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Biomass CHP Technical and Economic Assessment applied to a Sawmill Plant

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Abstract. Due to the risk of spreading the nematode infection to other regions or countries the Portuguese pine wood producers must perform a heat treatment to their products before exporting. This heat treatment increases the production costs and reduces the competitiveness of the industry.

One possible solution to increase the income of the pine wood producers is the installation of CHP units in sawmills, fuelled by biomass (wood shavings), generating the heat needed for the treatment and simultaneously generating electricity to be sold to the grid.

In the present paper it is developed and implemented a methodology to perform a technical and economic assessment of CHP units installation in sawmills.

The methodology is applied to a case study and, due to the need of using biomass as fuel, only the steam turbine and organic Rankine cycle (ORC) technologies are assumed as suitable for the application.

The results of the economic assessment show that none of the considered technologies are economically viable. However, the results also demonstrated that clustering a set of pine wood producers from a same region could make the investment profitable for all the members of this cluster.

Key words

Biomass, combined heat and power, heat treatment, pine wood nematode, sawmill.

1. Introduction

The forest plays an important role in the Portuguese ecology and economy, corresponding to 39% of the Portuguese territory, with a contribution of 3.2% for the gross national product through the wood and cork processing industry and resin derivatives, and accounts for 11% of the Portuguese exports [1].

One of the main species of the Portuguese forest is the pine tree with a 27% share. The economic value of this crop comes from the use of its wood in the furniture industry and the manufacture of pallets for goods transportation [2].

In 1999, the discovery of the pine wood nematode (Bursaphelenchus xylophilus) in the Portuguese forests created a threat to the pine wood economic activity. The nematode is a microscopic insect that lives in coniferous trees, causing their death and consequently an extensive destruction in the coniferous forests, as happened for instance in the North America and Asia [3].

Due to the risk of spreading this infection to other regions or countries, the European Union (EU) has imposed some rules to the exports of the Portuguese pine wood. As such, before exporting, the pine wood should be subjected to a heat treatment in order to ensure that the wood is free from live nematode. That heat treatment consists of maintaining the wood core at a minimum temperature of 56°C for 30 minutes [4].

In order to fulfill the EU requirements for pine wood exports, sawmills have been installing greenhouse units able to perform the heat treatment. However, the installation of such greenhouse units and the respective heat generation increases the production costs and leads to a loss of competitiveness of the Portuguese pine wood industry.

In this regard, the pine wood producers need to look for solutions that can restore their competitiveness. One possible solution is the installation of combined heat and power (CHP) units in sawmills. The CHP units can be fuelled by the sawmills shavings and generate the heat needed for the pine wood heat treatment and simultaneously generate electricity to be sold to the electrical grid, taking advantage of the cogeneration tariff and increasing the incomes of the pine wood producers.

2. Objectives and Methodology

The main goals of this work are the identification of the CHP technologies that can be implemented in sawmills using the available biomass, to assess the economic viability of such CHP technologies installation and, through a sensitivity analysis, to evaluate what are the critical parameters that contribute for the economic viability of this solution.

In order to achieve these goals, a dedicated methodology was developed and implemented in MS Excel. The methodology comprises three main steps: the CHP system design, the cogeneration tariff simulation, and the economic viability assessment.

The main inputs of the methodology are related to the sawmill data, such as, the volume of wood treated, the average duration of each heat treatment and the number of heat treatments performed by week. Another important input is the average lower heating value (LHV) of the biomass that is intended to fuel the CHP unit.

According to the input data, the CHP unit is designed for the different technology available and respective capital and operation costs are determined. After that, the tariff simulator computes the incomes resulting from the sold electricity and finally, the economic indicators such as the net present value (NPV), internal rate of return (IRR) and payback time are determined for each one of the CHP technologies considered.

3. Case Study

The developed methodology is applied to a Portuguese sawmill that produces pine wood boards for pallets. This plant has a dedicated greenhouse for heat treatment, as presented in Fig. 1. According to the collected data, the greenhouse is usually used once in a week to perform the heat treatment of 40 m^3 of wood boards. The total duration of each heat treatment is about 10 hours.

The heat supplied to the greenhouse results from a furnace fuelled by wood shavings. The wood shavings are a sub-product of the sawmill activity and for each heat treatment

Fig. 1. General view of the greenhouse used for the pine wood heat treatments.

about 1.1 m^3 of this biomass is burnt in the furnace. The average density and LHV of such wood shavings is 377 kg/m^3 and 16.2 MJ/kg, respectively.

4. Biomass CHP System

A. Available Technologies

Several CHP technologies are available nowadays in the market. However, when a solid fuel is intended to be used, those options are considerably reduced. As such, two CHP technologies able to be fuelled by biomass were identified and assumed in this paper: 1) steam turbine and 2) organic Rankine cycle (ORC).

In spite of both technologies being based on Rankine cycle, comprising a boiler, a turbine, a condenser and a pump, the respective working fluid is different. While in the first case the working fluid is water, the second uses organic fluids which, in comparison to water, are best suited for small units because their operation temperature and pressure are lower, decreasing the safety measures and consequently the capital costs [5]-[7].

1) Steam turbine system

The operation of the steam turbine system is represented in the diagram flow of the Fig. 2, in which the primary and secondary fluid circuits (water) are identified by red color and blue color, respectively.

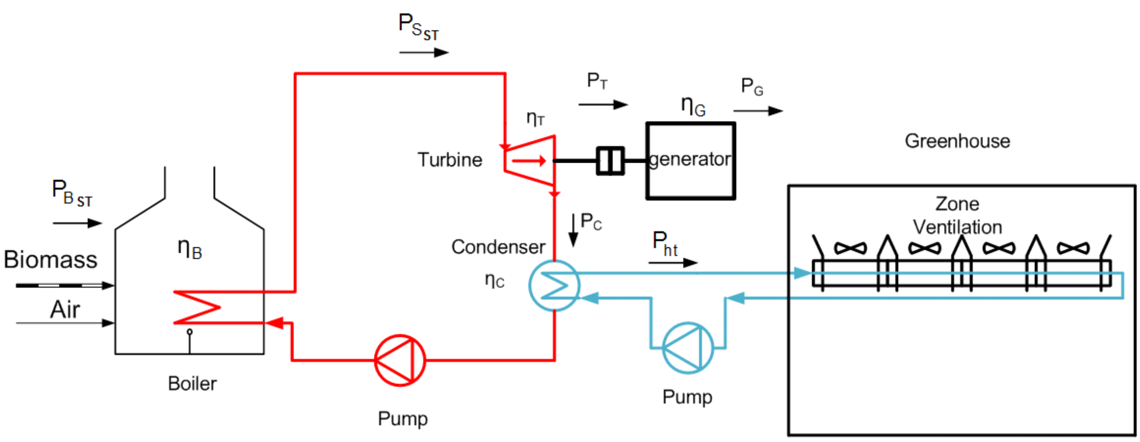

Fig. 2. Diagram flow for the steam turbine system

In the primary circuit, the steam is generated in the boiler, then, it is expanded inside the turbine in order to drive its shaft and consequently the generator. After that, the steam is condensed and the respective latent heat is transferred to the secondary circuit. The water leaving the condenser is pumped into the boiler to repeat the thermodynamic cycle.

In the secondary circuit, the water is heated by the steam condensation heat of the primary circuit and then releases this heat into the greenhouse through a heating system, comprising radiators and air fans. The water flow of the secondary circuit is maintained by a circulator pump.

2) *ORC system*

The solution based on the ORC system is presented in Fig. 3. This solution comprises three different circuits with three different working fluids [7]-[9]. For the three circuits of the ORC system, fluids flow is maintained by circulator pumps.

In the primary circuit (red), a thermal fluid is used to transfer the heat from a biomass fueled boiler to the heat exchanger 1.

In the secondary circuit (green), a hydro-carbon based fluid is vaporized in the heat exchanger 1, then the fluid drives the turbine shaft and is condensed in the heat exchanger 2, transferring the heat released to tertiary circuit. In order to increase the efficiency of the thermodynamic cycle, a regenerator unit is installed between the turbine output and the heat exchanger 2 input, used to pre-heat the fluid before vaporization.

The tertiary circuit (blue) in the ORC system is the same considered as secondary circuit of the steam turbine system, using both the water as working fluid. This water is heated in the heat exchanger 2, through the condensation of the secondary circuit fluid, and then releases the heat into the greenhouse through the heating system.

B. *Design*

In this section is intended to describe the CHP system design procedure for the steam turbine and ORC technologies.

The CHP system, regardless the applied technology, must meet the heat requirements to perform the heat treatment of the wood. In this regard, the CHP system design begins with the evaluation of the power that must be available to supply the greenhouse (P_{ht}). This power is determined based on the heat consumed (H_{ht}) and the time spent (T_{ht}) in each heat treatment:

$$P_{ht} = \frac{H_{ht}}{T_{ht}} \quad (1)$$

1) *Steam turbine system*

The steam turbine system uses the thermal power rejected by the turbine (P_C) to supply the power needed for the heat treatment (P_{ht}). This thermal power can be determined by:

$$P_C = \frac{P_{ht}}{\eta_C} \quad (2)$$

in which, η_C corresponds to the heat transfer efficiency of the condenser.

The main role of the steam turbine is to drive the electric generator, through the conversion of the steam thermal power into mechanical power. As such the power that must be available in the turbine shaft can be determined by:

$$P_T = \frac{P_G}{\eta_G} \quad (3)$$

in which, P_G is the power of the generator and η_G corresponds to its efficiency.

Assuming η_T as the turbine efficiency of converting heat into mechanical work, the power provided by the boiler

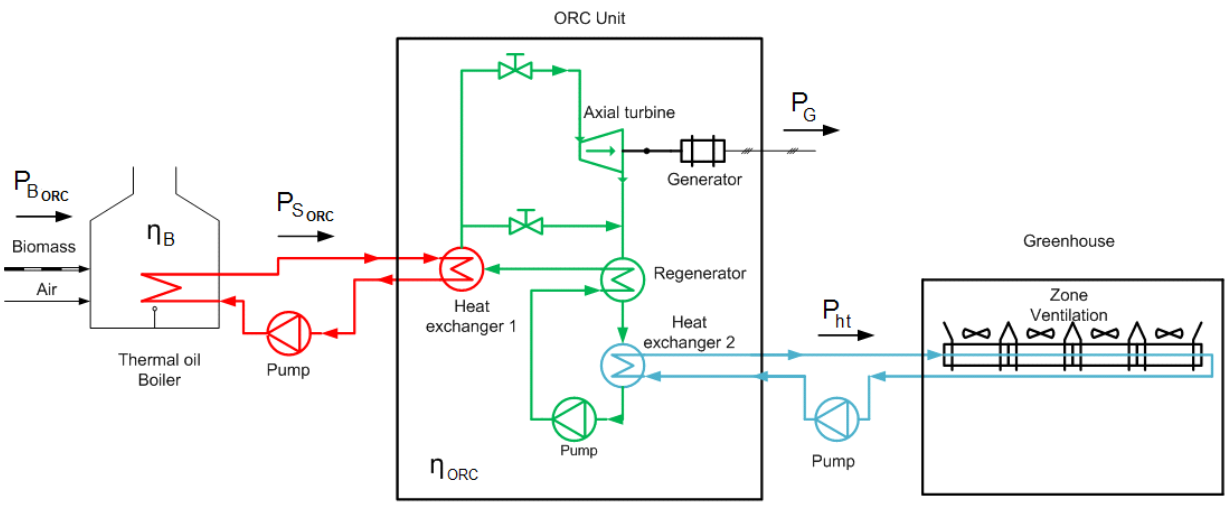

Fig.3. Diagram flow for the ORC system

($P_{S_{ST}}$) to the turbine is determined by:

$$P_{S_{ST}} = P_C + \frac{P_T}{\eta_T} \quad (4)$$

Combining (1), (2), (3), (4) and the boiler efficiency (η_B), the power supplied by the biomass combustion comes:

$$P_{B_{ST}} = \frac{\dfrac{P_{ht}}{\eta_C} + \dfrac{P_G}{\eta_T\,\eta_G}}{\eta_B} \quad (5)$$

In order to design the steam turbine system, besides the data collected in the sawmill, some additional assumptions must be considered. This is the case of the efficiency of the equipments, such as the boiler, assumed as 86%, the generator, assumed as 95%, the steam turbine, assumed as 90% and the efficiency of the steam condenser, assumed as 60% [6], [10]-[12].

Still, in what the steam turbine system design is concerned, according to [10], the CHP overall efficiency is maximized when a 2.4 ratio between the power supplied by the turbine to the generator (P_T) and the thermal power rejected by the turbine (P_C) is considered.

The main outputs of the steam turbine system design are presented in Table I.

Table I. – Design outputs for the steam turbine system

Heat treatment	1 700 kW
Electric generator	1 010 kW
Boiler	4 015 kW
Biomass combustion	4 668 kW

2) ORC system

The design of the ORC system, such as the steam turbine system design, begins with the assessment of the power needed to perform the heat treatment (P_{ht}).

Assuming the overall efficiency of the ORC unit (η_{ORC}), the power to be supplied by the boiler comes:

$$P_{S_{ORC}} = \frac{P_{ht} + P_G}{\eta_{ORC}} \quad (6)$$

On the other hand, the power that the biomass combustion must provide to the boiler, is determined by:

$$P_{B_{ORC}} = \frac{P_{S_{ORC}}}{\eta_B} \quad (7)$$

in which, η_B corresponds to the boiler efficiency.

Regarding the ORC system design, a 4.4 ratio between the electric power supplied by the generator (P_G) and the thermal power supplied to the greenhouse (P_{th}) is assumed. In what concerns the equipments efficiency, it is assumed 98% efficiency for the ORC unit and 86% efficiency for the boiler [7], [12].

The main outputs of the ORC system design are presented in Table II.

Table II. – Design outputs for the ORC system

Heat treatment	1 700 kW
Electric generator	385 kW
Boiler	1 128 kW
Biomass combustion	2 474 kW

C. Costs

The investment and operation costs of the steam turbine and ORC systems are assessed based on the data presented in Tables III and IV, in which the specific costs are defined as a function of the electric power installed [11], [13].

Table III. – Costs of the steam turbine system

Investment Costs	
Boiler	1 000 euro/kW$_e$
Pipes	150 euro/kW$_e$
Steam turbine and generator	1 150 euro/kW$_e$
Control System	32.5 euro/kW$_e$
Connection to grid	110 euro/kW$_e$
Engineering	250 euro/kW$_e$
Civil works and other	400 euro/kW$_e$
Operation Costs	
Labor	2 496 euro/year
Maintenance	213 euro/kW$_e$ year

Table IV. – Costs of the ORC system

Investment Costs	
Boiler	667 euro/kW$_e$
Pipes	61 euro/kW$_e$
Steam turbine and generator	1 278 euro/kW$_e$
Control System	36 euro/kW$_e$
Connection to grid	122 euro/kW$_e$
Engineering	194 euro/kW$_e$
Civil works and other	278 euro/kW$_e$
Operation Costs	
Labor	1 872 euro/year
Maintenance	84.3 euro/kW$_e$ year

According to the data presented, for the steam turbine system the total specific investment costs are about 3 093 euros per kW of electric power installed, a value 17% higher than the one presented by the ORC system. However, as the electric power to be installed in the steam turbine system is considerably higher than in the ORC system, the 3 069 thousand euros of the total investment on the steam turbine system is going to exceed 3 times the total investment on the ORC system.

5. Results

The analysis performed in this work assumes that all the thermal energy generated is used to perform wood heat treatments, while the electricity generated is injected into the grid. As such, the economic viability assessment of the CHP system installation involves computing the incomes of trading that generated electricity. In order to compute these incomes, the tariff is determined for the studied sawmill, based on the new Portuguese legislation, in which the tariffs for CHP units electricity and heat generation are defined. For the case study, due to the installed capacity, type of fuel used and overall efficiency, the electricity tariff corresponds to 0.15 euro/kWh [14].

The main outputs of the methodology applied to the case study, including the economic viability assessment (using a discount rate of 6%), are presented in Table V.

Table V. – Main methodology outputs for the case study

	Steam turbine	ORC
Operation Time	520 hours/year	
Thermal Power	1700 kW	
Electric Power	1010 kW	385 kW
Investment	3 069x10^3 euro	1 015x10^3 euro
Electricity Tariff	0.15 euro/kWh	
NPV	-3 015x10^3 euro	-802x10^3 euro

The results show that, for the both technology solutions considered, steam turbine and ORC, the economic viability is not reached, presenting a negative NPV. For this result, contribute the high investment costs, but also the reduced time of operation.

According to the legislation, the 0.15 euro/kWh electricity generation tariff only applies when the system is simultaneously generating heat and power. As such, the 520 hours/year operation time must be increased in order to increase the sawmill incomes and reach the economic viability.

Concerning that need to determine which time of operation turns the CHP unit economically viable, different time of operation values are considered and the their impact on the NPV are analyzed (Fig. 4).

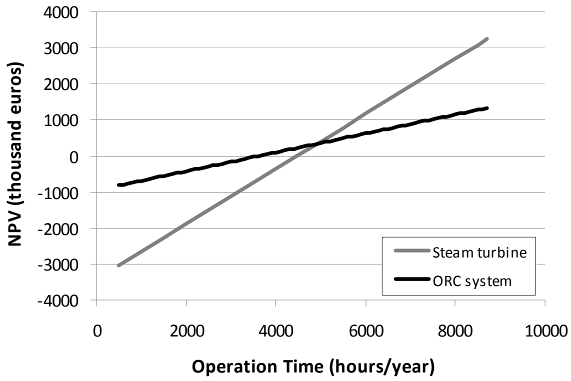

Fig. 4. NPV sensitivity analysis to the CHP unit operation time.

The results show that for the ORC solution the NVP becomes positive when the operation time is greater than 3600 hours/year. In this case, the payback time is 10 years. For the steam turbine solution, operation time greater than 4460 hours/year is needed to reach the positive NPV. In these conditions, the payback time of the steam turbine is 10 years. For operation time greater than 4900 hours/year, the steam turbine presents a better NPV than the ORC system. However, the ORC system payback time and IRR are still the best, 7 years and 12.8%, comparing with the 9 years and 8% values of the steam turbine system.

6. Conclusions

The pine wood nematode is a microscopic insect that lives in coniferous trees, causing their death and consequently an extensive destruction in the coniferous forests. In 1999, the pine wood nematode was discovered in the Portuguese forests and, since 2006, due to the risk of spreading this infection to other regions or countries, before exporting, the pine wood should be subjected to a heat treatment. This heat treatment increases the production costs and reduces the competitiveness of the Portuguese pine wood industry.

One possible solution to restore the competitiveness of the pine wood producers is the installation of CHP units in sawmills, fuelled by biomass (wood shavings), generating the heat needed for the pine wood heat treatment and simultaneously generating electricity to be sold to the grid.

In the present paper it is developed and implemented a methodology to identify the CHP technologies available for implementation in sawmills and to evaluate their economic viability.

The methodology is applied to a sawmill that produces pine wood boards for pallets and that owns a greenhouse to perform the respective heat treatment. In this case study, due to need of using biomass as fuel, only two CHP technologies are available: steam turbine and ORC.

The results of the CHP design procedure show that for both technologies, the sawmill thermal power needs correspond to 1700 kW, while the electrical installed capacity corresponds to 1010 kW for the steam turbine solution and 385 kW for the ORC solution.

Regarding the economic results, due to the higher operation temperature and pressure, the steam turbine solution is the most expensive solution. However, in spite the ORC system investment corresponding only to one third of the steam turbine value, none of the technologies are economically viable.

Finally, the results demonstrated that the parameter that mainly contributes for the economic infeasibility of the CHP solutions is the reduced time of operation. However, an increase in this parameter can be attained by clustering a set of pine wood producers from a same region that instead of investing in their own greenhouse and CHP systems could share it, turning the investment viable and more profitable for all member of the cluster.

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