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System profitability of excess heat utilisation – A case-based modelling analysis

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ABSTRACT

The use of EH (excess heat) in DH (district heating) may contribute to increased sustainability through reduced use of primary energy. In Sweden, while biomass has become the most important DH fuel during the last decades, there is a significant amount of industrial EH that could be utilised in the DH systems if it could be shown to be an economically viable alternative. This study addresses the long-term system profitability of a large heat network between a cluster of chemical industries and two DH systems that enables an increased use of EH. An assessment is carried out by scenario and sensitivity analyses and by applying the optimising energy systems model MARKAL_WS, in which the DH systems of the Västra Götaland region of Sweden are represented individually. The results show heat network profitability under most assumptions, and that the profitability increases with biomass competition, phase-out of natural gas use and higher CO_2 charges, whereas it decreases with the availability of other EH sources in the base load of the DH systems.

1. Introduction

DH (District heating) systems represent a structural and organizational energy efficiency measure since they enable low temperature EH (excess heat) recovery from thermal power plants, waste incineration, and industrial processes [1]. The recovered heat (together with heat from other sources) is distributed through a heat network to supply residential and commercial buildings and industries with space heating and hot tap water. This heat recovery system could increase the utilisation of EH in the European Union (EU27) member states by four times compared to current average levels (9%) [2]. The European Commission proposes strategies to cut 80–95% of annual greenhouse gas emissions by 2050 compared to 1990 levels in the Energy Roadmap 2050 report [3]. The utilisation of EH in DH systems would also effectively decrease the cost of these CO_2 emission reductions in the EU energy system [4].

In Sweden, DH systems had in 2010 a market share of nearly 60% (66.5 TWh) of the total heat supply to the residential and service sectors [5]. While biomass (including forest residues and energy crops), municipal solid waste and peat combustion contributed a large share (63% or 42 TWh), industrial EH had a relatively small share of less than 7% (4.5 TWh) of the heat supply [6]. The high share of biomass is due to favourable policies, including an energy tax and a CO_2 emission tax on fossil fuels as well as a tradable certificate system for renewable electricity generation [6]. As a result, biomass is used both in HOB (heat-only boilers) and, increasingly, in CHP (combined heat and power) plants.

Biomass is a limited resource, which can be utilized not only in DH systems for heat and electricity generation but also in biorefineries to produce transport biofuels. In Sweden, there is now a strong interest in transport biofuel production [7,8], which is likely to lead to stronger competition for biomass and consequently higher biomass prices. Therefore, incentives for substitution of biomass with other heat sources or technologies are anticipated to grow.

Various studies have shown environmental benefits of industrial EH utilisation in DH systems [9], [10]. In a recent study, a total of 21 TWh/year of unused industrial EH was identified that could possibly be utilized in Swedish DH systems, of which 2 TWh/year can be utilized directly (i.e. available at suitable temperatures, meaning that additional heating is not required) [11]. Capturing the available potential of EH depends on the willingness of industries and DH companies to collaborate. Such collaborations concern

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mainly ownership costs (e.g. how to share construction costs of heat exchangers and heat networks) and ownership benefits (e.g. how to share the expected revenues). Parameters affecting such collaborations have been analysed in several studies. Techno-economic parameters were analysed and classified as obstacles or facilitators of the collaboration; structure, length of contract, and cultural distance (rather than geographical distance) were identified to be crucial in initiating the cooperation [12]. Parameters that could hinder the collaborations included unwillingness to take risks, imperfect information, asymmetric information, credibility and trust, opposition to change [13]; high interest rate and short payback time for investments within industries [11], policy instruments, and international energy prices [1]. In contrast, involvement of universities through the application of energy system optimization models of DH systems and industries was shown to facilitate the collaboration, resolving the imperfect information parameter [13].

A few studies have addressed economic aspects of industry-DH utility collaborations and assessed the potential economic benefits. In one of these it was concluded that EH sources close to large cities in combination with fossil fuel taxes, and CO_2 emission taxes may justify the high investment cost of heat distribution networks in DH systems, and increase the competiveness of DH systems compared to individual heat supply solutions [2]. Large heat networks, shared between different stakeholders, including several DH systems and industries, have also been identified to be an attractive solution for increased utilisation of industrial EH [14–16].

Ignoring the infrastructure cost, in a study including three DH systems and three industries it was shown under different scenario conditions that most of the stakeholders would benefit from a large heat network and the total system net benefit was also large in the mid-term [16]. In a study addressing short and mid-term environmental and energy system impacts of a large-scale DH utilisation of industrial EH, it was concluded that the EH utilisation would reduce the use of primary energy resources as well as reduce CO_2 emissions [17].

In a recent study, including only the cost of extraction of EH within a cluster of industries, the economic feasibility of potential industrial EH supply to DH systems was analysed. It was shown that the EH delivery could be profitable for a wide range of heat extraction capacities [18].

In these studies, the major part of the investment cost for EH utilisation, the cost of the construction of the large, sometimes long-distance, heat pipelines connecting the EH source (industries) with the sink (larger DH systems) were totally or partly ignored. Since the construction of large heat networks, including both the pipelines and necessary heat extraction investment capacities within industries, is associated with large investment costs and lock-in effects, it is important to obtain comprehensive knowledge on the economic consequences of such heat networks. Thus, by including pipeline and heat extraction investment costs, we aim at assessing whether the construction of a large heat network allowing for long-distance transmission of EH is profitable from a societal point of view.

DH systems, particularly in Sweden, show very different characteristics with regards to the choice of fuels and technologies for DH production. Therefore, only by including the local characteristics the required level of detail can be obtained [19]. The assessments of EH utilisation often were based on specific cases in order to address real conditions and system differences (e.g. Refs. [9,14–16,20,21]). Furthermore, in a study identifying European sites suitable for future heat synergy collaborations between industries and DH systems, landscape aspects, site-specific factors and contextual circumstances were emphasized as critical parameters to capture the full potential of unutilised industrial EH [22]. Based on these arguments we chose to focus on a case, which is presented below.

Biomass accounts for a large share of the energy supply to the DH systems in Sweden. Changes in the biomass demand due to the construction of an industrial EH network will thus likely have an impact on biomass markets. However, the DH systems biomass supply is characterised mostly by a local-regional rather than national scale and, thus, a regional approach is selected.

In line with the current strong interest in transport biofuel production [8] a future demand for biomass from the transport-sector is included in the study, which below is referred to as an inter-sectoral approach.

Due to the long technical lifetimes of major infrastructure investments, a long-term focus is applied.

2. Case

In the VG (Västra Götaland) region in western Sweden there is now strong interest in constructing a large heat network between a cluster of chemical industries (located in Stenungsund) and the Kungälv/Gothenburg DH systems to utilise the large amount of industrial EH available at the chemical industries in the DH systems. Therefore, this industrial EH collaboration was selected as our case. In VG, Gothenburg is the main town in the region with about 530,000 residents. The Mölndal DH system (a part of the southern Gothenburg urban area) is connected to the Gothenburg DH system by a 1.1 km transmission pipeline with the capacity of 10 MW. Stenungsund is a small town with a population of about 25,000 people located about 50 km north of Gothenburg. Currently, the chemical industries are supplying the Stenungsund DH system with heat; however, their EH capacity is considerably larger than the demand in Stenungsund (see Ref. [18]). Between Gothenburg and Stenungsund is also the small town of Kungälv with a DH system currently supplied by a biomass CHP. Kungälv was recently connected to the Gothenburg DH system through a transmission pipeline with a capacity of 19 MW.

In 2011, the total heat supply in the Gothenburg DH system amounted to 4 TWh [23]. Excess heat from municipal solid waste CHP and two oil refineries (currently supplying 23% of total heat load), natural gas CHP and HOB, biomass CHP and HOB, bio oil HOB, and large-scale heat pumps contributed to supply the heat to the system. The system met the demands of 90% of the apartment buildings, about 12,000 smaller residential houses, plus numerous industries, offices, business and public buildings [24] in the town itself and in Partille, a municipality within the same urban area.

3. Method

The method applied, which includes two major steps, is based on energy system modelling, scenario analysis and data of the selected case. The first step aims to find the key parameters that would substantially affect the profitability of the heat network. Fig. 1 schematically shows the method applied in the first step. We assume two options: either that an investment in the SK (Stenungsund – Kungälv) and/or SKG (Stenungsund – Kungälv – Gothenburg) pipelines will not be made ("no connection"), or that the operation of the SK and/or SKG pipelines will be possible from 2025 if investments in these pipelines are profitable ("connection"). We design two main policy scenarios (see Section 3.2) and six sensitivity cases (see Section 3.2). Then, we apply an energy system model to generate future developments of the DH sector for each scenario/sensitivity case for the "no connection" and "connection" options, respectively. Next, we assess the difference, in terms of heat supply technologies, total system costs and total CO_2 charges,