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Integration of large-scale heat pumps in the district heating systems of Greater Copenhagen

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This study analyses the technical and private economic aspects of integrating a large capacity of electric driven HP (heat pumps) in the Greater Copenhagen DH (district heating) system, which is an example of a state-of-the-art large district heating system with many consumers and suppliers. The analysis was based on using the energy model Balmorel to determine the optimum dispatch of HPs in the system. The potential heat sources in Copenhagen for use in HPs were determined based on data related to temperatures, flows, and hydrography at different locations, while respecting technical constraints. The Balmorel model was developed further in order to provide a better representation of HPs, for analysing the seasonal variations of COP (Coefficient of Performance), and to represent the difference in performance of HPs connected to either distribution or transmission networks. The optimization yields roughly 3500 FLH (full load hours) for the HPs connected to the DH distribution networks when considering a current scenario. In a zero carbon-dioxide emission scenario expected in year 2025, approximately 4000 FLH, are achieved. In the case where HPs are connected to the DH transmission network at elevated temperatures, their operation decreases by roughly 1000 FLH. No significant impact was found when comparing fixed and varying operation characteristics of the HP.

1. Introduction

In the future, biomass and wind are expected to play dominating roles in energy systems around the globe, not least in the Danish energy system. In Denmark, the change is mainly due to a political 100% renewable energy target, which is set to be fulfilled by 2050 [1]. However, biomass resources may in the longer term be prioritized for the parts of the transport sector that cannot easily be supplied by electricity. Such a change would require a large fraction of heating and cooling to be generated from other sources. One proposed solution is increased electricity production by wind turbines and photovoltaics, and increased electricity transmission capacity to Denmark's neighbouring countries in order to balance supply and demand. With a smaller fraction of thermal units for electricity production, CHP (combined heat and power plants) may no longer fulfil the desired heat demand in the large cities. This issue can be solved by converting electricity into heat, which at the same time may assist in maintaining the electricity supply/demand balance. Heat pumps may utilise the electricity from intermittent sources efficiently and are expected to play an important part in the conversion to an energy system based on renewables.

The City Council of Copenhagen agreed in 2013 on a climate plan attempting to make Copenhagen the first CO_2 neutral capital by 2025 [2]. A main focus is to achieve CO_2 neutral district heating, as this currently supplies 98% of the heat demand of the Copenhagen municipality. This will be done by using biomass in the existing CHP plants and by implementing “new heat production units in Copenhagen” [2, p.16].

Connecting heat pumps to the district heating systems of greater Copenhagen is supported by the municipality in order to increase the flexibility and security of supply. The increased focus on heat pumps will require knowledge of the economical and

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technical challenges related to implementing the technology in a large and complex district heating system.

The aim of this study is to determine if, and to what extent, heat pumps can be implemented in the district heating system of the Greater Copenhagen area. This is done by assessing the availability of heat sources in the system, and analysing the competitiveness of heat pumps for each source using the energy system model Balmorel. A detailed review on many of the available energy system models is performed by Ref. [3]. Balmorel was chosen for this analysis because of its high level of detail for Danish power and heat supply, and the possibility for running hourly dispatch, which is an important factor when analysing the impact of heat pump integration in district heating systems. Balmorel is open source, which opens for the possibility to modify and model it.

When integrating combined heat and power plants with heat pumps, several configurations are possible [4]. By directly combining the two technologies, increased performance of the combined system may be achieved, compared to when operated individually, but the performance is gained at the expense of an increased amount of operational constraints for the heat pump unit. The reason for this difference is that CHP performance tends to be significantly higher compared to heat pumps operating at the same temperature level [5]. In this study, a heat pump configuration which enables heat production independently of other production units, is investigated, as heat pumps in a 100% renewable energy scenario may be most feasible to operate in periods where the fraction of combined heat and power is insufficient to cover the demand. The heat pumps will thus provide a temperature lift from the heat source temperature to the forward temperature of the district heating network.

Integration of heat pumps in district heating systems has significant focus due to the possibility for utilizing power from renewable sources efficiently. Blarke (2008) [6] sees heat pumps as the "missing link" for the Danish society in the future and introduces a concept of intermittency-friendliness. A number of energy system studies e.g., Blarke & Lund (2007) [7], Kiviluoma & Meibom (2010) [8], Münster et al. (2012) [9], and Blarke (2012) [10], show that heat pumps are profitable for a system. This is also found under some conditions for more detailed analyses of the plants in the system as in Ommen et al. (2014) [4] and Ommen (2015) [11], even if challenges are apparent. For other countries the potential of heat pumps as a mean to use to reach lower greenhouse gas emissions has also been acknowledged, e.g. Luickx et al. (2008) [12], Dagilis (2013) [13], Dragićević & Bović (2009) [14], and Rinne & Syri (2013) [15]. However, the difference between the technologies depends highly on the complete system and the conditions for renewable energy at the given time. In district heating systems based on combined heat and power, extraction steam power plants may be understood as heat pumps, because they may produce heat at the expense of power [5]. This is done at a quite high efficiency, which may make it hard for heat pumps to compete only based on efficiency.

In general heat pumps, as well as other supply technologies, will benefit from access to energy sources at highest possible temperature and consumption at lowest possible temperature. Investigations of the possible integrations is found in Ommen et al. (2014) [4] and Ommen (2015) [11]. A mapping of the heat sources available in Denmark is provided in Bühler et al. (2015) [16]. Other authors have presented similar studies for other locations in varying level of detail, e.g. Reistad (1975) [17], Bonilla et al. (1997) [18], Utlu & Hepbasli (2007) [19], and Dupont & Sapora (2009) [20].

Other studies of the future Copenhagen district heating system are presented in literature. These document some of the challenges to be expected by integration of heat pumps for efficient utilization of wind power.

Ommen et al. (2013) [21] showed that implementing the optimal heat pumps capacity, would give a 1.6% reduction in fuel consumption. Münster et al. (2012) [9] found in all their scenarios that individual heating will be based on heat pumps in 2025, whereas heat pump integration in the district heating system will be negligible due to the availability of high-efficient CHP based on biomass. Both of these studies have analysed heat pumps as a homogeneous mass, and the integration does not take into consideration if there is a heat source of an appropriate size in the area where the modelled heat pump was placed. Instead of optimising the location and capacity of heat pumps, it is relevant to investigate how competitive they are, if placed in areas where the capacities are actually physically possible to integrate with potential heat sources other than air.

Other studies of heat pump integration in Copenhagen have assumed a constant Coefficient of Performance (COP) in the simulations, e.g. Münster et al. (2012) [9], Ommen et al. (2016) [22], Ommen et al. (2013) [21], and Hedegaard & Münster (2013) [23]. Heat pumps utilising natural heat sources will in most cases experience variations in temperature of the source stream which influences both COP and capacity of the heat pump. For the sink stream (the DH network), capacity constraints of the district heating network necessitate increasing temperatures under winter conditions, resulting in decreased COP for these periods. In order to investigate the impact of varying heat pump performance based on both source and sink variations, both fixed and variable performance is considered to investigate how this impacts the results.

Furthermore, the location of the heat pumps in the network is investigated. The network consists of one transmission network at high temperature, which connects the largest of the production units, and the distribution networks which supplies heat to the consumers. It is important to determine whether the heat pumps should be integrated into the distribution network or the transmission network. Connecting heat pumps to the distribution network has the advantage that the temperature lift is lower, i.e. the COP is higher. Connecting them to the transmission network gives a lower COP, but the production is not limited to the distribution area demand, i.e. it can compete with neighbouring generation technologies on a bigger market.

The paper thus has three main objectives:

1. to determine if integration of heat pumps is competitive in the district heating system when also focussing on the variable costs
2. to determine if it is better to connect heat pumps to the district heating distribution or transmission network
3. to determine the impact of a season-dependent COP on the results compared to a simpler assumption of constant COP.

The paper is organized as follows. Section 2 presents the methodology of the study providing a description of the district heating system analysed, explanation and building of scenarios, obtained data and assumptions, and description, development and verification of the setup of Balmorel. Section 3 shows and discusses results for the scenarios in the current (2013) and a future (2025) system. Section 4 is a more detailed discussion of the study, methodology and results. Lastly, Section 5 concludes the paper.

2. Method

The integration of heat pumps in the district heating system of Greater Copenhagen is analysed with the energy dispatch model Balmorel. Four scenarios are set up to analyse the three objectives explained in the introduction.