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Industrial excess heat use: Systems analysis and CO_2 emissions reduction

Sarah Broberg Viklund *, Magnus Karlsson

Department of Management and Engineering, Division of Energy Systems, Linköping University, SE-581 83 Linköping, Sweden

HIGHLIGHTS

- A systems analysis of excess heat (EH) use is performed.
- It is favorable to recover EH in the DH or DC system.
- Tradeoff of EH use between the DH and DC systems depends on energy market prices.
- Tradeoff of EH use between the DH and DC systems depends on the heat production.

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ABSTRACT

The adopted energy efficiency directive stresses the use of excess heat as a way to reach the EU target of primary energy use. Use of industrial excess heat may result in decreased energy demand, CO_2 emissions reduction, and economic gains. In this study, an energy systems analysis is performed with the aim of investigating how excess heat should be used, and the impact on CO_2 emissions. The manner in which the heat is recovered will affect the system. The influence of excess heat recovery and the trade-off between heat recovery for heating or cooling applications and electricity production has been investigated using the energy systems modeling tool reMIND. The model has been optimized by minimizing the system cost. The results show that it is favorable to recover the available excess heat in all the investigated energy market scenarios, and that heat driven electricity production is not a part of the optimal solution. The trade-off between use of recovered excess heat in the heating or cooling system depends on the energy market prices and the type of heat production. The introduction of excess heat reduces the CO_2 emissions in the system for all the studied energy market scenarios.

1. Introduction

In the work to counteract the unsustainable use of the world's resources and climate change, the European Union (EU) launched the "20–20–20 objectives" in 2008. One of the EU targets is to reduce the use of primary energy with 20% coming through energy efficiency measures [1]. The adopted energy efficiency directive (EED) raises the importance of using excess heat as a way to reach the EU target [2]. Efficient use of resources can reduce the use of primary energy and reduce the emissions of greenhouse gases (GHG); and one way to achieve this could be through the use of available industrial excess heat.

The use of industrial excess heat can be seen as a well-established concept and has been implemented in several industries and societies. Efficient use of resources can be from both internal and external improvements, and there are several options for utilization of these unused heat resources [3–6]. It is important to first reduce the amount of excess heat from industrial processes. Then, heat recovery can be done in the processes in which it arose, used for other internal applications, or for external use. Excess heat can either be recovered for heating applications (e.g., delivered as district heating), or the energy can be used for generating electricity. The use of excess heat may result in decreased energy demand, reduced CO_2 emissions and economic gains and, furthermore, improved energy efficiency resulting from excess heat recovery is attractive from a resource use perspective [7].

A number of district heating (DH) systems in Sweden accept industrial excess heat as a part of their fuel mix and in 2011 excess heat accounted for 7.2% of the heat deliveries in the Swedish DH networks [8,9]. Several research studies investigate excess heat recovery (both thermal applications and heat driven electricity generation) and heat storage technologies [10–18]. Johansson and Söderström [13] compare and evaluate heat driven electricity

* Corresponding author. Tel.: +46 13 281103.
E-mail address: sarah.broberg.viklund@liu.se (S. Broberg Viklund).

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Nomenclature

Abbreviation

HOB	heat-only boilers
CHP	combined heat and power
COP	coefficient of performance
DC	district cooling
DH	district heating
EED	energy efficiency directive
EMS	energy market scenario
ENPAC	Energy Price and Carbon Balance Scenarios
EU	European Union
FT	Fischer Tropsch diesel
GHG	greenhouse gases
IO	investment opportunity
MILP	mixed integer linear programming
NG	natural gas
NGCC	natural gas combined cycle plant
ORC	Organic Rankine cycle

generation technologies for recovery of low-temperature industrial excess heat based on heat source temperature, efficiency, capacity, economy and potential electricity production. The study indicates that investments in heat driven electricity generation technologies could be profitable, however not all associated costs are included in the study [13]. Campana et al. [11] estimates the potential power output from excess heat driven Organic Rankine cycle (ORC) in the cement, steel, glass and oil and gas industry in 27 European countries. The authors conclude ORC to be a viable option for heat recovery and estimate the potential electricity generation from ORC to approximately 21.6 TW h per year [11]. Persson and Werner [16] studies recovered excess heat in the DH system in the EU27 to reduce primary energy demand and identify a great potential for increased excess heat use if applying best member state practices. Ammar et al. [10] discusses low-grade heat recovery and the authors bring forward the importance of a holistic view to increase the number of opportunities to reduce the environmental impact by heat recovery.

2. Aim and implementation

Several research studies present benefits of heat recovery, but even though there are examples of use of industrial excess heat, studies show that there are still large untapped potentials [19,20]. The importance of a holistic view is raised in Ammar et al. [10] and hence, there is a need for system studies within the field of excess heat use. The overall aim of this paper is to perform an energy systems analysis in order to recognize implications of future heat recovery (e.g. district heating deliveries) and electricity generation (e.g. through ORC) from industrial excess heat. A large number of factors (e.g. what the heat replaces) influence how the system is affected and several different factors have therefore been analyzed by using consistent energy market scenarios. The optimization tool, reMIND [21], is used to minimize the system cost for the different factors that are altered. By using this method, the changes occurring in the energy system and its boundary conditions can be analyzed. The optimization tool used in this study minimizes the system cost and finds the optimal system solution for excess heat recovery (based on the given assumptions) from a large number of variable factors.

The aim of this study has been to investigate how available industrial excess heat should be used to reduce system cost. The aim has also been to study the effects on CO_2 emissions due to excess heat use. The aim of this study is not to present the overall system cost, and therefore only costs that differ between the studied scenarios will be included in the model. Use of excess heat will require different types of investments (e.g. in infrastructure and technology) and the investment opportunity will be calculated and presented. The results presented in this study are based on one studied case, but the results presented in this paper contribute to the understanding of excess heat use in general. The results may be used as a part of a decision basis for heat recovery investments or when developing strategies for climate change mitigation in general.

3. Method

3.1. Case study

A case study was conducted to investigate the implications of industrial excess heat use. The energy system and the consequences for excess heat use were studied using energy systems modeling. This study is based on a study presented in Broberg Viklund and Johansson [3] where a questionnaire was sent to producing companies classified as firms holding high environmental impact (according to the classification in [22]) in Gävleborg County, Sweden in spring of 2012 [3]. The energy use in Gävleborg County adds up to approximately 20 TW h (in 2011) [23], which results in direct CO_2 emissions totaled approximately 1580 kton [24]. The county holds a large share of energy intensive industry (e.g. pulp and paper, and steel industries) and the annual use of energy in the county within this sector (2011) adds up to approximately 11.3[1] TW h [23]. The firms answering the questionnaire reported a total untapped industrial excess heat potential of approximately 0.8 TW h/year corresponding to 8.4% of the energy input among the firms that completed the questionnaire. The heat could be found in different energy carriers (water, flue gases, air and heat in materials) and the temperature of the heat ranged from 45 to 1600 °C [3]. The manner in which the excess heat is used will affect the system, e.g. the CO_2 emissions. Though the purpose is not to fully reflect this county, the study is based on the industrial excess heat potential in water, flue gases, and air in Gävleborg County as presented in [3], and summarized in Table 1. However, it is assumed in this study that the potential is the actual potential available at the point of use for the heat use technologies in this study, that is, the recovered heat that has been exchanged to a suitable medium.

3.2. Energy systems modeling tool

The studied system is modeled using the energy systems modeling tool reMIND.[2] The tool has been developed for optimization of dynamic industrial energy systems and uses mixed integer linear programming (MILP) to minimize system costs (system costs include e.g., energy costs and costs for raw materials). reMIND can be used for several purposes. For example, it can be used to find the optimal structure of an industrial energy system, and/or to find the optimal flow distribution in a fixed structure, and/or be used to investigate changes occurring in an industrial energy system or its boundary conditions.

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

[2] reMIND is publicly available tool and can be downloaded from: https://code.google.com/p/tremind/.