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Assessing the climate impact of district heating systems with combined heat and power production and industrial excess heat

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ABSTRACT

Heat demand is a large contributor to greenhouse gas (GHG) emissions in the European Union (EU), as heat is largely produced using fossil fuel resources. Extended use of district heating (DH) could reduce climate impact, as DH systems can distribute heat produced in efficient combined heat and power (CHP) plants and industrial excess heat, thus utilising heat that would otherwise be wasted. The difficulty to estimate and compare GHG emissions from DH systems can however constitute an obstacle to an expanded implementation of DH. There are several methods for GHG emission assessments that may be used with varying assumptions and system boundaries. The aim of this paper is to illuminate how methodological choices affect the results of studies estimating GHG emissions from DH systems, and to suggest how awareness of this can be used to identify possibilities for GHG emission reductions. DH systems with CHP production and industrial excess heat are analysed and discussed in a systems approach. We apply different methods for allocating GHG emissions between products and combine them with different system boundaries. In addition, we discuss the impact of resource efficiency on GHG emissions, using the framework of industrial symbiosis (IS). We conclude that assessments of the climate impact of DH systems should take local conditions and requirements into account. In order for heat from CHP production and industrial excess heat to be assessed on equal terms, heat should be considered a by-product regardless of its origin. That could also reveal opportunities for GHG emission reductions.

1. Introduction

Heating makes up a large share of the energy use within the European Union (EU), approximately 30% of primary energy supply (Connolly et al., 2014). With the main technologies for heat production being individual gas or oil boilers (Connolly et al., 2014), greenhouse gas (GHG) emissions from heating are high. In order to reduce GHG emissions from heating, EU policy encourages district heating (DH) (EC, 2009, 2012). Europe has a large unutilised heat potential, estimated to over 3000 TW h, mainly accessible by implementation of combined heat and power (CHP) plants and utilisation of industrial excess heat (Connolly et al., 2014; Persson and Werner, 2012). This heat could be distributed in DH grids, thereby reducing the need for individual boilers. DH could also be used to produce cooling, and CHP plants would add efficiently (and possibly renewably) produced electricity to the European energy system. Currently, DH is primarily implemented in the Nordic and Baltic countries, but it is estimated that more than 1000 TW h of new DH could be implemented in population-dense areas throughout the EU until 2050 (Connolly et al., 2014). The ongoing urbanisation entails challenges for citizens and the environment, but it also offers opportunities for increased well-being (EC, 2014; Nijkamp and Kourtit, 2013). DH could make an important contribution to efficient and cost-effective use of energy and resources in urban areas (EC, 2012; Persson and Werner, 2011). Positive effects include improved urban air quality, as DH drastically reduces particulate matter compared to individual boiler installations (Caserini et al., 2010).

The difficulty to estimate GHG emissions and to compare the climate impact of DH to that of other heating options may constitute an obstacle to expanded implementation of DH. There are several methods to calculate GHG emissions, in which different system boundaries and assumptions about the system under study can be applied. Depending on which method that is used, the results and the possibility to compare the results to other heating options may differ. In a DH system with CHP production, estimating climate impact is a complex task because of the issue of allocation of GHG

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emissions between the two products, electricity and heat. Adding industrial excess heat to the DH system adds another dimension to the estimation of climate impact: what are the GHG emissions from a by-product of an industrial production process? This question introduces resource efficiency as an additional variable in the climate impact assessments, thus further increasing the complexity of the analysis.

The results from energy system analyses estimating GHG emissions have an impact on policy decisions, and thus also the future development of European energy systems. Therefore, it is crucial that such analyses provide reliable and comparable results, and that there is transparency in the use of methods and assumptions. In this paper, the consequences of using different allocation principles and system boundaries when estimating GHG emissions from CHP production and industrial excess heat are analysed. The aim is to illuminate the influence of methodological choices on the results and to suggest how awareness of this can be used to identify GHG emission reduction possibilities in DH systems with CHP production and/or industrial excess heat.

The climate impact of DH is a well-researched area (see for example Connolly et al., 2014; Lund et al., 2014; Magnusson, 2012; Persson and Werner, 2012; Rezaie and Rosen, 2012). There are also several previous studies of the consequences of applying different system boundaries (see for example Borrion et al., 2012; Grönkvist et al., 2003; Wetterlund et al., 2010) and GHG emission allocation methods (see for example Beretta et al., 2012; Jungmeier et al., 1998; Rosen, 2008), with regard to heat as well as other energy carriers. In this paper we complement previous research by applying different methodologies to a DH system with CHP production and industrial excess heat, thus illuminating the difficulties that appear when assessing the two great potential heat sources in the EU. We do this by bringing together GHG emissions calculation methods with the concept of industrial symbiosis (IS), which addresses resource efficiency in collaborations between industries and/or energy utilities. Results from this approach to the assessment of GHG emissions from DH systems could be useful in the design of policies intended to encourage further development of DH in the EU.

The structure of this paper is as follows: In Section 2, we provide a background with regard to DH, CHP production, and industrial excess heat. Section 3 presents the systems approach used to analyse GHG emissions and resource efficiency in this paper. Section 4 illustrates the complexity of estimating GHG emissions and resource efficiency of DH systems. In Section 5, we discuss the consequences of using different methodologies for the implementation of DH systems. Section 6 concludes the paper and offers suggestions for further research.

2. An overview of district heating

2.1. Using district heating

Current DH systems primarily supply space heating and hot tap water to multi-family dwellings and non-residential buildings. Research shows that DH may contribute to reducing energy use in industries, by replacing other energy use in production processes (Difs et al., 2009; Henning and Trygg, 2008). Using DH for cooling purposes may also have large potential, through absorption cooling (Difs et al., 2009; Svensson and Moshfegh, 2011). Connolly et al. (2014) estimate that by 2050, absorption cooling could provide approximately 20 TW h to district cooling grids, thus satisfying 10% of the EU's cooling demand. The diversity of applications ensures that DH may be useful not only in countries with a cold climate but also in regions where space heating is not extensively required. Buildings and industrial production processes are becoming more energy efficient, thereby reducing the need for heating (Magnusson, 2012). For instance, buildings may be made energy efficient by improving insulation and ventilation or modifying the heating system. However, studies show that energy efficiency measures in buildings with DH are beneficial from a GHG emissions perspective, as they reduce peak load and level out the annual demand for DH (Åberg and Henning, 2011; Åberg et al., 2012). Thus, DH may continue to be useful. It has also been shown that DH offers flexibility to national energy systems, not only with regard to heat utilisation but also for energy storage capacity (Münster et al., 2012). In that respect DH could contribute to a renewable electricity system, as for instance a large share of wind power requires system functions that can manage fluctuations in electricity supply.

2.2. Heat supply

2.2.1. Combined heat and power production

In a CHP plant, heat and electricity are produced simultaneously. The EU acknowledges the important role of CHP production in the energy efficiency directive (EED), in which the efficiency of cogeneration as opposed to separate production of electricity and heat is emphasised (EC, 2012). In particular, the efficiency of electricity production is targeted, as the total efficiency of a CHP plant is around 85% whereas the efficiency of a condensing power plant is 30–50% (Odenberger et al., 2009). Waste, biomass, and natural gas (NG) are commonly used fuels in CHP plants. Using waste in CHP production is one option to reduce landfilling, which is common in several EU member states (Persson and Werner, 2012). Studies also show that CHP plants may effectively reduce GHG emissions in the energy system (Henning and Trygg, 2008; Knutsson et al., 2006). In a renewable energy system, CHP plants are considered important for regulation and stabilisation of the electricity grid (Lund et al., 2014).

2.2.2. Industrial excess heat

A significant amount of heat is generated as a by-product from industrial production processes (see for example Broberg Viklund and Johansson, 2014). The heat flows have different characteristics, for example regarding quality (temperature) and form (such as exhaust gases, cooling water, or materials). In some cases the heat may be recovered and used in other processes within the industry, but if that is not possible it is considered excess heat. There are different definitions of exactly what constitutes excess heat, but in this paper we use the following definition: "Excess energy that cannot be utilised internally and where the alternative is that the heat is released into the surroundings" (SEA, 2008: p. 23).

Although the use of industrial excess heat, for example in DH systems, is endorsed in the EED (EC, 2012), it is currently not widely established. In Sweden, the EU member state where industrial excess heat is most widely used, 4.9 TW h was used in 2008 (Persson and Werner, 2012). Meanwhile, the total EU potential of available industrial excess heat has been estimated at 750 TW h per year, of which less than 1% is currently used in DH systems (Connolly et al., 2014). Several barriers to excess heat collaborations have been identified, mainly related to social, cultural, and economic factors (Grönkvist and Sandberg, 2006; Thollander et al., 2010). The technical opportunities for using industrial excess heat in DH systems exist, and studies demonstrate a great deal of potential for this. For example, Johansson and Söderström (2011) found that the Swedish steel industry could become more energy efficient by supplying excess heat to DH systems; Johansson et al. (2012) identified excess heat supply to a DH grid as an option for the oil refining industry to reduce GHG emissions; and Jönsson and Algehed (2010) found that a DH collaboration would be an economically robust alternative for the pulp and paper industry to reduce GHG emissions.