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Economic feasibility of district heating delivery from industrial excess heat: A case study of a Swedish petrochemical cluster

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ABSTRACT

The present work discusses the potential and the economic feasibility of DH (district heating) delivery using industrial excess heat from a petrochemical cluster at the Swedish West Coast. Pinch Analysis was used for estimating the DH capacity targets and for estimating the cost of heat exchanger installation. A discounted cash flow rate of return of 10% was used as a criterion for identifying the minimum yearly DH delivery that should be guaranteed for a given DH capacity at different DH sales prices. The study was conducted for the current scenario in which no heat recovery is achieved between the cluster plants and for a possible future scenario in which 50% of the fuel currently used for heating purposes is saved by increasing the heat recovery at the site. The competition between excess heat export and local energy efficiency measures is also discussed in terms of CO_2 emission consequences. The maximum capacity of DH delivery amounts today to around 235 MW, which reduces to 110 MW in the future scenario of increased site heat recovery. The results of our analysis show that feasible conditions exist that make DH delivery profitable in the entire capacity range.

1. Introduction

Large investments in DH (district heating) networks have been made in Sweden during the last decades and expansions of existing networks are also currently being investigated [1]. The main advantages associated with centralized DH systems with respect to separate heating systems are: (1) possibility of electric power cogeneration; (2) possibility of combining heating and cooling by use of absorption chillers; (3) opportunities for industrial heat pump technologies with improved performance compared to small size systems; (4) ability to fire “difficult” fuels such as municipal solid waste or low-grade biomass. Ultimately, DH networks allow connecting multiple heat demands with varying characteristics with various energy sources and are well suited to include renewable energy technologies [2,3] especially if provided with heat storage [4].

An additional advantage of DH networks is the possibility to collect and distribute industrial excess heat, which is heat at medium low temperature that is not used in industrial processes and that is normally dissipated to the environment.

The use of industrial excess heat for DH applications has a great potential, especially in cold climate countries where heat demand for space heating is high during a large part of the year. It is a particularly attractive option if the industrial plant is located close to a large urban area and if investments in the DH infrastructure have partially already been made [5]. Although there are a number of examples of collaboration between industries and DH operators regarding delivery of excess heat to DH networks, the actual amount of industrial excess heat in cold climate regions is still not fully exploited [6]. Increased delivery could be favored by appropriate policy instruments [7]. Whenever industrial excess heat export appears profitable for both the industry and the district heating system, the risks associated with possible discontinuous availability of industrial processes are often the major barrier to the viability of excess heat export, especially for small networks.

In many cases a considerable share of industrial excess heat could also be theoretically re-used in the industrial process if heat recovery is improved. The competition between internal and external use of industrial excess heat has been discussed in the literature, a relevant example being the case of Swedish Kraft pulp mills discussed in Refs. [8,9]. An overview of excess heat utilization opportunities for the process industry in UK is discussed in Ref. [10].

It should be emphasized that the terms “excess” or “waste” heat are often misused. In particular, what is commonly regarded as waste heat could be often partially recovered by proper retrofit of

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the heat recovery and utility systems [11]. For this reason we prefer to use the term "excess heat" to suggest that in practice there is always an excess of heat available from a process due to non-ideal heat recovery and that such heat is often at sufficiently high temperature to be used internally or to be exported at least as district heating. Pinch Analysis can be used for quantifying the avoidable and unavoidable part of industrial excess heat [12], and in combination with exergy analysis can be used to estimate the most appropriate excess heat utilization [13].

In principle, since investment in heat exchangers and piping should be made independently if heat is recovered between industrial plants or if it is exported to households, it is impossible to reach general conclusions about whether excess heat export is a cheaper option than internal recovery and re-use. Other factors that affect the decision to export excess heat or recover it for internal use include, for example, different energy market conditions for industry and the heating sector, collaboration barriers between different industries, and the minor impact of the low temperature heat savings on the overall revenues of the industrial activity. Furthermore, the actual economic performance and the global environmental consequences of industrial excess heat export depend to a significant extent on the heat production technologies that are displaced in the DH system, and are therefore be affected by fuel and electricity prices [8,9].

1.1. Description of the case study and objectives

The present work focuses on a case study of a petrochemical cluster located on the Swedish West Coast and deals with the estimation of the theoretical potential and the economic feasibility of DH delivery from the industrial site to a regional DH network that in a near future could be expanded to accommodate excess heat from the cluster.

The industrial cluster is located in Stenungsund approximately 50 km north of the city of Göteborg. It consists of six production sites operated by five different companies. Stenungsund lies within a heat synergy opportunity zone, meaning that the geographical location of the cluster is advantageous for delivering excess process heat to a DH system in the area [14]. The cluster's current electricity and fuel use are approximately 1.8 TWh y^{-1} and 4.9 TWh y^{-1} respectively, corresponding to loads of 225 MW and 624 MW respectively, since most of the plants operate at a steady-state almost all year round.

The theoretical potential for primary energy savings within the cluster has been estimated in previous studies. It was shown that an improved use of refrigerant and recovery of cooling capacity throughout the cluster can save cold utility and slightly reduce the power demand for refrigeration [15]. More encouraging results were found when looking at the heat savings potentials at the site [16]. By using TSA (Total Site Analysis) it was found that the hot utility demand covered by boilers fired with purchased fuels could theoretically be avoided completely, and an excess of steam could even be achieved if the total site's utility system is modified to allow optimal heat distribution across the cluster. It should, however, be noted that a significant fraction of the fuel currently fired within the cluster is in fact needed for direct firing in steam crackers and other reactors and cannot be replaced by internal heat recovery. Process heating is achieved by 17 different hot utilities, more specifically: 13 steam levels, 2 hot water systems, circulating hot oil and flue gas heating. On average 122 MW of heat is required for process heating other than reactors, corresponding to approximately 150 MW of fuel firing that could be avoided by properly managed heat recovery across the site.

These theoretical savings do not account for economical, technical and geographical constraints. An estimate of practical heat savings potential was conducted in collaboration with company experts and based on the results of the TSA study and was found to be approximately 50% of the current hot utility usage, i.e. approximately 60 MW heat [17]. Further economic analysis showed that this reduction could be achieved by investments with an average pay back period of about 4 years. Practical heat savings opportunities were identified through heat recovery at temperatures similar to those of district heating water.

In the light of the results from previous work we observe that a large number of alternatives are available when investigating possible uses of the available excess heat. Excess heat that is currently discharged to the ambient could be recovered not only internally through a site wide utility network but also for DH delivery as discussed in the present work. Low temperature drying of biomass feedstock to feed an integrated biorefinery process for production of chemical intermediates or fuels [18] or low temperature cooling by means of absorption chillers to partially substitute the current compression refrigeration units [19] are also interesting opportunities. Heat can also be upgraded to a temperature level where it can be more easily utilized by means of heat pumps [20] or heat transformers [21]. In principle any kind of energy conversion technology based on a thermal process can be adapted to make better use of low temperature heat [22]. Electricity can be produced through organic Rankine cycles [23], or binary cycles similar to those used for geothermic power generation [24]. Thermoelectric generators can also be employed [25]. An additional excess heat utilization concept which may exhibit large potential in more advanced power networks consists in using excess heat to boost the power discharge capacity of thermal energy storage [26].

It is clear that the competition between cluster internal heat recovery and excess heat export must be studied by comparing all the above options adopting a holistic approach. This work is a first attempt in this sense and focuses on the estimation of the potential and the economic performance of DH delivery not only for the case where the totality of the current cluster excess heat is available for export (current scenario), but also for the case where half of theoretical cluster internal heat recovery potential is achieved thus reducing the excess heat and the DH delivery opportunities.

The study was basically conducted in three steps. Firstly the maximum amounts of DH that can be delivered by the cluster under different conditions of local heat recovery and integration of the heat collection systems (separate parallel system for each plant or cluster wide network) were estimated. Based on these targets, CO_2 emissions were allocated to the exported heat and general conclusions on the environmental consequences of industrial excess export were drawn. Finally an economic analysis was performed to identify the conditions that make the DH delivery from the cluster economically interesting for a minimum and maximum value of the DH sales price at the cluster battery limits. The methodology and the results of the study are presented in the next two sections following the same structure.

2. Methodology

In this section the main methodology is described, including the following:

- Discussion of critical assumptions used for the investigation (Section 2.1).
- Description of the Pinch Analysis targeting procedure used for estimating the maximum amounts of DH that can be delivered by the cluster (Section 2.2).
- Description of the procedure for allocating CO_2 emissions to the excess heat based DH, based on the results of the Pinch Analysis (Section 2.3).