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Low-energy buildings heat supply–Modelling of energy systems and carbon emissions impacts

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ABSTRACT

Construction of new low-energy buildings (LEB) areas is attracting attention as a climate mitigation measure. Heat can be supplied to buildings in these areas through individual solutions, through a small, on-site heat network, or through a heat connection to a close-by district-heating (DH) system. The choice between these options affects the energy supply systems and their carbon emissions far beyond the LEB area. We compare the long-term systems impacts of the three heat-supply options through dynamic modelling of the energy systems. The study draws on data collected from a real LEB area in Sweden and addresses scale-dependent impacts on district heating systems. The results show that, generally, the individual and on-site options increase biomass and electricity use, respectively. This, in turn, increases carbon emissions in a broader systems perspective. The systems impacts of the large heat network option depend on the scale and supply-technologies of the DH system close to the LEB area.

1. Introduction

The world is rapidly becoming increasingly more urban. While in 1950 0.75 billion people (30%) were living in urban areas, in 2014 the corresponding figure was 3.9 billion (54%). This trend of urbanization is expected to continue (UN, 2014). Thus, in order to reach carbon mitigation targets, the carbon impacts of heating and cooling in new urban areas need careful consideration in particular considering the long lifetime of heating and cooling infrastructures. Today, in the European Union, the building sector accounts for 40% of the total energy consumption and 36% of the carbon dioxide (CO_2) emissions (EC, 2015a).

In urban areas, various heating and cooling options may have widely different climate impacts, in particular when addressed in a systems perspective. Thus, it is the point of departure of this work that climate impacts of heating and cooling of future building areas should be addressed within a broad systems perspective since only then the full climate impact of the various heating and cooling options can be assessed. This is particularly true for district energy options being capable of improved resource efficiency by connecting to waste heat streams within the urban landscape.

Due to widely varying climatic conditions and thus varying demand for heating and cooling, and also due to large differences of the heating and cooling infrastructure in place today, the options for heating and cooling to new building areas, and their climate impacts, differ between countries and localities. Hence, in order to provide for a better calculation accuracy, we will in this work focus on one country only. We have chosen to focus on Sweden. There are several reasons for this choice:

- The three heating and cooling options we will consider in this work are already widely applied in Sweden, and there are thus real cases, data and experience to build upon.
- There are strong plans for a huge expansion of the urban building stock (in 2015, the Board of Housing, Building and Planning (Boverket) forecasted that 700,000 new homes needed to be built in ten years (Boverket, 2016)). A large share of this is planned to be built according to low-energy buildings (LEB) standards (requiring only a small amount of space heating even during the cold seasons) (Valik and Petersson, 2015; SEA, 2012).
- The current heating sector is almost carbon neutral but future heating and cooling options might have a strong impact on the entire countries´ possibilities to become carbon neutral in a few decades´ time.
- There are governmental regulations for the calculation of energy use for space heating & cooling and hot tap water which might not lead to environmentally optimal solutions. (The Board of Housing, Building and Planning (Boverket) has proposed a method for

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Nomenclature

450PPM	450 ppm
BAU	business-as-usual
Bio	Biomass
CCS	carbon capture and storage
CHP	combined heat and power
CO2	carbon dioxide
DH	district heating
Eff	Efficiency
EH	excess heat
el	electricity
ELC_EXP	electricity generation
ELC_IMP	electricity use
EOL	end of life
ETSAP	Energy Technology System Analysis Program
HOB	heat only boiler
HP	heat pump
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
IP	integer programming
LDH	large disctrict heating
LEB	low energy buildings
LTDH	low-temperature district heating
MDH	medium district heating
MSW	municipal solid waste
NG	natural gas
NGCC	natural gas combined cycle
NGGT	natural gas gas turbines
O & M	operation and maintenance
OIL1	light oil
OIL5	heavy oil
PELLETS	bio pellet
RES	reference energy system
SDH	small district heating
TIMES	The Integrated MARKAL-EFOM System
TPP	thermal power plant
UH	urban heating
WGT	wind + gas turbine
WOOD_CHIP	wood chip

calculation of the energy use for space heating & cooling, and hot tap water of the low-energy (near-zero energy) buildings. This method is based on a rather narrow systems boundary and only accounts for bought energy, which means that the use of free energy flows, i.e., from wind, sun, the ground, air and water are excluded from the calculation. Consequently, the proposed method promotes individual heat pumps not only in one-family buildings but also in apartment and public buildings (Boverket, 2015).)

In Sweden, the residential and service sector accounted for 40% of the total final energy use, 529 PJ (147 TWh) in 2013. About 60% of this was used in the heat sector for space heating and to provide hot tap water (SEA, 2015). Although the heat sector accounts for a large share of the total energy use, it is associated with very low CO_2 emissions. District heating (DH) has developed substantially since the 1960's and today accounts for over 60% of the heat market in the residential and service sectors (Frederiksen and Werner, 2013). While biomass, municipal solid waste (MSW) and industrial excess heat account for 72% of energy supply to the DH sector, fossil fuels, i.e. oil, natural gas and coal, have a share of only 8% (SDH, 2014). In addition, due to high fuel and CO_2 taxes on oil and natural gas, individual heat pumps are the main competitors of DH. In 2013, they supplied heat in 997,000 (52% of total) single-family and two-family detached buildings. In the same year, while DH use was 22 PJ (6 TWh), electricity and biofuels (e.g., wood chips and pellets) use in single-family and two-family detached buildings accounted for 54 PJ (15 TWh) and 40 PJ (11 TWh), respectively (SEA, 2015).

As indicated above, the choice of heating technology affects the energy systems far beyond the LEB area; also the entire DH system, the electricity system, and regional and international fuel markets are to various extents impacted. This should ideally be taken into account when deciding on directives on heat supply in new LEB areas. Investments in infrastructure have a long life, which means that there is a risk for lock-in effects into technologies for heating that are attractive today but might be a poor option in the future. To avoid such risks national directives on heat supply in new LEB areas need to take into account impacts not only in a wide but also in a long-term systems perspective in order to efficiently contribute to meeting international climate mitigation goals.

The options to supply heat to new LEB areas within or in the vicinity of urban areas can be divided into three categories: installation of a heat production device in each individual building, heating through a small on-site heat network, or through a heat connection to a DH system in the urban area. The last option, the large heat network, assumes that there is a district heating (DH) system already in place in the urban area, which is the case in almost all urban areas in Sweden. The "on-site" option implies heat supply by a local district heating (DH) system within the LEB area, including a centralized heat production unit and a distribution network for heat distribution to each building. Similar to the "on-site" option, the "large heat network" option also includes a distribution network within the LEB area while the heat is produced in the DH system of the urban area and transmitted to the LEB area by a transmission pipeline.

Energy systems and carbon emissions (CO_2) impacts of one or two of the heat supply options to energy efficient building areas have been studied before (Dalla Rosa and Christensen, 2011; Åberg, 2014; Lidberg et al., 2016; Mahapatra, 2015). Dalla Rosa and Christensen (Dalla Rosa and Christensen, 2011) compared low-temperature DH (LTDH) system with individual heat pumps in a new LEB area in Denmark and they showed that in the long-term the LTDH leads to 14.3% lower primary energy use. For Swedish cases, Åberg (2014) and Lidberg et al. (2016) presented consequences of energy savings in DH-connected multi-family buildings on current DH systems in terms of changes in fuel use, electricity generation and use and impact on global CO_2 emissions. Åberg (2014) modelled twelve DH systems with different DH production unit composition and different fuel use, and concluded that mainly fuel use for peak and intermediate DH load is reduced. Electricity generation is reduced when combined heat and power (CHP) is supplying the DH peak load. Lidberg et al. (2016) modelled the DH system of Borlänge and concluded that the biofuel and oil use in HOBs and the electricity input to heat pumps decreased, but that electricity generation from CHP plants would increase or decrease depending on the selected energy saving measures in the buildings. Mahapatra (2015) identified that DH supply to 180 new single- and two-family houses in Växjö, built based on Boverket's standards (Valik and Petersson, 2015), leads to less primary energy use and CO_2 emissions compared to individual heat pumps.

In contrast to the previous studies, in this study we will compare energy systems impacts and CO_2 emissions of the three heat supply options, for various types of district heating systems in a dynamic approach. The heat supply options will have a strong impact on the local energy systems but due to evolving biomass and international electricity markets, energy systems will indirectly be affected also far beyond the local scale. Thus, we will assess the impacts in a wider perspective. More specifically we account for the dynamics of the heat and electricity supply systems and for their interactions with each other and