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Economic and environmental benefits of converting industrial processes to district heating

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ABSTRACT

The aim of this study was to analyse the possibilities of converting industrial processes from electricity and fossil fuels to district heating in 83 companies in three Swedish counties. Effects on the local district heating systems were explored, as well as economic effects and impacts on global emissions of greenhouse gases. The study was conducted considering two different energy market conditions for the year 2030.

The results show that there is a potential for increasing industrial district heating use in all analysed counties. The greatest potential regarding percentage is found in Jönköping, where the annual district heating use in the manufacturing companies could increase from 5 GW h to 45 GW h. The annual industrial district heating use could increase from 84 GW h to 168 GW h in Östergötland and from 14 GW h to 58 GW h in Västra Götaland. The conversion of the industrial production processes to district heating would lead to district heating demand curves which are less dependent on outdoor temperature. As a result, the utilization period of the base load plants (above all of the combined heat and power plants) would be prolonged; this would decrease district heating production costs due to the increased income from the electricity production. The energy costs for the industrial companies decrease after the conversions as well. Furthermore, the increased electricity production in the combined heat and power plants, and the decreased electricity and fossil fuel use in the industrial sector opens up a possibility for a reduction of global greenhouse gas emissions. The potential for the reduction of global greenhouse gas emissions is highly dependent on the alternative use of biomass and on the type of the marginal electricity producers. When the marginal effects from biomass use are not considered, the greenhouse gas emissions reduction is between 10 thousand tonnes of CO_{2eq} and 58 thousand tonnes of CO_{2eq} per year, depending on the county and the type of marginal electricity production plants. The highest reduction is achieved in Östergötland. However, considering that biomass is a limited resource, the increase of biomass use in the district heating systems may lead to a decrease of biomass use in other energy systems. If this assumption is included in the calculations, the conversion of the industrial processes to district heating still signify a potential for reduction of greenhouse gas emissions, but this potential is considerable lower.

1. Introduction

District heating (DH) can play a decisive role in a future sustainable society [1–3]. Beside the possibility of using a variety of different fuels (waste, biomass...), one of the largest benefits of DH is the possibility of utilizing combined heat and power (CHP) production technology [4–6]. Due to high investment costs and low operating costs, CHP plants in a DH system (DHS) are usually used as base load production plants. Despite this, large biomass-fuelled CHP (BCHP) plants are commonly taken out of operation during the summer, since the minimum operating effect of these plants is often higher than the load demand curves in the DHS then. Some of the solutions to this problem may be to introduce long-thermal storage into the DHS [7] or to introduce DH-driven absorption-cooling production for the purposes of comfort-cooling, since this cooling demand is highest during the summer [8]. Furthermore, due to global warming, DH demand in the future is expected to decrease. This means that DH producers will face new challenges and need to develop new business strategies [9].

Abbreviations: BCHP, biomass-fuelled combined heat and power; CCP, coal condensing power; CHP, combined heat and power; CO_2, carbon dioxide; COP, coefficient of performance; DH, district heating; DHS, district heating system; GHG, greenhouse gas; HOB, heat-only boiler; EM, energy market; EMS, energy market scenario; ENPAC, Energy Price and Carbon Balance tool; FTD, Fischer-Tropsch diesel; IEA, International Energy Agency; MeHLA, Method for Heat Load Analysis; NGCC, natural gas combined cycle; NGCHP, natural gas-fuelled combined heat and power; RES-E, Electricity produced from renewable energy sources; WEO-np, "New Policies Scenario"; WEO-450, "450 scenario".

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New ways to use DH, and the possibilities to decrease DH production costs by including by-production of other energy carriers than electricity, have been of great interest during the last years. In order to achieve this, possibilities for cooperation between DHSs and other energy systems has been studied. One of the examples is cooperation between a DHS and industrial sector. This cooperation can be achieved in two possible ways: by delivering industrial waste heat into the DHS or by converting industrial processes to DH.

The economic and environmental benefits of utilization of industrial waste heat into DHSs are shown to be case-specific [10,11]. If the waste heat reduces the DH production in CHP plants, the revenues from electricity production in those plants would decrease, which would make this business strategy not profitable for DH producers [11]. Furthermore, the reduction of the electricity production in the CHP plants would also lead to an increase marginal electricity production (this term is explained more in Ådahl and Harvey [12]) in the power sector. Thus, if the marginal electricity is produced in coal condensing power (CCP) plants this would lead to an increase in global carbon dioxide (CO_2) emissions [10].

On the other hand, the second way of cooperation (the cooperation by converting industrial processes to DH) is often a cost-effective and energy-efficient measure, which results in an increased utilization of CHP plants in the local DHS, and subsequently leads to a reduction of global CO_2 emissions. Industrial heat demand is generally categorized in three different temperature levels (see Section 4.4 in Frederiksen and Werner [13]): low temperature level (below 100 °C), medium temperature level (between 100 °C and 400 °C) and high temperature level (above 400 °C). The major low temperature demand can be found in the manufacture of food and tobacco products, manufacture of machinery and equipment, manufacture of chemicals and chemical products, and manufacture of textiles [13]. Some of the industrial processes which required low temperature heat are washing, rinsing, food preparation, drying, and heating. The low temperature heat demand can be supplied from local DHSs. However, the possibility to supply the demand depends on the temperature required and on the variations of DH supply temperature during the year; this is more discussed in the Section 3.1. In 2007, the low temperature demand amounted to 30% of the annual total industrial heat demand in the 27 EU countries (approximately 3.12 EJ [13]).

A number of previous studies have been performed in order to analyse the benefits and the possibilities of increasing DH use in the Swedish industrial sector; the share of DH use in the total energy use in the industrial sector in Sweden (approximately 150 TW h) was only 4% in 2012, while the shares of electricity and fossil fuels were 36% and 23% respectively [14]. Difs et al. [15] analysed how conversion of industrial processes from electricity and fossil fuels to DH in 34 Swedish industries from different sectors of trade would influence the DH load duration curves in the local DHSs. The results showed that the conversion would lead to a DH demand curve which is less dependent on outdoor temperature, and thus would increase the utilization of the base production plants (CHP plants). The electricity use and the fossil fuel use in the analysed industries would decrease as well. When it is assumed that the increased electricity production in the CHP plants and the decreased electricity use in the industrial companies would reduce marginal electricity production in the power sector (electricity production in CCP plants), there is also a potential for reduction of global CO_2 emissions. Trygg and Amiri [16] analysed the most cost-effective technology for cooling by comparing DH-driven absorption-cooling with vapour compression chillers for seven industrial companies in Norrköping, Sweden, where the base production plant is a waste-fuelled CHP plant. When higher European electricity prices are considered, the absorption-cooling was shown to be a more cost-effective solution. The conversion to absorption-cooling production would also result in reduced global CO_2 emissions, when CCP plants are assumed to be the marginal electricity sources. In order to make the conversion to DH more economically attractive choice for the industry, Difs and Trygg [17] suggested applying the marginal costs for DH production as DH tariffs for the industry. The research was done through a case study which included the local DHS in Linköping, Sweden, and eight local industrial companies. The results show that this business strategy would lead to economic benefits not only for the industry but also for the DH providers, since it would result in higher electricity production in the DHS and subsequently in higher revenues from electricity sold. When CCP plants are assumed to be the marginal electricity sources, this strategy opens up a possibility for a reduction of global CO_2 emissions [17] as well. Henning and Trygg [18] recognized the conversion of industrial processes to DH as a vital measure when redirecting the energy systems toward sustainability. They also pointed out that replacing the electricity by DH produced in CHP plants would have a dual impact on the power sector; the marginal electricity production would be reduced not only because of the decreased electricity use in the industry, but also because of the increased electricity production in the CHP plants. The reduced marginal electricity production would subsequently lead to lower global CO_2 emissions.

1.1. Aim

The aim of this paper is to analyse the potential for converting production processes and support processes from electricity and fossil fuels to DH in the Swedish manufacturing sector. The paper also analyses the potential for more efficient operation of DH production plants in local DHSs when the DH use in the researched industry is increased. Both economic consequences as well as impacts on global greenhouse gas (GHG) emissions are studied considering two different energy market (EM) conditions.

Eighty-three manufacturing companies in three Swedish counties were used as the case studies, but the results may be relevant also for other manufacturing companies from the same branches as those included in this study. The objective of the study was to provide information which can be used by industrial and DH companies when considering possibilities for cooperation, and as a decision basis for policymakers when considering different strategies for climate change mitigation.

2. Methodology

The study includes three counties: Västra Götaland, Östergötland and Jönköping. Information about the manufacturing industry in the counties was collected from energy efficiency audits performed during the last few years. The industrial support and production processes that could be converted to DH were identified and data about the characteristics of those processes (e.g. temperature levels and seasonal variations) were collected from the audits. The expected annual DH demand for those processes were adjusted to the time division which is divided into 88 periods (Table 8; Appendix). The division reflects the seasonal variation of the existing DH load duration curves in the local DHSs [19,20]. The effects of the conversion of industrial processes to DH on the existing DH load duration curves were analysed using the Method for Heat Load Analysis (MeHLA) which was developed at Linköping University by Difs et al. [15].

When changes of energy costs for industry and changes of global GHG emissions caused by the conversion were estimated, sensitivity analyses on different EM conditions were performed. For that purpose two future EM scenarios (EMSs) for Sweden were developed using a tool called ENPAC (Energy Price and Carbon Balance tool) [21–23].