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Research paper

Exergoenvironmental analysis concerning the wood chips and wood pellets production chains

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ABSTRACT

The wood energy conversion into power and heating processes concerning the chips and pellets production chain is analyzed. An exergy analysis and a life cycle assessment are performed, considering the wood chips for electricity generation in a central power plant and wood pellets for distributed generation. The consumption of diesel oil, electricity and biomass itself were carried out along both production chains. The results showed the best way to avoid exergy destruction and environmental impacts based on carbon dioxide emissions. Considering the same energy conversion plant efficiency, the exergetic performance and the environmental impact are very close when both the technological routes are compared. However, taking into account a distributed generation and the high efficiency characteristic of micro cogeneration plants (combined heat and power), the pellets technological route presents a better exergetic and environmental performance. Also, a sensitivity analysis along the production chain stages have demonstrated that large variations of about 50% on the specific fuel consumption represents a very small influence on the overall exergetic efficiency, in order of just 1.5%.

1. Introduction

The wood energy demands increase progressively in consequence of the population growth, continuous fossil fuels replacement and new technologies available for electricity generation. In this context, the wood chips and the wood pellets emerge as important alternatives to meet the increasing needs of the industry. In Brazil, the biomass is available throughout the country, presenting a wide range of agro-industrial and forest wastes, excluding the native tropical forests. The fuels and electricity high costs as well as the high availability and low cost of the biomass open a good opportunity to explore the wood biomass in the country. In the technical literature, many works can be found about the use of wood biomass to produce heat and electricity. Peter and Niquidet [1] evaluated the feasibility of residual biomass in the production of pellets, electricity and heat in the paper industry in the Southern region of Canada. Considering the current electricity price in the region, they concluded that only sawmill is economically feasible. The forest residues are not feasible due to the processing and transportation costs. Röser et al. [2] investigated different forest biomass chains to supply fuel for heating and electricity to the Northern Scotland, stating the road chips production as the basis for the best chain configuration and proposed minimum prices for chip commercialization for distances in the range of 50–100 km from the forest to the consumption center. Sosa et al. [3] recommended an optimization model to minimize the biomass cost as a function of the moisture content, considering two different production chains, one for log tops and other one for the whole trees. The study indicated that the production chain supplied with whole trees was more advantageous. Timmons and Mejia [4] have studied the forest biomass production chain diesel fuel dependence in the state of New Hampshire, USA, and their results indicate that energy spent with diesel fuel represents only 2% of the energy contained in the biomass available to the consumer. Anttila et al. [5] evaluated the feasibility of the forest biomass energy exploitation in northeastern China. At the end, they concluded that due to the availability of raw material in that region and the operational costs, there was no economic justification for the enterprise. Mobini et al. [6] reported a comparative study regarding the cost, energy consumption and environmental impact between conventional and torrified pellets. Their results show that the torrified pellets cost more than the conventional pellet in mass basis. However, both pellets presents similar cost on energy basis, once the torrified pellet has a higher heat value.

Karklina et al. [7] performed an exergy analysis in a biomass combined heat and power plant in Jelgava, finding somewhat about 64% of exergy destruction just in the steam generator, followed by the heat exchangers of the district heating system. Mafakheri and Nasiri [8]

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state that pre-treatment at the roasting and pelletizing level is good for reducing transport and storage costs. However, the found results are based just on cost and emissions analysis using simulators (or models), rather than thermodynamics. And, as state by Shabani et al. [9], the improving in quality of the raw materials and process efficiency through more advanced technologies is an important path for the competitiveness of the biomass production chain. Risse et al. [10] applied an exergetic life cycle assessment in Germany, considering the energy generation as final step to compare the resource use as well as the efficiency between a wood cascading and a primary wood system. Their results indicated that cascading leads to less resource consumption compared to primary wood, indicated by higher resource efficiency (46% vs. 21%) at life cycle level. Cherubini et al. [11] make a broad literature review on the application of LCA along the energy biomass production chain (not only the forest) and perform different simulations including the uncertainties analysis in the results. They argue that due to regional specificities, indicators of greenhouse gas emissions and energy consumption leads to an increase in the uncertainty of the analysis of these production chains. Fantozzi and Buratti [12] conducted a LCA on the production chain of wood pellets for energy purposes, from forest production to energy conversion. They used the Simapro software to build the chain, adopting the EcoIndicator99 method for measuring the environmental impacts and collected operational data from a pelletization plant in Italy. Their results showed the forest production stage as the great responsible for the generation of environmental impacts.

Regarding the transportation, Machado et al. [13] show a classification of truck models used for road log transport according to their load capacity. On an industrial scale, as reported by Guimarães [14], the medium and large-sized companies in the forestry and lumber sectors have worked almost predominantly with high load capacity models. They are mainly bi-articulated (57 t) truck models. So, as verified in the studies here presented, the use of forest residues is not always economically feasible. However, it is observed that the determining factor for the feasibility or not of this type of enterprise is the price of electricity in the energy market of the studied region. Currently Brazil generates around 46.8 million tons of forest and sawmill residues [15], which is equivalent to 19.6% of all electricity consumed in the country, in order of 523 TWh [16]. However, even considering the forestry dedicated to energy production, the thermoelectricity generation from wood biomass has represented just 0.6% of this total [17].

The reasons for the low use of the available biomass in Brazil must be better understood. A first reason could be the spread condition and sparse number of companies collecting and trading the biomass. Despite the great potential for exploring the wood energy in Brazil, the corresponding technological routes must be managed efficiently. In this way, the present work shows results regarding the best way to convert the wood energy into useful energy (heat and/or electricity) from the exergetic and environmental point of view. The whole production chain is considered, from the forest harvest to the final consumption. Two technological routes are evaluated for comparison, the wood chips production chain and the wood pellets production chain. Operational data were collected from forestry, wood processing and energy companies located in a representative region of Santa Catarina state, in the southern region of Brazil, relatively strong in the processing of wood for pulp and paper production, as well as for the production of electricity. It is clear from the literature data that a wood biomass production chain vary strongly from one region to another, making it hard a general analysis, in such way that the found results can be extended outside the selected region. However, the proposed method is able to evaluate precisely the effective exergy destruction as well as the corresponding CO_2 emission impacts concerning any region of the country or region of the world, where applicable. And that is the main goal and contribution of the present work, a life cycle analysis associated to the exergy destruction as a tool for comparison the wood chips and wood pellets technological routes.

2. Methodology

As said before, an exergetic and a life cycle analysis are considered in order to compare the performance between two technological routes. The basic data collected to perform the analysis are the productivity (t/h), diesel fuel consumption (l/h) and electricity consumption (kW) of every unitary operation along the biomass production chains. The environmental impact considered is the CO_2 emission at every process. Thus, the proposed method takes into account the following steps: (i) modeling the production chains, (ii) the application of the life cycle analysis, (iii) application of the exergetic analysis and (iv) sensitivity analysis. The sensitivity analysis is an important tool to evaluate the applicability of the proposed method to others regions. The corresponding description of each step is presented in the following.

2.1. Modeling of the production chains

The first step defines the production chains, by the configuration of the unitary operations. Basically, five main stages were considered: (a) forest extraction, (b) transportation, (c) processing, (d) energy conversion and (e) transmission/distribution. Furthermore, for every stage, different operations can be found, resulting in different production chain configurations in order to attend different regions.

2.1.1. Wood chips production chain

The first stage of this technological route is the forest extraction, which consider the operations of harvesting, primary transportation and loading of logs on trucks for road transportation. The second stage is the road transportation from the extraction site to the biomass processing plant. There are many truck types that carry wood logs. In this work the most commonly one used by the industrial companies, the bi-train of 56 tons is considered. The third stage is the biomass processing in forms of chips, consisting, basically, of four operation types, the loading of the chipper, chipping, sorting and moving by belts. However, taking into account the production scale, layout of the stock area and equipment, the number of operation types can be changed and, consequently, also the energy performance of each stage. The fourth stage refers to the energy conversion, from biomass chemical energy to heat and electric power. Finally, the last stage is the transmission and distribution of the electricity.

The proposed boundary of the wood chips production chain is shown in Fig. 1, including the forestry extraction, transportation, processing, conversion and the electricity transmission. The raw material (tree), diesel oil and auxiliary electricity represent input data. Only electricity production is the output data, once no heating process are usual in central power plants. The transmission and distribution of the electricity is also considered into the analysis, once there is exergy destruction that affects the performance of the chain as a whole. The moisture content is considered in the range of 30–60%, here values commonly found in biomass, as informed by the companies and carried out on the second step.

2.1.2. Wood pellets production chain

The pellet technological route differs slightly from the chip route, being similar up to the transportation stage, as shown in Fig. 2. Here, the processing stage includes the operations of chipper loading, chipping, grading, drying, pelletizing, moving belts, cooling and packaging. As observed in the chip route, depending on the scale of production and layout of the equipment, the unitary operations, mainly, classification and moving belts, can be found in different numbers from one company to another, which affects the energy performance of the processing plant.

The fourth stage in Fig. 2 is related to the distribution of pellets to the final consumer. As noted from data collecting in the companies, this stage, concerning pellets distribution, is performed by using a single or double shaft trucks up to 23 tons. Finally, as the last stage related to the