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Technologies for utilization of industrial excess heat: Potentials for energy recovery and CO_2 emission reduction

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ABSTRACT

Industrial excess heat is a large untapped resource, for which there is potential for external use, which would create benefits for industry and society. Use of excess heat can provide a way to reduce the use of primary energy and to contribute to global CO_2 mitigation. The aim of this paper is to present different measures for the recovery and utilization of industrial excess heat and to investigate how the development of the future energy market can affect which heat utilization measure would contribute the most to global CO_2 emissions mitigation. Excess heat recovery is put into a context by applying some of the excess heat recovery measures to the untapped excess heat potential in Gävleborg County in Sweden. Two different cases for excess heat recovery are studied: heat delivery to a district heating system and heat-driven electricity generation. To investigate the impact of excess heat recovery on global CO_2 emissions, six consistent future energy market scenarios were used. Approximately 0.8 TWh/year of industrial excess heat in Gävleborg County is not used today. The results show that with the proposed recovery measures approximately 91 GWh/year of district heating, or 25 GWh/year of electricity, could be supplied from this heat. Electricity generation would result in reduced global CO_2 emissions in all of the analyzed scenarios, while heat delivery to a DH system based on combined heat and power production from biomass would result in increased global CO_2 emissions when the CO_2 emission charge is low.

1. Introduction

In recent years, the unsustainable use of the world's resources has gained increased attention. Efficient use of resources can reduce the use of primary energy and thus reduce emissions of anthropogenic greenhouse gases (GHG). In its work against climate change, the European Union (EU) has promoted the importance of energy efficiency measures to reduce the use of primary energy and set a goal to increase energy efficiency by 20% compared to 1990 levels [1]. The Energy Efficiency Directive (EED) stresses the use of industrial excess heat as a way to reach the EU target [2].

There is no clear definition of what can be considered as excess heat. Several definitions have been proposed such as "heat that is left over after an industrial process has become (thermodynamically) optimized" or "excess heat that cannot be used directly in the industrial process" [3]. The definition of industrial excess heat that will be used in this paper is as follows: Industrial excess heat is heat generated as a by-product of industrial processes. This heat is not used today, but could be used to create benefits for the industry and the society.

2. Aim and delimitations

The aim of this paper is to map and investigate different options for the recovery and use of industrial excess heat. The study does not claim to review the whole market of heat recovery technologies; however, the paper will show the diversity and complexity of the technologies that might be used for industrial excess heat recovery and will classify them according to purpose. The paper will put the use of excess heat into a context by applying some of the measures to the untapped excess heat potential in Gävleborg County and will report the energy recovery potentials and global CO_2 emission reductions. The paper also aims to investigate how different future energy markets affect global CO_2 emissions related

Abbreviations: Bio-CHP, bio combined heat and power ; CHP, combined heat and power; COP, coefficient of performance; DC, district cooling; DH, district heating; EED, Energy Efficiency Directive; EMS, energy market scenarios; ENPAC, Energy Price and Carbon Balance Scenarios; EU, European Union; FT, Fischer Tropsch; GHG, greenhouse gases; HOB, heat-only boiler; IS, industrial symbiosis; LiBr, lithium bromide; NGCC, natural gas combined cycle; ORC, organic Rankine cycle; PCM, Phase Change Material; PV, photovoltaic; TEG, thermoelectric generator; TPV, thermophotovoltaic.

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to the implementation of different heat recovery options. The objective of the analysis is to provide information that can be used as a decision basis, e.g., by industry when considering investment in heat recovery equipment, and by policymakers evaluating different strategies for climate change mitigation.

Excess heat can be used in-house and transferred to other facilities. The focus of this paper is on recovery measures for external use of industrial excess heat. The recovery potentials are not put in a geographical context; distances between the heat source and potential users were not considered. Further, this study does not investigate industrial excess energy in the form of combustible waste gases or by-products.

3. Industrial excess heat

Efficient use of energy can take the form of improvements in a single production process as well as improvements in a larger system where the energy flows in the system are connected and thermodynamically and/or economically optimized. Several options are available for the use of industrial excess heat. An important first step is reduction of the amount of excess heat released by the production processes. If the available heat can be used in the industrial process in which it arose, this is, in most cases, the best choice and often a relatively inexpensive and easy way to use the heat. This recycling of heat can be achieved by heat exchange, for example, by preheating of incoming air, water, or material. Recovery of the heat for external use is another possible use. As it may lead to heat losses, the recovery process must be located close to the heat source and/or maintain a high efficiency in heat transfer. The heat can also be used to generate electricity, which could be used internally or externally.

The use of excess heat may result in several savings. Not only may the primary energy demand decrease, but CO_2 emissions may also be reduced and economic gains realized [4]. Industrial excess heat characteristics determine the feasibility of recovering the heat. Quantity and quality are two important parameters: quantity describes the amount of energy contained in the heat streams, while quality measures the usefulness of the stream and is determined by the temperature [5].

The use of available industrial excess heat has been studied e.g., [6–9], but it is argued that a large untapped potential exists [10,11]. The energy efficiency target and the possibility of the use of industrial excess heat resulting in environmental and economic gains [4] has drawn attention to the importance of recovery of excess heat and the development and implementation of recovery technologies.

4. Gävleborg County

This study applied measures for the recovery and utilization of industrial excess heat to an industrial area and calculated the energy recovery potential and effects on global CO_2 emissions. The industrial area considered in the paper is Gävleborg County, which is located in central Sweden on the Baltic Sea coast and is Swedeńs tenth most populated county (out of 21 counties) [12]. The county's business activity is diversified, but it has a large share of energy-intensive industry (e.g., pulp and paper and steel industries) and this study focuses on these industries. The annual use of energy (2010) within the county's industry sector is approximately 11.2[1] TWh. This corresponds to about 6.7% of energy use in this sector in Sweden [13]. The annual use of district heating (DH) in the county sums to approximately 2 TWh [13], of which approximately 11% originates from industrial excess heat [14].

[1] This includes electricity use in the construction sector.

5. Methodology

5.1. Questionnaire

Approximately 67%[2] of Gävleborg County's energy end-use in 2008 was used within the industrial sector [13]. Due to the complexity of the energy flows in energy-intensive industries, a questionnaire rather than an energy audit was used by the authors to gather information. This enabled firms to contribute their own data regarding energy flows and, at the same time, allowed for a larger sample than would be possible with energy audits.

A web-based questionnaire was sent to 58 industrial firms within different industrial sectors in the spring of 2012. The list of respondents was obtained from the County Administrative Board of Gävleborg. All the firms are classified as firms holding a high environmental impact [15]. The questionnaire focused on excess heat quantity and quality (temperatures of the heat flows and flow rates of the excess heat flows) in different energy carriers at the firms and the potential for heat recovery (internally and externally). The questionnaire was answered by the person in charge of energy issues at the firm, who was either the energy manager or the production manager, and the response rate of the study was approximately 33%.

5.2. CO_2 emission evaluation

To handle the uncertainty regarding the future energy market and to evaluate the effects of heat recovery on global CO_2 emissions, different scenarios predicting future energy markets for 2030 were used. By using consistent energy market scenarios (EMS) that predict possible cornerstones of the future energy market, more robust results can be obtained. To obtain a consistent scenario, it is important that the energy market parameters are correlated to each other. In this study, the Energy Price and Carbon Balance Scenarios (ENPAC) tool was used. A more thorough description of the tool can be found in Axelsson and Harvey [16] and Axelsson et al. [17]. Inputs to the tool were prices of fossil fuel and charges for emitting CO_2. Input prices were taken from the scenarios presented in *World Energy Outlook* 2011 [18]. In the evaluation of the effects on global CO_2 emissions, biomass was considered a limited resource on the market, and a marginal electricity system was assumed. Based on the inputs to the ENPAC tool, the marginal technology for electricity production (build margin) and the marginal user of biomass were determined. Moreover, two potential DH systems were considered: a small Swedish system based on bio heat-only boilers (bio-HOB) and a large Swedish system based on bio combined heat and power (bio-CHP).

When electricity is produced from excess heat, the marginal electricity approach results in the marginal electricity producer reducing its electricity production by an equal amount, which affects the global CO_2 emissions. When excess heat replaces energy originating from biomass use, biomass will be available and can be used by the marginal user of biomass. The ENPAC tool could choose between two marginal users of biomass: a coal power plant with co-firing of biomass or a producer of the biofuel Fischer Tropsch (FT) diesel. The resulting impact on global CO_2 emissions if industrial excess heat is utilized can be seen in Table 1.

6. Excess heat potential in Gävleborg County

Energy use by the firms that completed the questionnaire totalled approximately 9.5 TWh/year. The firms accounted for

[2] The county's total energy end-use does not include electricity use within the transportation sector.