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Effect of the use of industrial excess heat in district heating on greenhouse gas emissions: A systems perspective

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ABSTRACT

European policy promotes increased use of excess heat as a means to increase the efficiency of resource use. By studying possible effects on greenhouse gases, this article aims to analyze and discuss system aspects of the use of industrial excess heat in district heating. Effects on greenhouse gas emissions are studied by applying different energy market conditions with different system boundaries in time and space. First, life cycle assessment is used to assess the introduction of excess heat in district heating in a contemporary system with different geographical system boundaries. Thereafter, future energy market scenarios for Europe are investigated to explore possible future outcomes. This study concludes that both the heat production system and the energy market conditions affect the system emission effects of using excess heat in district heating. Industrial excess heat in district heating can be beneficial even if it leads to reduced local electricity production when unused biomass can be used to replace fossil fuels. It is recommended that a strengthened EU policy should encourage the use of biomass where it has the most favorable effects from a systems perspective to ensure emission reductions when industrial excess heat is used in district heating.

1. Introduction

The European Union (EU) has developed strategic objectives for 2020 that are intended to achieve sustainable economic growth, increase EU competitiveness, and achieve a secure energy supply. As part of this strategy, the EU set 20-20-20 climate targets. The targets are that there will be a 20% reduction in greenhouse gas (GHG) emissions compared to the 1990 level, that 20% of the final energy used will be derived from renewable resources, and a 20% reduction in primary energy use by implementing energy efficiency measures (European Commission, 2010). However, the European Commission agreed to a new framework for EU energy and climate targets in October 2014. The new targets for 2030 aim to reduce GHG emissions by 40%, increase the share of renewables by 27%, and increase energy efficiency by 27% (European Commission, 2014). These targets are related in that improved energy efficiency may at the same time reduce GHG emissions. Even though the EU and its member states promote energy efficiency, forecasts indicate that the measures taken will not be sufficient and that the target of a 20% reduction in primary energy use will not be met. Estimates show that merely half of the 20% objective will be achieved by 2020 (European Commission, 2011). Therefore, additional effort is needed to get the EU on the right course and further improve energy efficiency.

Measures to tackle these challenges are presented in *The Energy Efficiency Plan 2011* (European Commission, 2011). For example, effective heat recovery systems could utilize excess heat from electricity and industrial production processes. This unused resource could among others be used for heating and cooling services (European Commission, 2011), thus reducing the need for primary energy resources and reduce CO_2 emissions (Cruz et al., 2011; Nomura et al., 2010; Ruohonen et al., 2010; Thekdi and Belt, 2011). Policies are needed to achieve the energy savings target. The Energy Efficiency Directive 2012/12/EU (also known as EED) provides a framework for the development of an energy efficiency policy. The directive appoints recovery of excess heat as one way to reach the EU target (European Commission, 2012). With the aim of promoting an efficient energy supply, the national proposal for the implementation of the EED in Sweden states that a cost-benefit analysis should be performed, in the context of certain investments, to evaluate the use of excess heat in comparison with other thermal supply systems (Ministry of Enterprise Energy and Communications, 2013). Connolly et al. (2014) also highlight industrial excess heat as an unused resource that could be used to improve energy efficiency and reduce climate impact in Europe.

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Estimates of the total industrial excess heat in Sweden conclude that there is a large unutilized heat potential (Broberg et al., 2012; Cronholm et al., 2009; Holmgren and Sjödin, 2008). Despite somewhat rough estimates and uncertainty in the final figures, the estimated several TWh of industrial excess heat per year indicates the potential of this resource, even though it may not be technically or economically feasible to recover the full potential. For Europe as a whole, the figure would be even higher (Persson et al., 2012), as merely 3% of the available industrial excess heat is utilized today (Connolly et al., 2012).

In Sweden, district heating (DH) companies are currently obliged to negotiate with potential new heat suppliers, although they do have the option of rejecting these heat deliveries. Delivery of excess heat into existing DH grids is, however, problematic. The challenges posed include management of intermittent energy supplies, the need to divide energy generation businesses into separate production and distribution companies, and the fact that additional heat in DH systems based on combined heat and power (CHP) could reduce electricity production and hence overall system efficiency [SOU (Ministry of Enterprise Energy and Communications), 2005, 2011]. Recognizing these challenges, the Swedish government bill states, "The DH company has no obligation to allow regulated access if the company can show that there is a risk that it will suffer damage as a result of the access." (Swedish Government, 2014). This means that Swedish policy neither promotes nor advises against using excess heat in DH. Nor does the policy distinguish between factors such as different production systems for DH, that is, whether the current systems are CHP-based or not.

This article aims to analyze and discuss systems aspects of the use of industrial excess heat in district heating. The analyses are based on calculations of GHG emissions using life cycle assessment (LCA) and general energy price and carbon balance (ENPAC) scenarios (Axelsson et al., 2009; Harvey and Axelsson, 2010). Combining these two methods enables a comprehensive systems analysis, which is used for a discussion of policy implications for excess heat use in DH. This paper focuses on the use of industrial excess heat in a Swedish perspective. Thus excess heat generated at other facilities will not be discussed. Technical changes in energy facilities are also not discussed.

2. Systems aspects of CHP and industrial excess heat

There are two main production technologies for DH, CHP, and heat boilers. In a CHP plant both electricity and heat are produced simultaneously. Due to the simultaneous production of heat and electricity, the total plant efficiency is high compared to condensing power plants (approximately 90% compared to approximately 40%). CHP is therefore generally considered to be an energy efficient electricity and heat production system.

Industrial excess heat can also be recovered and used as a thermal source for DH. The heat can be used to heat either the supply or return water in DH. In 2012 approximately 7% of the supplied energy in the Swedish DH systems came from excess heat (Swedish District Heating Association, 2014). When it comes to European DH systems, Sweden reports the largest share[1] of the total industrial heat deliveries: approximately 70% of the reported deliveries in 2008 (Persson and Werner, 2012).

Other types of heat production are displaced if excess heat is used in the DH system. If heat produced by CHP is displaced, less electricity will be produced in the CHP plant. This is because, at a constant heat demand, the use of excess heat will result in a decreased demand for CHP-produced heat. Other complementary electricity generation technologies will then cover the reduced electricity production from the CHP plant. On the other hand, increasing the use of excess heat in the DH system reduces the need for fuel in the thermal production system. These fuel resources can then be used by alternative users. This makes the consequences of such systems intervention complex to assess.

Given this background, the complexity of the problem needs to be considered to avoid the risk that excess heat use leads to undesirable side effects. Fig. 1 illustrates the relationship between thermal sources in a DH system, its fuel use, electricity distribution, and industrial excess heat.

A financial support system, the electricity certificate system, was introduced to increase the proportion of electricity production derived from renewable resources (SEA, 2010). The profitability of investments in new bio-based CHP plants has been shown to have increased significantly with the introduction of the certificate system (Knutsson et al., 2006). Thus this financial support has increased the profitability of bio-CHP compared to excess heat utilization. Competition between the two thermal supply systems has previously been discussed from an economic perspective (Broberg Viklund, 2015; Grönkvist et al., 2008; Holmgren and Sjödin, 2008). However, environmental impacts were omitted from these papers.

3. Research methods

This article assesses systems aspects of the use of industrial excess heat in DH system. This assessment is made in two steps. First, the introduction of industrial excess heat in an average contemporary Swedish DH system is assessed for different production cases using LCA. In the second step, the ENPAC tool is used to further explore systems aspects of the use of excess heat in DH, focusing on future energy market for the years 2020 and 2030. Systems approaches in the tools are illustrated in Fig. 2.

Two different assessment tools were chosen in order to illuminate a wide range of cases of industrial excess heat in contemporary DH settings, as well as to explore the possible effects of future energy markets. This methodological choice was made to mirror many aspects of this complex issue and to identify risks for undesirable side effects of the use of industrial excess heat in district heating. The use of more than one analytical tool to scrutinize different energy system choices has been recommended by researchers such as Hochschorner and Finnveden (2003) and Pietrapertosa et al. (2009). Being aware of a wider range of consequences from systems changes enables policy makers to make more informed decisions (English et al., 1999) and also helps policy makers avoid undesirable side effects from the changes at hand (Wrisberg and Udo de Haes, 2002).

3.1. *Life cycle assessment of contemporary DH production systems*

LCA is predominantly used by the scientific community to assess environmental impacts and the use of resources throughout a products or technology's life cycle—from production, through use, to disposal (ISO, 2006a,b). A product in this sense is not necessarily a physical item, but may also be a service, such as DH. LCA has been used to evaluate different aspects of the choices of energy carriers for DH as well as options for electricity generation using CHP (Eriksson et al., 2007; Ghafghazi et al., 2011; Guest et al., 2011).

3.1.1. *Analysis framework and production cases for substituted district heating production*

In this article LCA is used as a framework to assess what happens if industrial excess heat is introduced in different production systems for DH. To make this framework manageable, standardized production cases delivering a functional unit of 1 GJ heat

[1] Compared to Sweden, France, Denmark, Germany, and Italy.