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Investigating the impact of heat demand reductions on Swedish district heating production using a set of typical system models

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HIGHLIGHTS

- Four typical district heating systems is defined to represent the entire Swedish DH sector.
- A scenario for heat demand reductions due to building energy efficiency improvements is studied.
- Heat demand reductions in Swedish district heating systems reduce CO_2 emissions and reduce the use of biomass and fossil fuels.
- The heat production in different district heating systems should be considered to maximise the reduction of CO_2 emissions.

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ABSTRACT

The European Union (EU) aims at reducing its CO_2 emissions and use of primary energy. The EU also aims to improve the energy efficiency in buildings and promote the use of combined heat and power (CHP) plants in district heating (DH) systems. Due to significant differences among DH systems regarding fuel use and heat production units, results for one individual DH systems are not generally valid for other DH systems. Therefore, there is a need to generally describe entire DH sectors in a way that considers the heat production plant merit-orders of the individual DH systems. Here, four models of typical DH systems are defined to represent the Swedish DH sector. A scenario for stepwise heat demand reductions due to building energy efficiency improvements is studied. The results show that heat demand reductions in Swedish DH systems generally reduce global CO_2 emissions and mainly reduce the use of biomass and fossil fuels, while the use of waste and industrial waste heat (IWH) is less influenced. The results further show that in order to maximise the reduction of CO_2 emissions by energy conservation in buildings, the heat production technologies of the DH system should be considered. A large share of CHP production with a high electricity-to-heat output ratio decreases the possibilities to reduce global CO_2 emissions through heat demand reductions.

1. Introduction

According to the EU directive on energy efficiency (2012/27/EU) the member states of the European Union (EU) are obliged to reduce the use of primary energy. The reason is that the EU aims to reduce the use of primary energy by 20% compared to projected levels for 2020. The directive states that energy efficiency in existing buildings needs to be improved and also that co-generation of heat and electricity in CHP plants should be promoted. These obligations also aim to reduce the impact on the climate through reduced emissions of CO_2 from the European countries [1].

In Sweden, 40% of the total energy use take place within the building sector and is mainly for space heating (SH) and domestic hot water (DHW). District heating (DH) supplies 55% of the total heat demand in Swedish buildings. In Swedish multi-family residential buildings, 92% of the demand for SH and DHW are supplied by DH [2,3]. This can be compared to the 83 European cities investigated by Persson and Werner where the average heat market share of DH in urban areas is merely 21% [4].

The main benefits of DH are the possibilities to utilise energy from sources that are generally difficult to use, such as domestic waste, waste heat from industrial processes and low-temperature waste water. Another benefit is the possibility to co-generate heat and electricity in combined heat and power (CHP) plants. In Sweden, 68% of the total DH fuel mix are made up of domestic waste and biomass. Fossil fuels constitute about 14% (including peat) and the remaining 18% consist of industrial waste heat utilisation, heat (for heat pumps) and electricity. About 40–45% of the total heat deliveries in Swedish DH systems are produced in CHP plants [5].

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Nomenclature

C_f	capacity factor. The quota between the average heat capacity demand and the maximum heat capacity demand in a district heating system
CC	acronym for Coal Condensing. Refers to the use of coal fired condensing power plants to assess electricity generation on the margin
CHP	acronym for Combined Heat and Power. A CHP plant produces electricity as well as heat that can be used for, as an example, district heating
CO_2	carbon dioxide
COP	acronym for Coefficient of Performance. Used here as the quota between the heating capacity generated in a compressor heat pump, and the electric power needed to run the compressor
DH	acronym for district heating
DHW	acronym for domestic hot water
E_{DHW-S}	annual amount of energy needed for domestic hot water during summer months (June, July and August)
E_{DHW-W}	annual amount of energy needed for domestic hot water during non-summer months (September until May)
E_{HD}	total annual amount of energy needed for heating
E_{SH}	annual amount of energy needed for space heating
EU	acronym for the European Union
FMS	acronym for Fixed Model Structure, a district heating cost optimisation model structure
HD	acronym for heat demand
HD_{Sce}	calculated heat demand used in the heat demand reduction scenario
HO	acronym for heat only. Used here to address hot water boilers in district heating systems only used for heat generation
IWH	acronym for industrial waste heat. Refers to excess heat from industrial processes that can be utilised in district heating systems
NGCC	acronym for natural gas fired combined cycle. Refers to the use of natural gas fired condensing power plants to assess electricity generation on the margin
NRM	acronym for Nordic residual mix. The approach for electricity assessment proposed by *Swedish energy* and the Swedish district heating association
P	plant output capacity
Q	annual heat deliveries in a district heating system
S	time period subset that includes the time periods of summer months (June, July and August)
SDHA	acronym for Swedish district heating association
SH	acronym for space heating
a	parameter to describe the reduced share of domestic hot water demand in the heat demand reduction scenario
b	parameter to describe the reduced share of space heating demand in the heat demand reduction scenario
α	electricity-to-heat output ratio of a combined heat and power plant
ρ	the share of the annual heat demand beeing reduced in the heat demand reduction scenario
λ	the total heat demand reduction in the scenario
η	plant efficiency

The future demand for SH and DHW in Swedish buildings is expected to decrease due to building energy efficiency improvements and climate change. According to a report published by the Swedish district heating research programme, the reduction potential of the total demand for DH in Sweden until 2025 is 20% and in residential buildings the DH demand will potentially be reduced by 39% [6]. A reduced heat demand in buildings will affect DH production. It can be argued that a reduced heat demand might limit the possibility to co-generate electricity in CHP plants and cause a need to replace CHP electricity with other less efficient forms of power generation. In Åberg and Henning [7], Difs et al. [8] and Åberg et al. [9] optimisation models have been used to investigate the impact of heat demand reductions due to building energy efficiency measures on DH production in the Swedish cities of Linköping and Uppsala. The results from these studies showed that global CO_2 emissions were not increased when the heat demand was reduced. These studies are however made for individual DH systems and yield results that cannot be generalised to other DH systems due to significant differences between DH systems in terms of fuel use and heat production units.

An aggregated optimisation modelling of Swedish DH as in [10,11] yields results that are optimal on a national level of operation while, in reality, DH systems are operated locally. Heat production in DH systems is adapted to the variations of the local heat demand and plants are used depending on demand level. Base-load production plants are dimensioned to operate at full capacity for about 6000–8000 h a year. Mid-load plants operate about 2000–6000 h a year. Peak-load plants and back up production plants are operated between 0 and 2000 h a year. Base-load plants have generally required large investments while the costs for operation are low. Peak-load plants, on the other hand, are low-investment plants that are expensive to operate. In a DH system, the yearly heat production capacities of the plants are normally not fully utilised because of the limited and time-dependent local demand for DH, which means that during parts of the year there is available capacity in most heat production plants. The problem with an aggregated model is that such available capacity in low-cost heat-production plants can be used to replace more expensive heat production in a way that is not possible in the real case because the plants are not operated within the same local DH system. Therefore, there is a need to, as simply as possible, describe the heat production in the entire Swedish DH sector in a way that yields realistic plant merit orders.

In [12] a static simulation model (HEATSPOT) was used. In HEATSPOT all Swedish DH systems are modelled separately and then the results are aggregated in order to yield generally valid results. The HEATSPOT model does not have the problems of an aggregated model described above, but uses relatively low-detailed descriptions of the DH systems and does not consider diurnal and seasonal variations in electricity prices.

An approach where typical systems are used to represent the Swedish DH sector is presented by Sköldberg in [13]. Sköldberg uses detailed descriptions of 18 individual Swedish DH systems as typical systems. These were scaled and implemented in the models Martes [14] and MARKAL [15] to approximate the potential of increasing the share of CHP production in the entire Swedish DH sector. Since Sköldberg used individual systems to describe the Swedish DH sector, a relatively large amount of DH systems was necessary to achieve a proper representation of the whole sector. The 18 DH systems were not primarily chosen to describe differences in heat production technologies among DH systems. Therefore, even though these 18 systems constituted 50% of the total Swedish DH production in 2003, there is a risk that these systems are not representative for the entire sector. Specific characteristics