THERMOECONOMIC ANALYSIS OF CO2 ALLOCATION AND INFLUENCE OF THE APPLICATION OF SOLAR COLLECTORS IN A THERMAL MDF PRODUCTION PLANT IN THE NORTH OF ESPÍRITO SANTO

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Abstract. *The use of energy resources from renewable sources has become a growing trend in contemporary times. It can be justified due to the predicted depletion of energy matrices originated from fossil fuels and the significant pollution promoted through the burning of these fuels to the environment. Therefore, industries of vast sectors have made it a habit to substitute alternative sources of energy supply for industrial thermal plants, such as solar collectors and biomass. Thus, the use of biomass in wood panel industries is provided through the chips not destined for MDF production during screening. As for the use of parabolic solar collectors, an area is used for the installation of collectors in series and in parallel, promoting the heating of the water, thus generating the steam used in the process. Similarly, the steam originated through the use of biomass or solar collectors can be used to generate energy through the use of turbines, becoming an industrial cogeneration plant. In this way, the present work consists of a thermoeconomic study with the objective of analyzing the environmental charges through the allocation of CO_2 in g/kWh. Thus, it is possible to study the addition of counterpressure turbines and parabolic solar collectors according to the six configurations of the thermal plant. Plant 1 corresponds to the real thermal plant, where all the saturated steam is destined to the process of making MDF boards. Plants 2 and 3 correspond to the addition of counterpressure turbines, varying the design parameters, considering the actual and maximum capacity of the boiler. Plants 4 to 6 are directed towards the addition of parabolic solar collectors, where in Plant 4 the design parameters are used through the maximum capacity, and in Plants 5 and 6 the optimization by genetic algorithms for minimizing the emission of CO_2 emission in g/kWh and maximization of thermal efficiency, respectively. Finally, an equivalent emission of 2521 g/kWh for Plant 1, 1352 g/kWh for Plant 2, 1044 g/kWh for Plant 3, 932 g/kWh for Plant 4, 914 g/kWh for Plant 5, and 931 g/kWh for Plant 6 was obtained*

Keywords: *Biomass. Collectors. CO_2. Optimization*

1. INTRODUCTION

Eucalyptus over the years has proved to be a rich source for the manufacture of products that meet the needs of society. Industries such as wood boards, paper, cellulose and cardboard have turned their eyes to this forest species as a fundamental part of a technology with sustainable production profit. According to the Brazilian Tree Industry (2021), following the use of wood, the pulp and paper industry represented in 2020 in Brazil 67% of the Federal Tax collection, followed by 24% in the manufacture of wood products and 9% in forestry production, as well as the productive chain of trees occupied the 22nd position in the same year in relation to 50 activities that contribute to the Brazilian GDP (Gross Domestic Product). For the manufacture of boards from eucalyptus wood, Brazil occupies the 8th position in the world, where the largest industrial concentration for production is located in the southern region of the country.

It is also known that with the imminent depletion of natural resources and the growing demand for pollution on a global scale, world governments have sought efficient alternatives with energy potential that have the capacity to meet the demands for industrial production. However, it is observed that in contemporary times the use of fossil matrix energy resources is still predominant. In the year 2020, according to the Ministry of Mines and Energy (2022), 71.4% of the

world's energy matrix used in the production of electricity corresponded to non-renewable sources, although 82.9% of the Brazilian energy matrix for the production of electricity came from renewable sources. In this way, the use of fossil and nuclear resources tends to decrease, which can be seen in Figure Figure 1, taking into account that alternative sources have become viable for the production of bioenergy, even if the use of these resources does not yet have the capacity to fully solve the energy barrier on a global scale (GOLDEMBERG et al., 2008, Apud MARAFON, 2016).
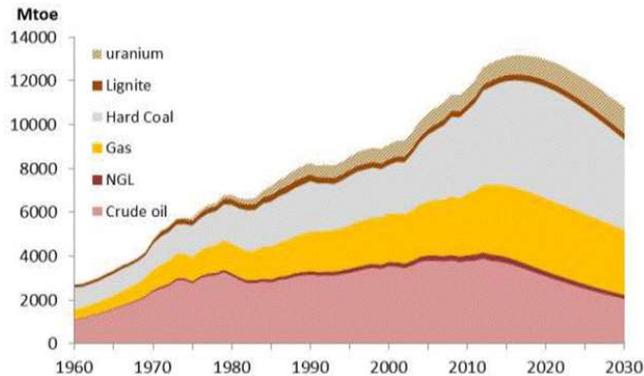

Figure 1 - Scenario for the supply of fossil fuels and uranium on a world scale over the years. Zittel et al. (2013).

As an alternative source of energy, for example, biomass, which is characterized as a low-cost raw material and large energy storage capacity for large-scale energy production, becoming a source of sustainable social development (MARAFON et al., 2016). In addition, one can also mention the use of energy in the form of radiation from the sun as a renewable energy resource, which has become a very common practice in industrial areas. This energy source has been used in many countries around the world, especially those close to the Equator where there is satisfactory solar radiation (CAVALCANTI et al., 2015).

Considering the energy source, in industrial areas of production, economic analysis becomes necessary to monitor input and output costs of a system. It is essential to use more efficient energy systems, and through cogeneration, the use of cost allocation techniques for heat and power (SANTOS, 2009). However, only the economic viability analysis is not enough, considering that the input and output energy parameters in each equipment of a thermal plant are not taken into account. Therefore, through thermoeconomics it is possible to find the connection between thermodynamic and economic concepts for the evaluation of efficiency and costs of consumption systems (COLOMBO, 2016).

Thermoeconomics is a science that can be subdivided into 3 areas: diagnosis, cost allocation and optimization. For diagnostic analyses, the objective is to analyze possible failures in thermal systems in terms of efficiency, identification and accounting of the effects produced and the consequences developed (VALERO et al., 2004). For cost allocation applies to cogeneration due to the products developed: heat and power. With that, since cogeneration is a technique to increase efficiency in thermal cycles, it becomes necessary to share costs (SANTOS, 2009), taking into account that it is characterized as the best way to compare the methodologies developed to thermoeconomics (FARIA, 2014). Finally, there is the optimization with the role of determining the best operating and design point of a system without having the need for careful evaluation within infinite possibilities through an objective function (FRANGOPOULOS, 2003).

The study for thermoeconomic analysis for MDF production is still scarce in the scope of scientific research. Due to this deficiency, some industries in the field differ in the use of energy sources to power the thermal plant, either in the use of Biomass generated in the process or in the use of solar collectors, where there is no expressive thermoeconomic quantification considering the different renewable energy sources mentioned, and the industrial processes involving the manufacture of wooden boards drive a relevant amount of thermal energy in the form of steam, hot air and hot water (SANTIAGO, 2007). Therefore, it is necessary to use the allocation of CO_2 and optimization to evaluate the mass emissions of CO_2 by steam production. Therefore, the case study will be applied to a company located in the municipality of Pinheiros, north of the state of Espírito Santo, responsible for the manufacture of MDF (Medium Density Fiberboard) wood boards from eucalyptus forests.

The main objective of this study is to assess the thermoeconomic viability through CO_2 allocation and optimization, by incorporating solar parabolic collectors and a backpressure turbine with different operating parameters in a thermal power plant used for vapor production in the manufacturing of Medium Density Fiberboard (MDF). Specifically, the study aims to compare the CO_2 emissions of the thermal plant in g/kWh based on both real operational parameters and those projected from a technical catalog. Additionally, the thermoeconomic model UFS will be applied, including the integration of a backpressure turbine, and the analysis will extend to examine the CO_2 emissions in g/kWh with the implementation of solar parabolic collectors, using the same UFS model. Furthermore, the performance of the thermal power plant will be evaluated based on the criteria of maximizing energy efficiency and minimizing CO_2 emissions in g/kWh.

2. MATERIALS AND METHODS

For the development of this article, all the thermodynamic and heat transfer modeling applied to solar collectors was used, as well as the physical dimensions of the equipment according to Martins et al. (2021).

2.1 literature review

The use of chips as biomass from wood has been widespread in MDF industries. It is known that, due to its energy potential, it is possible to produce heat at rates sufficient for use in the process or for energy generation. Likewise, it is understood that the use of energy resources from the sun also has the capacity to generate satisfactory energy. However, in the state of the art there are no data that show the advantage of using these energy sources in industrial timber areas through the use of thermoeconomics as a tool.

Miranda (2015) analyzed in his study the feasibility of using forest biomass from Eucalyptus chips to generate thermal energy. Therefore, the SWOT (Strengths, Weaknesses, Opportunities and Threats) methodology was used, in which it was noticed that for the same production demand, the cost of steam generation through biomass was approximately 34% lower when compared to fossil fuels.

Through the technical economic analysis developed by Santiago (2007), the viability of using the wood chip originated from Eucalyptus to obtain Biomass for thermal energy generation is analyzed. Currently, this technique has been widespread in industries that manufacture wooden boards, in which all the raw material is used both for manufacturing the product (MDF and MDP) and for power generation, where only the ashes are discarded during the process. With this, it was noticed that the use of bark from Eucalyptus becomes viable for the industry under analysis, resulting in a payback of 2.43 years.

Martins et al. (2021) carried out a study in which the monetary costs for producing power and desalinated water in different configurations for the Rankine solar cycle were analyzed using cost allocation (Level IIb) and optimization by genetic algorithms. Therefore, parabolic solar collectors were used to power the cycle using Therminol VP1 oil.

To carry out the system of equations and optimization, the software EES® (Engineering Equation Solver) was used. In this way, a system of thermal resistances was defined along the collectors, which can be observed through Figure 2
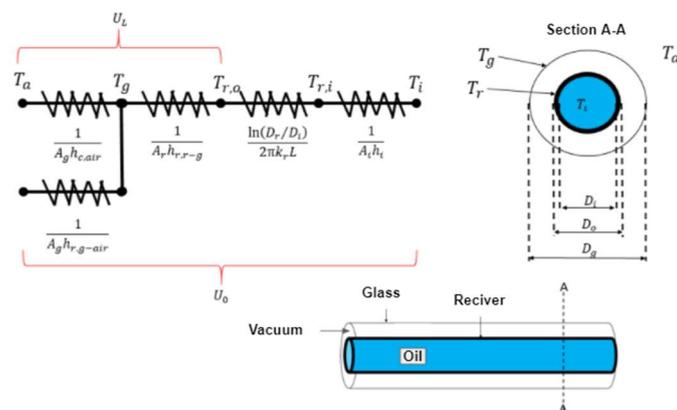

Figure 2 - Parabolic solar collector resistance network. Source: Adapted from Martins et al. (2021).

In the use of thermoeconomics in the optimization bias, Ribeiro (2017) developed an analysis of the use of heat from thermoelectric power plants through the operation of an organic Rankine cycle. In this way, the author used the optimization of genetic algorithms through the survey of five decision variables: evaporation temperature, condensation temperature, evaporator pinch point, pump and turbine isentropic efficiency. The aim of the optimization was to minimize the hourly costs of the equipment and maximize the electrical power produced, as can be seen in Eq. 1. In this way, it was noticed that Toluene has a greater capacity in the generation of energy 659 kW, given that it was proven that the use of regenerative cycles results in a production of 864 kW.

$$F_{obj} = \frac{\sum \dot{Z}}{\dot{W}_{net}}$$ **Erro! Fonte de referência não encontrada.**

Where, F_{obj} is the objective function (R$/kWh), $\dot{Z}$ is the hourly cost of the equipment (R$/s) and $\dot{W}_{net}$ is the net power (KW).

Santos (2012) carried out a study related to environmental charges in thermal power plants, through the allocation of CO_2 using thermoeconomics. Thus, two cogeneration systems were analyzed. The first case corresponds to a combined steam cycle with a condensation and extraction turbine and a desalination plant. The second case corresponds to a cycle with internal combustion engines and recovery boilers, with absorption refrigeration chillers. Therefore, the author

compared the emission of CO_2 in g/kWh for occasions when the plant operates only as a thermoelectric plant, and for occasions that operate as a cogeneration cycle. Therefore, the emission of CO_2 becomes greater for both cases when the plants operate only as thermoelectric plants, in which the advantage to the environment of working with cogeneration systems, instead of just electricity, has been demonstrated.

In the study of the allocation of CO_2 for different thermal cogeneration plants and thermoeconomic methodologies, Dos Santos (2015) noticed that the disaggregation models E, E&S, H&S and UFS present similar average values, given that the recommendation of the H&S and UFS methodologies for better precision in dissipative elements still remains. Meanwhile, it was proved that the adaptation for quantification of specific emissions of CO_2 in g/kWh is independent of the previously mentioned thermoeconomic methodologies.

Fortes (2017), in his master's thesis, when observing the need to allocate monetary, exergetic and emission costs of CO_2, a thermoeconomic analysis was carried out using the UFS methodology for a heat pump applied to a drying process. Thus, the objective was to identify equipment with significant contributions to the emission of $CO2$ in kg/kJ in the refrigerated cycle analyzed. Knowing that the cogeneration unit analyzed by the author consists of producing condensed water and removing moisture from the product subjected to drying, an allocation of CO_2 equivalent to $0{,}745 \times 10^{-2}$ kg/kJ and $0{,}781 \times 10^{-2}$ kg/kJ, respectively, was obtained.

Similar to Santos (2012), Carvalho et al. (2020) analyzed a dual cogeneration plant for the production of electricity and desalinated water. In view of this, the author used the energy and exergy base for the allocation of CO_2, and observed that regardless of the level of disaggregation, the emission of CO_2 in g/kWh became greater on an exergy basis, when compared to the energy base, even if, on the other hand, the specific emission in g/m³ for the production of desalinated water became greater. It is justified, therefore, the analysis on an energy basis does not take into account the real quality of the energy parcels, evaluating them equally (CARVALHO et al., 2020).

2.2   Data

In order to structure and obtain the thermodynamic states of the analyzed thermal cycle, the EES® software will be used. Through it, it will make it possible to record in its calculation log the physical and thermophysical properties of the materials used in the parabolic solar collector system, as well as the structuring of energy conservation and thermoeconomic equations, and the use of optimization by genetic algorithms.

For the dimensioning of parabolic solar collectors, it is necessary to know the climatic parameters of the city where the company in question is located. However, there is no meteorological record in the INMET database (National Institute of Meteorology) for the city of Pinheiros - ES. Thus, it became necessary to use data from the city of São Mateus - ES, as can be seen in Table Table 1, located about 70 km from the municipality of Pinheiros.

Table 1 - Climatic parameters for maximum solar radiation in the year 2021 in the municipality of São Mateus - ES.

Parameters	Values
Solar irradiation	1153.12 W/m²
Date	02/14/2021
Time	12:00 hours
Ambient temperature	31.30°C
Wind speed	3.30 m/s

For the generation of energy in the form of steam, the thermal plants under analysis use Eucalyptus as an energy source, in which a watertube energy recovery boiler is used. Thus, it is known that the boiler used has a burning capacity equivalent to 45 MW, where the average LHV (Low Heat Value) of Biomass is equivalent to 2800 kcal/kg, these being the values used in the preparation of the analysis, as can be seen in Figure 3 Figure 3 - Boiler thermal capacity. Source: Vincke (2015)., obtaining a flow rate equivalent to 13.68 ton/h of fuel. the chemical composition of Eucalyptus biomass and their respective percentages. Thus, through Table 2, these values can be observed.

In a stereometric balance for determining the flow rate of CO_2, it is provided according to the fuel flow rate. Where $\dot{m}_{CO_2}$ is the flow of CO_2 in g/s, m_{fCO_2} is the mass fraction of CO_2 in g of CO_2 /g of fuel and $\dot{m}_{fuel}$ is the fuel flow in g/s.
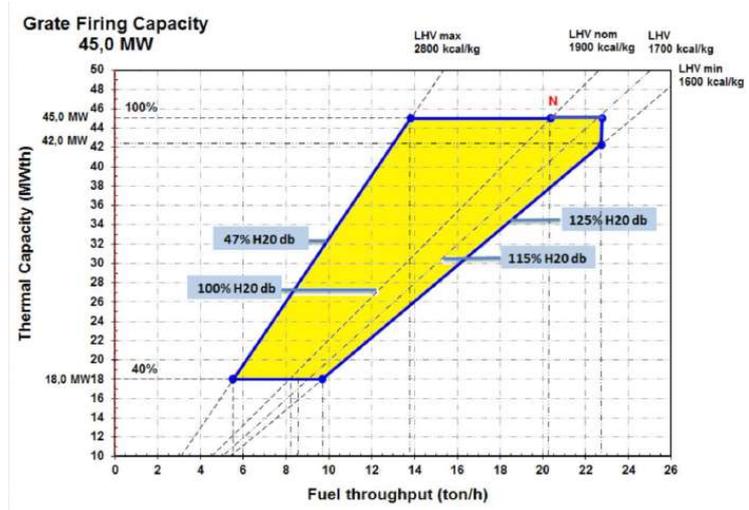
Figure 3 - Boiler thermal capacity. Source: Vincke (2015).

Table 2 - Eucalyptus biomass composition. Source: (Renewable Resource Data Center, 2015, Apud Zhang, 2015).

CHEMICAL COMPOSITION	PERCENTAGE (%)
C	44,89
H2	5,21
O2	39,87
N2	0,13
S	0,03

$$\dot{m}_{CO_2} = m_{fCO_2} * \dot{m}_{fuel} \tag{2}$$

For the elaboration of thermodynamic analyses, the physical structure which corresponds to the thermal plants under analysis must be defined. Thus, Figure 4a represents the standard plant used in the generation of steam for the production of MDF used by the industry located in the northern region of Espírito Santo. In this thermal plant, the use of steam is limited to the MDF production process only. Another characteristic of this thermal cycle is represented by the absence of superheaters, which limits the production in saturated steam.
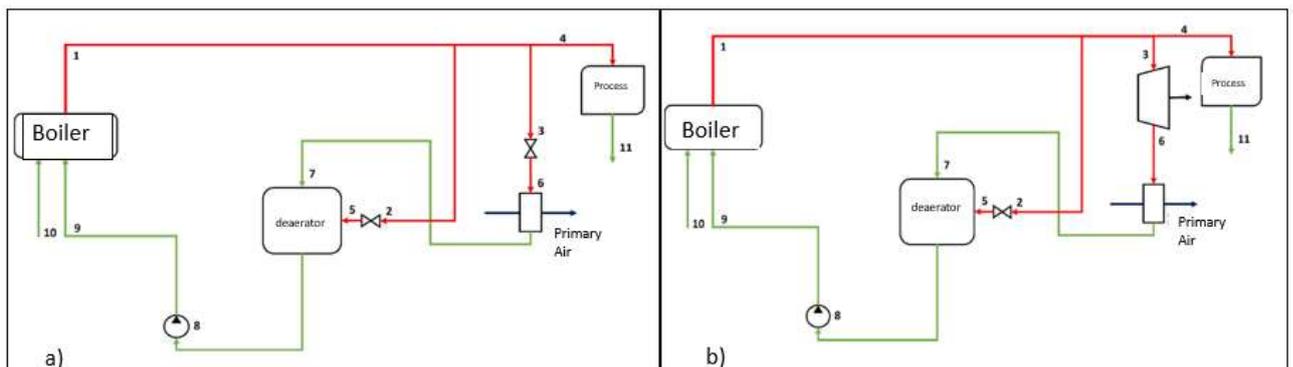

Figure 4 – a) Thermal plant used to generate steam in the production of MDF b) with the addition of a back pressure turbine. Source: Own authorship (2022).

It is also observed that the plant represented in Figure 4a represents an open cycle, where the boiler feed is constant through Point 10, and part of the flow that comes out of the process is destined to the river networks in the region at Point 11. Ahead, the thermal plant is composed of a watertube boiler, 2 expansion valves, 1 heat exchanger, 1 deaerator and 1 pump. In the heat exchanger, the primary air enters and leaves the heat exchanger at a temperature equivalent to 90°C and 120°C, respectively, where this heated air is used in the process and its condensate returns to a feed tank.

Knowing that thermoeconomics applies only to cogeneration processes due to the need to share costs for heat and power (SANTOS, 2009), the proposed plant in Figure 4b is proposed, which corresponds to the addition of a backpressure turbine to replace the isenthalpic valve between flows 3 and 6.

Although the addition of a turbine allows the application of thermoeconomic modeling, it is known that the operation becomes inefficient due to the low energy potential of entering the turbine, given that it is saturated steam. With that, the third plant consists of the addition of solar collectors of the parabolic type in the plant of Figure 4b, thus becoming superheated steam. Therefore, it became necessary to draw up the physical diagram of the solar plant, consisting of a heat exchanger, a pump and solar collectors, as can be seen in Figure 5. In this way, the addition of a heat exchanger in the steam production plant will result in the physical diagram shown in Figure 6.
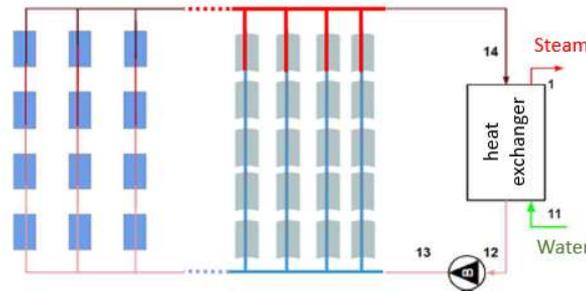

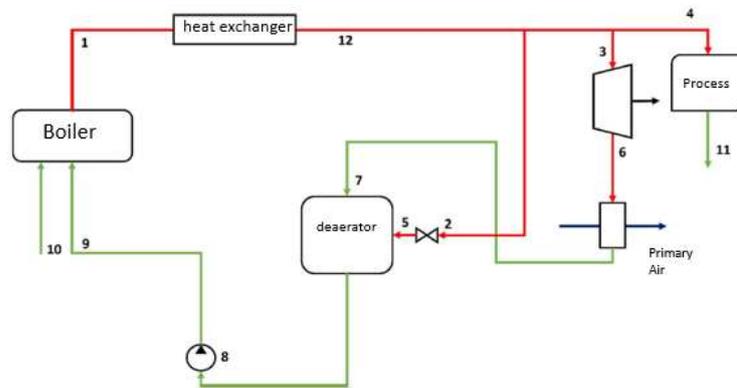*Figure 5 - Physical diagram of solar plant. Source: Author (2023).*

Figure 6- Thermal plant used for steam generation in the production of MDF with the addition of a back pressure turbine and parabolic solar collectors. Source: Author (2023).

Finally, six comparative analyzes will be taken into account. For the first comparison, the plant in Figure 4a and Figure 4b will be used with the current capacity of the plant, as can be seen in Table 3. The current capacity of the plant represents its operation in a given instant of time.

Table 3 - Current operation of the thermal plant. Source: Vincke (2015).

Parameters	Operating capacity
Flow	24.8 ton/h
Boiler outlet pressure	15.2 bar
Maximum steam temperature	199°C

Table 4 - Maximum design capacity of the thermal power plant. Source: Vincke (2015).

Parameters	Operating capacity
Flow	32.8 ton/h
Boiler outlet pressure	16 bar
Maximum steam temperature	201°C

For the second comparison, only the plant in figure x can be considered, comparing the current capacity (Table 3) and the maximum design capacity (**Erro! Fonte de referência não encontrada.**).

For the third comparison, consider the plant in Figure 4b with the current operating parameters and their respective maximum capacity (**Erro! Fonte de referência não encontrada.**). For the fourth comparison, the plant in Figure 4b will be compared with the plant in Figure 6 using the optimization of genetic algorithms, with the objective function of minimizing the emission of CO_2 in g/kWh. Finally, the fifth comparison corresponds to the plant in Figure 6 with a

minimum emission of CO_2 in g/kWh and with maximum efficiency, using genetic algorithm optimization in the same way.

For thermoeconomic modeling, the UFS model will be used due to the presence of valves and dissipative elements, given that it allows the disaggregation of physical exergy in a coherent way for expansion devices (FORTES, 2017), considering the portions of internal energy, flow work and entropy (CARVALHO, 2020). In this way, the mechanical and chemical exergy portions will be neglected, and according to Santos (2009), the chemical exergy portion can be neglected in steam cycles, where water and steam do not enter into a chemical reaction during flows. The mechanical exergy can also be neglected, given that it has a much smaller proportion when compared to the thermal exergy portion. In this way, Eqs. (3) and (4).

$$E = E^M + E^T \tag{3}$$
$$E^T = \dot{m}[(u - u_0) + (pv - p_0 v_0) + T_0(s - s_0)] \tag{4}$$

Where, E is the total exergy (kW), E^M is the mechanical portion of the exergy (kW), E^T is the thermal portion of the exergy (kW), $\dot{m}$ is the steam flow rate (kg/s), u is the internal energy (kJ/kg), u_0 is the internal energy of the dead state (kJ/kg), p is the pressure (kPa), p_0 is the pressure of the dead state (kPa), v is the specific volume (m³/kg), v_0 is the dead state specific volume (m³/kg), T_0 is the dead state temperature (K), s is the entropy (kJ/kgK) and s_0 is the dead state entropy (kJ/kgK).

To obtain the specific emissions of the internal flows and the product, according to Carvalho (2020), use Eq. (5), where CO_2 is the specific emission of CO_2 in g/s, where the final products (λ) are expressed in g/kWh. Where, λ_{out} is the emission of CO_2 in the equipment output flow (product) (g/kWh), λ_{in} is the emission of CO_2 in the equipment input flow (input) (g/kWh), Y_{out} is the equipment output flow (kW) and Y_{in} is the equipment input flow (kW);

$$\sum(\lambda_{out} Y_{out}) - \sum(\lambda_{in} Y_{in}) = CO_2 \tag{5}$$

That said, knowing that the thermal plant used nowadays uses steam only for the process, there is no need to use the production diagram (Figure 4a). With the addition of the backpressure turbine in the cycles of Figure 4b and Figure 6, we have the respective production diagrams in Figures 20 and 21, taking into account that it is necessary to obtain the emission of CO_2 in g/kWh.

To carry out the optimization process, it was necessary to define optimization variables according to their respective minimums and maximums. Thus, through Table 8, five optimization variables can be observed.

Table 5 - Decision variables for the elaboration of the optimization. Source: Author (2023).

Parameters	Minimum value	Maximum value
Y	20	100
P_1	12,0 bar	16,0 bar
ΔT_{SH}	50ºC	190ºC
ΔT_{air}	5ºC	50ºC
$\dot{m}_2$	0,001 kg/s	1,0 kg/s
$\dot{m}_1$	4,0 kg/s	9,1 kg/s

It can be mentioned that for the plant in Figure 6, the Objective Function will be used as the efficiency of the cycle, with the aim of maximizing it through the variations of the parameters in Table 5 (Eq. (6)). Soon after, the Objective Function will become the specific emission of CO_2 ($\lambda_{process}$) for the process, which will be minimized in the optimization process, as can be seen in Eq. (7).

Where, $\dot{W}_{net}$ is the net power, represented by the subtraction between the power generated in the turbine by the power consumed by the pump (kW), $\dot{Q}_t$ is the total heat, represented by the sum of the heat generated by burning the biomass and the heat generated through the addition of parabolic solar collectors (kW) and $\lambda_{process}$ is the amount of CO_2 emission emitted by the plant in g/kWh

$$F_{obj1} = \frac{\dot{W}_{net}}{\dot{Q}_t} \tag{6}$$
$$F_{onj2} = \lambda_{process} \tag{7}$$

Figure 7 - Production diagram of the thermal plant used for steam generation in the production of MDF with the addition of a back pressure turbine (Figure 4b). Source: Author (2023)

Figure 8 - Production diagram of the thermal plant used for steam generation in the production of MDF with the addition of a backpressure turbine and parabolic collectors (Figure 6). Source: Author (2023)

3. RESULTS

Different possibilities for the operation of the thermal plant under analysis were analyzed, taking into account Figure 4a, Figure 4b e Figure 6. To facilitate the elaboration of the results, one can observe Table 9 in which the analysis process is described.

Table 6 - proposed thermal power plant analyzed according to the description. Source: Author (2023).

THERMAL POWER PLANT	DESCRIPTION
Plant 1	Original thermal plant: Actual capacity and steam generation only for the MDF manufacturing process (Figure 4a).
Plant 2	Original thermal plant + backpressure turbine: Actual capacity and steam generation for the MDF manufacturing process and electric power generation (Figure 4b).
Plant 3	Original thermal plant + backpressure turbine: Maximum design capacity and steam generation for the MDF manufacturing process and electricity generation (Figure 4b).
Plant 4	Original thermal plant + backpressure turbine + parabolic solar collectors: Maximum design capacity and steam generation for the MDF manufacturing process and electricity generation (Figure 6).
Plant 5	Original thermal plant + backpressure turbine + parabolic solar collectors: Maximum design capacity steam generation for the MDF manufacturing process and electric power generation optimized for minimum emission of CO_2 in g/kWh (Figure 6).
Plant 6	Original thermal plant + back pressure turbine + parabolic solar collectors: Maximum design capacity steam generation for the MDF manufacturing process and electric power generation optimized for maximum thermal efficiency (Figure 6).

It can be observed through Figure 9a and Figure 9b the emission of CO_2 and thermal efficiency for each analyzed thermal plant, respectively. With regard to energy in the form of steam for the process, Figure 9c shows a considerable increase in plants that use parabolic solar collectors.
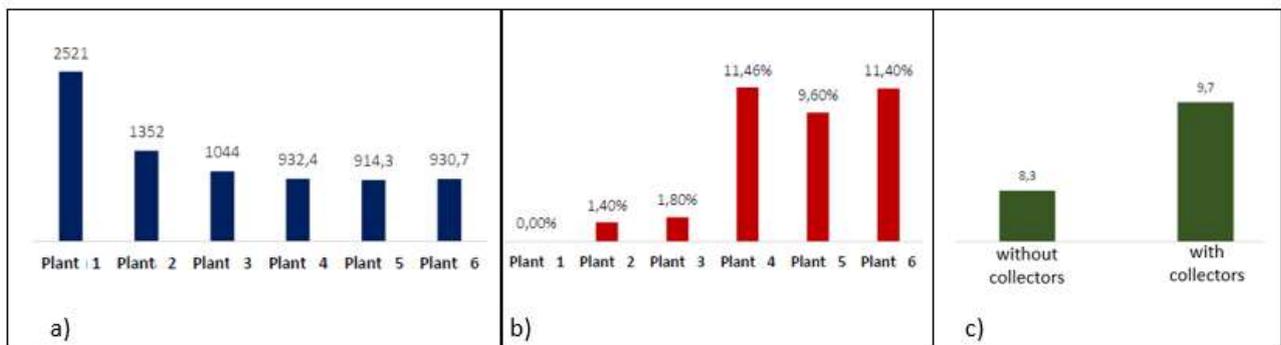

Figure 9 – for the six thermal plants analyzed a) Emission of CO_2 in g/kWh, b) Thermal efficiency and c) Energy in the form of steam used in the MDF manufacturing process in MW. Source: Author (2023).

4. CONCLUSIONS

in this paper, it was observed that thermoeconomics has the ability to provide an effective perspective for quantifying the emission of CO_2 from a thermal cogeneration plant.

It was noted that the use of steam only for the MDF manufacturing process has the ability to emit a greater amount of CO_2 per process steam, when compared to the addition of a backpressure turbine. However, just adding a turbine is not enough in the thermal power plant under study, given that

the use of saturated steam to generate electricity becomes thermally inefficient (1.4%), although the emission reduction of CO_2 is significant (46.4%). It was also noticed that the use of the current capacity of the plant is not ideal for a maximum reduction of CO_2, and the use of the mass flow and operating pressure established in the project is ideal for the thermal plant under analysis.

This optional section must be placed before the list of references. Authorship should be limited to those who made a significant contribution to the conception, design, execution, or interpretation of the reported study. If other individuals were involved in specific substantive aspects of the research project, they should be identified in this section. In addition, all sources of financial support for the project should be disclosed, as well as any potential situations that could be perceived as a conflict of interest.

The addition of a superheater is crucial for the use of steam for the process and turbine, respectively, having a steam with a greater exergy capacity, which also provides an increase equivalent to 1.4 MW in relation to the steam used in the process, being able to increase the production capacity of MDF. With this, seeking a more sustainable generation of energy and with a greater reduction in emission of CO_2, the use of parabolic solar collectors becomes an opportunity for implementation, having as a priority the non-change of the already established thermal cycle. However, the optimization of operating parameters is ideal for pursuing the objectives established in this work (minimum emission of CO_2 in g/kWh and maximum thermal efficiency). For maximum thermal efficiency, there is no significant increase in the emission of CO_2 (increase of 1.8%), where likewise the increase in thermal efficiency is around 1.8%, when compared to the use of the Objective Function to minimize the emission of CO_2.

On that occasion, due to the vast number of variables involved in the operation of the thermal power plant for steam generation, in this initial study all the parameters were not evaluated as decision variables in the optimization process, opening several proposals for future work, such as:

- Use of other thermal and physical plant parameters as decision variables for optimization processes;
- Evaluation of vast working fluids for the cycle of parabolic solar collectors, such as molten salt, allowing working with temperatures above 400°C;
- Economic viability analysis for the implementation of the back pressure turbine and parabolic solar collectors;
- Cost allocation in R$/kWh in the analyzes developed in this work;
- Thermodynamic and thermoeconomic analysis for the use of other solar collectors, such as Fresnel.

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