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Socioeconomic potential for introducing large-scale heat pumps in district heating in Denmark

Rasmus Lund [a, *], Danica Djuric Ilic [b], Louise Trygg [b]

[a] Department of Development and Planning, Aalborg University, A. C. Meyers Vænge 15, 2450 Copenhagen, Denmark
[b] Department of Management and Engineering, Linköping University, 581 83 Linköping, Sweden

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ABSTRACT

Denmark has a national political goal of a 100% renewable energy supply in 2050. This requires a comprehensive transition of the energy system. For some decades, district heating in Denmark has been contributing to high fuel efficiency as well as to the integration of the electricity and heating sectors. Large-scale compression heat pumps would improve the integration between the district heating and power sectors by utilising the fluctuations in the supply from wind power, solar photo voltaic and other sources. Previous studies indicate that the introduction of heat pumps in Denmark will have a positive impact on the total costs for energy supply in the transition towards 100% renewable energy. In this paper, this is further investigated to assess the feasibility of heat pumps in the Danish energy system. The assessment is made by applying two different energy system analysis tools, named EnergyPLAN and MODEST. The comparison and discussion of these tools is a secondary purpose of the study. In general, the results show a potential for introducing heat pumps in Denmark between 2 and 4 GW-thermal power and a total potential benefit around 100 M€/year in 2025.

1. Introduction

The national political goal for the Danish energy system is to have a 100% renewable energy (RE) supply in 2050 (The Danish Government, 2012). This involves a transformation of the existing energy system, which is at present supplied with approximately 73% fossil based energy (Danish Energy Agency, 2015a). Currently, the transition is challenged by extraordinary low electricity prices, which reduce the short-term feasibility of wind turbines and the incentive to invest in new turbines. The low electricity prices also limit the operation of combined heat and power (CHP) plants in district heating (DH) systems. Hence, CHP is replaced with heat production in biomass based heat-only boilers and the incentive to reinvest in CHP capacity is small. This is reflected in the Danish transmission system operator's projection of the CHP capacity in Denmark, which is expected to decrease significantly during the coming decades. See Fig. 1.

This development will reduce the general fuel efficiency of the energy supply in Denmark and heat pumps (HPs) are often suggested as a solution to this. HPs can increase demand for electricity and produce heating at a high efficiency replacing production in heat-only boilers. HPs are generally not a feasible technology for the DH plants to invest in because of the current tax structure. It will require a revision of the regulatory framework for HPs in DH to become feasible. In the neighbour countries Sweden, Norway and Finland, which have similar conditions as Denmark, there are already large HPs operating in DH. In (Clausen et al., 2014) a number of examples are given from these countries above 10 MW-scale per plant, and using different heat sources.

1.1. Related studies

In the transition towards 100% RE, the biomass used for energy supply is an increasingly critical resource, as it is the only naturally available fuel that can directly substitute fossil fuels. Hence, the biomass resources used in energy systems should be prioritised for purposes where fuel is needed or for process energy where other options are not viable. This is discussed further in (Mathiesen et al., 2012). Andersen and Lund (2007) present one solution to strengthen the position of CHP plants by establishing new

List of abbreviations: CHP, Combined heat and power; COP, coefficient of performance; DH, District heating; HP(s), heat pump(s); RE, renewable energy.

* Corresponding author.
E-mail addresses: rlund@plan.aau.dk (R. Lund), danica.djuric.ilic@liu.se (D.D. Ilic), louise.trygg@liu.se (L. Trygg).

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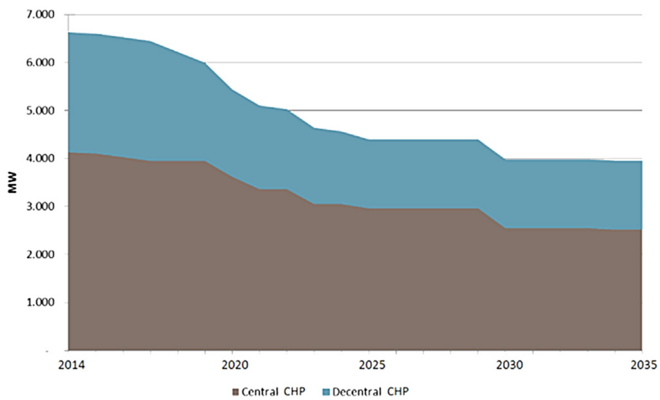

Fig. 1. Projected development in CHP capacity in Denmark for central and decentralised CHP plants (Energinet.dk, 2015).

partnerships between decentralised CHP plants. Thereby, the plants become able to deliver new electricity system services by cooperating on bidding in the electricity markets. Karschin and Geldermann (2015) also focus on the fuel efficiency of using CHP for heat production recognising the availability of biomass resources as a parameter in planning for systems based on RE.

According to Connolly and Mathiesen (2014), the development towards a 100% RE system requires a combination of DH and flexible HPs to integrate the fluctuating energy sources in the most feasible way. Thermal storage in the DH system is needed to allow HPs and CHP to operate more independent of heat demand and electricity prices. As larger capacities of fluctuating power supply is introduced, other storage technologies may be needed as well. Even the island of Samsø, which is known for innovative solutions; is a net-exporter of RE and can be seen as a front runner on RE in Denmark, has no HPs in its DH supply, but a large share of biomass boiler production (Nielsen and Jørgensen, 2015). For the context of Greater Copenhagen, Bach et al. (2016) have analysed the potential for using large HPs in the DH supply, considering different heat sources and COP's. The results indicate that there is a potential for HPs in the region but do not conclude on overall feasibility.

A number of studies have shown that HPs have a potential for integrating fluctuating renewable heat and electricity production. Pensini et al. (2014) show how fuels for heating can be replaced with electricity from renewable sources by using HPs. Ommen et al. (2014) suggest and assess a number of specific ways of integrating HPs in DH. Blarke and Dotzauer (2011) suggest a new concept of integrating CHP and HP units creating a more intermittency-friendly system. This indicates that a higher capacity of HPs will increase the ability of the system to integrate fluctuating renewable electricity sources. In Blarke (2012), HPs are compared with electric boilers in terms of cost effectiveness for that same purpose.

1.2. Contribution of the present study

The purpose of this study is two-fold. The primary purpose is to assess the economic potential for introducing HPs in DH in Denmark. The secondary purpose is to compare and assess the differences of two types of tools for performing the analysis. This is done by developing energy system models for the Danish energy system in 2013 and 2025, respectively, and identifying the economically optimal capacities of HPs in these models. This analysis is done in two different energy systems analysis tools, EnergyPLAN and MODEST, and the results and differences are compared and discussed. The knowledge produced can support political decisions on the energy system development in Denmark.

Chapter 2 presents central theoretical considerations and methods regarding the energy systems modelling followed by Chapter 3, which presents the concrete applied analysis assumptions. In Chapter 4 the results of the analysis is discussed and in Chapter 5, conclusions are given.

2. Theory and methods

In this chapter, the main theoretical concepts and background for the choice of the modelling tools are elaborated.

2.1. A system approach

To apply a system approach is a way of thinking (Churchman, 1968) about the total studied system and its components. According to Wallén (1996), a wide definition describes a system as a group of objects that interact. As a totality, the system has qualities which are more diverse than what can be expected in the single objects. Also Ingelstam (2002) claims that a system entails two types of parameters: the components of the system and the connection between them. In system analyses, it is vital to identify the connections between the different components of the system and the interaction between them as well as to interpret the system itself.

When conducting a system analysis, the first assignment is to find an appropriate delimitation: what is inside and what is outside the system. In addition to system delimitation, some of the main points in theoretical system analyses are the creation of a system and studies of, for example, energy flows inside the system and flows between the system and the surroundings; connections between the different parts of the system, and how the system alters over time (Wallén, 1996).

2.2. Theory of energy system analysis

Energy systems can be seen as networks connecting sources of energy with end-use demands through various conversion and storage technologies and energy grids transporting the different types of energy.

Energy system analysis tools are computation tools to structure and simplify the complexity of the real energy systems in models describing the energy sources, conversion technologies, energy flows, etc., in a systematic way. The model forms the basis for making analyses of issues related to the modelled system.

The modelling is the process of establishing the framework and a starting point for the analysis. This can include the definition of available energy sources, capacities of conversion and storage technologies and energy demands. The analysis is the way in which the computation tool handles the data in the model together with possible analysis parameters. The combination of these two and the possible analysis outputs makes the tool fit a specific type of application. See Fig. 2.

Lund points out in (Lund, 2014) that all energy system analysis tools are developed with a specific purpose and with the ability to handle a specific type of energy systems and analysis questions. It is important to be aware of this when choosing a tool for analysis. Hence, some tools might be used for an analysis that answers a question outside the scope and purpose of the tool, which might generate misleading results.

2.3. Choice of energy system analysis tools

Since the purpose of this study is to investigate the potential for introducing large-scale HPs in DH in Denmark, where the electricity production from wind and solar is expected soon to reach