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Excess heat from kraft pulp mills: Trade-offs between internal and external use in the case of Sweden—Part 2: Results for future energy market scenarios

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ABSTRACT

In this paper the trade-off between internal and external use of excess heat from a kraft pulp mill is investigated for four different future energy market scenarios. The work follows the methodology described in Svensson et al. [2008. Excess heat from kraft pulp mills: trade-offs between internal and external use in the case of Sweden—Part 1: methodology. Energy Policy, submitted for publication], where a systematic approach is proposed for investigating the potential for profitable excess heat cooperation. The trade-off is analyzed by economic optimization of an energy system model consisting of a pulp mill and an energy company (ECO). In the model, investments can be made, which increase the system's energy efficiency by utilization of the mill's excess heat, as well as investments that increase the electricity production. The results show that the trade-off depends on energy market prices, the district heating demand and the type of existing heat production. From an economic point of view, external use of the excess heat is preferred for all investigated energy market scenarios if the mill is studied together with an ECO with a small heat load. For the cases with medium or large district heating loads, the optimal use of excess heat varies with the energy market price scenarios. However, from a CO_2 emissions perspective, external use is preferred, giving the largest reduction of global emissions in most cases.

1. Introduction

With the growing concern for climate change and increasing energy prices, the need for energy efficiency measures has become more urgent. The Swedish pulp and paper industry, being one of the major Swedish energy users, has a potential for significant energy savings through investments in energy efficiency, such as process integration and new technology (Axelsson et al., 2006; IEA, 2004; Wising, 2003). One way of saving energy is to use industrial excess heat in a more efficient way. Industrial excess heat from kraft pulp mills can be utilized both internally, for example in process-integrated evaporation (PIvap)[1] and/or drying of pulp, and/or externally for production of district heating.

Previous research using model mills and simulations has shown that, with improved heat integration and installation of new equipment, substantial process steam savings (20–30%) can be made (Algehed, 2002; Axelsson et al., 2006; Wising, 2003). This potential has been verified by a case study (Laaksometsä et al., 2007). The energy efficiency investments that reduce the steam demand also lead to increased amounts of excess heat. The temperature and amount of excess heat depend on the combination of energy efficiency investments chosen (Axelsson et al., 2006; FRAM, 2005). Previously the economic profitability among different internal utilization options such as PIvap, using high-temperature excess heat, and new conventional evaporation (Convap) (no utilization of the excess heat) has been studied (Olsson et al., 2006).

Diverse aspects of energy cooperation between the pulp and paper industry and other actors have also been studied. However, the focus has not been on the economic competition and trade-off regarding the use of industrial excess heat, but rather on the driving forces of and obstacles to cooperation (Gronkvist and Sandberg, 2006; Mollersten and Sandberg, 2004), the potential for industrial symbiosis (Wolf, 2007), and the potential for joint investments in large-scale combined heat and power (CHP) (studying paper mills that have steam deficits, not steam

Abbreviations: BAU, business as usual (cases); BP, back pressure; Convap, conventional evaporation; CHP, combined heat and power; DH, district heating; DME, dimethyl ether; EE, energy efficiency (cases); ECO, energy company; FGHR, flue gas heat recovery; HWWS, hot and warm water system; NGCC, natural gas combined cycle; PIvap, process-integrated evaporation

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[1] PIvap is a novel evaporation design which reduces the live steam demand through use of process excess heat.

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surpluses, together with energy companies (ECOs)) (Gebremedhin, 2003; Marbe et al., 2004). The techno-economic potential for the external use of excess heat from kraft pulp mills has only been briefly studied (Bengtsson et al., 2002; Fjärrvärmeföreningen, 2002) and has not included the competition with internal use. Thus, the trade-off between the possibilities of internal process use and external use, for example as district heating, of excess heat from kraft pulp mills has not yet been systematically investigated.

To address this question of trade-off between internal and external use of industrial excess heat from kraft pulp mills, a systematic approach was developed and tested in a previous study by the authors (Svensson et al., 2008). However, the approach has not yet been used to investigate the trade-off between internal and external use under different future energy market scenarios.

2. Objective

The overall objective of this paper is to examine the trade-off, in terms of economics and CO_2 emission consequences, between internal process use and external use for district heating of excess heat from an average Scandinavian kraft pulp mill in Sweden, under different future energy market scenarios. In pursuing the overall objective of this paper the following questions are addressed:

- How do external factors[2] affect the economic profitability for the external use of industrial excess heat as district heating?
- How does the choice of use of the excess heat affect the electricity production and the use of biomass in the system?
- How does the choice of use of the excess heat influence the system's global CO_2 emissions?
- Are any of the utilization options for the industrial excess heat more robust to the uncertainty of future energy prices than the others?

The work follows the methodology presented in Svensson et al. (2008), which is further described in Section 3.

3. Methodology and input data

In this study, an approach for investigating the trade-off between internal and external use of industrial excess heat, previously presented by the authors (Svensson et al., 2008), is used. The approach consists of a systematic methodology for assessing the potential for profitable excess heat cooperation between industries and ECOs, and an energy system model portraying an industry, in the form of a kraft pulp mill, and an ECO.

Investments in energy efficiency (utilization of excess heat and/or increased electricity production) are usually evaluated from the perspective of either an industry or an ECO. With the methodology used in this study, the industry and the ECO are evaluated within the same system boundary. In this way the *potential* for profitable excess heat cooperation can be assessed. However, how the common profit from such excess heat cooperation (and the related investment burden) can be divided between the industry and the ECO is not included in the methodology.

[2] Such as e.g. size of the district heating system, the occurrence of biomass CHP and energy market prices.

The model of the studied energy system, and a surrounding system, is constructed by using the energy systems modelling tool reMIND, which is a graphic interface to the MIND method (Method for analysis of INDustrial energy systems). With the reMIND tool, the objective function of the constructed model is minimized using mixed-integer linear programming (Nilsson and Söderström, 1992; Sandberg, 2004). The model is optimized for different boundary conditions, in this study modelled as energy market scenarios.

Using the mentioned methodology, together with the reMIND tool, different energy efficiency investments can be evaluated from both an economic and an environmental point of view and for different future energy market scenarios.

In the following text, key characteristics and data for the modelled system are displayed. For a more thorough description of the model and methodology used, see previous work by the authors (Svensson et al., 2008).

3.1. Energy system model

The general structure of the model and the changes possible through investments are shown in Fig. 1. Broken lines indicate investment options and solid lines indicate the already existing capacities in the system. Note that the lines do not necessarily denote physical flows, but represent choices of action.

The mill is modelled with a fixed pulp production rate and corresponding energy balance. In the model of the mill, there are possibilities to invest in excess heat utilization (process energy efficiency) and new technology (new larger turbines and/or a superheater in the recovery boiler). The ECO is modelled as boilers and CHP plants that supply heat to a fixed seasonal district heating demand. For the ECO there are opportunities to invest in new efficient production technologies, including excess heat from the mill, replacing the existing heat production plants. A more detailed view of how the mill and ECO are modelled is given in Fig. 2.

For some of the investments in energy efficiency (including the utilization of excess heat) and new technology in the mill, there are technical restrictions; some investments cannot be combined,

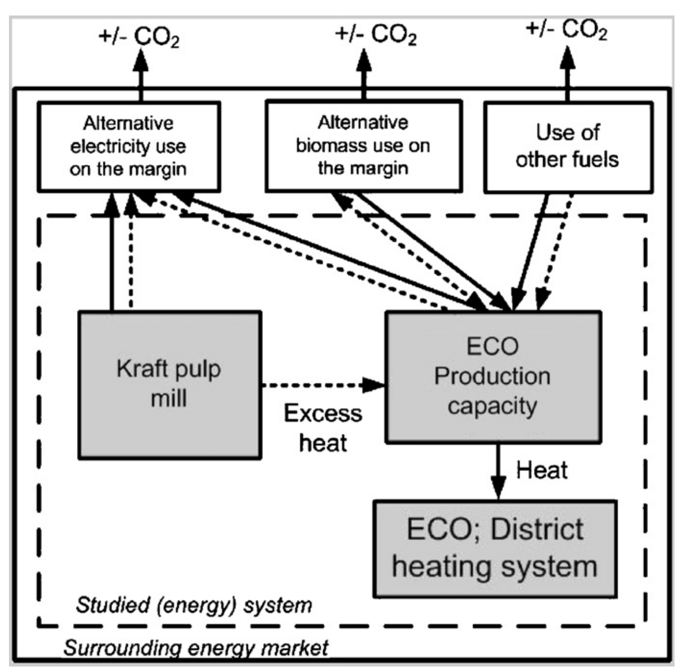

Fig. 1. The general structure of the model (for use on the margin, see Section 3.2.1).