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Heat savings in buildings in a 100% renewable heat and power system in Denmark with different shares of district heating

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ABSTRACT

The paper examines implementation of heat saving measures in buildings in 2050, under the assumption that heat and power supply comes solely from renewable resources in Denmark.

Balmorel – a linear optimisation model of heat and power sectors in Denmark is used for investigating economically viable levels of heat savings, which can be implemented by reducing heat transmission losses through building elements and by installing ventilation systems with heat recovery, in different future Danish heat and power system scenarios. Today almost 50% of heat demand in Denmark is covered by district heating. A further expansion of district heating network in Denmark is assessed and penetration of heat savings is analysed in this context.

If all heat saving measures, included in the model, are implemented, heat demand in Danish buildings in 2050 could be reduced by around 40%. Results show that it is cost effective to reduce from approximately 12% to 17% of future heat demand in buildings depending on assumed lifetime and costs of heat saving measures. Individual heating areas have higher penetration of heat savings than district heating areas. When district heating systems are expanded, an overall penetration of heat savings slightly decreases along with lower capacity investments and system costs.

1. Introduction

Energy related emissions account for almost 80% of the total greenhouse gas (GHG) emissions in the European Union. At the same time the European Council has committed to a long term target for the EU, namely to cut GHG emissions by 80–95% by 2050 [1]. There is no doubt that, in order to achieve this ambitious and necessary goal, greater energy efficiency in both demand and supply sectors as well as the move towards secure, non-fossil energy resources is required. The existing building stock is identified as one of the areas with the largest potential for energy efficiency improvements. Furthermore, it is also recognised that development of renewable heating has to be accelerated.

Today around 20% of energy consumption in Denmark is covered by renewable resources [2]. The Danish Government has in 2008 appointed the Commission on Climate Change Policy (further in article – the Climate Commission) to work out a plan for achieving the future goal of the fossil fuel-free Denmark. In fall 2010 the Climate Commission concluded that it is possible for Denmark to rely entirely on renewable resources in the energy system by 2050 [3]. Untapping efficiency potential in buildings, such as reducing energy consumption for space heating, is one of the recommended initiatives alongside with the increased diffusion of heat pumps, fuelled by electricity from wind turbines. The important role of district heating (DH) in efficient utilisation of renewable energy resources, such as biomass, waste, solar heating and geothermal heat sources has been acknowledged as well. The feasibility of a 100% renewable Danish energy system has also been analysed and recognised by the Danish Society of Engineers in Refs. [4,5]. The viability of the national energy supply, relying solely on renewable resources, has also been demonstrated outside Denmark – for Ireland. There district heating has also been identified as an efficient way to utilise biomass resources – in cogeneration plants [6]. On the local level renewable energy system in Frederikshavn Municipality (in the very North of Denmark), with focus on district heating, has been analysed in Refs. [7,8].

Around a quarter of the primary energy in Denmark in 2009 was consumed for heating purpose in buildings [9]. Some reports have estimated that as much as 80% of this demand can be reduced in households [10] and 75% in public buildings

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if all technical heat saving[1] possibilities are utilised [11]. As a consequence, around 20% of the primary energy consumption can be reduced by investing in better insulation of building envelopes, more energy efficient windows, mechanical ventilation systems with heat recovery, increased efficiency in hot water systems and other saving measures. Such measures could reduce the need for investments into renewable energy generation capacities and consumption of energy resources, such as biomass.

Extensive efficiency improvements on the demand side can have consequences for efficiency of technological solutions on the supply side. Effectiveness of a district heating network depends on heat consumption density in the supplied area and might decrease, when the heat demand in the district heating area is reduced [12]. For instance, in Refs. [8,13] investment costs of district heating system expansion, per supplied heat unit, increase, when heat savings of 20% are implemented and district heat supply is reduced. Furthermore in [14] results show that heat savings in district heating areas with combined heat and power (CHP) plants can be less beneficial if they reduce potential for cogeneration-based electricity production. On the other hand, large scale heat pumps, solar district heating and heat storage, connected to a district heating system, facilitate the move to a 100% renewable energy system, and, together with CHP plants, increase flexibility of the energy system to integrate fluctuating renewable energy, for instance, wind power. Moreover, district heating enables utilisation of renewable energy resources such as municipal waste, industrial surplus heat, waste heat in sewage water and geothermal heat sources, which would otherwise not be used. Reduced heat demand in buildings also enables space heating with low temperature heat. Low temperature district heating supply would allow more efficient utilisation of e.g. solar and geothermal energy resources and reduce heat losses in DH distribution network. In this relation, heat savings are important in enabling heating of buildings by low temperature district heating medium. Østergaard and Lund in Ref. [7] investigate the use of local renewable resources for energy supply and focus on the utilisation of the available geothermal energy potential for district heating. Based on the spatially explicit economic modelling of expansion of the district heating infrastructure, Möller and Lund [13], suggest expanding DH systems in Denmark to cover up to 70% of the heat market. Lund et al. [15] further analyse different alternatives for heat supply in around 25% of the Danish buildings, which currently produce heat by individual natural gas and oil boilers, and which potentially could be supplied with district heat. The supply of heat is analysed in the context of the future 100% renewable energy system in Denmark in 2060. They conclude that, even with large (75%) heat savings, district heating, utilising biomass, biogas and industrial excess heat is the best alternative for the analysed buildings small heat pumps being the best alternative for the buildings not connected to the expanded district heating systems. In Ref. [8] Sperling and Möller conclude that the combination of 20% heat savings and district heating expansion, improves fuel efficiency of the energy system in the Danish municipality of Frederikshavn.

The level of implemented heat savings on the demand side can influence decisions on the supply side by reducing district heating supply potential. On the other hand, diffusion of low cost district heating supply can reduce attractiveness of heat saving investments, since cost effectiveness of these investments depends on the avoided heat supply costs [16]. Due to this dependency it is useful to analyse different possibilities together and in the context of the whole renewable energy system, where heat, electricity and transport subsystems become increasingly interrelated.

District heating expansion and other alternative heat supply options in Denmark have been analysed when demand for space heating is to a different extent reduced, by the means of heat savings in Refs. [8,13,15]. Additionally, in Ref. [8] the marginal heat saving costs in buildings (of the savings up to 20%) are compared to the short-term district heat generation and long-term infrastructure costs, combination of which is higher than the heat saving costs.

The current study examines cost effective levels of heat saving investments at the current level of district heating supply, covering almost half of the heating demand, and when the existing district heating areas are expanded and supply close to 70% of heat demand, as suggested in Ref. [13]. Long-term heat generation and heat saving costs are compared in the study.

The goal of the present study is, by the use of a heat and power system optimisation model, to analyse cost-effectiveness of heat savings by improving energy efficiency of building envelope and by installing ventilation systems with heat recovery – both in district heating supply areas and in buildings with individual heat generation – at different levels of district heating penetration. This means that heat savings decisions are endogenous in the model as opposed to the most of energy system models, which usually exogenously assume a certain level of heat savings. The analysis is performed when only renewable energy resources and technologies are available for heat and power generation in Denmark. We do not claim to design the best possible 100% renewable energy system, but rather investigate possible paths with included technologies and assumed resource potentials.

2. The model

An optimisation model Balmorel, which covers the Danish heat and power generation and supply is used in this study. Originally, the model was developed for analysis of heat and power sectors in the Baltic Sea Region [17]. The model is compared to other energy system analysis tools and its many applications are described in [18]. Two new features, which were used in this study, have been recently added by the authors – internalisation of health-related externalities [19,20] and the possibility to invest into heat savings in buildings [21]. Consequently, in the Danish heat and power optimisation, described in this paper, different heat saving measures compete with heat generation technologies, and external costs of local air pollution are included in the optimisation.

The model minimises total annual cost of heat and power production and supply including investment costs into new generation capacities, operation and maintenance, and fuel costs, as well as resulting local and global external costs. Additionally, annualised costs of implemented heat saving measures and related maintenance costs (for ventilation systems) are included in the cost function in this analysis. Thus, long-term energy generation costs are considered in this analysis. Investment in new generation capacities and operation decisions are optimised for one year, which can further be divided into weeks and hours. The yearly heat and electricity demand in the model is given exogenously and has to be satisfied in each time period of a year. Balmorel includes also geographical division of the Danish heat and power system. For electricity consumption and production the system is divided into two regions – east and west. The regions are further divided into the areas, representing different district heating systems by current technology and fuel (21 areas) and areas with individual heat production technologies (2 areas) (Table 1). The geographical map with the heating areas is included in Appendix A. On the contrary to the electricity regions that are connected by a transmission line

[1] The term “heat savings” in this article refers to the reduction of thermal energy demand in the existing buildings.