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Modelling environmental and energy system impacts of large-scale excess heat utilisation – A regional case study

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ABSTRACT

EH (excess heat) is an important, but yet partially unused, source for DH (district heating). This study analyses energy system and CO_2 emission impacts at a regional scale of integration of EH from a large chemical cluster and local DH systems. The assessment is carried out with the optimising energy systems model MARKAL_WS, in which the DH systems in the Västra Götaland region of Sweden are represented individually. In addition, options for transport biofuel production are included. The results show that the connection contributes to a reduction of biomass and fossil fuel use, and to a related reduction of CO_2 emissions, in the DH systems. This opens opportunities for earlier production of transport biofuels but instead electricity generation from combined heat and power plants in the region decreases. In the short term, total CO_2 emissions increase if an expanded systems view is applied in which effects on the DH systems, transport system and European electricity system are accounted for, while in the mid-term they decrease. The study is based on a case and due to the diversity of Swedish DH systems in terms of use of fuels and local available resources, a generalisation of the results is not straightforward.

1. Introduction

DH (district heating) is a way to supply residential and commercial buildings, and industrial users with heat for space heating, hot water and process heat, through a heat distribution network. The network is often fed with heat from heat plants using locally available fuel or heat sources that would otherwise be wasted. Generally, heat plants are located close to the heat market in order to minimise capital investments in the distribution network [1]. Thus, most DH systems have a limited geographical extension and are located within a municipality.

Countries with a cold climate and large heating demand are the main users of DH for space heating and water heating purposes. The largest relative diffusion of DH is seen in the Scandinavian countries, Northern and Eastern Europe, Russia and China [1]. In Sweden, DH was introduced in the late 1940s and a continuous expansion then followed. This resulted in significant CO_2 reductions and other environmental benefits. Currently, DH is the dominant form of heating in central areas of more than 240 of the 290 municipalities, and accounted for over 50 TWh (60% [1]) of supplied heat in Sweden in 2011 [2]. As a result of the oil crises in the 1970's and a high oil taxation combined with governmental subsidies for domestic fuels such as peat and biomass, oil has almost been phased out in the Swedish DH sector [3]. The introduction of a national TGC (tradable green certificate) system in 2003 encourages investment in biomass-based CHP (combined heat-and-power) plants [4]. Consequently, biomass accounts for the major share[1] of the fuel use in Swedish DH systems and is used both in HOB (heat-only boilers) and, increasingly, in CHP plants. Further, EH (excess heat) from industries (defined as heat which cannot be utilised directly in industrial process [6]) and municipal solid waste incineration constitutes a large amount of the base load heat in many DH systems, but it has been estimated that in Sweden there is still 2 TWh/year of unused primary EH which can be directly utilised for DH [7]. Analyses of utilisation of industrial EH in local DH systems indicate that this can result in reduced total system cost and CO_2 emissions, and increased utilisation of locally available energy resources [8,9]. A study on eight co-operations

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[1] Biomass, peat and municipal waste together accounted for 71% of energy supplied to DH in Sweden in 2011 [5] SEA. Energy in Sweden- Facts and Figures 2012. Eskilstuna: Swedish Energy Agency; 2013.

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between DH utilities and industries in Sweden concluded that the main benefits of the EH use are reduced primary energy use, total system cost, and environmental burdens [6]. A multi-actor viewpoint in utilising residual EH for a sustainable DH system was analysed, concluding that the involvement of various stakeholders and the promotion of their participation already from the early phases of the project design plays a crucial role for the successfulness of the project [10]. In all of these studies, the economic, environmental and social aspects of EH use are assessed only in local DH systems.

Currently, there is a growing interest in integration of local DH systems into larger, regional systems (for the purpose of this study, local DH systems are defined as DH systems with grids only covering a single town/city while regional DH systems are DH systems with grids connecting several towns/cities). One incentive for such developments is the possibility to transmit heat from distant EH sources. The integration is also driven by the advantages of scale. As fuel and electricity prices increase, DH production from larger CHP plants with higher electric efficiency becomes more cost-effective, while the heat demand in a local DH system is limited. These drivers for DH systems integration encourage the construction of transmission pipelines between local DH systems and between DH systems and industries. However, such decisions are associated with large investment costs and lock-in effects. Thus, it is important to obtain comprehensive knowledge on the consequences of such integration for the energy system and the environment.

The literature on modelling of regional energy systems is not extensive. Examples include modelling studies on strategies, measures and interventions [11] and waste management strategies [12], both in the Basilicata region of Italy, on greenhouse-gas mitigation from waste-to-energy [13] and from the replacement of electricity and fossil fuel use for heating with biomass [14], both at the regional scale in Sweden, on the economic performance of biomass gasification utilities and cost-effective biogas utilisation in the Västra Götaland region [15,16] of Sweden, and finally, on the optimum level of interaction between energy system components in the Yazd district of Iran [17].

Regional integration of DH systems and industries has rarely been studied. The few examples include modelling studies in a mid-term perspective on the economic potential and environmental impact of heat connections of industrial plants and local DH systems in Sweden forming a small regional heat market [18–20]. In this paper, we assess energy system impacts, in regard to DH technology choices, energy flows and CO_2 emissions, of utilisation of large amounts of EH in DH systems through regional integration of large-scale heat sources and sinks.

Large scale EH utilisation will have a strong impact on the systems directly connected by the pipeline but due to the regional scale of biomass markets in Sweden, there will likely also be indirect regional DH system consequences that should be taken into account. Thus, impacts should be assessed in a wider regional perspective. Our analysis will apply a time horizon up to 2030, and we will consider long-term marginal electricity generation for CO_2 emission calculations since changes in the local and regional electricity generation can affect investment decisions elsewhere in the electricity system.

Due to the strong diversity and importance of local conditions both with regards to Swedish DH systems [21] and with regards to industrial EH sources (character and location), studies on EH utilisation have to be based on a detailed local representation in order to well reproduce real conditions. Therefore, we need to select one particular case for the purpose of this paper. Currently, there is a strong stakeholder interest focussing on the possibility of utilising EH from a large industrial cluster in DH systems in the VG (Västra Götaland) region of Sweden. Hence, we have chosen this as our case, which consists of the cluster of chemical industries in Stenungsund, the DH systems of Kungälv, Göteborg, Partille and Mölndal, and heat integration through a 50 km heat transmission pipeline.

The VG region has a population of 1.6 million [22] and is located in the south-west of Sweden. Currently, there are local DH systems in 37 of the 49 municipalities in VG [23]. These 37 DH systems differ widely with regards to scale, heat production technologies and fuels used. In Göteborg, the largest town in VG, with about 530,000 residents [22], the DH system supplies heat to 90% of the apartment buildings and to about 12,000 smaller residential houses plus numerous industries, offices, and business and public buildings [24] in the town itself and in Partille, which is part of the same urban area. In 2011, the total heat production in the Göteborg DH system amounted to 4 TWh. Municipal waste, natural gas, industrial EH, and renewables (including biomass) contributed to the heat production [25]. The Mölndal DH system (a part of southern Göteborg urban area) is connected to the Göteborg DH system by a 1.1 km transmission pipeline with the capacity of 10 MW.

50 km to the north of Göteborg lies the small town of Stenungsund (population only about 25,000 [22]) next to the cluster of chemical industries where a large amount of EH (in the order of 100–200 MW) is available. The cluster includes the AGA, AkzoNobel, Borealis, Perstorp and INEOS companies. Between Göteborg and Stenungsund is also the small town of Kungälv located. Kungälv has a DH system, currently primarily based on a biomass CHP, that was recently connected to the Göteborg DH system through a 4 km transmission pipeline with a capacity of 19 MW [26]. See Fig. 1 for a map of the VG region.

2. Method

The method applied is based on a case study, scenario analysis and energy system modelling. This section presents the model, our main input data and our most important assumptions.

We design two main scenarios and five sensitivity cases. For each of these, we assume two options: either that the SKG (Stenungsund – Kungälv – Göteborg) pipeline will not be built ("no connection"), or that the SKG pipeline is constructed and will be in operation from 2020 ("connection"). Then, we apply an energy system model to generate future developments of the DH sector for each scenario for the "no connection" and "connection" options respectively. Next, we assess the difference, in terms of energy use and CO_2 emissions, between "connection" and "no connection" for each of the scenarios as:

$$\Delta X = X_{\text{Scenario/case, "connection"}} - X_{\text{Scenario/case, "no connection"}} \quad (1)$$

Thus, 'ΔX' presents the "connection" impacts on the energy use and CO_2 emissions.

Our assessment of the pipeline impact addresses two different systems levels: (1) the "regional level" and (2) the "local level". The first represents an *energy market level*; a broader systems approach taking all DH systems in the VG region into account for the estimation of impacts on the regional biomass market. It also accounts for impacts on marginal emissions of the European electricity system from changes in electricity generation and use in the regional system. The second is a level addressing only the direct impacts on the connected DH systems (DH systems directly affected by the EH supply), i.e. the DH systems of Stenungsund, Kungälv, Göteborg plus Partille and Mölndal. Finally, we compare the regional and local level impacts and reflect on the importance of the choice of system boundary in this particular research.