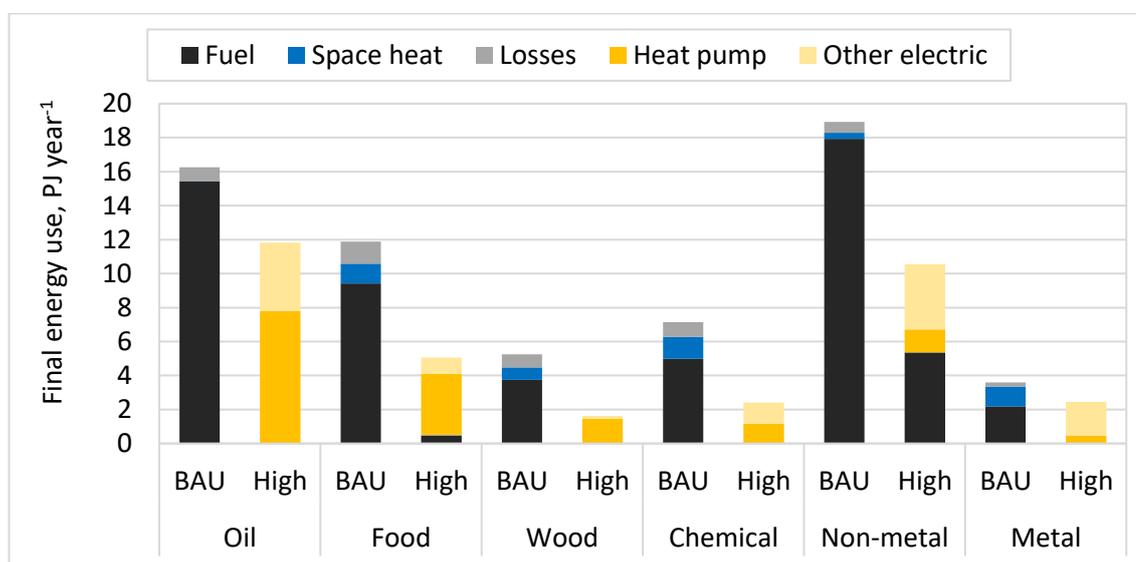
Figure 4-2: Potential for heat pumps in an electrified industrial sector. Based on (Bühler et al., 2019a).

A more detailed analysis of the use of excess heat for industrial process heating was done, using the data for process heating and excess heat presented in the previous chapter. Two cases where assumed for the heat sink: (i) it was assumed that the sink is heated from the excess heat temperature to the maximum heat pump supply temperature or the process heat temperature if below the maximum supply temperature, (ii) it was assumed that all heat is supplied at the lower of the maximum heat pump supply temperature and the required process heat tempera-ture. The possible heat supply temperature was varied, to investigate which potentials are avail-able. The results are shown for the cases in Figure 4-3 and Figure 4-4.
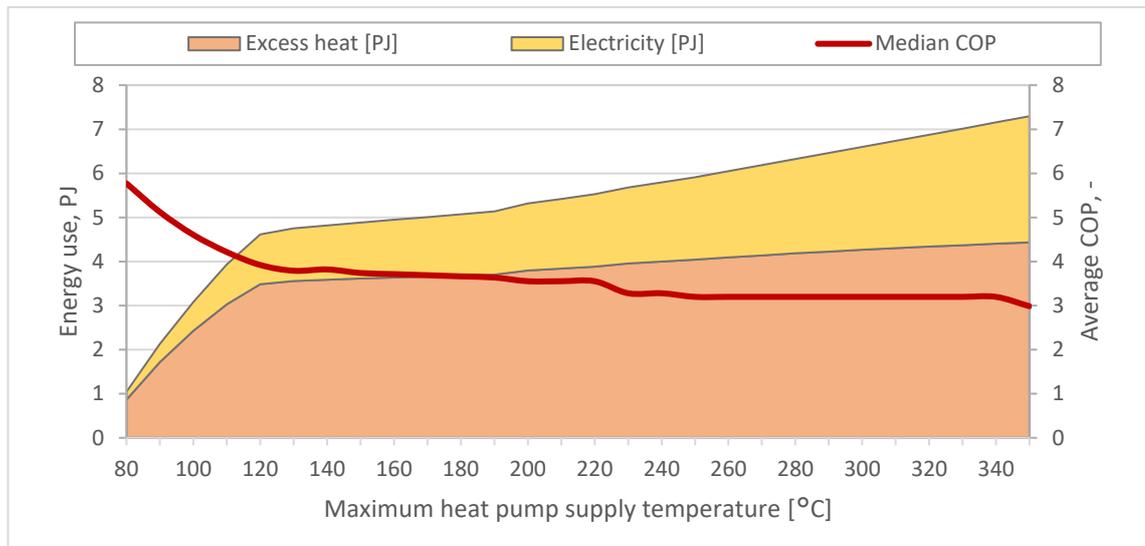
Figure 4-3: Utilization potential of excess heat with heat pumps and average COP in the Danish manufacturing industry assuming the heat pump sink is heated from the excess heat temperature to the maximum supply temperature, (Bühler et al., 2019b).
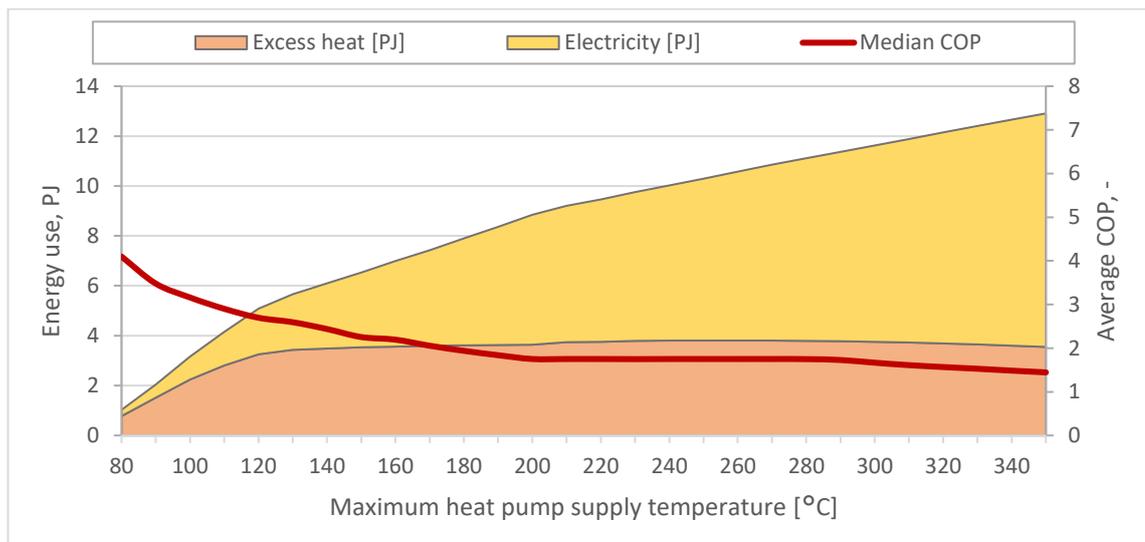
Figure 4-4: Utilization potential of excess heat with heat pumps and average COP in the Danish manufacturing industry assuming all heat is supplied at the maximum heat pump supply temperature, (Bühler et al., 2019b).

It can be seen that for a glide on the heat sink, there is a strong increase in the amount of process heat that could be supplied by heat pumps that are recovering excess heat below 120 °C. The lower increase above 120 °C is caused by the requirement of process heating below this temperature and the decreasing availability of excess heat at temperatures above. From 120 °C onwards, the used excess heat increases slightly while the COP decreases, increasing the overall amount of process heat supplied over-proportionally.

The same increase until 120 °C can be observed in the second case, where the heat is provided at the highest temperature without glide. However, the amount of utilized excess heat is almost constant thereafter, as the obtainable COP is low and thereby increases the share of electricity in the supplied heat.

5 Economic boundary conditions and political strategies for heat pumps in Denmark

This chapter presents an overview of the economic boundary conditions, political strategies and other influential boundary conditions for the applications in industry and district heating. These explanations provide a basis for comparisons in an international context and for determining which boundary conditions might have high impacts.

Energy costs in Denmark:

In the following the electricity and natural gas prices to be paid for space heating and industrial process use are described. The taxation of energy use in Denmark (Danish Tax Authority (SKAT), 2016a, 2016b) comprises taxes on fuels (solid, gas, and liquid) and electricity in addition to the VAT. The tax on fuels can be split into a part on emissions (CO_2, NO_x, and SO_2 tax) and on fossil fuel energy content (tax based on the heating value). Renewable energy such as biogas and biomass are only taxed based on emissions while no additional fuel tax is applied.

For electricity, all emission taxes are included in the overall electricity price, including the CO_2 tax. The electricity price consists of the electricity spot market price, a mark-up for the electricity company[1], transmission and distribution costs, electricity tax and the PSO (Public service obligations). According to a recent political decision the PSO will be phased out. Hence, PSO cost on all electricity purchase is expected to drop from approximately 250 DKK/MWh (33.5 €/MWh) in 2016 to 0 €/MWh in 2021 (Energi- Forsynings- og Klimaministeriet, 2016).

Figure 5-1 shows the total cost for electricity used in industrial processes and Figure 5-2 shows the total cost for electricity used for space heating, which corresponds to both installations for supply to district heating as well as installations in industry supplying e.g., office buildings. Similarly the cost for natural gas used for processes is shown in Figure 5-3 and for space heating in Figure 5-4. The transmission and distribution tariff is based on an estimation from the Danish Energy Agency. "Energy savings" is a tax, which the energy companies uses for advice and grants on energy savings. The changes in taxation and PSO for electricity being implemented between 2018 and 2021, decrease the costs for electricity considerably in this period. Especially the electricity price for space heating is decreased by around 200 DKK/MWh in this period. The price for natural gas will increase steeper in the future than the one of electricity, due to higher fuel costs. However, increases in CO_2 quota prices are not included in this price and could be significant for natural gas consumers.

Costs for alternative fuels in Denmark:

The prices of biobased fuels to replace natural gas vary. Biogas prices are expected to lie between 64 €/MWh and 75 €/MWh for upgraded biogas (Danish Energy Agency, 2014). The market price of biomass (wood chips and wood pellets) in Denmark in 2017 was between 24.3 €/MWh and 27.5 €/MWh for industries (Danish Energy Agency, 2017a). This price is expected to increase to up to 33 €/MWh by 2020. All prices are based on the Lower Heating Value by the Danish Energy Agency.

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[1] A mark-up can be seen as an expression of contribution margin on the sale of an electrical product. The mark-up is being set by The Danish Utility Regulator (Forsyningstilsynet, former Energitilsynet).

Electricity for production
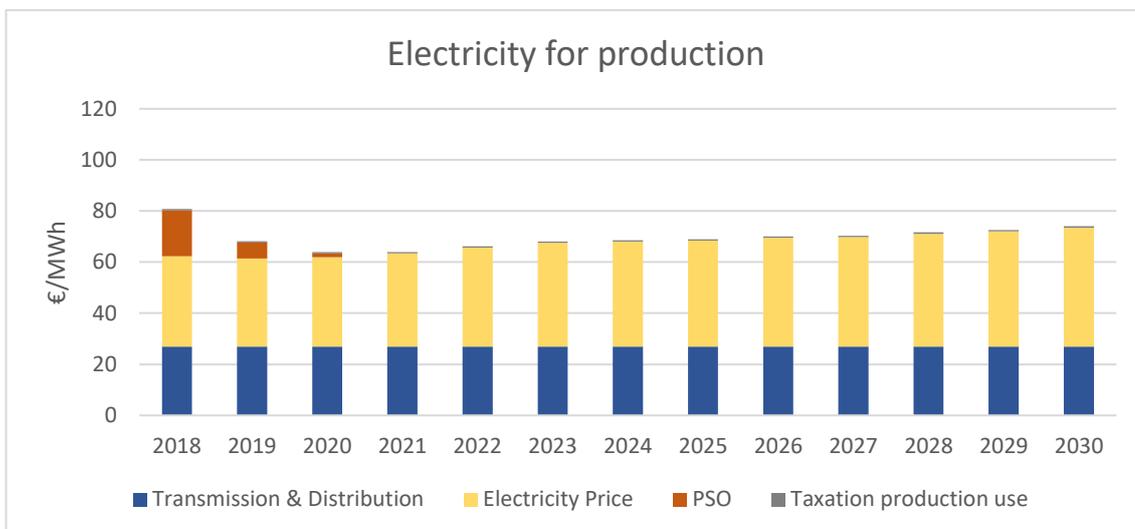
Figure 5-1: Current and forecasted electricity prices with taxes and fees for electricity used for production processes. Own representation based on (Danish Energy Agency, 2017a; Energi-Forsynings- og Klimaministeriet, 2016; Energinet.dk, 2017; PricewaterhouseCoopers, 2018)(Danish Energy Agency, 2017a; PricewaterhouseCoopers, 2018).

Electricity for space heating
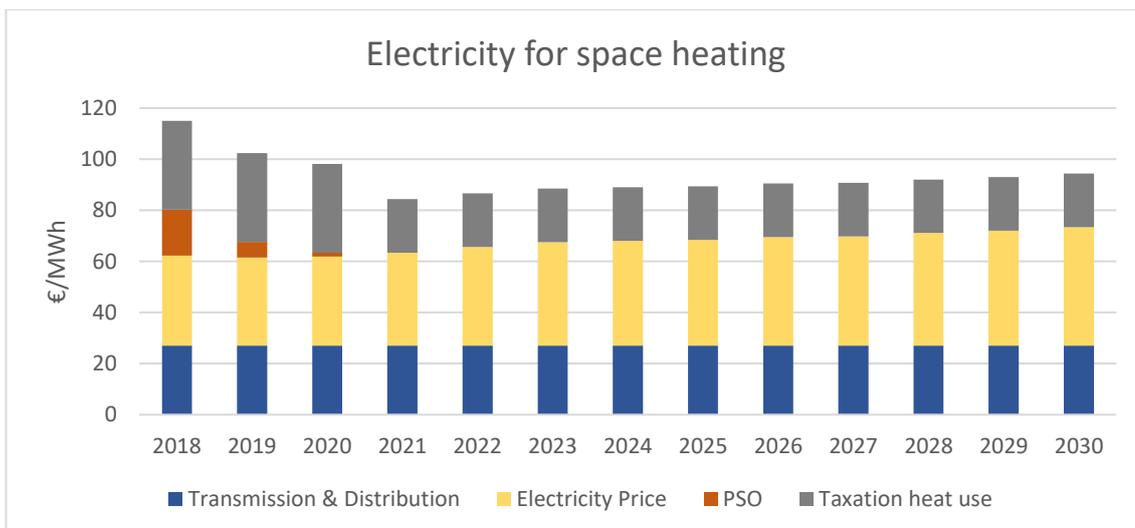
Figure 5-2: Current and forecasted electricity prices with taxes and fees for electricity used for space heating. Own representation based on (Danish Energy Agency, 2017a; Energi- Forsynings- og Klimaministeriet, 2016; Energinet.dk, 2017; PricewaterhouseCoopers, 2018).

Natural Gas for production
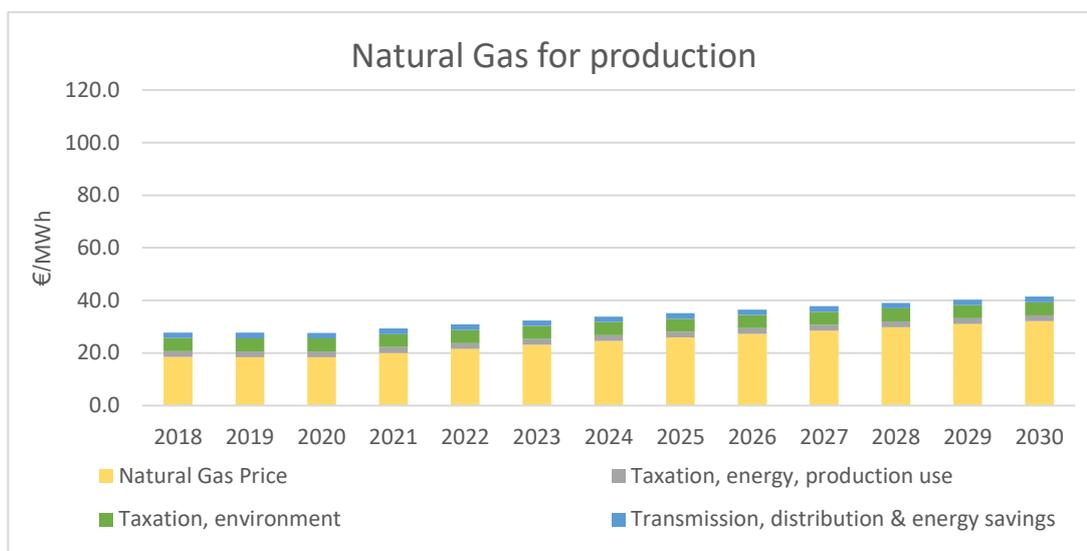
Figure 5-3: Current and forecasted natural gas prices with taxes and fees for use in production processes. Own representation based on (Danish Energy Agency, 2017a; PricewaterhouseCoopers, 2018).

Natural Gas for space heating
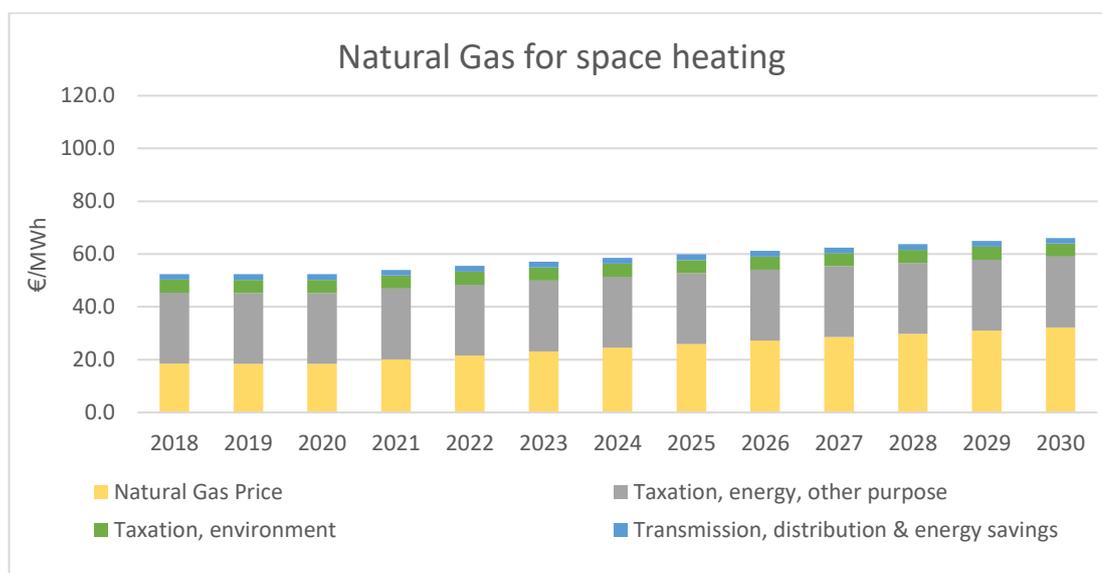
Figure 5-4: Current and forecasted natural gas prices with taxes and fees for use in amongst other space heating applications. Own representation based on (Danish Energy Agency, 2017a; PricewaterhouseCoopers, 2018).

Figure 5-5 shows the ratio of electricity to natural gas price for heat pumps for process heat supply and space heating supply. This ratio may be interpreted as the minimum required COP to cover operational expenses. It may be seen that the ratio is generally lower when supplying heat for space heating purposes, indicating higher revenues at the same COP. For space heating applications, the ratio is decreasing from above 2 in 2018 to 1.5, where it stabilizes from 2021 onwards. For process heat supply, the ratio was around 2.8 in 2018 and decreases more steadily, while approaching 1.7 in 2030.
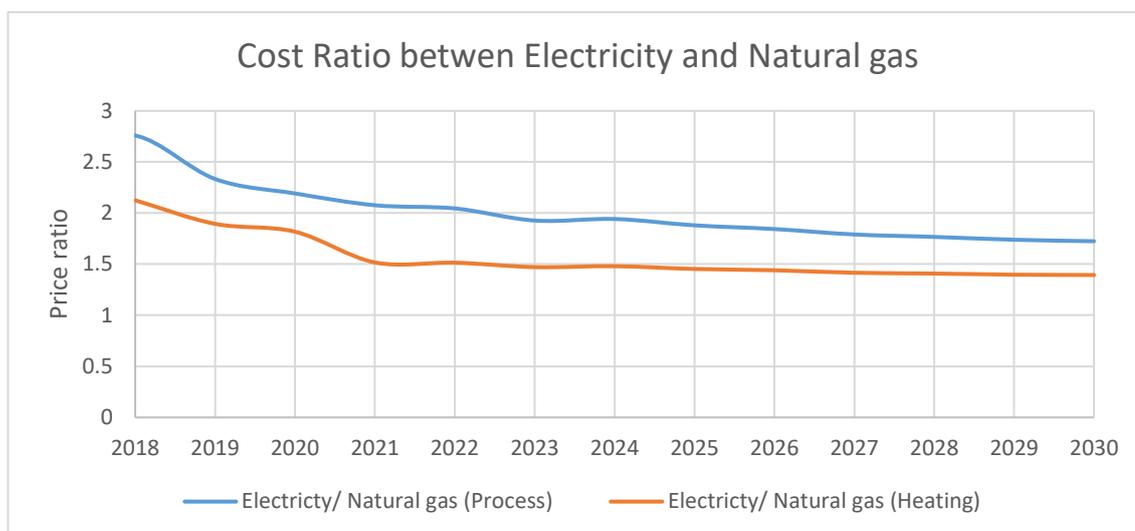
Figure 5-5: Ratio of electricity prices to natural gas prices for process heating and space heating.

Excess heat tax in Denmark:

In general, Danish companies must pay a tax on utilized excess heat when the heat comes from a process and is being used by a special installation for a non-process purpose. The reason for the excess heat tax can be found in the way energy for process and non-process purposes is taxed. The aim of Danish excess heat tax is to secure that no speculation is made in order to avoid paying energy tax. The tax on excess heat is put in place to compensate for a missing tax payment when process excess heat subsequently is used for a higher tax category such as space heating. The excess heat tax is often mentioned as a cause of confusion about the benefits excess heat utilization in Denmark.

If excess heat from process is used for a process heating, no excess heat tax is paid. Also, if excess heat from ventilation systems (categorized as excess heat from space heating) is used for space heating, no tax has to be paid. However, if excess heat from a process is used for district heating or space heating a tax of 25 DKK/GJ has to be paid. If the process excess heat is used for district heating the tax can be reduced to 10 DKK/GJ if a special agreement with the Danish Energy Agency is made. The agreement binds the company to undertake energy saving efforts.

If a heat pump is installed to utilize the process excess heat for district heating, then the excess heat tax is only paid for the amount of district heat generated, which is above three times the electricity use of the heat pump. This rule is currently under revision and the factor 3 might be adjusted. The idea of this tax is to motivate the implementation of high-performance equipment with high COPs instead of low-cost equipment working with lower COPs.

Subsidies in Denmark:

In Denmark, energy saving obligations are in place for utility companies. The Danish Network and Distribution companies are obligated to save 10.1 PJ per year in the period 2016 to 2020 (Danish Energy Agency, 2017b). These are required to reduce energy consumption by a certain amount each year. In cases where a utility company cannot achieve the energy savings target, it has the possibility to buy energy savings on the market. The implementation of heat pumps to decrease final energy use can be eligible to account as energy savings. The value of energy savings ranges between 30 €/MWh and 60 €/MWh of energy saved in the first year of operation. This system will however end in 2020 and a replacement is not yet found.

Example of economic boundary conditions in Denmark:

To exemplify the economic boundary conditions the following simple case study calculations are made. It is assumed that an excess heat source at 40 °C is available which can be cooled down to 15 °C, having a total heat volume of 2500 MWh per year during 6000 operating hours. A heat sink, requiring heating from 45 °C to 85 °C, is assumed to be present which is in the first case space heat and in the second case process heat. The required heat pump is assumed to operate at a COP of 5 with a specific investment cost per heat supply capacity of 700 €/kW (Danish Energy Agency, 2015). For district heating and industry an investment time frame of 20 years was assumed.

From the Table 5-1 it can be seen that the utilization of excess heat has in general favorable conditions for both space heating and process heat with the given assumptions. The expected decrease in electricity costs between 2018 and 2021 would improve the business case, however the type of subsidy is unknown as the current support scheme ends in 2020. Therefore, it was assumed that no subsidy is available in 2021 and that the excess heat tax only applied on the heat generated above four times (instead of three) the electricity consumption. The reduction in tax and PSO compensates in the simplified example the subsidy.

For the industry, higher payback times are found. This is primarily caused by a smaller difference between electricity and natural gas prices for process use. The heating price is however lower for the industry as energy prices are lower.

Table 5-1: Example economic calculation of excess heat utilization with a heat pump for district heat/ space heat and process heat use with a COP = 5 and an installed heat supply capacity of 520 kW.

		District heat/ Space heat		Process heat	
		2018	Expected (2021)	2018	Expected (2021)
Investment	[€]	364,583	364,583	364,583	364,583
Subsidy	[€]	125,000	-	125,000	-
Electricity cost	[€/year]	71,857	52,723	50,488	39,970
Excess heat tax	[€/year]	1,173	587	-	-
Natural gas savings	[€/year]	169,113	173,840	91,533	96,260
Payback time	[years]	2.4	3.00	5.8	6.5
Heating price	[€/MWh]	27.2	22.9	20.0	18.6

Summary of economic barriers and drivers for heat pumps in Denmark:

The case study shows that several elements in Denmark support the use of heat pumps. A summary of the major aspects promoting and inhibiting the implementation of heat pumps is given in Table 5-2.

Table 5-2: Overview of main drivers and barriers for the implementation of heat pumps in industry and district heating

Drivers	• Subsidies for energy saving applicable to heat pump projects (Sale of energy savings to utility/ energy saving obligation)
	• Reduction in electricity taxation for heating use and phase out of PSO
	• Simplification of excess heat taxes
	• Legal obligation to consider socioeconomic cost as main investment criteria for heat pumps in district heating
Barriers	• Relative low price/ taxation for alternative combustion fuels, including natural gas and biomass, is promoting the use of natural gas boilers instead of heat pumps
	• Energy saving obligation scheme will stop in 2020, uncertainty of new support scheme
	• Currently there are obligations for certain heating areas to be connected to the natural gas grid
	• Uncertainty and complicated rules
	• Rather short required Payback periods for feasibility

6 Summary

This report documents the current situation of heat pumps in industry and district heating and brings it into the context of the technical potential and the economic boundary conditions. As a basis, information about existing heat pump installations were collected and compared. In total, 69 cases were found, of which 47 were supplying heat to district heating networks, while 22 were supplying heat to industrial processes or buildings. The total installed capacity accumulates to 119 MW, while 100 MW are installed in district heating. The capacity of the installations for district heating supply accumulated in the size of around 1 MW to 2.5 MW, while the installations in industry showed a relatively even distribution in the range between 250 kW to 2.5 MW. The most utilized refrigerant was R717 (ammonia).

This mapping was substantiated with an analysis of the technical potential for heat pumps in industry and district heating as well as with an analysis of the economic boundary conditions. The analysis in which the excess heat from industrial processes was mapped and combined process heat demands showed a considerable potential for heat pump-based process heat supply in a wide range of temperature levels. The capacities for the heat pump installations could be derived from the capacity of the available heat sources. The total availability of heat sources in different capacity categories varied relatively evenly in terms of capacity in a range from 10 kW to 10 MW. The number of smaller installations is accordingly higher.

The cost of fuels are subject to different taxes according to their utilization for supply of either industrial process heat or space heat. The analysis of the boundary conditions showed that the ratio of electricity cost to cost for natural gas is generally lower for district heating applications and decreases for both industrial and district heating installations in future. The decrease in the energy cost ratio for installations in district heating is faster before it stabilizes at around 1.5 in 2021, while the ratio approaches 1.7 in 2030 for industrial process heat supply installations.

7 Acknowledgements

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