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Improving energy efficiency of sawmill industrial sites by integration with pellet and CHP plants

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HIGHLIGHTS

- An integrated industrial site with sawmill, pellet plant and CHP plant is studied.
- Different material and energy flow connections among the plants are explored.
- Up to 18% of sawmill biomass output can be saved.
- Heat and biomass prices strongly affect the economic result.

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ABSTRACT

An essential strategy to lower energy and resources consumption is the development of highly integrated industrial sites including different kind of plants complementing one another. Sawmills are huge biomass suppliers to other industries, such as pulp and paper mills, pellet plants and CHP plants, and part of the biomass is also used for the internal heat requirement. In this paper the integration of a sawmill with a pellet plant and a CHP plant is investigated using advanced process integration techniques, so that the thermal energy and the electricity produced in the CHP plant by burning part of the sawmill biomass output are used for the heat and power requirements of the other two industries. The results show that up to 18% of the biomass by-products from the sawmill can be saved, but from the economic point of view the ratio between prices of the thermal energy sold for district heating and the low quality biomass has to be lower than the present one to make the integrated design solution more attractive than separate plant operation.

1. Introduction

Due to the increased concern about the growing energy demand, the EU authorities have recommended that energy resources should be used with the highest possible efficiency in industrial processes in order to optimize their usage. In the forest and wood processing industry the production and consumption of woody biomass, which is already considered as a renewable energy resource, can be critically evaluated with different methodologies to achieve further savings both in the primary and intermediate material streams and in the heat and electricity demand.

About 50% of the domestic wood which is forested in Sweden is used by sawmill [1], but a substantial part of it (around one fifth) is used in the plant itself to cover the internal thermal energy demand [2]. The biomass output from a sawmill is considered as a by-product of the main process chain. This biomass has a moisture content of about 60% and a great share of it is sold and transported for long distances to be used for the production of pellets, heat and electricity in pellet plants, combined heat and power (CHP) plants or paper and pulp mills. In a pellet plant about one fourth of the energy content of the pellets is used in the productive processes, and most of it for supplying thermal energy by means of combustion in a furnace or other heating systems, as it occurs in sawmills. Biomass-fired CHP plants are now an established technology for the cogeneration of power and heat that is used for district heating or in other industrial processes. Recent advances and reviews about these three types of industries can be found, e.g. in [3–9].

1.1. Aim

Sawmills, pellet plants and CHP plants make use of biomass as raw material for their main products and as energy resource for heat supply. Accordingly, the potential for increasing the overall efficiency in the usage of the biomass resource is high if an integrated industrial site involving these three types of industry is considered. Resource savings from increased energy efficiency should

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also provide benefits from the economic and environmental points of view (e.g., cost savings, less pollutant emission and/or non-renewable resource consumption per unit of final product).

The present paper investigates the possibility of including a sawmill, a pellet plant and a CHP plant in a theoretical green field integrated industrial site, in order to evaluate how much the overall biomass resource usage due to these three industries can be decreased with the help of thermal integration and of design parameters optimization in CHP plant steam cycle.

1.2. Outline

The paper is organized as follows. Section 2 offers an overview of the theoretical reference plants which are used in the investigation. The reference sawmill and pellet plant were conceived according to an inventory analysis of the technical situation of these industries in the Nordic Countries, and the information about the material and energy streams was taken from this large and almost exhaustive collection of data [1]. In Section 3 the methodology followed for the investigation is introduced and the strategies for the energy and material integration within the industrial site are analyzed. The considered integrated industrial site configurations, the details about the design parameter optimization (decision variables, constraints and objective function) and the tools used in the search for the optimal solutions are also discussed. In Section 4 the obtained results are presented and discussed, and an economic analysis compares the operational profitability of the optimal integrated sites with that of the separate operation of the three plants. This is used to determine the maximum amount of investments per unit of product that can be made to reach the break-even point at end of the considered technical lifetime.

2. Description of the plants to be integrated in the industrial site

The plants that are considered for the integrated industrial site are described in the following sections. They all reflect typical average plants existing in the Nordic countries.

2.1. Sawmill

In sawmills large quantities of timber are sawn into boards (lumber). Deforested logs without branches, treetop and roots are transported to the sawmill and used as the main input material stream. In the lumber handling process, the raw material undergoes debarking, then sawing, sorting, drying and in some cases grinding. The desired output of this productive chain is lumber, which accounts for 47% of the incoming timber on a dry weight basis, whereas the remaining part becomes bark, sawdust and wood chips, which are considered as by-products (see Table 1 and Fig. 1 [1,10]). Nowadays most sawmill plants are stand-alone facilities, and the thermal requirement of their processes is satisfied by burning part of the by-products into a biomass furnace combined with the plant. Bark would surely be the least commercially interesting among the by-products, due to the high moisture, low heating value and high ash content. However, for the same reason the combustion of bark alone is difficult and therefore the biomass fuel mix which is burnt in the furnace actually is mainly composed by bark, but with the addition of sawdust and wood chips: the percentages of the three by-products in the mix, referred to dry mass, are 85%, 9% and 6%, respectively. The excess by-products that are not burnt in the furnace are sold to other plants of the forest industry, such as pellet plants, CHP plants and pulp and paper mills.

Table 1
Material and energy streams in a reference sawmill in Nordic countries (per dry kg of lumber).

Input	Timber	2.12 kg dry
Output	Lumber	1 kg dry
	Sawdust	0.17 kg dry
	Wood chips	0.55 kg dry
	Bark	0.40 kg dry
Cold streams	Drying	2645 kJ at 75 °C
	Room heating	353 kJ at 30 °C
Electricity demand	Debarking, handling, sawing, sorting, drying, grinding	680 kJ

The thermal and electric requirements of a reference sawmill in the Nordic countries are summarized in Table 1. More than 70% of the whole sawmill energy requirement is due to the drying process, which is operated in a dedicated building called drying kiln. Dry cold outdoor air is heated to the temperature of the drying environment (75 °C) and is then forced to re-circulate among the lumber [1,11]. The difference between air humidity and lumber moisture content is the driving force of the drying process, which is considered as a constant temperature heat sink at 75 °C. The continuous replacement of the humidified air with new dry air is the reason for the high thermal energy requirement of the drying process.

In order to cover the thermal demand of the sawmill, 46.0% of the available biomass fuel mix at sawmill output would be burnt in the plant furnace (this corresponds to 0.103 dry kg per dry kg of timber input to the sawmill itself, see Fig. 1). Sawmill electricity requirement can as well be expressed in terms of biomass consumption, if it is assumed that the same biomass fuel mix is used to feed a steam power plant with 30% LHV based electric efficiency (see Section 2.3 for more details). In this case the share of the available mix requested for internal consumption will raise at 76.5%, which corresponds to 0.171 dry kg per dry kg of timber (Fig. 1).

2.2. Wood pellet plant

A wood pellet plant transforms wood wastes from different types of forest industry into small and compact particles, sawdust being mainly preferred as raw material for the process. The incoming stream of sawdust undergoes rough and fine grindings and drying before being pelletized. Some thermal energy is generated during the pelletizing process due to internal chemical reactions, which make the pellet break up and this would decrease the quality of the pellets because of an increase of the small-sized fraction. To prevent this phenomenon, the pellets are cooled with air circulation fans in the last part of the process (the final temperature of this air stream is however too low to have this stream participating in the thermal cascade).

The largest share of the energy requirement in the pellet plant is needed by the drying process. The sawdust entering the dryer has a moisture content of 60% (wet basis) and a temperature of 5 °C, while at the exit the temperature is 110 °C and the moisture content is very close to the final moisture of the wood pellets (10% weight wet basis against 8%). The drying air is taken from the ambient at 2 °C and heated at 250 °C before entering the dryer, whereas the air temperature at dryer exit is equal to that of the sawdust (110 °C). Accordingly, 27.6 kg of air are needed per each kg of dry wood pellet, and the resulting thermal load is shown in Table 2. At the exit of the pellet plant, the humid air has still a temperature of 80 °C and some heat can recovered by cooling it down to 60 °C, but not further in order to avoid the condensation of water vapor. The resulting available heat is listed in Table 2 as well [12–16].

The heat required to satisfy the net thermal demand resulting from the streams reported in Table 2 is usually supplied by a