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On the benefit of integration of a district heating system with industrial excess heat: An economic and environmental analysis

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HIGHLIGHTS

- Utilized industrial excess heat in district heating system with CHP plant is studied.
- Advantages are gained when the district heating system utilize industrial excess heat.
- Fuel-based plant heat production and total system cost are substantially reduced.
- Industrial steam is preferred when costs are below alternative heat production cost.
- Restricted industrial hot water utilization occurs in periods of low heating demand.

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ABSTRACT

Energy-related cooperation using industrial excess heat (IEH) in district heating (DH) networks shows economic and environmental benefits. A rarely investigated approach is the energy cooperation which incorporates a jointly operated CHP plant also producing process steam for nearby industry. The present study aims to evaluate economic and environmental effects on the Hofors DH system with jointly operated CHP plant when the nearby steel mill extends the supply of recovered IEH. Various IEH supply opportunities with different capacities of hot water and steam were designed and compared with existing IEH utilization, plant heat and electricity production and DH system performance. The energy system model MODEST is used for cost-optimization. A parametric study is used to analyze influences of increasing IEH cost and fluctuating electricity prices. The results show advantages for the DH system to utilize IEH for deliveries of DH and process steam and the cogeneration of electricity. Economic and environmental benefits are decreased total system cost (−1.67 MEUR/a), less use of fuels and electricity, and reduced CO_2 emissions with a maximal reachable amount of 28,200 ton/a when the use of biofuel is assumed as limited resource and the substituted marginal electricity production is based on coal-condensing power plants. The results also show that industrial steam is a preferred heat supply source as long as the steam cost is below the alternative heat production cost, irrespective of the electricity price. While the cost-effective utilization of industrial hot water for DH is more sensitive and affected by a beneficial CHP production based on higher electricity price segments, it is also shown that utilization of continuously supplied industrial hot water is limited during seasons of low DH demand.

1. Introduction

The concept of DH provides a variety of heat supply options such as geothermal heat, IEH, heat from thermal power generation and waste incineration as well as heat from thermal applications using energy carriers from biomass and fossil fuels [1]. Heat is distributed via local pipe networks to final users (e.g. sectors of building, service, industry) to satisfy their heat demands (e.g. space and process heating, hot water preparation). With appropriate applications, DH is efficient and can be environmentally beneficial and cost effective [2]. DH systems are most competitive in urban areas with high density of heat demand [3], but to some extent also cost-effective in sparsely populated areas with e.g. access to IEH [4]. DH, CHP and the use of IEH are energy efficiency measures promoted in line with EU energy strategies [5,6]. With best Member State practices, the EU27 excess heat utilization by means of DH distribution

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to residential and service sectors can be fourfold [7]. The expansion of DH together with heat savings, heat recovery, and renewable energy sources in the EU is explored as a cost-effective potential to provide the transition towards a low-carbon energy system with reduced primary energy use [8].

A DH system is characterized by local conditions such as size of heat demand, heat load profile and a set of heat supply technologies [9]. If the DH system is located in proximity to an energy-intensive industry, this characteristic may also be affected by mutual supply options leading to increased or decreased plant heat production and changed heat load duration [10–12]. With regard to energy-related cooperation using IEH in DH networks, favorable aspects are cost reduction due to lower fuel purchases and environmental benefits [13]. Available potential in the industry to increase energy efficiency [14,15] and to highlight the economic feasibility and environmental benefits [16,17] of IEH deliveries to DH networks are well studied, as is the competition of IEH with other heat supply sources [18] and fuel savings with related CO_2 emissions on large-scale IEH utilization [19] in a DH system, and how cost-optimal use of IEH is achieved [20]. Some crucial factors emphasized for a beneficial IEH supply are level of DH demand [14] and price for selling IEH [15], and for a cost-effective IEH utilization in the DH system the type of existing heat production and energy market prices [14,20]. If the existing heat production includes CHP technology, the increased IEH utilization has the potential to reduce electricity production [19,20]. Key issues can also be the collection and integration of multiple-grade IEH sources with long-distance delivery and peak shaving of the system [21], the identification of economically acceptable distance for the transfer of IEH to the DH network [22] and how policy instruments promote or discourage IEH recovery [23].

However, a rarely investigated approach with potential to provide economic and environmental benefits is the energy cooperation which incorporates a jointly operated CHP plant also producing process steam for industry. According to Grönkvist and Sandberg [13], this type of CHP cooperation can be configured in many different ways to balance process steam and DH production and will highly depend on local circumstances. The associated benefit is the increased annual operation time of a jointly operated CHP plant in comparison to ordinary plants producing either DH and electricity or process steam and electricity [13]. Marbe et al. [24] highlight the potential of synergy effects with combined operating conditions and merged heat loads, and conclude a clear economic advantage when a biofuel CHP plant delivers both process steam and DH within energy cooperation. The increased total efficiency is also enhanced by flue gas condensing common for biofuel boilers. Other aspects are proximity between industry and DH network and that existing connections at the industry enhance opportunities to utilize excess heat from industrial processes [13], e.g. by changes in industrial process that increase the amount and/or quality of excess heat, by the need to replace old heat production equipment or by the need for external cooling and high costs associated with this cooling.

1.1. Aim and approach

The general idea in this study is to highlight the economic and environmental impacts of increased IEH utilization on a DH system. The study will also explore the novel idea that IEH has the potential to increase the cogeneration in a jointly operated CHP plant; this is usually conflicting with ordinary biofuel CHP plant applications. A system study can also show implications on how to use existing heat production or industrial processes and indicate possible future measures. The ideas are reflected in a case study approach of a municipal DH system with a nearby steel mill. The supplied IEH from the steel mill is classified as belonging to the use in the DH system and defined as follows:

– Indirect usable hot water for preheating of DH heat return flows
– Direct usable hot water for DH with sufficient supply temperature
– Direct usable steam for cogeneration and process steam.

Various techno-economic factors will affect optimal DH system solutions and the beneficial integration of multiple IEH supplies, e.g. level of DH demand, price for selling IEH, type of existing heat production and energy market prices. Based on the local circumstances (small to medium-sized DH demand, existing cooperation and infrastructure, aging steam turbine), the influence of the IEH supply capacity, the IEH cost and the electricity price were analyzed in particular. Ammar et al. [25] highlight the importance, among other aspects, that recovered low-grade heat can economically be transferred from the source to the sink and that coincidence of heat supply and demand occurs. Without the consideration of investment costs for heat recovery technologies in this study, the IEH price, a part of the overall IEH economy [26], is used to indicate whether or not the IEH is a cost-effective solution in comparison to the alternative heat production plant, while how the IEH supply capacities are utilized will be important for the efficiency of an IEH recovery project. The electricity price will be crucial for the beneficial CHP production [18], especially without extra subsidies[1] and by using a cost-optimizing model.

The aim of the study is therefore twofold: first, the economic and environmental effects on the Hofors DH system performance with increased IEH supply capacities from the steel mill were evaluated with three designed scenarios, where the heat and electricity production as well as the performance outcomes measured as total system cost, energy use and CO_2 emissions were compared with reference case results. Second, based on the scenario with the highest IEH supply capacity, a parametric study was used to examine the influence of increasing IEH costs and fluctuating electricity prices on the competitive IEH utilization, the alternative plant heat and electricity production and the DH system performance. The CO_2 emissions were accounted for local energy use, with marginal electricity models and average accounting scheme based on a Nordic power market perspective. Biofuel was considered as a CO_2 neutral option but also debited with CO_2 emissions in a limited biofuel model with European system perspective. The reference case and scenarios were optimized with the energy system model MODEST.

1.2. Paper structure

The structure of the sections in the paper is as follows: material and methods (2) describe the MODEST optimization and modeling approach with all relevant aspects (2.1), followed by a description of the studied system with defined boundaries (2.2) and the reference case with designed scenarios of IEH supply opportunities (2.3). Thereafter, interconnected energy flows between the system units are illustrated and described in detail with model structure, techno-economic input data and demand assumptions (2.4). Next, the CO_2 emissions accounting method with emission factors (2.5) and criteria for the parametric study (2.6) are described. The results (3) present the model validation (3.1), the scenario analysis with production and system performance outcomes (3.2) and the parametric analysis with effects of increasing IEH costs and fluctu-

[1] In a Swedish context, subsidies in the form of electricity certificates can be credited for maximal 15 years and only for renewable electricity production, which means that utilized IEH recovered from processes mainly based on electricity and fossil fuel usage cannot be considered for such subsidies.