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Targeting capital cost of excess heat collection systems in complex industrial sites for district heating applications

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ABSTRACT

The objective of this study is to develop a methodology for estimating the investment costs for heat collection systems gathering excess heat from complex industrial sites and delivering it to a DH (district heating) network. The paper presents a case study conducted on Sweden's largest chemical cluster. In a previous paper, the economic feasibility of delivering heat from the cluster to a regional DH system proved to be favorable under a wide range of price conditions. We develop the methodology used previously in order to identify how each of the plants should contribute to the heat delivery in order to achieve the lowest total investment cost within the cluster. The optimization problem is formulated with the constraint that each plant delivers heat to the DH network separately and at the temperature required by the network.

Investments for heat collection systems were estimated for the current configuration of the cluster's energy system (Base case) and for two possible future configurations with increased levels of internal heat recovery. The resulting optimal contribution mix provides a detailed overview of how the plants compete at different specified levels of DH delivery. In the Base case, two plants strongly compete due to similar investment costs.

1. Introduction

Almost 40% of global CO_2 emissions are attributed to industrial activities and industry accounts for about 30% of global final energy use [1]. In the European Union's EED (energy efficiency directive) [2], increased use of excess heat is highlighted as significant in order to reach the EU target of increasing energy efficiency by 20% by the year 2020, compared to 1990 levels [3]. Using excess heat from industry for production and export of additional energy products is an energy efficiency measure, since heat, instead of being dissipated to the environment, can save primary energy when used for production of DH (district heating), electricity or for biomass drying.

Connolly et al. [4] have shown that including a heat strategy with district heating and heat savings in buildings can substantially reduce the costs for reaching the goals set by EU of 80% reduction of GHG (greenhouse gas) emissions by 2050 [5]. In the described strategy, DH is assumed to be implemented in all EU countries at a level similar to that of today's best practice countries. Person et al. [6] have estimated that it is possible to increase the excess heat utilization fourfold in the future, by means of district heat distribution to residential and service sectors, if applying best Member State practice. Note that in Person's work, excess heat refers to heat from industry and combined heat and power plants including waste incineration. In both studies [4,6], Sweden is one of the countries considered as best practice since the ratio between energy recovered to DH and primary energy input to industry is 0.4% on average in EU27 while it is 7% in Sweden.

The potential amount of available industrial excess heat in Sweden has been estimated in several studies using different methodologies. A possible top-down approach is to use statistics on fuel use and excess heat deliveries to DH systems from different industries [7]. A bottom-up approach can also be used where results from a case study with information obtained from questionnaires are scaled up to a national level [8]. In another study, results from the top-down study presented in Ref. [7] are compared with detailed analysis of five types of energy-intensive industrial processes [9]. All these studies argue that there is a large un-tapped potential in Sweden which means that regardless of the fact that

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Sweden is internationally considered as best practice in this field, there is nevertheless still a potential to increase heat recovery and utilize more of the industrial excess heat in DH networks. However, excess heat delivery to a DH network competes both economically and in terms of impact on GHG emission balances with combined heat and power plants in the DH systems and with primary energy savings in industry achievable through increased internal heat recovery. Different options for on-site and off-site excess heat utilization are evaluated in a recent paper [10] using a hierarchical approach taking into account energy performance, greenhouse gas emissions and economics. The environmental impact and influence on the energy system from large scale utilization of excess heat for district heating is modeled in Ref. [11].

The minimum energy demand of an industrial plant can be estimated using energy targeting methodologies. For processes largely based on thermochemical conversions, such as process industries, process integration tools based on Pinch Analysis are often used. The Pinch Analysis method is based on the algebraic addition of the process heat demand and availability at various temperature levels. It follows the principle of extending the counter-current heat transfer between two streams to all the process heat sinks and heat sources organized respectively in a cold and a hot composite curve. For introduction, overview and user guide to Pinch Analysis methods and tools, the reader is referred to [12].

Process integration studies for complex multi-process industrial sites often show a significant potential for energy savings, on average 20–25% of the total energy use for the site [13]. Even for plants that are inherently highly efficient, it is possible to further improve the overall site energy efficiency by sharing energy with other facilities at the site [14]. The TSA (total site analysis method) is based on Pinch Analysis and provides goals for minimum heat requirement and possible heat recovery between the different processes at an industrial site. Hence this method enables investigation of the possibilities to supply excess heat from one process to another, through a common network, but also the potential for heat integration within a larger geographic area, which apart from the industrial sites also include buildings, offices and homes [15]. A detailed description of the TSA methodology can be found in Ref. [16].

1.1. Description of previous work, case study and objectives

This study is part of a larger project with strong stakeholder involvement studying utilization of industrial excess heat together with two other studies addressing respectively economic and environmental impact on the regional heating system from utilizing industrial excess heat [11] and the possible market models for excess heat sales.

This paper focuses on the Stenungsund chemical cluster situated on the Swedish West Coast about 50 km north of Gothenburg. The cluster consists of six plants run by five companies. Large amounts of excess heat have been identified in a previous paper [17], where a more detailed description of the cluster can be found.

Previous studies of the cluster, based on Total Site Analysis methodology, have shown that all the current fuel import used for firing utility boilers could theoretically be avoided [18]. All the heat integration opportunities can be exploited through a common utility system for distribution of steam and hot water flows within the cluster [18]. The theoretical heat savings potential is 122 MW of which around 50 percent has been estimated to be feasible. To reach this conclusion the process streams were grouped, with the help of company experts, into three categories corresponding to different degrees of difficulty for implementing energy efficiency measures: A) possible: no practical constraints, moderate investment costs are expected; B) possible, with constraints: several or more complex changes are necessary, higher investment costs are expected; C) impossible: process constraints make changes impossible. In order to take these expected difficulties into account all process streams categorized as C were excluded from our analysis.

Note that the common hot water network, proposed for achieving the suggested heat recovery between cluster industries, operates at temperature levels similar to those commonly encountered in DH networks. This means that the possibility to increase energy efficiency within the cluster is theoretically in close competition with increased export to a DH network.

The research question that we aim to address is whether it is technically and economically feasible to recover the excess heat available within the cluster and whether it is best to use such heat within the cluster or to deliver it to a DH network. To identify long term sustainable solutions both economic and environmental aspects need to be considered.

Overall the problem is complex, since it includes multiple objectives and involves a large number of variables regarding the heat exchanger network and the layout of the heat collection system at the cluster with non-linear and discontinuous functions. Unlike many studies in the literature dealing with a mathematical formulation of the whole global optimization problem, we opted for a decomposition of the problem in smaller steps which allowed us to develop the methodology step-wise based on practical issues discussed with industrial partners over a long period of time. In addition, we aim at evaluating a large range of possible solutions and comparing them under different boundary conditions regarding for instance the energy market and the regional energy system.

In previous work, the economic feasibility of delivering heat from the cluster to a DH network was investigated for a large heat delivery capacity range and for different prices at which the heat could be sold to a nearby network [17]. DH delivery was shown to be feasible in the entire capacity range, provided that the utilization time can increase as investment costs increase with larger delivery capacities. It was also concluded that several plants strongly compete with each other for a total delivery below 20 MW, since they have similar investment costs, and that collaboration between industrial plants achieves economic gains for higher levels of heat delivery. From these conclusions it is clear that if the cluster wishes to deliver larger quantities of heat to the DH system, several industrial plants should be involved. However, the optimal level of excess heat recovery from each individual plant, i.e. the delivery mix that achieves the lowest total investment cost, was not investigated.

In this work we focus on refining the targeting method for estimating the capital cost of heat collection systems when excess heat is collected and delivered to a DH network as well on the estimation of the optimal heat delivery contributions from the different plants within the cluster.

The problem of heat exchanger networks synthesis has been studied to a great extent and a variety of methods have been proposed in the past. An extensive description of methods for heat recovery synthesis, both in greenfield and retrofit situations, with their difficulties and limitations can be found in Ref. [19].

This study can be considered a particular case of heat exchanger network synthesis from a stream set that involves a single cold stream (the cold side of the heat collection system). While heuristic methods allow easier implementation [20], more elegant problem formulations have been proposed based on mathematical programming based on sequential [21] or simultaneous [22] approaches. Recent development of the sequential approach for Total site purposes can be found in Ref. [23].