Renewable Energy 88 (2016) 102–111

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Economics and greenhouse gas balance of distributed electricity production at sawmills using hermetic turbogenerator

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ARTICLE INFO

Article history:
Received 27 January 2015
Received in revised form
3 September 2015
Accepted 7 November 2015
Available online 5 December 2015

Keywords:
LCA
GHG emissions
Economy
CHP
Sawmill
Turbogenerator

ABSTRACT

This article focuses on greenhouse gas (GHG) emissions reduction and on the economics in renewable electricity production at sawmills. Electricity production application in this study is a hermetic turbogenerator (HTG). The HTG is a small-scale steam turbine-generator unit of compact size that achieves high efficiency. The paper studies GHG emissions and the economics of HTG use in sawmills using life cycle assessment methodologies. Small- and large-scale HTG processes are studied in three scenarios. Sawmills produce large volumes of biomass by-products which are mainly used to produce heat needed in lumber dryers. However, due to remote location of sawmills there may be no use for excess biomass. HTGs can be used to produce electricity in addition to heat (CHP), which may help to increase renewable electricity production in sparsely populated areas. It is concluded that from the economic perspective HTGs may be an attractive option but financial viability is dependent on energy prices, required investments, and by-product value. From the climate change perspective, electricity production with HTGs may be a good option if there is excess biomass sources available.

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1. Introduction

Climate change due to increased greenhouse gas (GHG) emissions is one of the greatest environmental challenges humankind is facing. Heat and power production are the most important source of GHG emissions and its share is approximately one fourth of total global GHG emissions. GHG emissions from energy production are mainly related to combustion of fossil fuels [11]. Various targets have been set for reductions in GHG emissions from the energy sector, such as EU's 20-20-20 target [7]. GHG emissions reduction demands both energy efficiency improvements and the adoption of heat and power production methods with low GHG emissions, such as biomass-based power generation.

Sawmills consume approximately one third of total wood consumption of the forest industry sector in Finland and half of the total wood consumption of forest industry in Sweden [21,28]. However, only 50% of timber is manufactured into to lumber and the other 50% is converted into by-products such as wood chips, bark and sawdust [1]. These by-products from sawmills serve as a significant biomass resource for renewable energy production.

Sawmills consume electricity and heat in their manufacturing processes. The most energy intensive process step is drying of lumber, which consumes the majority of total energy consumption of sawmills as heat [1]. The aim of the drying process is to ensure steady properties at the use application, reduce risks related to microbes and pests, and to reduce transportation weight of lumber. By-products from sawmilling operations are usually combusted in order to produce the heat needed in the drying process. Sawmills are self-sufficient in heat and therefore excess by-products are sold for other uses such as fuel for district heating plants or raw material for pulp mills. In some cases, sawmills may be located in sparsely populated areas where there is no demand for the excess biomass in the immediate vicinity.

Hermetic turbogenerators (HTGs) for producing electricity from steam require relatively low investment costs. Investment costs for HTG vary for example depending on size and quantity of HTGs produces. HTG investment is approximately 200–1000 € kW_e^{-1}. For other CHP technologies investments vary from 600 to 1000 € kW_e^{-1}

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http://dx.doi.org/10.1016/j.renene.2015.11.029
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[12]. HTG does not require large scale feed water plant, it has high rotation speed and low material requirements and due to power electronic grid connection it does not require an expensive gear.

Use of HTGs in sawmills may provide an opportunity to produce renewable electricity and reduce GHG emissions. HTGs may also improve the economics of sawmills by offering a cheap electricity source. In some cases, sawmills may even become electricity providers, contributing to decentralized renewable electricity production.

Although it is possible for sawmills to reduce GHG emissions by using by-products in power production, economic constraints impinge on the feasibility of this approach. Dowaki & Mori [9] presented that using biomass energy in sawmills would lead to GHG emission reductions compared to use of conventional fossil-energy systems. Anderson & Toffolo [1] found that integration of a pellet plant with a sawmill could lead to greater utilization of sawmill by-products but, from an economic perspective, high prices for thermal energy and low prices for biomass pose problems. Anderson &Westerlund [2] studied ways to improve energy efficiency in drying processes of sawmills. According to their study, there is potential to save significant amounts of energy and reduce sawmill by-product biomass waste by using available energy recovery technologies. Danon et al. [6] studied the economics of combined heat and power production in the wood industry. Their results showed that the use of CHP production is limited by high investment costs. A literature review by Dong et al. [8] concluded that electricity production efficiency is a key issue when considering the economic and environmental perspectives of biomass-based small-scale electricity production.

Despite the above-mentioned work, the advantages of using sawmill residues for electricity production in addition to heat production still remain somewhat unclear. The HTG process can be utilized with steam boilers, but it is not clear how feasible such an approach might be in sawmill operations. In addition, the potential for GHG emissions reductions is also unclear. By-products may currently be utilized for some other purpose, for example, district heating, in which case using the by-products for electricity production would mean that the by-products, or a part thereof, would have to be replaced by other feedstock. In view of the complexities of the subject, a wider scale LCA study would be beneficial to gain a more complete understanding of the environmental impacts, in terms of GHG emissions reduction, and the financial implications of using HTGs for CHP in sawmills.

This study aims to determine if it is possible to gain benefits from a climate change perspective by using the HTG-process in sawmills and what are the main factors affecting the GHG balance in such an application. The economic feasibility of the HTG-process and the cost of CO_2 reduction with this method are also estimated.

2. Materials and methods

2.1. Background information

Income from both woodchips and lumber affect the economic viability of sawmills. In Nordic countries, woodchips produced in conjunction with sawmilling operations are commonly sold to companies operating in the paper and pulp industry. Other by-products from the sawmill process are sawdust and bark, which are generally used on-site to produce the heat required in sawmill operations. In most cases, more sawdust and bark are produced than required for heat production and this excess may be utilized for example in district heating. The material flows on dry weight basis and energy flows at a typical sawmill are presented in Fig. 1.

Increased steam production resulting from the use of excess by-products would allow electricity production with the HTG process while still providing enough heat for the dryers. A basic assumption is that selling wood chips to the pulp industry and using bark and sawdust for heat or CHP production at the sawmill leads to optimal profitability [26].

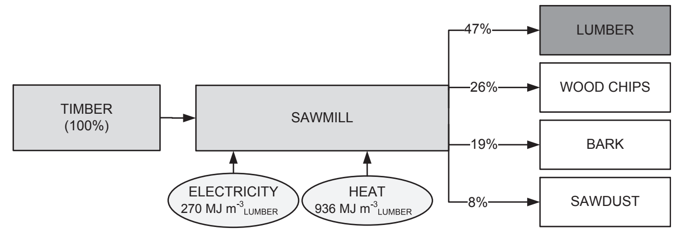

Fig. 1. Material flows at a typical sawmill [1,2].

Two types of boilers are commonly used in sawmills: hot water boilers and steam boilers. Hot water boilers, although very common and relatively inexpensive, cannot be used with the HTG steam process. The HTG-process requires superheated steam and therefore only sawmills with steam boilers are applicable. In most cases, there is usually extra capacity in sawmill boilers to combust more bark and sawdust and therefore a base assumption is that in the HTG case investment in a new steam boiler is not needed. On the other hand, if a sawmill invests in a new boiler, it could use more biomass and produce more renewable energy. There may also be other biomass sources, such as logging residues, which are not utilized but left to decay in forests. In this case, in addition to covering its own electricity and heat consumption, sawmills could produce additional electricity and heat for the energy market.

The two main types of dryers used in sawmill operations are steam dryers and hot air dryers. Hot air dryers are more commonly used in Finland. Steam temperature after the HTG process is around 100–120 °C and could therefore be used in hot air dryers that demand air in this temperature range [31]. Some high temperature dryers, however, require air at higher temperatures and the applicability of HTG use with steam dryers thus depends on the steam temperature needed at the dryer.

2.2. Hermetic turbogenerator

The optimal rotational speed of a small steam turbine can exceed 10 000 min^{-1} and the turbine cannot be directly coupled with conventional 3000 min^{-1} generator designs. Therefore, a turbo-generator is used to convert the energy of the rotating motion into electricity. Several types of turbogenerators are available on the market. In conventional turbogenerator constructions, a mechanical power transmission (a step-down gear) is used between the turbine and the generator to set the rotational speed of the generator as desired. In sophisticated high-speed designs where the turbine and the electric generator are coupled on the same shaft and the electricity is converted to the grid frequency with a frequency converter, losses from the mechanical gearbox are avoided while maintaining full control over speed. A similar design has been realized for example in an Organic Rankine Cycle power plant [30]. The hermetic design, presented in Fig. 2, comprises a steam cooled permanent magnet generator, water lubricated bearings and a multi-stage radial outflow turbine (ROT). The main advantages of the hermetic structure are its modular structure and that no additional water purifying supply unit is needed because no water losses occur. The turbine consists of successive stator and rotor rows and allows relatively simple design in comparison with Ljungström type counter-rotating configurations. Compared with the axial flow turbines typically used in the 500–2000 kW power scale, the ROT has several characteristics that in principle improve

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