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System analysis in a European perspective of new industrial cooling supply in a CHP system

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ABSTRACT

In the municipality of Södertälje two large industries use much of the electricity, district heating (DH) and chilled water in the area. The Södertälje energy system is not isolated, however, but is connected to the DH systems of southern and central Stockholm, and a change in the Södertälje energy system will also influence the connected energy systems in Stockholm. The cooling demand in Södertälje is currently covered by lake water cooling and compression chillers, but in order to reduce the use of electricity, conversion to absorption cooling or increased lake water cooling can be considered. The large combined heat and power (CHP) plant in Södertälje is not used to its full potential today, but investment in absorption cooling and/or a cold condenser unit integrated with the CHP plant could increase the plant's operation hours. In this paper the system effects of introducing new industrial cooling supply in Södertälje has been investigated through optimizations of a model including both the industries and the district heating supply in Södertälje and Stockholm. The results show that, independently of whether condensing power production is feasible in the CHP plant or not, investments in both increased lake water cooling and absorption cooling are profitable. A sensitivity analysis of how energy market prices affect the results shows that even though the system cost will change depending on energy market prices, the optimum cooling technology mix will remain the same. However, a sensitivity analysis of the transfer DH capacity between the Södertälje and Stockholm energy systems shows that if the transfer DH capacity is increased, absorption cooling will be less profitable since more heat can be sold from Södertälje to Stockholm while at the same time reducing the use of fuel resources.

1. Introduction

Increased focus on carbon dioxide emissions related to global warming has created a need to adopt energy conservation and efficiency as well as energy resource abatement measures. According to the EU directive concerning climate and energy, the EU will have to reduce the emissions of greenhouse gases by 20% and increase the use of renewable energy by 20% by 2020 [1]. The industrial sector stands for 39% [2] of the total amount of energy usage in Sweden, which makes efficiency in industries concerning both the manufacturing processes and supporting processes, such as heating and cooling, essential factors in reducing the total use of energy and resources in this country.

Previous studies have shown that a joint system perspective is beneficial when studying industries located in close proximity to a district heating (DH) system. Through modeling the industries and the DH system as a coherent system, the wider system perspective can provide information about possibilities of cooperation concerning heating and cooling and the system effects of investments in both industries and energy companies [3–6]. In a research project called SEAST (System design for Energy efficiency – Astra Zeneca, Scania and Telge Nät), two large industries and an energy company in the municipality of Södertälje very near Stockholm are working together to reduce the region's global climate influence. The two industries (Astra Zeneca and Scania) are the municipality's major energy users, together using about 150 GW h/year of heat which can be compared to the municipality's total DH supply of about 700 GW h/year. Combined, the industries also use about 450 GW h of electricity annually of which a substantial part is used for cooling. This corresponds to about 0.6% of the total amount of electricity used in Swedish industry and 40% of the total amount electricity used in Södertälje, which has a population of about 85,000.

In Södertälje the need for energy efficiency, combined with an increased cooling demand due to increased industrial production, will create a possibility for investments in new efficient technologies in the industries as well as system solutions for cooling supply. The present cooling system is based on free cooling using lake water which is complemented by compression chillers. The increased cooling demand could be supplied by investments in increased capacity of the lake water cooling system, as well as in new cooling technology like an absorption cooling system. An absorption cooling system can provide longer operation hours for the combined heat and power plant in Södertälje, but another option to increase the

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operation hours would be to invest in an additional condenser operating with lower condensing temperature for the plant. Due to the connection between the Södertälje and the southern and central Stockholm DH systems, any system change in Södertälje will also influence the system performance of the Stockholm energy system.

The energy system of Södertälje and Stockholm is unique in its size, but the results can be implemented also in other industrial areas with large CHP plants and district heating and cooling systems. Extensive energy conservation and efficiency-related measures in large industries may have a great impact on the regional energy system.

2. Aim of the study

The aim of this study is to investigate, on a high system level, how investments in new cooling supply system will influence heat production, electricity use, electricity production, carbon dioxide emissions, energy resource use and the total system cost. The higher system level means that not only the involved industries are analyzed, but also the surrounding energy systems, in this case the DH systems of Södertälje and Stockholm. The trade-off between the cooling technologies will be evaluated by using the energy system optimization's tool reMIND. A sensitivity analysis will be performed using future energy market scenarios in order to analyze the profitability of the investments under different boundary conditions such as energy prices and policy instrument support. In addition, a sensitivity analysis of the transfer capacity between the Södertälje and Stockholm DH systems will be conducted in order to analyze how an increase or decrease in the transfer capacity would influence Södertälje's energy system.

3. Methodology

The study presented in this paper has been conducted using a methodology previously developed by the authors [3,5]. The methodology enables analysis of possible new investments in an energy system for different energy market prices, policy instruments and emission targets. The method can be described as follows:

1. The studied system is defined (in this case the two industries and the energy utilities of Södertälje and southern and central Stockholm selling district heating and cooling).
2. The possible system changes that will be analyzed are defined (in this case new cooling solutions and investment in a cold condenser for the CHP plant).
3. The surrounding system is defined (different energy market price scenarios).
4. A model is built based on 1–3 using the optimization tool reMIND; the industries and the energy utility are modeled within the same system boundary to investigate the energy system from a joint system perspective.
5. The model is optimized for different boundary conditions defined by the surrounding system (3).
6. The results are analyzed to investigate the economic potential for the different suggested investments.
7. When the economic potential is known, other factors such as CO_2 emissions and resource use can be considered.

The model was built using the energy systems optimization tool reMIND, which is a graphical interface to the MIND method (Method for analysis of INDustrial energy systems). The reMIND tool uses mixed-integer linear programming to minimize the system cost [7,8]. The reMIND tool has previously been used for analysis of industrial energy systems [9,10] and DH systems [11,12] as well as systems where DH systems have been modeled together with industries [3,5,13]. The objective function Z of the optimization model includes the cost of new investments, fuel costs, cost of electricity and the income of sales of electricity. The objective function to be minimized can be formulated thus:

$$\min Z = \sum I * r + \sum C_{f\&e} - \sum B_e \quad (1)$$

where Z is the annual total system cost, I the investment cost, $C_{f\&e}$ the cost of fuel and electricity, B_e the benefit of sold electricity and r the capital recovery factor. Constraints in the model are the heating and cooling demand in the considered industries and the energy utility Telge Nät. Other constraints include the maximum capacity of CHP plants, boilers and chillers.

4. The studied system

Both of the studied industries use DH which is supplied by the energy utility, Telge Nät. In addition, Telge Nät is connected to the southern and central DH systems in the Stockholm area. The DH demand is based on the heat demand of 2007. The cooling demand is expected to increase and has been determined through estimates from the involved companies. The heating demand of southern and central Stockholm and Södertälje and the cooling demand of Södertälje can be seen in Fig. 1. The reason why only the cooling demand of Södertälje is included in this study is that the district cooling system is local and includes only the Södertälje region. However, the district heating system is integrated with the southern and central Stockholm system. As a result, the heat demand of southern and central Stockholm is also included in this study.

4.1. Astra Zeneca

Astra Zeneca in Södertälje consists of two sites, Snäckviken and Gärtuna. Both sites use DH supplied by Telge Nät to heat the facilities. The cooling demand at Snäckviken is supplied by lake water from Lake Mälaren in close proximity of the industry, although compression cooling is used to cover the peaks in the cooling demand. At Gärtuna all of the cooling demand is covered by compression chillers.

4.2. Scania

Scania uses DH for heating the industrial facilities and office spaces. Scania has access to some excess heat from the production which is used to decrease the need for buying DH. In addition, Scania has heat pumps which also complement the DH. The cooling demand at Scania is covered mainly by lake water which is supplied by a pipeline from Astra Zeneca through Telge Nät. Just like Astra Zeneca, Scania has compression chillers to cover the peak demand of cooling, but there are also some buildings that have separate cooling systems supplied only by compression chillers.

4.3. Telge Nät, Söderenergi and the Stockholm DH grids

The DH demand in Södertälje is supplied by Söderenergi which is partly owned by Telge Nät. Söderenergi has recently invested in a combined heat and power plant (CHP) but there are also older utilities in the system; see Table 1. The utilities are situated at four different locations, although the majority of the heat production takes place in Igelsta, where also the CHP plant has been built. The oil boilers are used for peak loads in the heat demand.

The DH system in Södertälje is connected to other DH systems in the Stockholm area, and there is an exchange of heat between the systems. The DH transfer capacity between the southern system (including Södertälje) and the other system in central Stockholm is of the magnitude 100 MW. In order to analyze the