FEASIBILITY OF HEAT PUMPS SUPPLYING DISTRICT HEATING SYSTEMS - CASE STUDY FOR AUSTRIA AND DENMARK

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1 SUMMARY

The frame conditions for large-scale heat pumps (HPs) in district heating (DH) systems were studied for Denmark and Austria. While large-scale HPs are becoming more and more often implemented as DH supply units in Denmark, examples from Austria are rare. An economic analysis was conducted for both countries, comparing DH solutions based on either large-scale heat pumps or wood-fired heat only boilers to individual HPs. The results showed that large-scale HPs were beneficial compared to individual units down to linear heat demand densities of 0.85 MWh/m/a for Denmark and 0.97 MWh/m/a for Austria. The levelized cost of energy of central HPs could compete with wood-fired boilers especially for low DH temperatures (60 °C /30 °C). From a socioeconomic perspective HPs were beneficial compared to wood-fired boilers. In Austria the private economic feasibility of wood-fired boilers benefits from subsidies, which showed to decrease the competitiveness of large-scale HPs.

2 INTRODUCTION

Recently, DH has been in the focus of research as it is expected to play a key role in the transition to more energy-efficient and fossil fuel free energy supply systems [1]. DH enables exploitation of large-scale heat sources that cannot be exploited using individual units. Further, DH has also been identified as a key element in integrated energy systems [2]. This integration can be achieved using large-scale power-to-heat units, such as HPs which use electricity to supply heat and might also help to balance the power grid [3]. Large-scale HPs represent an efficient way of heat supply using electricity in combination with low temperature sources, such as groundwater, seawater or air. Centrally supplied systems are well suited for areas with high heat demand densities, i.e. densely built areas and houses with space heating (SH) and domestic hot water (DHW) demand. The feasibility of centrally supplied systems is less certain in new areas with low energy demand buildings as well as in less dense areas.

Austria and Denmark both have high shares of renewable power production [4]-[5] and the use of DH is well established in urban and rural areas [6]-[7]. However, the boundary conditions and the current policies in place are very different. Despite the fact that both countries have high shares of renewable power production, the generation mix of both power and heating are different, compare Figure 1.

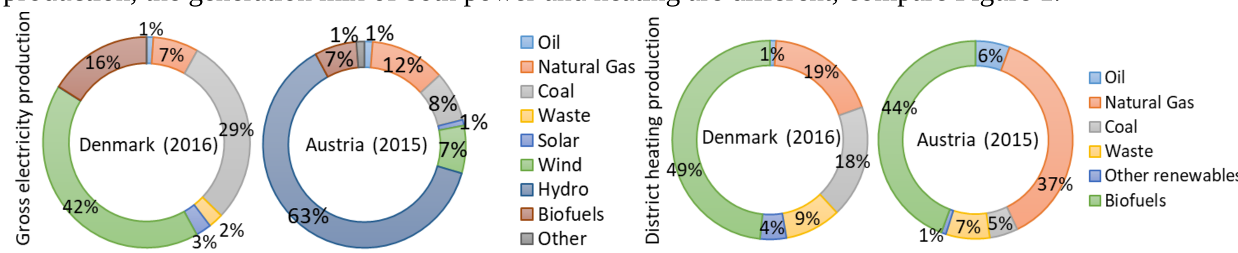

Figure 1 Composition of electricity generation and DH supply in Denmark and Austria [4], [5], [36]

This is mainly related to the geographical and meteorological conditions being different. The mountainous region in Austria provides favourable conditions for hydro power plants and just below half of the Austrian area is forestland, i.e. large resources of biomass are available. The Danish geography is especially suited for power generation from wind. The main source of biomass in Denmark is municipal waste, by-products from agricultural activities, like straw and manure, and wood-based biomass, of which ca. 50 % is imported [8]. An increase of biomass usage in Denmark would result in higher shares of imported biomass [9], which implies the risk of promoting non-sustainable land usage in other countries. As Denmark aims to achieve independency of fossil fuels, the available biomass resources might be needed in other sectors. Renewable electricity generation from non-biomass-based sources is thus expected to play a key role in the transition towards renewable supply of heat and electricity. To accommodate high shares of transient electricity generation in the energy system, the idea of an integrated energy system, utilizing synergies between different energy sectors is promoted in Denmark (e.g. [2]). This strategy has been widely acknowledged and current research and demonstration projects, and recent policy changes [10] undergird the vision of an integrated energy system. The integrated energy strategy for Austria is still in the green paper phase [11].

In both countries DH systems are common in cities and in rural areas. In Austria biomass-based DH systems are most common in rural areas. Biomass-based small-scale DH systems were supported as a subsidy for farmers, who often also own forestland in Austria, thereby exploiting synergies of sustainable forest management and creating an additional income to the farmers [12]. Nowadays, the funding has been harmonized and is available to communities and companies under the domestic environmental support scheme [13] and a quality management scheme is in place [14]. Financial support is available for heating networks and for industrial waste heat utilization for DH purposes, which can lead to indirect support of large-scale HPs. HP-specific subsidies are only available for self-supply and the use of biomass is still strongly promoted. A lack of information and dissemination has been identified as a further barrier for large-scale HPs for DH in Austria [15].

In Denmark, most rural DH networks were developed after the first oil crisis and were usually based on natural gas-fired units. DH companies in Denmark are mostly cooperatives or municipality-owned and so directly or indirectly owned by the customers [16]. They are obliged to work on a non-profit basis and a national benchmark system is in place, ensuring that the most cost-effective and environmental friendly solutions are promoted [17]. In combination with dedicated policy measures [17]-[18] this has led to high penetration of DH in Denmark (64 % in 2016 [4], compared to 25 % in Austria [19]). Today, many of the original natural gas units have been replaced by biomass-fired plants, and increasingly solar thermal plants and HPs. The diffusion of large-scale HPs benefits from research and demonstration projects, collection and dissemination of knowledge [20], and targeted tax-reduction and financial support, e.g. [10], [21].

Within this work the private and socio-economic feasibility of large-scale heat pumps supplying DH was analysed compared to supply from individual units and to wood-fired heat only boilers in Austria and Denmark. The aim was to identify beneficial boundary conditions and barrier for the implementation of large-scale HPs as supply units for DH.

3 METHOD

The feasibility of different integration possibilities of HPs into DH systems was assessed for Denmark and Austria using the district heating assessment tool (DHAT) published by the Danish Energy agency [22]. The DHAT is an MS Excel based tool that can be used to calculate the economic feasibility of establishing DH in areas currently supplied by individual units. The tool includes technical data and price projections that are adjustable for different countries. It includes a cost-benefit analysis for the local society, customers, and the DH company. It calculates the socioeconomic feasibility of the project according to Danish guidelines [23] and the levelized cost of energy (LCOE), including the total DH network cost, and investment, fuel and O&M cost for the supply units.

The economic evaluation for the local society refers to all entities involved in the project, while the socio-economic evaluation refers to the respective country [22]. The analysis takes the socioeconomic cost of fuels, investment and emissions into consideration, while assuming that the project itself does not have an impact on the electricity or fuel price level or the labour market. The socioeconomic as well as the local society net present value (NPV) were calculated as the difference between the net present value of the DH solution and the best individual supply solution.

The DHAT as published by the Danish Energy Agency was extended to represent the HP coefficient of performance (COP) and cost in more detail to account for the characteristics of different heat sources. An estimation of the network cost and the heat losses were included to account for different DH temperatures. The analyses focussed on newly developed areas without the possibility to be connected to an existing grid. The feasibility was assessed for varying plot ratios, i.e. the ratio between the built space area and the land area supplied by DH, and thus linear heat demand densities (LHDD). The supplied area was fixed to 340,000 m^2. Five central unit types were considered - air source HP, groundwater HP, sewage water HP, wood pellet and wood chips boiler. Different DH forward and return temperature cases (80/50 °C, 70/40°C, 60/30 °C) were analysed for two heat demand scenarios. The DH solutions were compared to air-to-water HP, brine-to-water (ground source) HPs and electric boilers.

3.1 Estimation of DH network cost

To identify beneficial boundary conditions for the economic feasibility of central HPs, the network layout was not predefined. Instead the total network cost was estimated based on the plot ratio, the expected specific heat demand, the effective width and an estimated average pipe diameter, as proposed by Persson and Werner [24]. The plot ratio was varied in this analysis between 0.1 (very sparsely populated) to 1.4 (urban area). The expected specific heat demand was based on the Danish 2020 building regulation, according to which the total heat demand has to be reduced to the DHW demand only [25]. But it was expected that there still was a small SH demand due to the behaviour of the inhabitants (NB-medium). A second scenario with higher SH demand was examined to account for less energy efficient buildings (NB-high) [26], see Table 1. The piping cost were based on estimates given by Rambøll in DHAT [22]. The necessary electricity grid investment was disregarded.

Table 1 Specific heat demand scenarios

Scenario		SH demand	DHW demand	Total demand
New built (NB) medium	$[W/m^2/a]$	3	20	23
New built (NB) high	$[W/m^2/a]$	22.5	20	42.5

3.2 Heat supply units data

The central HPs for the analysis were sized to have a heat capacity which was 80 % and 65 % of the maximum demand for the NB-medium and NB-high case, respectively. The sizing criteria for the two scenarios were chosen to be different, as the scenario with very low space heating demand was dominated by daily variations of heat demand rather than seasonal variations. A restriction to less than 80 % of the maximum demand would lead to increased utilization of peak units, in this case an electric boiler, and thus a considerably reduced system efficiency. Accordingly, the HPs' thermal capacities varied between 0.2 MW and 3.2 MW depending on the heat demand scenario and the plot ratio. Investments into a backup natural gas boiler and a heat storage were considered. The COP of the central and individual HPs was calculated from the sink and source mean logarithmic temperatures and estimated exergy efficiencies [27]. Exergy efficiencies of 0.5 for the central HPs and 0.3 for individual HPs were assumed. The source temperatures for air-source HPs were hourly values from the Danish Design Reference Year [28] and the standard temperature development for Vienna [29]. The sewage water temperature was assumed to be constant at 12.5 °C. The groundwater temperature was assumed to be 10 °C. Weather compensation was applied to the DH supply temperature for ambient air temperatures below 5 °C [30]. Cost functions and assumed lifetime of all technologies are depicted in Table 2. As the cost functions were based on only few data and many of the HPs considered in this study have capacities lower than the values given in [31], an additional power function was fitted to the data to account for insecurities.

Table 2 Investment cost and lifetime for central and decentral units

Technology	Investment [M€/MW] linear/power function		Lifetime [a]	Sources
HP Groundwater	$1.1117\ \dot{Q}_{nom}^{-0.23105}$	$1.236\ \dot{Q}_{nom}^{-0.2599}$	25	[31]
HP Sewage water	$1.2166\ \dot{Q}_{nom}^{-0.33122}$	$1.1038\ \dot{Q}_{nom}^{-0.2435}$	25	[31]
HP Air	$0.9366\ \dot{Q}_{nom}^{-0.1418}$	$1.0503\ \dot{Q}_{nom}^{-0.3078}$	25	[31]
Wood chips boiler	0.9		20	[32]
Wood pellet boiler	0.48		20	[32]
Electric boiler	0.11		20	[32]
Gas boiler	0.06		25	[32]
Indv. Air to water HP	0.95		15	[32]
Indv. Brine to water HP	1.52		20	[32]
Indv. Electric heater	0.86		30	[32]

4 RESULTS

4.1 Levelized cost of energy

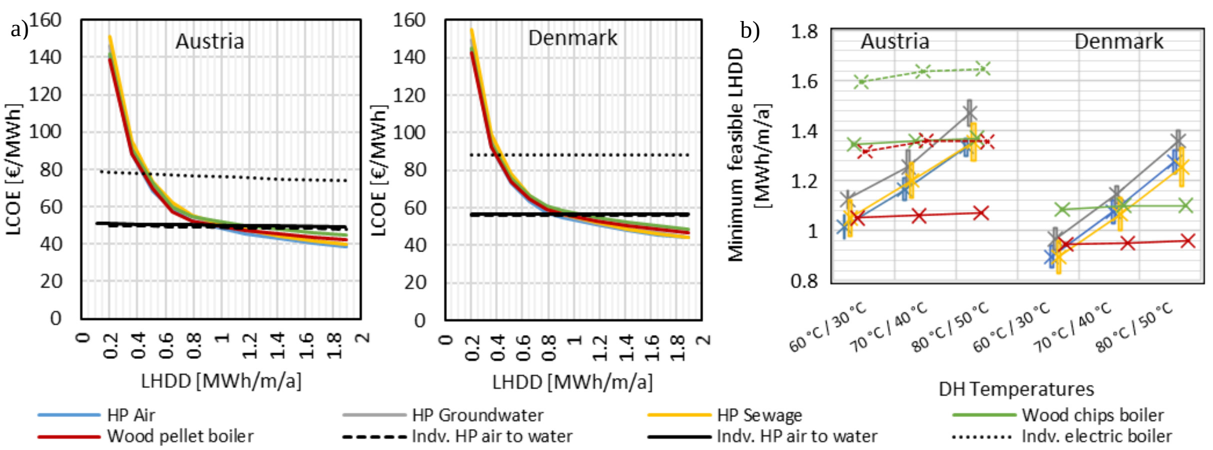

Figure 2 a) LCOE for central and individual units for Austria and Denmark, DH temperatures of 60/30 °C, NB-medium and linear HP cost functions , b) Range of minimum feasible LHDD for central solutions for different DH temperature cases, dashed lines refer to cases without subsidies

Figure 2 a) the LCOE of all central units are compared to the three decentral units for the NB-medium heat demand scenario and distribution temperature of 60 °C forward and 30 °C return for Austria and Denmark.

The cheapest individual solution was using air to water HPs. The LCOE development for decreasing LHDD was similar for all central generation units. It was lower than the LCOE from individual units for LHDD higher than 1.34 (1.08) MWh/m/a for wood chips boiler to 0.97 (0.85) MWh/m/a for air-source HPs for Austria and Denmark (in brackets), respectively. These LHDD translate to plot ratios of 0.5-0.6 with NB-medium demand buildings, this could e.g. be in suburban areas with 1-2 family houses. For lower LHDD the LCOE increase drastically. This had two major reasons, firstly the share of network cost of the total cost increased with lower LHDD. Secondly, the heat losses in the system increased as LHDD decreased. The LCOE of all technologies was lower in Austria due to differences in electricity taxation. In both cases, central heat pumps were in in the same LCOE range as wood-fired boilers.

The level of LCOE and thereby the minimum feasible LHDD depended on various factors. Figure 2 b) shows the minimum feasible LHDD for different DH temperature cases. The minimum feasible LHDD was lower in Denmark compared to Austria. The representation as bars accounts for the uncertainties in the HP cost functions, which is largest for sewage water HPs. In the Austrian case also the cost for wood-fired boilers without subsidies is shown. Compared to these all HP types would have lower minimum feasible LHDD and thus LCOE than the wood-fired boilers for DH temperatures of 70 °C/40 °C and 60 °C/30 °C. The implementation of HPs seemed especially beneficial for low DH temperatures, where the HPs benefited from better COPs due to the lower temperature lift. The calculated HP COPs can be seen in Table 3.

Air-source HPs were cheaper than groundwater HPs for NB-medium. This was due to new buildings considered, i.e. there were no large demand peaks in winter. Accordingly, the advantage from a better COP in winter for the groundwater HPs was lower and the cheaper investment cost for air source HPs made the difference. For the NB-high case the seasonal variation was considerable and the air-source HP could not compete with groundwater and sewage water HP.

The influence of the electricity and wood price (excl. taxes) on the economic feasibility of the different solutions was assessed. Figure 4 shows that the minimum feasible LHDD for central solutions increased for decreasing electricity price. This was due to the reduction in production cost in the individual unit. As the LCOE for central solutions also included the investment in the DH network, the effect of a reduction in fuel cost was less pronounced than for individual units. For increasing electricity prices wood-fired boilers became cheapest, especially for low LHDD. The variation of wood prices showed that a reduction in wood prices would decrease the minimum feasible LHDD and increase the feasibility for wood-fired boilers also for low DH forward and return temperatures. It was further studied how a variation in network cost, central HP COP and central unit investment cost influenced the minimum feasible LHDD. The results showed that the LCOE for heat sparse networks was most sensitive to a change in distribution network investment.

Table 3 COP of central HPs for different DH temperature cases and HD scenarios for Austria / Denmark

	HP air			HP groundwater			HP sewage water		
DH-Temp. [°C]	60/30	70/40	80/50	60/30	70/40	80/50	60/30	70/40	80/50
NB-medium	4.26/4.10	3.47/3.37	2.96/2.89	4.31	3.50	2.98	4.62	3.70	3.11
NB-high	4.15/3.99	3.40/3.29	2.91/2.83	4.31	3.50	2.98	4.62	3.70	3.11

4.2 Socioeconomic net present value

----- wood chips boiler DK ----- wood pellet boiler DK

Figure 3shows the socioeconomic NPV of a DH project for different central solutions compared to supply by individual air-to-water HPs in Austria and Denmark. The NPV of the HP cases obtained for Denmark were slightly higher than for Austria. From a

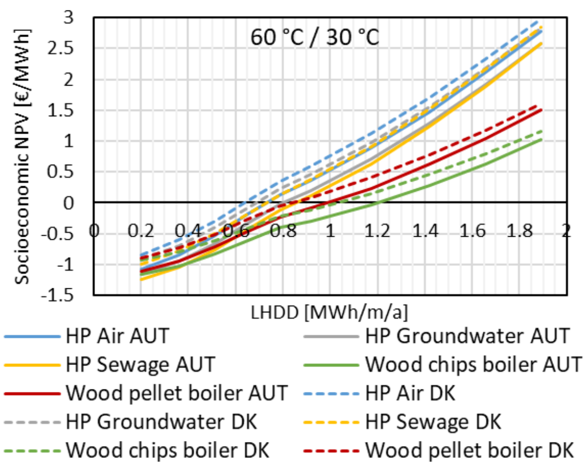

Figure 3 socioeconomic NPV for DK and AUT, DH temperatures of 60 °C/ 30°C, NB medium, lin. cost function

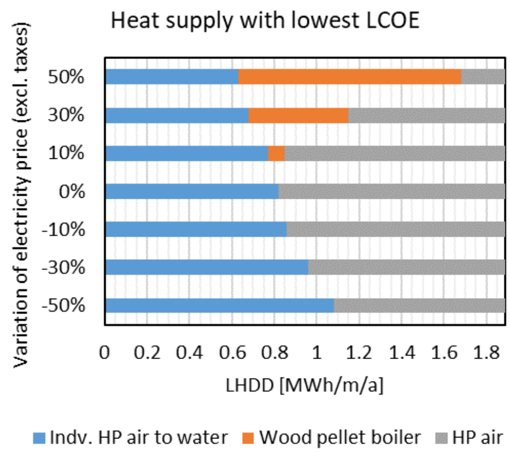

Figure 4 Solution with lowest LCOE for varying LHDD and electricity price, DH temperatures of 60 °C/ 30°C, NB medium, lin. cost function

socioeconomic perspective the DH solutions based on HPs were clearly better than the wood-fired boilers due to the emission cost caused. It has to be noted that this result was based on the assumption that the realization of the respective project will not change the countries' electricity generation portfolio.

When varying wood and electricity price it was observed that the wood-fired boilers became socioeconomically more feasible than the best HP solution, only for a reduction in wood price of 50 %. And even for an increase of 50 % in electricity price the heat pumps were socioeconomically more feasible than the boilers. Varying the DH temperature sets, it was observed that the increase in NPV with decreasing temperature was much more pronounced for HPs than for wood-fired boiler. This was due to the assumption of a constant boiler efficiency, while the HP COP changed with DH temperatures.

5 DISCUSSION

Comparing the results to current values from Denmark it was found that distribution cost, LCOE and LHDD showed to be in good agreement with the values from realised projects [33].

In areas with very low LHDD central DH solutions based on HPs have to compete with heat supply from individual units and DH supply based on biomass-fired units. The feasibility of HPs supplying DH in heat sparse areas was better in Denmark than in Austria. Lower DH-temperatures and reductions in distribution costs were beneficial. These may be obtained by new piping types, and cost efficient digging [34].

However, the case of heat sparse areas is a very special case and it needs to be mentioned that the economic feasibility of heat pumps supplying DH in terms of LCOE and socioeconomic NPV improved for larger LHDD compared to the studied alternatives. Further, the heat pump cost functions used were based on very few built heat pumps all larger than 800 kW and thus showed insecurities for smaller HP capacities. It should be kept in mind that the study presented aimed at identifying overarching trends but cannot replace a detailed planning for a specific project in question.

The feasibility of the different solutions depended on the boundary conditions in place. The available subsidies for wood-fired boilers in Austria made this type of heat supply units especially attractive for small-scale networks. As shown would central HPs be a better option for low temperature networks (60 °C / 30 °C and 70 °C / 70 °C) in Austria, without the subsidies for wood-fired boilers. As the wood used as a

fuel in Austria is often produced in close vicinity to the heating plant, it can be assumed that lower prices than the assumed market prices can be obtained. As showed this results in cheaper LCOE than central heat pump units can provide, even for low DH forward and return temperatures.
Within this study ambient heat sources were considered for the HPs. However, if industrial waste heat, even at low temperature levels was available, heat source exploitation cost could be lower compared to e.g. groundwater HPs and subsidies would be available for waste heat utilization in Austria, which would improve the economic feasibility of HPs [35]. There is however no financial support available for ambient heat sources or waste heat sources from communal sewage water.
The implementation of large-scale HPs in Denmark benefits from their socioeconomic feasibility, as heat supply projects in Denmark must prove private- and socioeconomically beneficial. Further, the Danish owner structure and regulation provides stable conditions for long-term investment into DH systems.
Finally, from an energy system perspective, HPs could play an important role in terms of system integration and thereby provide flexibility to the power system. Providing regulation power might generate further income opportunities for HPs and thereby increase the economic feasibility, also in heat sparse areas.

6 CONCLUSION

It was shown that DH supplied by central HPs compared to individual heat supply from air-to-water HPs was economically feasible in Denmark and Austria down to LHDD of 0.85 and 0.97, respectively, depending on the DH supply temperatures and the type of HP. The economic benefit increased with increasing LHDD, i.e. less energy efficient buildings or higher plot ratios. The reduction of seasonal peaks in low energy buildings benefited the economic feasibility of ambient source HPs. A barrier large-scale HPs in Austria is the promotion of wood-fired boilers as an alternative heat supply solution, while financial support to ambient source HPs is currently not available. A reduction in electricity cost would as well reduce the feasibility of central HP solution in heat-sparse areas (without a priori existing DH network), as this would decrease the LCOE of individual units more than of central units. Apart from recent tax reductions on electricity, research and dissemination activities the non-profit regulation and the condition of socioeconomic feasibility enhance the feasibility of large-scale heat pumps for DH supply in Denmark.

7 ACKNOWLEDGEMENT

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