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Cost-efficiency of urban heating strategies – Modelling scale effects of low-energy building heat supply

Akram Fakhri Sandvall [a, *], Erik O. Ahlgren [a], Tomas Ekvall [b]

[a] Energy Systems Technology, Division of Energy Technology, Department of Energy and Environment, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

[b] Swedish Environmental Research Institute (IVL), SE- 400 14 Gothenburg, Sweden

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ABSTRACT

There is now a strong demand in Sweden for construction of new low energy buildings (LEB) areas. There are essentially three options for heat supply to these LEB areas: “individual”, “on-site” and “large heat network” supply. The chosen option is of strategic societal interest. Thus, this study aims at comparing the long-term system cost of the three heat supply options. A dynamic modelling approach is applied in a systematic analysis designed to investigate the threshold for the various options' cost-efficiency. The study addresses scale impacts of hypothetical LEB areas and district heating systems. The results show that, generally, the large heat network option has the lowest system cost whereas in most cases the individual option has the highest system cost.

1. Introduction

The building sector accounts for 40% of the total energy consumption and 36% of carbon dioxide (CO_2) emissions in the European Union [1]. The European Commission has passed two Directives - the 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive - aiming at reducing buildings energy consumption.

In Sweden, the residential and service sector accounted for 38% of the total final energy use, 144 TWh, in 2011. About 60% of this was used for space heating and to provide hot tap water [2]. The national goal is to reduce the total energy use per unit of area in residential and commercial buildings by 20%–2020 and by 50%–2050 compared to the 1995 level [3]. The development of buildings with very low energy use (i.e., at least 50% lower than the present requirements; see Ref. [4]) is supported by the Swedish Energy Agency, which aims at promoting energy efficient new construction and renovation [3]. Consequently, in some new residential areas there are buildings built based on low energy building (LEB) standards. These buildings require little space heating even during the cold seasons.

Due to ongoing urbanisation, new building areas are often built within or in the vicinity of a city or town, and thus there is the possibility of district heating (DH) supply to the LEB areas. There are generally three options to supply heat to new LEB areas within or in the vicinity of urban areas: an “individual”, an “on-site” and a “large heat network” option, assuming that there is a DH system in the urban area (which is the case in almost all urban areas in Sweden). These heat supply options are able to independently meet 100% of end-user's heat demand. The “individual” option means that each building has its own heat production device, installed within the building, to meet its heat demand. The “on-site” option implies heat supply by a small local DH system within the LEB area, including a centralized heat production unit within the area and a distribution network for heat distribution from the heat production unit 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 close-by urban area and transmitted to the LEB area by a transmission pipeline.

In Sweden, DH has developed substantially since the 1960's and today accounts for over 60% of the heat market in the residential and service sectors [5]. The rate of construction of new buildings and residential areas is likely to be high in the foreseeable future because of increasing population in Sweden but DH is not always

* Corresponding author.
E-mail address: akram.sandvall@chalmers.se (A.F. Sandvall).

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the preferred heat supply option to new LEB areas, implying that opportunities associated with large DH systems might be missed: the greater efficiency of energy conversion in large-scale heat production plants, co-generation of heat and electricity, and the use of excess heat from industrial processes, waste incineration or thermal power plants. Four parameters that could discourage investments in the large heat network are: low heat demand of LEB areas leading to large heat losses [5], high investment cost of construction of DH transmission and distribution pipelines [6,7], business strategy disagreements between building and energy companies [8] and fossil fuel use in the DH production.

Impacts of different heat supply options to LEBs have been assessed by studying a single building [9,10]. Since such assessments do not include the full systems effects of simultaneously implementing heat supply options at a greater scale, sub-optimization could occur if the conclusions from such studies are implemented in areas with many LEBs.

Studies at the national level (e.g. [11–13]) represented the existing building stock in Sweden and applied various energy efficiency measures to the buildings to assess energy system impacts of different heat supply options with a long-term perspective. They also investigated trade-offs between heat supply options and energy efficiency measures by minimizing the total system cost. In these studies the local conditions, of great importance for optimal heat supply, were partially ignored since the buildings were represented in an aggregate way.

The environmental and energy system impacts of heat supply options in LEB areas have also been assessed at the local level. The connection of 20,000 new energy efficient apartments to an existing DH system led only to a small increase of DH demand while it contributed to leveling of the annual DH demand profile [14]. The study excluded changes in the DH system (e.g. forward temperature reduction in the DH network) that could occur due to low heat demand of the apartments. A recent study compared energy system impacts of on-site and individual heat supply options in a new building area in which half of the buildings are built as LEB. The area, located in mid-Sweden, would be occupied by 10,000 inhabitants by 2025 [8]. The study excluded an assessment of a heat connection between the new building area and its close-by town.

Decisions on heat supply to new LEB areas are of strategic importance for the countries' ability to mitigate greenhouse gases in a cost-efficient way and to combat local air pollution, and have long-term impacts due to infrastructural lifetimes and system inertia. Further, economic optimality of the heat supply investment is stakeholder dependent and the best option from the developer's point of view might not be the best from the societal point of view. Thus, due to the importance of the investment decision, comprehensive knowledge is essential and, due to the dynamics of the systems and fuel costs, a long-term system approach taking into account the dynamics and the interactions between the heat, electricity and buildings energy systems is needed to acquire the necessary knowledge.

This study thus aims at assessing the system scale economy of the three presented heat supply options to LEB areas in a systematic way, and to determine the approximate thresholds for the cost-efficiency of the various options. In this way, the following two question will be answered:

- Which is the most cost-efficient heat supply option to LEB areas from a societal point of view?
- How do the various cost components of the long-term system cost compare between the three heating options?

The study will apply an approach with system boundaries widened to include both the LEB area and its assumed nearby urban DH system in the assessment. This allows for a comparison of the three heat supply options. Unlike previous studies, a dynamic approach is applied, implying that the heat and electricity systems are allowed to develop with time during the studied time period. Finally, strategic implications of the results are discussed.

2. Method

The study is carried out based on 1) a literature review, 2) creation of hypothetical cases, 3) dynamic energy system modelling, and 4) policy scenarios and assumptions. The literature review presents recent literature findings on the three heat options to be analyzed and serves as a basis for the study (see Section 2.1). The data used in the study are inspired by three real LEB areas and three real DH system (see Section 2.2). In order to be able to draw general conclusions and to investigate the threshold for the most cost-efficient of the various heat supply options under varying conditions, a systematic analysis combining parameters is implemented. A dynamic energy system model, including the heat sector and part of the electricity and building sector (see Section 2.3), is built and used for the calculations. Two scenarios (see Section 2.4) corresponding to different climate ambitions are designed and applied in order to test the robustness of the results.

2.1. Literature review

2.1.1. Individual heat supply

Environmental and economic impacts of individual versus DH supply to buildings were assessed for Danish conditions in Möller and Lund [15], who assessed the economic potential of DH expansion into areas supplied with individual natural gas boilers in a future energy system with higher shares of renewables. In the cost-effective solution, the boilers were replaced with individual heat pumps in rural and remote areas. Petrovic and Karlsson [16] showed by using the marginal cost of DH expansion into different areas where buildings were supplied with heat by individual options that DH supply has low socio-economic potential for buildings located in areas requiring not only investments in DH distribution but also in transmission infrastructure.

In Sweden, because of high fuel and CO_2 taxes on oil and natural gas, individual heat pumps are the main competitors of DH in low linear heat density (i.e. the ratio between annul heat quantity sold to customers and the trench length) areas [2,7]. In 2011, while DH use was 6 TWh, electricity and biofuels (e.g., wood chips and pellets) use in single-family and two-family detached buildings accounted for 14 TWh and 12 TWh, respectively [2]. In the same year, individual heat pumps supplied heat in 923,000 (46% of total) single-family and two-family detached buildings [2].

2.1.2. On-site heat supply

The concept of 4th generation DH or low-temperature DH (LTDH) (i.e. forward/return temperatures of 50/25 °C rather than the current 80/40 °C), was recently introduced to describe a development including several different measures that each contribute to a more sustainable system [17]. Brand [18] showed the LTDH system to be competitive to individual heat supply options in LEB areas. Dalla Rosa and Christensen [19] identified the LTDH systems to be a cost-effective option leading to reduced primary energy use for heating purposes in areas with linear heat densities down to 0.20 MWh/m/year (0.72 GJ/m/year). Moreover, the system resulted in 50% lower distribution heat losses and slightly lower investment cost of pipelines compared to the current DH networks. Li and Svendsen [20] designed different hypothetical LTDH systems to meet the heat demand of 30 LEBs in an area with a heat density of 187 kWh/m/year (0.67 GJ/m/year). When the LTDH